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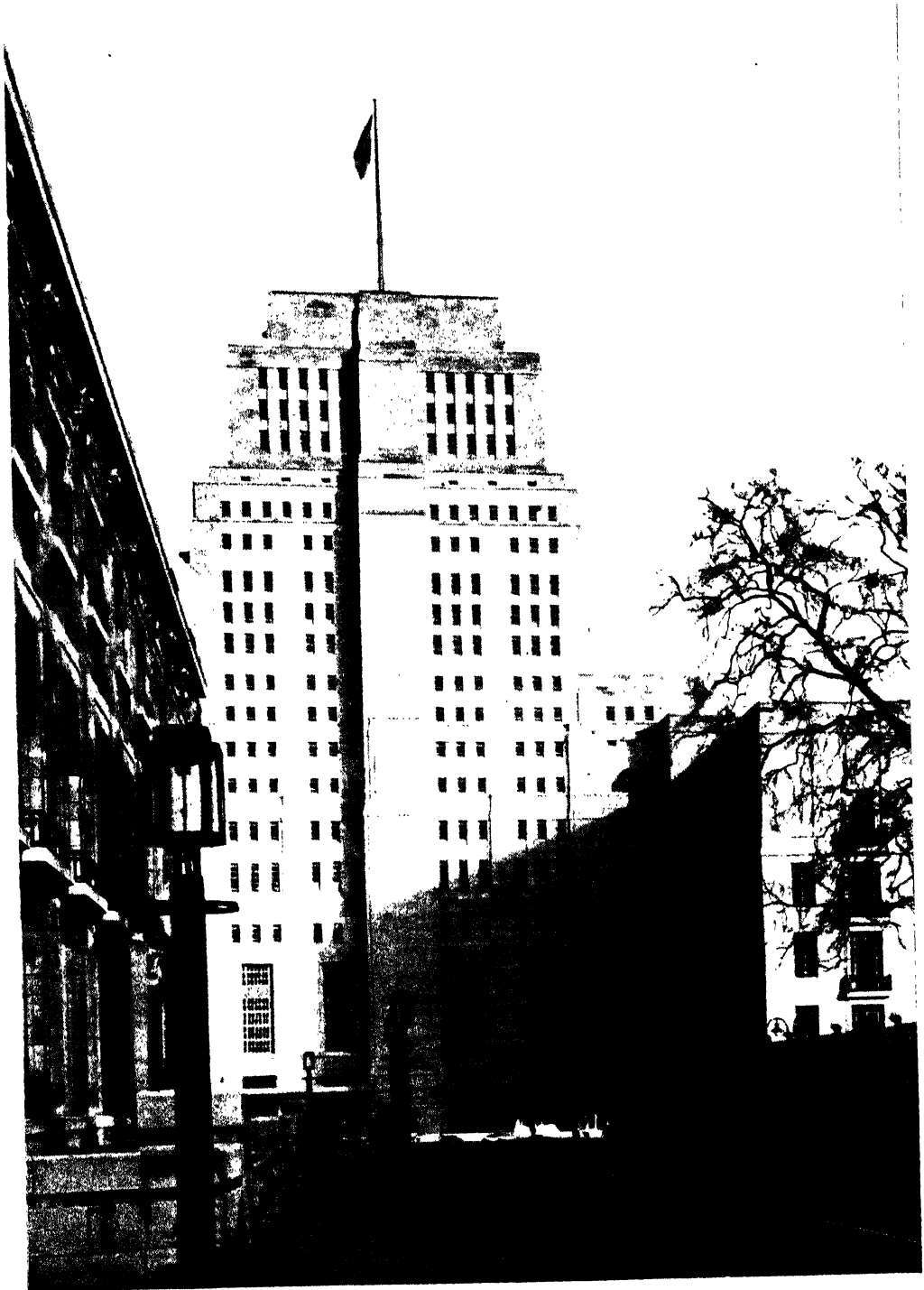
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MODERN BUILDING CONSTRUCTION



UNIVERSITY OF LONDON

New Buildings designed by Dr. Charles Holden, F.R.I.B.A. The walls are of Portland stone with brick backing

(T 8,61)

Fronispiece

MODERN BUILDING CONSTRUCTION

A COMPREHENSIVE, PRACTICAL, AND AUTHORITATIVE GUIDE
FOR ALL ENGAGED IN THE BUILDING INDUSTRY

Edited by

RICHARD GREENHALGH

A.I. Struct. E.

ASSISTED BY MANY SPECIALIST
CONTRIBUTORS



IN THREE VOLUMES—VOLUME ONE

LONDON

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FOREWORD

MODERN BUILDING CONSTRUCTION is a comprehensive work dealing with the many aspects of building technique. It lays stress on construction as carried out by the various trades, but also gives preliminary scientific instruction necessary for efficient building practice, and in addition deals with the designing and estimating of buildings and the administrative procedure necessary to erect them. This treatise will thus be found to be of service to students and apprentices, to craftsmen who aspire to better jobs calling for an all-round knowledge of building work, and to architects and builders who require a comprehensive reference work of building and architectural data. Each contributor, of whom there are about fifty, is a specialist of national reputation in his particular subject, and each of these subjects is dealt with as simply as possible and as comprehensively as the space allows.

The contents of the volumes have been designed to supplement normal courses of training, not to replace them, and have been arranged as a progressive course of study. First, come the basic subjects such as mathematics, geometry, and building science. Next, the individual crafts or trades of the building industry are explained, their significance in the whole field of building defined, and the accepted skilled methods in the shop and on the job expounded and illustrated in detail by master craftsmen. These subjects occupy about half the complete work, and are followed by authoritative contributions written especially for the practical builder by specialists in their own fields. The third volume covers the professions allied to building. Architectural and surveyor students will be specially interested in this part of the work, which also includes contributions on the latest materials introduced into building operations, and a survey of the professional examinations.

A special advantage of this work is that, in the long run, it will prove to be a time-saver. It may be possible to buy a score or more separate books to cover the same wide and varied field, but these books would necessarily either overlap their subjects or leave gaps, whereas this work has been designed to cover the complete ground without serious omissions or overlapping, and with such emphasis on the many sections as their practical value demands.

MODERN BUILDING CONSTRUCTION is based on *The Building Educator*, which had a large sale between the two wars, but the contents have been rearranged, revised, and brought up to date so that they will adequately meet the latest demands in modern building technique.

At the present time the nation is embarking on the greatest building programme in its history, and it is hoped that these volumes will supplement and extend the new and necessarily hasty and incomplete courses of training for new entrants to the industry. As many and varied specialists have combined their knowledge to produce this treatise, it is hoped that everyone engaged in building work will find much of value in it, and also that it may be of service in preparing for the various trade and professional examinations.

THE EDITOR.

MODERN BUILDING CONSTRUCTION

Edited by RICHARD GREENHALGH, A.I.Struct.E.

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ARCHITECTURAL DESIGN
ARCHITECTURAL DRAWING
BOOK-KEEPING, ACCOUNTING, AND COSTING
BRICKWORK
BUILDERS' GEOMETRY
BUILDERS' OFFICE AND ROUTINE
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MASONRY
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STAIRS AND HANDRAILS
STRUCTURAL ENGINEERING
SUPERINTENDENCE
SURVEYORS' INSTITUTION
TRAINING AND OPPORTUNITIES OF ARCHITECTS
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MODERN BUILDING CONSTRUCTION

CRAFTSMANSHIP IN BUILDING

By SIR BANISTER FLETCHER, P.P.R.I.B.A., F.S.I.

ARCHITECTURE may be described as art expressed in terms of building, and it is carried out by means of various crafts which together produce the required structure. If there is an absence of any recognized style or standard in architecture, then the building fails as a work of art; if there is an absence of sound and skilled craftsmanship, then the building fails as a structure for utility. Thus we realize the importance of the combination of the trained taste and judgment of the architect and the trained hand of the craftsman. Any building to-day, for whatever purpose it is erected, is the product, not of one craft but of many crafts, which are all interdependent one on the other for the production of the finished article, whether it be a cathedral or a cottage. In the building world it is not merely a question of the best and latest type of machinery, but of the best and keenest type of workers, of craftsmen, if our building is to be pronounced good.

The crafts which are employed in the various departments of building have a technical and traditional history, reaching far back into the life of civilized man, and have materially contributed to the evidences we see around us of past human activities. These crafts, extended in application, and losing nothing of their vitality, are in demand to-day just as much as ever.

The building industry is of national importance: firstly, because of the vast amount of necessary work which it produces; secondly, because of the insistent and varied needs of the community for which it caters; and, thirdly, because of the considerable population actually engaged in it. It is, therefore, essential that the architects, builders and craftsmen, who act in a working partnership in rearing our public buildings and domestic dwellings, should be thoroughly equipped for the execution of their respective tasks, which, all taken together, constitute the finished edifice.

The aspect of craftsmanship which chiefly

concerns the architect is the part it plays in relation to his design for the complete structure. The craftsman of to-day cannot be allowed the same liberties of design in the work he executes as his predecessor in the Middle Ages, for he has lost the common guiding tradition which in those days ensured that his work, however much the creation of his own spirit, was still in conformity with the general style of the work in hand. Nowadays, the work of all contributors to a large building can be brought into uniformity only by subordinating them to the master-mind of the architect. Yet there are still occasions when the craftsman may have a freer hand to work out in his own manner the general idea which an architect gives him; in any case the actual execution is in his hands, and its success depends largely on his loyalty to, and sympathy with, the requirements of the complete work in the production of which he has his assigned part.

These introductory remarks are directed to emphasize the necessity for studying and appraising the technical difficulties of craftsmanship, as well as the purely architectural principles of building, so that the painstaking labour and enthusiasm of the craftsman may be appreciated. Different crafts will be briefly reviewed, partly from an historical and partly from a technical standpoint.

Brickwork. As clay forms the soil in many vast tracts of low-lying land, it has been used for the making of bricks for buildings, from Babylonian times down to our own day. In our country, thin Roman bricks were followed by the slightly thicker medieval bricks, and then by the Tudor brick of rich hues and rugged texture, which gave character to many buildings. In the Renaissance period a brick more like the modern type was in use, and has influenced domestic architecture down to the present day.

With the improved facilities of transport in modern times, greater possibilities for producing picturesqueness and colour in buildings have

MODERN BUILDING CONSTRUCTION

been afforded by the variety of bricks obtainable from various parts of the country, including machine-made bricks, which, however, have not the texture of the old hand-made types. The well-known Fletton and the London yellow stock have done good service for cheaper and internal work; while for facing bricks many kinds are available, including the mottled varieties of grey, brown, red and orange hues, and other sand-faced bricks, Blue Staffordshires for withstanding pressure, and glazed bricks of various kinds for hygienic and ornamental purposes. The arrangement of bricks, known as "bond," has in its different forms given interest to brickwork. A variegated effect is sometimes produced by the use of headers and stretchers, and "flared" or black headers form a conspicuous pattern in much Georgian work, while criss-cross patterns were similarly formed in Tudor times.

Much depends upon the manner of laying the bricks, as well as upon their composition, and the effect of the best bricks can be spoilt by slovenly workmanship. Mortar joints, indeed, play an important part, for a neat joint, either weather-struck or flat, sets off the texture of a brick wall to its best advantage. By the use of rubbed, carved and moulded brickwork, as used by Sir Christopher Wren, rich and varied effects of design have been produced, and terra-cotta can be carefully manipulated to give point and finish to a building.

The work of the tiler and slater must not be overlooked, and much of the character of English domestic buildings is due to the texture and delightful hues of roof coverings, toned down by time, such as hand-made sand-faced tiles and the beautiful Westmorland green slates.

Masonry. Stone, marble, and granite, have been staple building materials in many countries from earliest times, and the history of architecture may almost be said to be the history of stonework. In the earliest days, stone or granite was worked into gigantic monuments; in Egypt it was used for pyramids and temples; in Greece marble was used to produce some of the noblest architecture and sculpture the world has seen—and so on to the Middle Ages, when stone was made the expression of religious devotion, and in the Renaissance period great dignity and symmetry were obtained by the use of the same material.

Much variety can be gained from stone, not only from the differences in texture, but from the methods of cutting and laying—whether as

random rubble or polygonal masonry, or quarried in rectangular blocks, and laid irregularly or in straight courses. Again, the face can be left "rock-faced" or hammer-dressed. Ashlar for important buildings, accurately cut, and with its surface or margins dressed smooth, entails much skilled labour. Rustication to add emphasis, obtained by channelling joints or working a rough surface, has again been much resorted to in recent years. Many processes are entailed in cutting stone for building, and stereotomy is now in general use for determining the accurate jointing and surfaces in arches and other structural features.

Plastering. Plaster, plain and ornamental, came into use because of the need for a smooth continuous coat to finish the interiors of buildings. The timber ceilings of Tudor times were followed in the Elizabethan period and afterwards by elaborate plaster ceilings in small panels; in the later Renaissance, larger and more deeply recessed panels were produced, giving way again to delicate patterns in the Adam period. Externally also, plaster and stucco were needed from early times, for the Greeks made a stucco from marble-dust to cover coarse-grained stone, as in Sicily, and to produce the effect of marble. In our country, stucco has been used with good effect in plaques, and even for whole façades. Decorative pargeting forms a familiar feature in some rural districts, while in modern times delightful effects are provided by rough-cast over buildings requiring weather protection. Stippled and daubed textures have been evolved, which, enhanced by their gleaming white and cream hues, have relieved many other featureless elevations.

Woodwork. Wood is the material from which the internal finishings and fittings of a rigid nature in a building are made—worked by carpenters for structural features like roofs and floors, and by joiners for stairs, doors and windows. In primitive architecture, in many countries, wood framing seems to have been much used. In this country timber was employed in framing up walls on the post-and-beam principle, with brick filling, especially in districts such as Shropshire and Cheshire, where forests abounded. Wood was also wrought into open timber roofs of great ingenuity and beauty, from the simple tie-beam roof to the trussed rafter, arch-braced and hammer-beam types. It has been utilized in all its possibilities for church fittings of great beauty. Doors were first boards nailed together, panelled and moulded types afterwards being evolved,

while the window-casement of earlier times was largely superseded by the Georgian sash-window, but is now returning to favour. Much depends here, as in other crafts, upon the execution. Medieval work was usually hewn out of the solid, the posts being secured by oak pegs, while carving was done vigorously, but in accord with the nature of the material.

In Renaissance times also, much fine wood-work was carried out, of which the spacious balustraded staircases of Elizabethan, Jacobean, and Georgian times are noteworthy, and carving of great skill and excellence was done, especially in the style of Grinling Gibbons, whose remarkable simulations of natural forms have enriched many city churches and private houses.

Painting. Buildings, when substantially complete, need a protective and decorative layer inside and sometimes out, hence the importance of the painter's craft. In ancient Egypt vast temple walls were often painted in bright colours; the refined details of Greek temples were once picked out with painted ornament; and many medieval buildings were enlivened internally by a layer of gold and colours, fittings and furniture often being coloured in the same way. The plaster and cement of later times have been brightened by the same process, and colour schemes for internal decoration have received much attention. The treatment of woodwork has also called forth the processes of graining and varnishing. The great number of oil and water paints, distempers and enamels, and the graded tints in which these are produced, give ample facilities for the colour design of modern buildings. The application of washable distemper to walls, which has in many cases superseded wallpaper for small houses, has altered the character of interiors.

The art of glass painting has entered much into architecture, especially ecclesiastical. The stained glass of the early medieval period, actually coloured in the making, and formed chiefly in lead patterns, and the painted glass of the Renaissance period which replaced it, both offer suggestions for original work at the present day, while conventional treatment of the "comes" for domestic buildings has reached a high standard of design.

Plumbing. The structure, within and without, needs provision for the supply of water and the carrying away of refuse matter. The craft of the plumber has satisfied both these requirements by the use of pipes of lead and other materials, which have necessitated skilled

handiwork in bends, joints, welding, and other processes. Again, he has worked hand in hand with the tiler and slater in that most important work, the drainage of roofs, with his ridges, valleys, gutters, and flashings, rendering our buildings secure against the elements. Indeed, from early medieval times the plumber has often supplanted the tiler, and given us the immense advantage of a flat roof with maximum of headroom beneath, covering large areas with his lead sheets joined by carefully worked "rolls." The leadworker has also used his material decoratively, such as in the lead cisterns, of which eighteenth-century examples are familiar, and fine rain-water heads, with their ornamental devices.

It will be clearly seen that much training, perseverance, and experience are necessary to produce the skilled craftsman. Apprenticeship was, and is undoubtedly, the best method of familiarizing the would-be craftsman with the practical details of the work at first hand, and it is commonly felt that it should be extended to ensure an adequate supply of skilled craftsmen in the future.

This daily practice can and should, however, be supplemented by technical training and instruction, so that the student may develop a capacity for more advanced and varied work than he is already doing in the limited scope of his daily routine, and this need is supplied by many technical evening and day schools and colleges all over the country. Such training is provided in London by the London County Council at their School of Building and the various polytechnics; and in the provinces, at technical institutions and colleges such as the Liverpool Technical College which has achieved notable successes. The Carpenters' and other City Companies have for years given highly specialized technical instruction in their Trades Training Schools, where the instructors are skilled men of long experience. It is of the utmost importance that there should be no lack of qualified operatives for the erection of buildings in the future. The efficient and extended training provided for architects in the schools of architecture can be used to good advantage only if the various classes of craftsmen employed in building have the necessary craft-skill and keen interest in their work. It is largely with the object of giving prominence to this aspect of building requirements that this publication has been undertaken.

TABLES

CAPACITY

4 gills = 1 pint.
 2 pints = 1 quart.
 4 quarts = 1 gallon.
 2 gallons = 1 peck.
 4 pecks = 1 bushel.
 8 bushels = 1 quarter.

LENGTH

12 inches = 1 foot.
 3 feet = 1 yard.
 5½ yd. = 1 rod, perch, or pole.
 220 yd. = 40 poles = 1 furlong.
 1,760 yd. = 8 furlongs = 1 mile.
 100 links = 22 yd. = 1 chain.
 10 chains = 1 furlong.

AREA

144 sq. inches = 1 sq. foot.
 9 sq. feet = 1 sq. yard.
 30½ sq. yards = 1 sq. pole.
 40 sq. poles = 1 rood.
 4 roods = 1 acre.
 4,840 sq. yards = 1 acre.
 10 sq. chains = 1 acre.
 640 acres = 1 sq. mile.
 (Note local differences; Cornwall
 acre = 5,760 sq. yards.)

WEIGHT (Avoirdupois)

16 drams = 1 ounce (oz.).
 16 oz. = 1 pound (lb.).
 14 lb. = 1 stone.
 28 lb. = 1 quarter.
 4 qr. (112 lb.) = 1 hundredweight (cwt.)
 2,240 lb. = 20 cwt. = 1 ton.

ANGLES

60 seconds = 1 minute.
 60 minutes = 1 degree.
 90 degrees = 1 right angle.
 360 degrees = circle.

VOLUMES

1,728 cub. inches = 1 cub. foot.
 27 cub. feet = 1 cub. yard.

METRIC SYSTEM

MULTIPLES			UNIT	SUB-MULTIPLES		
Kilo 1,000 K.	Hecto 100 H.	Deca 10 D.	{ Gramme. Litre. Metre. }	{ deci 1/10 d.	centi 1/100 c.	milli 1/1000 m.

The Metre is the unit of length.
 The Litre is the unit of capacity.
 The Gramme is the unit of weight.

Are = unit of area.
 Stere = unit of volume.

1 cm. = 1/100th of a metre. 1 Hm. = 100 metres.

The Are and the Stere are only used by surveyors and timber merchants, otherwise we use the square metre and cubic metre—

1 Are = 100 sq. metres = 10 m. × 10 m. = 100 m² = unit of land measure.
 1 Stere = 1 cub. metre = m. × m. × m. = m³ = unit of timber measure.

APPROXIMATE ENGLISH AND METRIC EQUIVALENTS

A metre = 1¹/₈ yards = 3 ft. 3⁷/₈ in. A stere = 1 cub. metre = 1 cub. yard + 8.32 cub. feet.
 A sq. metre = 10¹/₄ sq. feet. A litre = 213 gallons.
 4,000 sq. metres = 1 acre. A kilogram = 2.205 lb.
 An are = 100 sq. metres = 119.6 sq. yards = 1¹/₈ acre.

CONVERSION TABLE

To Convert	To	Multiply by
Acres	Hectares	0.4047
Centimetres	Inches	0.3937
Cub. centimetres	Cub. inches	0.061
Cub. metres	Cub. yards	1.308
Cub. feet	Gallons	6.23
Cub. inches	Cub. feet	0.00058
Metres	Feet	3.281
Ounces (Av.)	Grammes	28.35
Pounds (Av.)	Kilograms	0.4536
Pounds per sq. inch	Kilograms per sq. centimetre	0.07031
Sq. centimetres	Sq. inches	0.155
Sq. metres	Sq. feet	10.76
Sq. inches	Sq. feet	0.007
Sq. yards	Acres	0.0002067
Tons per sq. inch	Kilograms per sq. centimetre	157.5
Yards	Miles	0.000568

Notes. To reverse the conversion, divide column (2) by column (3) to give column (1), i.e.—

$$\frac{\text{Hectares}}{0.4047} = \text{Acres.}$$

Building Calculations

By T. CORKHILL, M.I.STRUCT.E., M.COLL.H.

Chapter I—ARITHMETIC (I)

THIS section contains the essential mathematics required by those engaged in the building industry. Modern building practice is becoming more of a science year by year, and the basis of science is mathematics. It is essential that the building industry shall keep pace with modern progress, otherwise the engineer will eventually take the prominent part both in building design and practice. This applies to all branches of building; "rule of thumb" methods are obsolete, and correct calculations are essential for successful competition.

The arrangement of the chapters has been considered with a view to the keen student continuing the subject beyond the limits of these pages. The miscellaneous examples will prove of great value to those students preparing for examinations and for understanding other sections in this work. Mensuration has been placed at the end, so that the student can apply trigonometry and logarithms to the solutions of the problems.

MATHEMATICAL ABBREVIATIONS

+	signifies addition	∴	signifies because
-	" subtraction	∝	" varies as
×	" multiplication	>	" greater than
÷	" division	<	" less than
=	" equality (equal to)	△	" triangle
∴	" therefore	±	" plus or minus

Other signs will be explained as they arise.

FUNDAMENTAL PROCESSES

I. Revision of Numbers and Arithmetical Rules.

EXPLANATION OF NUMBERS		Thousands	Hundreds	Tens	Units
	6 units				6
3,256 equals	5 × 10				50
	2 × 10 × 10				200
	3 × 10 × 10 × 10				3000
	Total units				= 3256

The total reads, three thousand, two hundred and fifty-six.

Each column increases in value, from right to left, in multiples of 10. The unit may represent any one

thing, such as bricks, feet, yards squares of flooring etc.

2. Addition. Find the sum of 3,765 and 276.

$$\begin{array}{r} 3,765 \\ 276 \\ \hline \end{array}$$

4,041 Ans.

EXPLANATION. (1) $6 + 5 = 10 + 1$. Place 1 in the first column and carry 1 to the 10's column. (2) $1 + 6 + 7 = 100 + 40$. Place 4 in the 10's column and carry 1 to the hundreds column. (3) $1 + 7 + 2 = 1,000$. Place 0 in the 100's column and carry 1 to the 1,000's column. (4) $1 + 3 = 4,000$.

3. Subtraction. Subtract 4,734 from 7,526.

$$\begin{array}{r} 7,526 \\ 4,734 \\ \hline \end{array}$$

2,792 Ans.

EXPLANATION. (a) Find how much must be added to the second line to give the first line, i.e. 4 and $2 = 6$; 3 and $9 = 12$, carry 1; 1 and 7 and $7 = 15$, carry 1; 1 and 4 and $2 = 7$.

This is the correct mathematical reasoning but probably explanation (b) will appeal to most readers.

EXPLANATION (b). (1) Take 4 from 6 = 2. (2) Take 3 from 12 (having borrowed 1 from the third column) = 9. (3) Take 7 from 14 (again borrowing) = 7. (4) Take 4 from 6 = 2.

EXAMPLE. To build a house 23,500 bricks are required. The bricks are delivered on the job in consignments of 3,500, 4,600, 4,200, 3,250, and 4,225. How many bricks are still required to complete the work?

HINT. First add together the consignments and then subtract from the required number.

3,500	23,500 = Number required.
4,600	19,775 = Number delivered.
4,200	
3,250	3,725 = Number of bricks required.
4,225	

Total = 19,775

4. Multiplication. Multiply 5 by 3.

This means 5 units are to be taken 3 times, and it is written 5×3 , therefore the answer is $5 + 5 + 5 = 15$ units. We refer to 15 as the product of 3 and 5; and we refer to 3 and 5 as the factors of 15.

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5 is the *multiplicand* and 3 is the *multiplier*.

Hence, MULTIPLICAND \times MULTIPLIER = PRODUCT.

The following table should be memorized before the student can expect to work the exercises easily. The larger figures show the method of reading the table; thus, $8 \times 7 = 56$.

MULTIPLICATION TABLES

1	2	3	4	5	6	7	8	9	10	11	12
2	4	6	8	10	12	14	16	18	20	22	24
3	6	9	12	15	18	21	24	27	30	33	36
4	8	12	16	20	24	28	32	36	40	44	48
5	10	15	20	25	30	35	40	45	50	55	60
6	12	18	24	30	36	42	48	54	60	66	72
7	14	21	28	35	42	49	56	63	70	77	84
8	16	24	32	40	48	56	64	72	80	88	96
9	18	27	36	45	54	63	72	81	90	99	108
10	20	30	40	50	60	70	80	90	100	110	120
11	22	33	44	55	66	77	88	99	110	121	132
12	24	36	48	60	72	84	96	108	120	132	144

Multiplication by Factors. Find the product of 256 and 24. We may write this example as $256 \times 6 \times 4$, because 6 and 4 are factors of 24.

$$\begin{array}{r} 256 \\ 6 \\ \hline \end{array}$$

$$1,536 = 256 \text{ taken } 6 \text{ times.}$$

$$\begin{array}{r} 4 \\ \hline \end{array}$$

$$\text{Product} = 6,144 = 256 \text{ taken } 6 \times 4 \text{ times.}$$

EXPLANATION. (1) $6 \times 6 = 36$. Place the 6 in the units column and carry 3. (2) $6 \times 5 = 30$, add 3 = 33. Place the 3 in the 10's column and carry 3. (3) $6 \times 2 = 12$, add 3 = 15. Place the 5 in the 100's column and the 1 in the 1,000's column. (4) Repeat the process for 1,536 \times 4.

When the multiplier is not easily factorized, proceed as in the following example—

EXAMPLE. Evaluate $3,462 \times 435$.

SOLUTION.

$$\begin{array}{r} 3462 \\ 435 \\ \hline 13848 \\ 10386 \\ 17310 \\ \hline \end{array}$$

$$1,505,970 = \text{Product.}$$

The product reads: one million, five hundred and five thousand, nine hundred and seventy.

EXPLANATION. (1) Multiply 2 by 4, that is 2 units by 400, which equals 800; therefore place the 8 in the 100's column. (2) Continue the multiplication of 3,462 by 4, = 13,848. (3) Multiply 2 by 3 (2 units \times 30 = 60), and place the 6 in the 10's column; continue the multiplication of 3,462 by 3 = 10,386. (4) Multiply 2 \times 5 (2 units \times 5 units = 10). Place

the 0 in the units column, and carry the 1 to the next column; continue the multiplication of $3,462 \times 5$, = 17,310. (5) Add together the three lines of working, for the product.

5. Division. Divide 756,324 by 236. This may be written in the form, $756,324 \div 236$ or $\overline{756,324}$.

$$\begin{array}{r} 236 \\ \hline \end{array}$$

In all three cases we have to find how many times 236 will go into 756,324; hence division is the reverse to multiplication.

$$\begin{array}{r} \text{Divisor} \quad \text{Dividend} \quad \text{Quotient} \\ 236 \overline{)756324} (3204 = \text{Ans.} \\ \underline{708} \quad \dots \\ 483 \quad \dots \\ \underline{472} \quad \dots \\ \dots \\ 1124 \\ \underline{944} \end{array}$$

180 Remainder.

Therefore, 236 into 756,324, goes 3,204 times. There is a remainder of 180, which will be considered later in connection with *decimals*.

EXPLANATION. (1) 236 goes into 756 three times; place 3 in quotient. (2) Multiply 236 by 3 and subtract from 756 = 48. (3) Bring down the next figure of the dividend, to make a new dividend of 483. (4) Repeat the process.

Division may be performed by factorizing the divisor, but the student must be very careful with the remainders to get the correct full remainder.

EXAMPLE. Evaluate $66,261 \div 315$.

SOLUTION. This may be written, $66,261 \div (5 \times 7 \times 9)$, because 5, 7, and 9, are factors of 315.

$$\begin{array}{r} 5 \overline{)66261} \\ 7 \overline{)13252} \text{ and } 1 \text{ remainder} \\ 9 \overline{)1893} \text{ and } 1 \text{ remainder} \\ \underline{210} \text{ and } 3 \text{ remainder.} \end{array}$$

Therefore 210 is the answer, but there is a remainder. Combining the three remainders, we have—

$$1 + (1 \times 5) + (3 \times 7 \times 5) = 1 + 5 + 105 = 111$$

Therefore 315 into 66,261, goes 210 times, with a remainder of 111.

6. Areas and Volumes of Rectangular Surfaces and Solids. We will now consider areas and volumes, so that the student can apply his exercises to practical problems.

Fig. 1 shows a cube, that is, a solid with all its edges equal and all its corners forming right angles. The solid is drawn in isometric projection so that we can see three faces. Each of

BUILDING CALCULATIONS

these faces is a square. Now let us consider the top face : all the edges are 12 in. long (these are called *linear dimensions*); therefore each edge is divided into 12 equal parts. If we take one strip of the top surface, 12" long by 1" wide, as

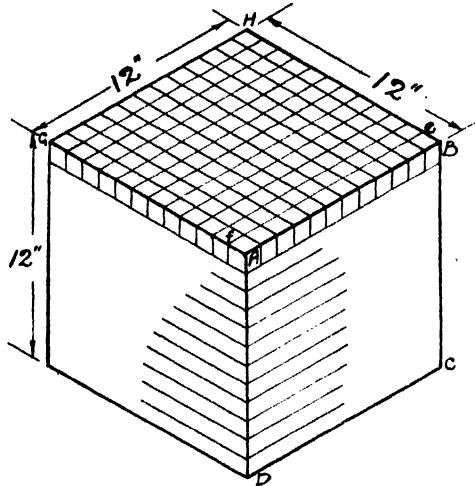


FIG. 1

shown by *ABef*, we find that we have 12 small squares each 1" × 1", i.e. 12 sq. in. If we take the whole of the top surface *ABHG* we get 12" × 12" = 144 sq. in.

Hence, LINEAR DIMENSIONS × LINEAR DIMENSIONS = SQUARE MEASURE.

If we now take a layer of the cube 1" thick, we have a thin slab 12" long, 12" wide, and 1" thick,

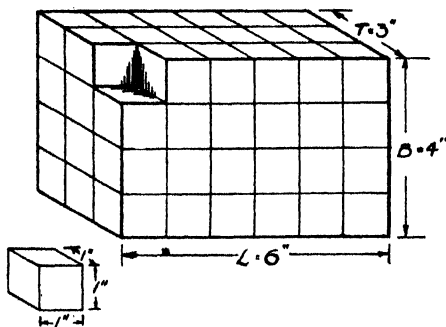


FIG. 2

that is, an area of 144 sq. in. × 1"; this equals 144 cub. in.

Hence, SQUARE MEASURE × LINEAR MEASURE = CUBIC MEASURE.

We can now see that the cube in Fig. 1

= 12" × 12" × 12" = 1,728 cub. in., or 1 ft. × 1 ft. × 1 ft. = 1 cub. ft.

Fig. 2 further illustrates the volume of a solid. It is a pictorial view of a block 6" × 4" × 3". The face is 6" long by 4" wide, therefore it contains 6 × 4 = 24 sq. in. The block is 3" thick, therefore it contains 24 × 3 cub. in. A small cube (1 cub. in.) has been removed so that the student can readily understand the term cubic inch.

From Fig. 2 we can see that—

$$\begin{aligned} \text{AREA} &= \text{LENGTH} \times \text{BREADTH} \\ &= \text{LB} \end{aligned}$$

$$\begin{aligned} \text{and, VOLUME} &= \text{L} \times \text{B} \times \text{THICKNESS} \\ &= \text{LBT.} \end{aligned}$$

EXAMPLE. Find the area of the floor shown in Fig. 3.

SOLUTION. The dotted lines show the method of dividing the floor into rectangles, the area of each rectangle will be *LB*.

Area of rectangle	<i>A</i>	=	22 × 23	=	506 sq. ft.
" "	<i>B</i>	=	16 × 9	=	144 " "
" "	<i>C</i>	=	9 × 3	=	27 " "
" "	<i>D</i>	=	8 × 2	=	16 " "
Total area =					693 " "

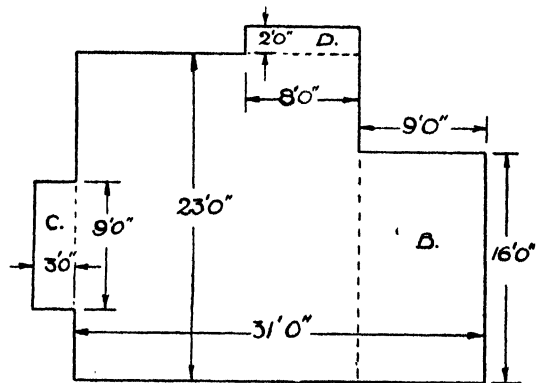


FIG. 3

EXERCISE I (Answers on page 10)

1. A large rectangular hall contains 203,320 cub. ft. of air space. The area of the floor is 8,840 sq. ft., and the width of the hall is 65 ft. Find the length and height of the hall.

2. 236 cottages are to be built, each cottage containing 5 rooms of the following dimensions: 14' × 13', 13' × 12', 13' × 11', 11' × 9', and 10' × 8'. How many squares of flooring are required, when 100 sq. ft. = 1 square?

3. A factory is six stories in height. There are 23 windows on each side and 14 on each end to every floor. The lighting area for each window is 9 ft. × 6 ft. What is the complete lighting area to each floor, and how many panes of glass 3 ft. × 2 ft. are required for the mill?

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DECIMALS

7. It has been shown that each succeeding column of a number *increases* in value by multiples of 10 from the units column. Similarly, in the opposite direction each column *decreases* in value by subdivisions of 10.

When we continue decreasing below the unit, we have parts of a unit, which are called *decimal fractions*. A decimal "point" is placed after the units column, to distinguish between the whole number and the fraction. We call the whole number the *integral* part, and the remainder the *fractional* part.

Consider the number 342.423 (the number reads, three hundred and forty-two, point four two three). To the right of the decimal point, the figure 4 represents 4 tenths of a unit, the figure 2 represents two hundredths of a unit, and the 3 represents three thousandths of a unit; that is, the fraction equals

$$\frac{4}{10} + \frac{2}{10 \times 10} + \frac{3}{10 \times 10 \times 10}$$

which equals $\frac{423}{1000}$.

8. **Addition and Subtraction of Numbers with Decimals** are worked in exactly the same way as previously described for whole numbers, keeping the decimal points under each other.

ADDITION	SUBTRACTION
$\begin{array}{r} 723.564 \\ 214.376 \\ \hline 937.940 \end{array} \text{ Ans.}$	$\begin{array}{r} 723.564 \\ 214.376 \\ \hline 509.188 \end{array} \text{ Ans.}$

9. **Multiplication.** If we move the decimal point one place to the right, the value of the number is *increased* tenfold; thus—

$$\begin{aligned} 346.23 &= 34.623 \times 10 \\ 3462.3 &= 34.623 \times 100 \end{aligned}$$

To multiply a number by 99 we move the decimal point two places, and then subtract the number.

Multiplication is the same for decimals as previously described for whole numbers; but the fixing of the decimal point in the answer may give trouble to the student; if so, the decimal point may be ignored until the result is obtained, and then found by the *rough check* method.

EXAMPLE. Multiply 652.34 by 273.26.

SOLUTION.

$$\begin{array}{r} 652.34 \\ 273.26 \\ \hline 130468 \\ 45663.8 \\ 1957.02 \\ 130.468 \\ 39.1404 \\ \hline 178,258.4284 \end{array} \text{ Ans.}$$

EXPLANATION. The first operation is to multiply 652.34 by the left-hand figure in the multiplier. That is, we commence with 4×2 , which is $\frac{4}{100} \times 200$, hence the result is 8 *units*; place the 8 in the units column. Complete the multiplication of the top line by 2. Proceed in the same way for the next multiplier, which is 7; but we do not require to consider the decimal point, because each succeeding line of working starts one place farther to the right. Note that the number of decimal places in the product equals the number of decimal places in the factors.

Rough check for fixing the decimal point—

$$600 \times 300 = 180,000$$

therefore, the decimal point comes after the sixth digit.

The student should apply the "rough check" method in every case. Take the nearest round numbers, then the multiplication can be done mentally. If we had taken 700×200 it would have given 140,000, which would again give the decimal point after the sixth digit.

10. **Division.** If we move the decimal point one place to the *left*, the value of the number is *diminished* to one-tenth of its original value.

$$\begin{aligned} 34.623 &= 346.23 \div 10 \\ 3.4623 &= 346.23 \div 100 \\ 0.034623 &= 346.23 \div 10,000 \end{aligned}$$

EXAMPLE. Divide 17.646 by 6.

$$\begin{array}{r} \text{SOLUTION.} \quad 6 \overline{)17.646} \\ \underline{2.941} \text{ Ans.} \end{array}$$

EXAMPLE. Divide 1346.7672 by 12.24.

$$\begin{array}{r} \text{SOLUTION.} \\ \text{Divisor} \quad \text{Dividend} \quad \text{Quotient} \\ 1224 \overline{)134676.72} (110.03 = \text{Ans.} \\ \underline{1224} \\ 1227 \\ \underline{1224} \\ 3672 \\ \underline{3672} \end{array}$$

EXPLANATION. (1) Move the decimal point to the end of the divisor, and the same number of places in the dividend. (2) Proceed as previously described for long division. (3) When the decimal point is reached in the dividend, place a decimal point in the quotient.

In this example when the 6 is brought down from the dividend, we ask how many times will 1224 go into 36, the answer is 0, therefore, we put 0 in the quotient. The same thing occurs when we bring down the 7, but the decimal point has intervened.

When all the digits in the dividend have been used and we still have a remainder, we can still continue the process by adding cyphers to the remainder, because 134676.72 has the same value as 134676.72000.

We often find that the decimal part of the quotient does not work out, but repeats itself ; it is then called a *recurring decimal*, which will be considered in "fractions."

Decimalisation of Money. It is often necessary to find the decimal equivalent of money, and the following should be memorised.

$$2s. 6d. = \text{£} \cdot 125, 2s. = \text{£} \cdot 1, 1s. = \text{£} \cdot 05, 6d. = \text{£} \cdot 025, 1 \text{ farthing} = \text{£} \cdot 001\frac{1}{4}.$$

RULES. 1. Place decimal point after the pounds. 2. Multiply shillings by 5, and place the last figure of the product in the 2nd decimal place. 3. Reduce pence to farthings and place the last figure in the 3rd decimal place. 4. Add ONE to the 3rd decimal place if there are more than 12 farthings, and add TWO if there are more than 36 farthings.

CONTRACTED METHODS

II. In building calculations we often require approximate values ; for instance, when finding the area of a floor, in squares of 100 sq. ft., we do not generally consider anything below .01, or 1 sq. ft.

When using logarithms we usually work to four figures ; the slide rule will only give accurate results to three figures ; and generally, in building calculations, if we are correct to four figures, the answer is satisfactory.

The student should be clear as to the meaning of significant figures. For example—

$$\begin{aligned} 347963 &= 348000 \text{ to 4 sig. figures.} \\ 0\cdot078543 &= 0\cdot07854 \text{ " " " " } \\ 6534\cdot976 &= 6535 \text{ " " " " } \end{aligned}$$

When we remove the unnecessary digits, if the last digit to be removed is more than 4, we add one to the last remaining digit. Hence, in the first example above, when we cut off the 6, we had to add one to the 9, which gave the answer as 348000.

12. Multiplication. 1ST METHOD. Find the product of $341\cdot625 \times 542\cdot26$ to 4 sig. figures.

$$\begin{array}{r} 341\cdot63 \\ 542\cdot26 \\ \hline 170815 \\ 13665 \\ 683 \\ 68 \\ \hline 185251 \end{array}$$

Rough check :
 $300 \times 600 = 180,000.$

Therefore, the answer to 4 sig. figures is 185300.

EXPLANATION. (1) Use five digits in both multiplicand and multiplier. (2) Multiply $341\cdot63$ by 5. (3) Fix the decimal point by considering $500 \times 1875 = 15$;

or fix the decimal point at the end, by the "rough check" method. (4) Cut off the right-hand digit, and multiply 3416 by 4, but take into consideration the figure we should have carried forward if we had used the right-hand digit. (5) Repeat the process for each digit in turn of the multiplier ; but for every new digit of the multiplier cross off a digit of the multiplicand.

EXAMPLE. Find the number of squares contained in a floor $123\cdot25$ ft. by $35\cdot75$ ft., using contracted multiplication. A square = 100 sq. ft.

SOLUTION.

$$\begin{array}{r} 123\cdot25 \\ 35\cdot75 \\ \hline 36975 \\ 6162 \\ 862 \\ 61 \\ \hline 4406\cdot0 \end{array}$$

Rough check,
 $\frac{100 \times 40}{100} = 40$ squares.

$4406\cdot0 = 44$ squares, 6 sq. ft. Ans.

2ND METHOD. A better method is to place the units column of the multiplier under the last column of the multiplicand, and proceed as before. This method fixes the decimal point of the answer as it is under that of the multiplicand.

Find the product of $176\cdot443 \times 3\cdot14159$ to 3 significant figures.

$$\begin{array}{r} 176\cdot4 \\ 3\cdot142 \\ \hline 529\cdot2 \\ 17\cdot6 \\ 7\cdot0 \\ \hline 554\cdot1 \end{array}$$

R.C. $170 \times 3 = 510$

Therefore the answer to 3 significant figures is 554.

EXPLANATION. (1) Use four digits in multiplicand and multiplier. (2) Arrange so that the units digit of multiplier, in this case 3, is under the last digit of the multiplicand, in this case 4. (3) Multiply $176\cdot4$ by 3 and place the last digit of the product under the 3. The decimal point is then under the decimal point of the multiplicand. (4) Cut off the last digit of the multiplicand, in this case 4, and multiply by 176 by 1, and put the last digit under the 2.

EXAMPLES. Find the product of the following to 4 significant figures.

(1) $3079 \times 50\cdot125$. (2) $43\cdot072 \times 0\cdot4372$. (3) $43\cdot26 \times 0\cdot03457$.

$$\begin{array}{r} (1) \quad 3079 \\ \quad 50\cdot125 \\ \hline 153950 \\ 308 \\ 61 \\ 15 \\ \hline 154334 \end{array}$$

R.C. $3000 \times 50 = 150000$

Ans. = 154300

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(2) $43 \cdot 072$
 $\quad 0 \cdot 4372$

$$\begin{array}{r} 17 \cdot 228 \ 8 \\ 1 \cdot 292 \ 2 \\ \underline{301 \ 5} \\ 8 \ 6 \end{array}$$

R.C. $40 \times \cdot 4 = 16$

$$\underline{18 \cdot 831 \ 1}$$

(3) $43 \cdot 26$
 $\quad 0 \cdot 03457$

$$\begin{array}{r} 1 \cdot 29 \ 78 \\ \cdot 17 \ 30 \\ \underline{2 \ 16} \\ 30 \end{array}$$

R.C. $40 \times \cdot 03 = 1 \cdot 2$

$$\underline{1 \cdot 49 \ 54}$$

13. Contracted Division. Divide $3214 \cdot 8$ by $84 \cdot 71$, approximately.

~~8471~~ $321480 \cdot (37 \cdot 95 \text{ Ans.})$

$$\begin{array}{r} 25413 \\ 6735 \\ \underline{5930} \\ 805 \\ \underline{762} \\ 43 \\ \underline{42} \end{array}$$

Rough check :

$$\frac{3000}{100} = 30$$

EXPLANATION. (1) Arrange the divisor with the decimal point at the end, and move the decimal point in the dividend correspondingly. (2) Proceed as in ordinary division for the first digit in the quotient. (3) Cut off the last digit in the divisor; then try how many times 847 will go into the remainder 6735; place 7 in the quotient. (4) Repeat the process, each time cutting off another digit from the divisor.

EXAMPLE. Solve approximately $\frac{3 \cdot 2981 \times 7 \cdot 4382}{0 \cdot 093724}$

SOLUTION.

$$\begin{array}{r} 3 \cdot 2981 \\ \quad 7 \cdot 4382 \\ \hline 23 \cdot 0867 \\ 1 \cdot 3192 \\ \quad 989 \\ \quad 263 \\ \quad \quad 6 \\ \hline 24 \cdot 5317 \end{array}$$

R.C. $\frac{3 \times 7}{\cdot 1} = 210$

$93724 \cdot 24531700 \cdot (261 \cdot 7 = \text{Ans. to 4 sig. digits})$

$$\begin{array}{r} 187448 \\ \hline 57869 \\ 56234 \\ \hline 1635 \\ 937 \\ \hline 698 \\ 656 \\ \hline 42 \end{array}$$

EXAMPLE. Solve approximately $\frac{0 \cdot 8643}{29 \cdot 63 \times 3 \cdot 397}$

SOLUTION.

$$\begin{array}{r} 29 \cdot 63 \\ \hline 3 \cdot 397 \end{array}$$

$$\begin{array}{r} 88 \cdot 89 \\ 8 \cdot 89 \\ \underline{2 \cdot 66} \\ \cdot 20 \end{array}$$

$$100 \cdot 64$$

$10064)86 \cdot 430(0 \cdot 008588 = \text{Ans. to 4 sig. digits}$

$$\begin{array}{r} 80 \cdot 512 \\ \hline 5 \ 918 \\ 5 \ 032 \\ \hline 886 \\ 805 \\ \hline 81 \\ 80 \end{array}$$

EXAMPLE.

The approximate value of $\frac{0 \cdot 03892 \times 29 \cdot 63}{0 \cdot 009328}$ is 123 \cdot 6.

Write down the approximate values of (1) $\frac{3892 \times 2963}{9328}$

(2) $\frac{38920 \times 2963}{93 \cdot 28}$ (3) $\frac{38 \cdot 92 \times 2 \cdot 963}{9328}$

Ans. (1) 1236. (2) 1,236,000. (3) 0 \cdot 01236.

EXERCISE II (Answers on page 14)

1. A load of timber contains 600 ft. super of 1 in. boards. How many loads will it take to floor 16 rooms $12 \frac{1}{2}$ ft. by $11 \frac{1}{2}$ ft.?

2. The area of windows for habitable rooms must equal at least $\frac{1}{10}$ th of the floor space, and half of the window space must open. Find the minimum size of the opening casements for a room $18 \frac{1}{2}$ ft. by $15 \frac{1}{2}$ ft.

3. Evaluate, by contracted methods $\frac{2328 \cdot \times 59 \cdot 27}{28 \cdot 361}$

ANSWERS TO EXERCISE I (page 7)

- (1) The hall is 136 ft. \times 65 ft. \times 23 ft.
- (2) 1557 squares and 60 sq. ft.
- (3) 3996 sq. ft. and 3996 panes.

Chapter II—ARITHMETIC (2)

FACTORS

14. THE numbers that will divide into another number, without leaving a remainder, are called *factors*; 1, 2, 4, and 8 are factors of 8.

A *common factor* is a number that is a factor of two numbers; 2 is a common factor of 4 and 6.

A *prime* is a number which has no factor except itself and 1, therefore a *prime factor* is a factor which is also a prime.

EXAMPLE. Find the prime factors of 2,310.

SOLUTION.

$$\begin{array}{r}
 2 \overline{)2310} \\
 \underline{3 \overline{)1155}} \\
 \underline{5 \overline{)385}} \\
 \underline{7 \overline{)77}} \\
 11
 \end{array}$$

HINT. Begin dividing by the smallest factor.

Hence the prime factors of 2,310 are 2, 3, 5, 7, and 11, because each of these numbers contains no factor, except itself and 1.

15. **Highest Common Factor (H.C.F.).** The *highest common factor*, or *greatest common measure*, of two or more numbers is the *greatest* number that will divide into them *without a remainder*; i.e. 2, 3, and 6 are *common factors* of 12 and 18, but 6 is the *highest* and is the H.C.F. of 12 and 18.

EXAMPLE. Find the H.C.F. of 44, 66, and 176.

SOLUTION.

$$\begin{aligned}
 44 &= 2 \times 2 \times 11, \text{ which are the prime factors.} \\
 66 &= 2 \times 3 \times 11 \\
 176 &= 2 \times 2 \times 2 \times 2 \times 11
 \end{aligned}$$

∴ The H.C.F. = 2 × 11 = 22, because only *one* 2 and 11 are common to the three numbers.

When the numbers are difficult to factorise, the H.C.F. may be found by the "long" method. First remove any factor evidently common to the numbers. If there are more than two numbers, find the H.C.F. of any two, and then of this H.C.F. and another number. The method is illustrated in the following example—

EXAMPLE. Find the H.C.F. of 1,311, 1,610, and 1,978.

SOLUTION.

$$\begin{array}{r}
 1311 \overline{)1978(1} \\
 \underline{1311} \\
 667 \overline{)1311(1} \\
 \underline{667} \\
 644 \overline{)667(1} \\
 \underline{644} \\
 23 \overline{)644(28} \\
 \underline{46} \\
 184 \\
 \underline{184} \\
 0
 \end{array}$$

∴ The H.C.F. of 1,311 and 1,978 is 23.

EXPLANATION. (1) Select any two of the given numbers and see how many times the smaller number will go into the larger number. Find the remainder as in ordinary division. (2) Repeat for the first remainder into the smaller number. (3) Repeat the process, until there is *no remainder*, then the *last divisor*, which is also the last remainder, is the H.C.F. (4) Now find the H.C.F. of the H.C.F. just found and the remaining number—

$$\begin{array}{r}
 23 \overline{)1610(70} \\
 \underline{161} \\
 0
 \end{array}$$

In this case the first H.C.F. divides into the third number; hence 23 is the H.C.F. of 1,311, 1,610, and 1,978.

The following will probably make the method more clear. Let *S* = small number, *L* = larger number, and *R* = the various remainders, then—

$$\begin{array}{l}
 S)L \quad (x \\
 \underline{S \times x} \\
 R_1)S \quad (y \\
 \underline{R_1 \times y} \\
 R_2)R_1 \quad (z \\
 \underline{R_2 \times z} \\
 \hline
 \text{Then } R_2 \text{ is the} \\
 \dots \text{ H.C.F. of } S \\
 \text{and } L
 \end{array}$$

16. **Least Common Multiple (L.C.M.).** The L.C.M. of two or more numbers is the *smallest* number which is divisible by each of the numbers, *without a remainder*. Thus 24 is divisible by 4 and 6, but 12 is the smallest number divisible by 4 and 6, therefore 12 is the L.C.M.

MODERN BUILDING CONSTRUCTION

To find the L.C.M. of several numbers, first find the prime factors.

EXAMPLE. Find the L.C.M. of 30, 36, and 48.

SOLUTION.

$$\begin{aligned} 30 &= 2 \times 3 \times 5 \\ 36 &= 2 \times 2 \times 3 \times 3 \\ 48 &= 2 \times 2 \times 2 \times 2 \times 3 \end{aligned}$$

$$\therefore \text{the L.C.M.} = 2 \times 2 \times 2 \times 2 \times 3 \times 3 \times 5 = 720.$$

EXPLANATION. Take the greatest number of twos from any set of factors, then the greatest number of threes, and so on, and then find the continued product.

720 is the L.C.M. of 30, 36, and 48, because it is the smallest number exactly divisible by 30, 36, and 48.

When the factors are difficult to find, proceed as follows.

Find the L.C.M. of 56, 70, 84, and 728—

$$\begin{array}{r} 2 \mid 56, 70, 84, 728 \\ 2 \mid 28, 35, 42, 364 \\ 2 \mid 14, 35, 21, 182 \\ 7 \mid 7, 35, 21, 91 \\ \hline 1, 5, 3, 13 \end{array}$$

If at any stage a number is not divisible by the divisor, bring the number down without any change.

The L.C.M. is—

$$2 \times 2 \times 2 \times 7 \times 5 \times 3 \times 13 = \underline{\underline{10,920 \text{ Ans.}}}$$

The L.C.M. of two numbers is equal to their product divided by their H.C.F.

\(\therefore\) L.C.M. of 56 and 70—

$$= \frac{56 \times 70}{\text{H.C.F.}} = \frac{56 \times 70}{14} = 280$$

17. To find the H.C.F. of fractions, we find the H.C.F. of the numerators for a new numerator, and the L.C.M. of the denominator for a new denominator.

Hence the H.C.F. of—

$$\frac{17}{9}, \frac{34}{3}, \frac{51}{8} \text{ and } \frac{17}{12}, \text{ is } \frac{17}{72}$$

because 17 is the H.C.F. of the numerators, and 72 is the L.C.M. of the denominators.

FRACTIONS

18. A fraction is a part of a whole. For instance—

1 in. is $\frac{1}{12}$ th of a foot.

2s. 6d. is $\frac{1}{4}$ th of a £.
6d. is $\frac{1}{2}$ of one shilling.

The *unit* of our calculation is divided into a number of equal parts, and the *fraction* tells us how many of those equal parts are being used.

The top figure is called the *numerator*, and the bottom figure the *denominator*; hence, if we divide one ton into 20 cwt. and take 7 cwt., the fraction will be—

$$\frac{7}{20} = \text{numerator} \\ 20 = \text{denominator}$$

which means $\frac{7}{20}$ of one ton.

When the denominator is 10, or 100, or 1,000, etc., it is omitted, and the numerator becomes a decimal fraction, i.e.—

$$\frac{145}{1000} = \cdot 145, \quad \frac{14}{100} = \cdot 14, \quad \frac{1}{10} = \cdot 1$$

All other fractions are vulgar fractions, and building calculations generally involve this kind of fraction.

19. Addition. Add together $\frac{1}{2}$, $\frac{2}{3}$, $\frac{1}{8}$.

First find a denominator common to all the fractions, i.e. the L.C.M. of the denominators; in this case it is 8. Then the fractions are—

$$\frac{4}{8}, \frac{6}{8}, \frac{1}{8} = \frac{4+6+1}{8} = \frac{11}{8} = 1\frac{3}{8}$$

Note that the value of a fraction is not altered when we multiply top and bottom by the same number.

The three fractions are *proper* fractions, because the numerator is less than the denominator, but when they are added together the result is an *improper* fraction, because the numerator is greater than the denominator, i.e. $\frac{11}{8}$. The final answer, $1\frac{3}{8}$, is a mixed number, because it is a combination of a unit and a part of a unit.

20. Subtraction. From $\frac{7}{8}$ take $\frac{5}{8}$.

Find the common denominator, which is 32.

Then the fractions are $\frac{28}{32}$ and $\frac{20}{32}$; therefore the answer is—

$$\frac{28-20}{32} = \frac{8}{32}$$

EXAMPLE. Find the result of $\frac{1}{2} + \frac{1}{6} + \frac{1}{12} - \frac{1}{4} - \frac{1}{18}$.

SOLUTION.

$$\frac{\cdot 30 + 9 + 28 - 12 - 15}{48} = \frac{40}{48} = \frac{5}{6} \text{ Ans.}$$

EXPLANATION. (1) Find the common denominator. (2) See how many times the denominator of each fraction will divide into the common denominator, then multiply the numerator by this number; i.e. for the fraction $\frac{1}{8}$, 8 goes into 48 six times, $\therefore 6 \times 5 = 30$, $\therefore 30$ is the numerator for the first fraction. (3) Add together the numerators with a plus sign in front, and then those with a minus sign in front, and see which is the greater; the difference is the numerator of the answer. If the minus quantities were the greater, then the answer would be a minus quantity.

21. Multiplication. Multiply together the numerators for a new numerator.

Multiply together the denominators for a new denominator.

$$\frac{5}{8} \times \frac{3}{4} \times \frac{1}{2} = \frac{15}{64} \text{ Ans.}$$

Division. Turn the divisor fraction upside down, and then proceed as in multiplication—

$$\begin{aligned} \frac{7}{8} \div \frac{3}{4} &= \frac{7}{8} \times \frac{4}{3} = \frac{7 \times 4}{8 \times 3} = \frac{7}{8} \times \frac{4}{3} = \frac{28}{24} \\ &= \frac{7}{6} = 1\frac{1}{6} \text{ Ans.} \end{aligned}$$

Therefore, we multiply the extremes for a new numerator, and the means, or insides, for a new denominator.

Note that when we divide by a fraction we increase the value, i.e.—

$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}, \text{ but } \frac{1}{2} \div \frac{1}{2} = \frac{1}{2} \times \frac{2}{1} = 1.$$

When the fractions are connected together by multiplication and division signs, we should *cancel* (or simplify) before finding the result; that is, we divide numerator and denominator by a common factor—

$$\frac{3}{4} \times \frac{4}{12} = \frac{\cancel{3} \times \cancel{4}}{\cancel{4} \times 12} = \frac{1}{4} \text{ Ans.}$$

because the fractions could be arranged as—

$$\frac{3 \times 4}{12 \times 4} = \frac{1}{4} \times \frac{1}{1} = \frac{1}{4}.$$

22. Conversion of Decimal Fractions to Vulgar Fractions. Place the decimal quantity over a multiple of 10, so that the denominator has one more digit than the numerator, then simplify, or cancel, if possible—

$$\cdot 125 = \frac{125}{1000} = \frac{1}{8}. \quad \cdot 75 = \frac{75}{100} = \frac{3}{4}.$$

23. Conversion of Vulgar Fractions to Decimal Fractions. Divide the numerator by the denominator.

The student should work out the decimal equivalents of the fractions common to building calculations, such as $\frac{1}{8}$, $\frac{3}{8}$, $\frac{1}{16}$, etc., and memorise the results; or memorise for $\frac{1}{8}$ and $\frac{1}{16}$, and multiply the decimal equivalent by the numerator of the vulgar fraction—

$$\frac{1}{8} = \cdot 125, \therefore \frac{3}{8} = \cdot 125 \times 3 = \cdot 375$$

HINTS. (1) Always convert improper fractions to mixed numbers before working, and add together (or subtract) the whole numbers separately from the fractions. (2) Reduce all proper fractions to their lowest terms (cancel), before working. (3) Keep the common denominator in factors until the last step.

EXAMPLE. Add together $2\frac{3}{8}$, $\frac{7}{8}$, $3\frac{1}{16}$, $4\frac{1}{16}$.

SOLUTION. Converting and cancelling, we have—

$$\begin{aligned} &2\frac{3}{8}, 1\frac{7}{8}, 3\frac{1}{16}, 4\frac{1}{16} \\ &= 2 + 1 + 3 + 4 + \frac{3}{8} + \frac{7}{8} + \frac{1}{16} + \frac{1}{16} \\ &= 10 + \frac{45 + 10 + 6 + 16}{2 \times 2 \times 2 \times 3 \times 5} \\ &= 10 + \frac{77}{80} = 11\frac{7}{80} \text{ Ans.} \end{aligned}$$

EXPLANATION. $\frac{3}{4} = \frac{3 \times 15}{4 \times 2 \times 2 \times 3 \times 5}$. Take the

factors of the common denominator that are not contained in the denominator of the fraction, in this case 3×5 , then multiply the numerator of the fraction by these factors, i.e. $3 \times (3 \times 5) = 45$. Place the 45 in the numerator. Repeat for each fraction.

Recurring Decimals are those decimals which continue indefinitely. For example—

$$\begin{aligned} \frac{1}{3} &= \cdot 333 \dots \text{ and is denoted by } \cdot \dot{3} \\ \frac{2}{3} &= \cdot 666 \dots \text{ and is denoted by } \cdot \dot{6} \end{aligned}$$

If the decimal recurs in groups, as $\cdot 407407407 \dots$ we place a dot over the first and last figures of the recurring part; therefore—

$$\cdot 407407 \dots = \cdot 40\dot{7}$$

When we require a recurring decimal as a vulgar fraction we place the recurring part over as many *nines* as there are figures in the numerator; therefore—

$$\cdot \dot{3} = \frac{3}{9}, \quad \cdot 40\dot{7} = \frac{407}{999}$$

EXERCISE III (Answers on page 15)

1. What is the length of steel rod required, to cut the following lengths, which are in inches? Allow $\frac{1}{8}$ in. per cut. $2\frac{1}{8}$, $7\frac{1}{8}$, $10\frac{1}{8}$, $14\frac{1}{8}$.

MODERN BUILDING CONSTRUCTION

2. The area of a circle is given by $\frac{2}{7} \times R \times R$. What is the weight of a circular slab of stone $1\frac{1}{2}$ ft. thick, when $R = 3\frac{1}{2}$ ft.? Weight of stone = $1\frac{1}{2}$ cwt. per cubic foot.

3. Find the value of $2\frac{5}{8} + 3\frac{1}{2} + 1\frac{1}{4} + 2\frac{3}{8} - 3\frac{1}{2}$.

ANSWERS TO EXERCISE II (page 10)

- (1) $3\frac{1}{2}$ loads, approx.
- (2) Opening casements = 14.15 sq. ft.
- (3) 4.865.

REDUCTION AND COMPOUND RULES

24. **Reduction.** When we have compound quantities in multiplication, i.e. 3 ft. 4 in., £2 6s., 2 tons 5 cwt. 10 lb., etc., we often reduce the *compound* quantity to a *simple* quantity of one unit, i.e. 40 in., 46s., 5,050 lb., etc., or we reduce them to decimal or vulgar fractions, i.e. $3\frac{1}{3}$ ft. or $3\cdot3$ ft., $\pounds 2\frac{2}{10}$ or $\pounds 2\cdot3$, $45\frac{5}{8}$ cwt. or 45.09 cwt.

NOTE. The term "reduction" applies to conversion in either direction, from farthings to pounds or from pounds to farthings.

EXAMPLE 1. Reduce 3 tons 7 cwt. $3\frac{1}{2}$ qr. to quarters.

$$\begin{array}{r} 3 \text{ tons} \\ 20 \text{ cwt.} \\ \hline 60 + 7 = 67 \text{ cwt.} \\ 4 \text{ qr.} \\ \hline 268 + 3\frac{1}{2} = 271\frac{1}{2} \text{ qr. Ans.} \end{array}$$

EXAMPLE 2. Reduce £3 9s. $6\frac{1}{2}$ d. to pence.

$$\begin{array}{r} \pounds 3 \\ 20 \\ \hline 69 \text{ shillings} \\ 12 \\ \hline 834\frac{1}{2} \text{d. Ans.} \end{array}$$

25. **Compound Quantities.** The following two examples show how to add and subtract compound quantities.

EXAMPLE 1. Add together 5 cwt. 3 qr. 7 lb.; 13 cwt. 2 qr. 21 lb.; 9 cwt. 19 lb.

$$\begin{array}{r} \text{SOLUTION.} \quad 5 \text{ cwt.} \quad 3 \text{ qr.} \quad 7 \text{ lb.} \\ 13 \quad 2 \quad 21 \\ 9 \quad - \quad 19 \\ \hline 1 \text{ ton} \quad 8 \text{ cwt.} \quad 2 \text{ qr.} \quad 19 \text{ lb. Ans.} \end{array}$$

EXPLANATION. 47 lb. = 1 qr. + 19 lb.
6 qr. = 1 cwt. + 2 qr.

EXAMPLE 2. Subtract £123 19s. 6d. from £135 2s. 3d.

SOLUTION.

$$\begin{array}{r} \pounds \quad s. \quad d. \\ 135 \quad 2 \quad 3 \\ 123 \quad 19 \quad 6 \\ \hline \end{array}$$

£11 2 9 Ans.

EXPLANATION. 6d. from 3d. will not go, borrow 1s., then 6d. from 15d. = 9d. (2) Borrow £1 for shillings' column.

26. **Multiplication.** To multiply a compound quantity by a number, factorise the number.

EXAMPLE. Multiply £26 10s. 3d. by 16.

SOLUTION. The convenient factors of 16 are 4 and 4.

$$\begin{array}{r} \pounds \quad s. \quad d. \\ 26 \quad 10 \quad 3 \\ \hline 4 \\ \hline 106 \quad 1 \quad - \\ \hline 4 \\ \hline \pounds 424 \quad 4 \quad - \text{ Ans.} \end{array}$$

When we are unable to factorise, we use the method given in the following example.

EXAMPLE. Find the cost of 265 rods of brickwork at £43 7s. 6d. per rod.

SOLUTION.

$$\begin{array}{l} \pounds \quad s. \quad d. \\ (1) \quad 43 \quad 7 \quad 6 = \text{cost per rod} = A \\ \hline (2) \quad 433 \quad 15 \quad - = A \times 10 \text{ rods} \\ \hline (3) \quad 4337 \quad 10 \quad - = A \times 100 \text{ rods} \\ \hline (4) \quad 8,675 \quad - \quad - = A \times 200 \text{ rods} \\ 2,602 \quad 10 \quad - = (2) \times 6 = A \times 60 \text{ rods} \\ 216 \quad 17 \quad 6 = (1) \times 5 = A \times 5 \text{ rods} \\ \hline \text{Total } \pounds 11,494 \quad 7 \quad 6 = A \times 265 \text{ rods} \end{array}$$

∴ Cost = £11,494 7s. 6d. Ans.

Another method is to decimalise the money factor.

$$\begin{array}{l} \text{Then } 265 \times \pounds 43\cdot375 = \pounds 11\,494\cdot375 \\ = \pounds 11,494\cdot7\cdot6. \text{ Ans.} \end{array}$$

27. **Division.** To divide a compound quantity factorise the divisor if possible.

EXAMPLE. Fifteen joists support an evenly distributed load of 5 tons 8 cwt. 24 lb. Find the load on each joist.

SOLUTION. The factors of 15 are 5 and 3.

$$\begin{array}{r} \text{tons} \quad \text{cwt.} \quad \text{lb.} \\ 5 \mid 5 \quad 8 \quad 24 \\ \hline 3 \mid 1 \quad 1 \quad 72 \\ \hline 0 \quad 7 \quad 24 = \text{load on each joist.} \end{array}$$

BUILDING CALCULATIONS

When unable to factorise, proceed as follows—

EXAMPLE. A builder decides to erect 35 detached villas on 5 acres, 3 roods, 22 sq. poles of ground. How much ground should he allow for each villa?

SOLUTION.

	a.	r.	sq.	a.	r.	sq.	sq.
			ps.			ps.	yd.
35)	5	3	22	0	0	26	27 $\frac{2}{3}$
Reduce 5a. to r.	4						
	—						
		23	roods				
Reduce to sq. ps.	40						
and divide by 35	—						
)942	sq. ps.			
			70				
			—				
			242				
			210				
			—				
Reduce to sq. yd.	32						
and divide by 35	30 $\frac{1}{2}$						
			—				
)968	sq. yd.			
			70				
			—				
			268				
			245				
			—				
			23				
			—				

∴ Ground for each villa = 26 sq. poles 27 $\frac{2}{3}$ sq. yd. *Ans.*

PRACTICE

28. **Simple Practice** is an alternative method for compound multiplication. When finding the cost of 265 rods in a previous example, instead of taking sub-multiples of 265, we could have taken sub-multiples of £43 7s. 6d.

EXAMPLE. What is the cost of 756 squares of flooring at £2 4s. 6d. per square?

SOLUTION. Note that £2 4s. 6d. can be split up into £2 + 4s. + 6d., or £2 + 2s. + 2s. 6d.; the latter = £2 + £1 $\frac{1}{2}$ + £ $\frac{1}{4}$.

	£	s.	d.	
	756	—	—	= cost of 756 sqs. at £1 per sq.
		2		
	—			
	1,512	—	—	= " " " £2 "
2/- = £ $\frac{1}{2}$	75	12	—	= " " " 2/- "
2/6 = £ $\frac{1}{4}$	94	10	—	= " " " 2/6 "
	—			
	<u>£1,682</u>	2	—	= cost of 756 sqs. at £2 $\frac{1}{4}$ /6 per sq.

EXPLANATION. $\frac{1}{2}$ th of £756 = £378 12s.
 $\frac{1}{4}$ th of £756 = £189 10s.

Compound Practice.

EXAMPLE. What is the cost of 3 tons 17 cwt. 2 qr. of lime at £4 12s. per ton?

	£	s.	d.		Tons	cwt.	qr.
	4	12	—	= cost of 1	—	—	—
			3				
	—						
	13	16	—	=	3	—	—
10 cwt. = $\frac{1}{2}$ ton	2	6	—	=	—	10	—
5 " = $\frac{1}{2}$ of 10 cwt.	1	3	—	=	—	5	—
2 $\frac{1}{2}$ " = $\frac{1}{2}$ of 5 cwt.	1	1	6	=	—	2	2
	—						
	<u>£17</u>	<u>16</u>	<u>6</u>		<u>3</u>	<u>17</u>	<u>2</u>

EXERCISE IV (Answers on page 18)

1. Add together

	Tons	cwt.	qr.	lb.
	4	17	3	16
	1	13	—	6
	3	4	4	9
	—	7	6	3

2. A plot of ground has a total area of 58 acres 3 roods 21 sq. poles 14 $\frac{1}{2}$ sq. yards. The following portions have been sold—

100 yd. × 75 yd., 200 yd. × 175 yd., 250 yd. × 50 yd., and 250 yd. × 75 yd.

How much ground remains to be sold, after taking away 155,000 sq. yards for an open space?

3. A plot of land is valued at £1,936 per acre. Find the value in francs per square metre, when £1 is equal in value to 25 francs and 1 metre = 39 $\frac{1}{2}$ in.

ANSWERS TO EXERCISE III (page 13)

- (1) 34 $\frac{1}{4}$ inches.
- (2) 62 $\frac{1}{2}$ cwt. approx.
- (3) 6 $\frac{1}{2}$.

AVERAGES

29. If we add together a series of quantities of the same kind and divide the total by the number of the quantities, the result is an *average*, or *mean*.

EXAMPLE. A series of tests was made to find the crushing strength of cement and sand mixed in the proportion of 1 to 3. The following six results were obtained: 1,420, 1,380, 1,460, 1,430, 1,400 and 1,410 lb. per sq. in. respectively. What was the average crushing strength of the mixture?

SOLUTION.	1420
	1380
	1460
	1430
	1400
	1410
	—
	<u>6/8500</u>
	<u>1416$\frac{2}{3}$</u> = 1416.6 lb. per sq. in. <i>Ans.</i>

MODERN BUILDING CONSTRUCTION

RATIO

30. A ratio between two quantities of the same kind is the relation that one bears to the other with regard to magnitude.

$$1 \text{ in.} = \frac{1}{6} \text{th of } 6 \text{ in.}$$

Therefore the ratio between 1 in. and 6 in. is $\frac{1}{6}$, or one to six; and can be expressed either as $\frac{1}{6}$ or 1 : 6.

The ratio of 5s. to £2 is $\frac{5}{40} = \frac{1}{8}$ or 1 : 8.

The ratio of 3 in. to 2 ft. 6 in. is $\frac{3}{30} = \frac{1}{10}$ or 1 : 10.

These ratios are of *less inequality*.

A ratio of 2 ft. 6 in. to 3 in. = $\frac{30}{3} = 10$; and is of *greater inequality*.

A ratio of 3 tons to 60 cwt. = $\frac{60}{60} = 1$; and is of *equality*.

The numerator of the ratio is called the *antecedent*.

The denominator of the ratio is called the *consequent*.

A ratio and a fraction mean practically the same thing, hence the rules applicable to one are applicable to the other.

RULES. 1. *If we multiply antecedent and consequent by the same quantity the ratio is not altered.*

2. *If we divide antecedent and consequent by the same quantity the ratio is not altered.*

3. *If we add the same quantity to antecedent and consequent the ratio is altered.*

4. *If we subtract the same quantity from antecedent and consequent the ratio is altered.*

i.e. $\frac{1+3}{2+3} = \frac{4}{5}$, which is greater than $\frac{1}{2}$.

$$\frac{3-2}{4-2} = \frac{1}{2}$$
, which is less than $\frac{3}{4}$.

EXAMPLE. The ratio of A's work to B's work is 3 : 4. B lays 300 sq. ft. of floor boards in a day. How many square feet will A lay ?

SOLUTION. A will lay $\frac{3}{4}$ of 300 = 225 sq. ft. *Ans.*

EXAMPLE. A house is drawn to a scale of $\frac{1}{4}$ in. = 1 ft. What is the representative fraction of the scale ?

SOLUTION. $\frac{1}{4} : 12$, or $\frac{1}{48} = \frac{1}{4} \times \frac{1}{12} = \frac{1}{48}$ *Ans.*

It is often necessary to find the greatest of several ratios, we then bring all the ratios to a common denominator.

EXAMPLE. Arrange the following ratios in descending order of magnitude: $\frac{1}{12}$, $\frac{1}{8}$, $\frac{1}{24}$, $\frac{1}{16}$, $\frac{1}{32}$. Bringing the ratios to a common denominator we have—

SOLUTION. $\frac{28}{64}$, $\frac{24}{64}$, $\frac{18}{64}$, $\frac{15}{64}$, $\frac{40}{64}$, $\frac{17}{64}$

∴ the ratios, in descending order, are $\frac{1}{8}$, $\frac{1}{12}$, $\frac{1}{24}$, $\frac{1}{16}$, $\frac{1}{32}$.

PERCENTAGES

31. When the consequent of a ratio is 100, we omit it, and speak of the antecedent as a *percentage*. Thus $\frac{3}{100}$ is three per cent, and is written 3%. Therefore when we speak of 3% of a quantity, we mean 3 parts out of every 100 parts.

∴ 3% of 1 cwt.

$$= \frac{3}{100} \text{ of } 112 \text{ lb.} = \frac{3 \times 112}{100} = \underline{3.36 \text{ lb.}}$$

EXAMPLE. A builder buys a standard of timber (165 cub. ft.) for £33. He considers that 5 per cent is waste. What must he charge for 10 ft. × 11 in. × 1½ in. to give him a profit of 20 per cent ?

SOLUTION.

$$5\% \text{ waste} = \frac{5}{100} \text{ of } 165 = 8.25 \text{ cub. ft.}$$

$$\therefore \text{Remainder} = 165 - 8\frac{1}{4} = 156\frac{3}{4} \text{ cub. ft.}$$

$$\therefore \text{Cost price per foot cube} = \frac{£33}{156.75} = 50\frac{1}{2} \text{ pence.}$$

$$20\% \text{ profit} = \frac{20}{100} = \frac{1}{5} \text{ of } 50.5 \text{d.} = 10 \text{d. approx.}$$

$$\therefore \text{Selling price} = 50\frac{1}{2} + 10 \text{ pence} = 58 \text{d.}$$

$$\text{But } 10 \text{ ft.} \times 11 \text{ in.} \times 1\frac{1}{2} \text{ in.} = 165 \text{ cub. ft.}$$

$$\therefore \text{Cost of } 10 \text{ ft.} \times 11 \text{ in.} \times 1\frac{1}{2} \text{ in.} = \frac{55}{48} \text{ of } \frac{60.5}{1}$$

$$= 58 \text{d. approx. } \underline{\text{Ans.}}$$

PROPORTION

32. When one ratio equals another ratio, we have to consider four quantities or terms, and these four terms are said to be *in proportion*.

Thus, 3 : 4 :: 6 : 8 gives four quantities in proportion.

Another method of stating the same thing is $\frac{3}{4} = \frac{6}{8}$.

In both cases we read "three is to four as six is to eight."

The *first* two terms, or quantities, should be of the same kind.

The *last* two terms, or quantities, should be of the same kind.

i.e. 3 lb. : 4 lb. :: 6s. : 8s.

Or 3 ft. : 4 ft. :: 6d. : 8d.

MEANS

EXTREMES.

In all cases of proportion the product of the extremes equals the product of the means.

$$\text{Since } \frac{3}{4} = \frac{6}{8} \therefore \frac{3 \times 8}{4 \times 8} = \frac{6 \times 4}{8 \times 4}$$
, hence the

denominators are equal and can be removed,

$$\text{i.e. } \frac{3 \times 8}{32} = \frac{6 \times 4}{32}$$

BUILDING CALCULATIONS

Therefore $3 \times 8 = 6 \times 4$. Hence if any one term is unknown it can be found.

EXAMPLE. 12 sq. ft. of flooring cost 7s. 6d.; what will 15 sq. ft. cost?

SOLUTION. $12 : 15 :: 7s. 6d. : \text{Answer.}$

$$\therefore 12 \times A = 15 \times 7s. 6d.$$

$$\therefore A = \frac{15 \times 7\frac{1}{2}}{12} \text{ (dividing both sides by 12).}$$

$$\therefore A = \frac{37\frac{1}{2}}{4} = 9\frac{3}{8}s. = \underline{9s. 4\frac{1}{2}d.} \text{ Ans.}$$

This process is known as finding the *fourth proportional*.

Third Proportional. When we are given two quantities and are required to find a third bearing a similar proportion we call the process finding the *third proportional*.

EXAMPLE. Given two quantities 5 and 12, to find a third proportional.

SOLUTION. $5 : 12 :: 12 : \text{Answer.}$

$$\text{Hence } 5 \times \text{Ans.} = 12 \times 12 \therefore \text{Ans.} = \frac{144}{5} = 28\frac{4}{5}.$$

Mean Proportional. When the means are both alike, the number is a *mean proportional*; that is, 12 is a mean proportional between 5 and $28\frac{4}{5}$.

EXAMPLE. Find a mean proportional to 4 and 25.

SOLUTION. $4 : \text{Answer} :: \text{Answer} : 25.$

$$\therefore \text{Ans.} \times \text{Ans.} = 4 \times 25 = (2 \times 2) \times (5 \times 5) \\ = (2 \times 5) \times (2 \times 5)$$

$$\therefore \text{Answer} = (2 \times 5) = 10.$$

EXAMPLE. Sheet lead is £49 10s. per ton; what is the cost of 16 cwt.?

SOLUTION. $20 \text{ cwt.} : 16 \text{ cwt.} :: £49\frac{1}{2} : \text{Answer.}$

$$\therefore \text{Answer} = \frac{16 \times 49\frac{1}{2}}{20} = £39\text{.}6 = \underline{£39 \text{ 12s.}}$$

Unitary Method. This is an alternative method for solving the above types of question.

EXAMPLE. If 12 yd. of c.i. drain pipe cost £2 18s., what will 15 yd. cost?

SOLUTION. 12 yd. cost 58s.

$$\therefore 1 \text{ yd. costs } \frac{58s.}{12}$$

$$\therefore 15 \text{ yd. cost } \frac{58}{12} \times 15 = \frac{145}{2} \\ = \underline{£3 \text{ 12s. 6d.}} \text{ Ans.}$$

MISCELLANEOUS EXAMPLES IN PROPORTION

EXAMPLE 1. A concrete consists of one part cement, three parts sand, and four parts broken ballast. What is the percentage of each material in the mixture?

SOLUTION. The total number of parts = $1 + 3 + 4 = 8$.

$$\therefore \text{Cement} = \frac{1}{8}, \text{ sand} = \frac{3}{8}, \text{ ballast} = \frac{4}{8}.$$

$$\therefore \text{Total} = \frac{1}{8} + \frac{3}{8} + \frac{4}{8} = \frac{12\cdot5 + 37\cdot5 + 50}{100}$$

\therefore The mixture consists of $\left. \begin{array}{l} 12\frac{1}{2}\% \text{ cement} \\ 37\frac{1}{2}\% \text{ sand} \\ 50\% \text{ ballast} \end{array} \right\} \text{Ans.}$

EXAMPLE 2. Four houses with frontages of 16 ft., 18 ft., 20 ft., and 22 ft. respectively, have to share the cost of levelling up the roadway, which amounted to £47 ros. Find the cost to each house.

SOLUTION. Total frontage = $16 + 18 + 20 + 22 = 76 \text{ ft.}$

One foot of frontage costs $£ \frac{47\cdot5}{76} = \frac{950s.}{76} = 12s. 6d.$

$$\begin{array}{l} \therefore \text{1st house costs } \frac{1}{4} \text{ of } £47\frac{1}{2} \text{ or } 16 \times 12/6 \\ \qquad \qquad \qquad = £10 \\ \therefore \text{2nd house costs } \frac{1}{4} \text{ of } £47\frac{1}{2} \text{ or } 18 \times 12/6 \\ \qquad \qquad \qquad = £11 \text{ 5s.} \\ \therefore \text{3rd house costs } \frac{1}{4} \text{ of } £47\frac{1}{2} \text{ or } 20 \times 12/6 \\ \qquad \qquad \qquad = £12 \text{ 10s.} \\ \therefore \text{4th house costs } \frac{1}{4} \text{ of } £47\frac{1}{2} \text{ or } 22 \times 12/6 \\ \qquad \qquad \qquad = £13 \text{ 15s.} \end{array} \left. \vphantom{\begin{array}{l} \therefore \text{1st house costs} \\ \therefore \text{2nd house costs} \\ \therefore \text{3rd house costs} \\ \therefore \text{4th house costs} \end{array}} \right\} \text{Ans.}$$

EXAMPLE 3. Three men, A, B, and C, enter into partnership. A puts £2,000 into the business; B, £1,500; and C, £1,000. They arrange to divide the profits in proportion to their respective capitals. If the profits, at the end of the first year, were 20 per cent of the capital, what were the respective amounts received by A, B, and C?

SOLUTION. Total amount = £4,500. \therefore profits = $\frac{20}{100}$ of £4,500 = £900. But their respective capitals were in the proportion of 4 : 3 : 2.

$$\begin{array}{l} \therefore \text{A received } \frac{4}{9} \text{ of } £900 = £400 \\ \therefore \text{B received } \frac{3}{9} \text{ of } £900 = £300 \\ \therefore \text{C received } \frac{2}{9} \text{ of } £900 = £200 \end{array} \left. \vphantom{\begin{array}{l} \therefore \text{A received} \\ \therefore \text{B received} \\ \therefore \text{C received} \end{array}} \right\} \text{Ans.}$$

EXAMPLE 4. If 16 men can do a piece of work in 24 days, how long will it take 36 men to do the same work?

SOLUTION.

16 men do the work in 24 days.

\therefore 1 man will do the work in (24×16) days.

$$\therefore 36 \text{ men will do the work in } \frac{24 \times 16}{36} = \frac{32}{3} \\ = \underline{10\frac{2}{3} \text{ days.}} \text{ Ans.}$$

EXAMPLE 5. A contractor agrees to complete the brickwork of a building in five months. At the end of three months, with 30 men, he finds that only half the work is completed. How many more men are required to complete the work to time?

SOLUTION.

30 men do $\frac{1}{2}$ the work in 3 months

1 man does $\frac{1}{2}$ the work in $3 \times 30 = 90$ months

$\therefore x$ men will do $\frac{1}{2}$ the work in $\frac{90}{x}$ months

but $\frac{90}{x}$ must equal 2 months, $\therefore x = 45$

\therefore 15 more men are required to complete the contract to time.

33. Similar Areas and Volumes. The two following important theorems enable us to solve many practical problems by proportion.

MODERN BUILDING CONSTRUCTION

1. The areas of similar plane surfaces are in proportion to the squares of their linear dimensions.

2. The volumes of similar solids are in proportion to the cubes of their linear dimensions.

If we had two similar rectangles with short sides 3 ft. and 5 ft. respectively, then their areas would be in the proportion of $3^2 : 5^2$; hence if the area of the small rectangle be 30 sq. ft., the area of the large rectangle will be found as follows—

$$30 \text{ sq. ft.} : x \text{ sq. ft.} :: 3^2 : 5^2, \therefore 9x = 25 \times 30$$

$$\therefore x = \frac{25 \times 30}{9} = \frac{250}{3} = \underline{83\frac{1}{3} \text{ sq. ft.}}$$

If we consider these two rectangles as the sides of two similar boxes, and the volume of one box is 90 cub. ft., then the volume of the other box will be found as follows—

$$90 \text{ cub. ft.} : x \text{ cub. ft.} :: 3^3 : 5^3$$

(NOTE. $3^3 = 3 \times 3 \times 3 = 27$, $5^3 = 5 \times 5 \times 5 = 125$.)

$$\text{Hence } 27x = 125 \times 90, \therefore x = \frac{125 \times 90}{27}$$

$$= \frac{1250}{3} = \underline{416\frac{2}{3} \text{ cub. ft.}}$$

These two rules are important, because the cost of many processes will be proportional to the area; hence if the cost of one job is known, the cost of a similar job may be found by substituting cost in place of area or volume in the above proportion.

EXAMPLE. The painting of a dome of 4 ft. diameter cost £4 10s. What will be the cost of doing the same work to a similar dome of 8 ft. diameter?

SOLUTION.

Area of first dome is proportional to 4^2

Area of 2nd dome is proportional to 8^2

$$\therefore 4^2 : 8^2 :: £4\frac{10}{20} : £x$$

$$\therefore 16x = 64 \times 4\frac{10}{20}, \therefore x = \frac{64 \times 4\frac{10}{20}}{16} = £18$$

EXERCISE V (Answer: on page 21)

1. Four boards measure 7 ft. 6 in., 10 ft. 6 in., 13 ft. 6 in., and 15 ft. 6 in. respectively. Find the average length of the boards.

2. Express the ratio of 7s. 6d. to £2.

3. Find the cost of 10 ft. \times 9 in. \times 3 in., when a standard of timber, of 165 cub. ft., costs £32. Allow 5 per cent for waste timber and 25 per cent for profit.

4. One pipe can fill a cistern in 20 minutes, another pipe can fill it in 25 minutes. How long will it take both pipes together to fill the cistern?

Hint. One pipe fills $\frac{1}{20}$ th of cistern in 1 minute.

2nd pipe fills $\frac{1}{25}$ th of cistern in 1 minute.

\therefore Both pipes fill $\frac{1}{20} + \frac{1}{25}$ of cistern in 1 minute.

ANSWERS TO EXERCISE IV (page 15)

(1) 10 tons, 4 cwt., 2 qr., 6 lb.

(2) 56,250 sq. yd., or 11 a. 2 r. 19 sq. p. $15\frac{1}{2}$ sq. yd.

(3) 12.036 frs. per sq. metre.

DUODECIMALS

34. ALTHOUGH the decimal or metric system simplifies calculation, the building trades generally use the British system. This involves bringing the dimensions to the same unit, which often entails a large amount of unnecessary labour. To avoid this waste of time, *duodecimals* are used as a substitute for decimals, whilst still retaining the English standard of measurement.

The method is to use *subdivisions* of 12, instead of 10 as in decimals, with the foot as the unit of measurement.

In Fig. 4 the square *ABCD* represents 1 sq. ft. The rectangle *EFCD* = $\frac{1}{12}$ sq. ft. = 12 sq. in.

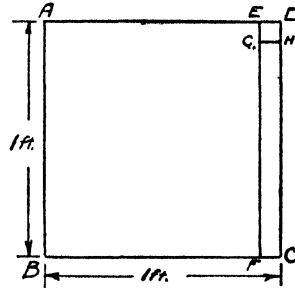


FIG. 4

The square *EGHD* = one-twelfth of $\frac{1}{12}$ sq. ft. = $\frac{1}{144}$ sq. ft. = 1 sq. in.

Hence the diagram shows three different units, each one-twelfth of the preceding one.

The *first unit* is 1 sq. ft., and is used as the unit of the system. The *second unit* is called a *prime*, or *part*, and is denoted by one dash, that is, six primes are shown by 6'. The *third unit* is a *second*, and is denoted by two dashes. A further subdivision is a *third*, and so on. (The three units are usually called feet, parts, inches.)

The terms are also applied to linear and cubic measurements—

A *linear prime* is one-twelfth of a foot; a *linear second* is one-twelfth of an inch.

A *square*, or *superficial*, *prime* is one-twelfth of a square foot.

A *square second* is one-twelfth of a square prime = one-twelfth of 12 sq. in. = 1 sq. in.

A *cubic prime* is one-twelfth of a cubic foot (one-twelfth of 1,728 cub. in.) = 144 cub. in.

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A *cubic second* is one-twelfth of 144 cub. in. = 12 cub. in.

A *cubic third* is one-twelfth of 12 cub. in. = 1 cub. in.

The cubic values are illustrated in Fig. 4A, which shows a cubic foot, or $12 \times 12 \times 12$ cub. in.

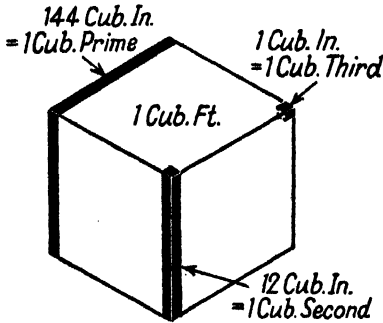


FIG. 4A

The conversion of linear dimensions is as follows: 7 ft. $5\frac{3}{4}$ in. is 7 ft. 5 primes 9 seconds, and is denoted by 7 ft. 5' 9".

For square or superficial measurements: 3 sq. ft. 74 sq. in. = 3 sq. ft. (72 + 2) sq. in. = 3 sq. ft. 6 primes 2 seconds = 3 sq. ft. 6' 2".

For cubic measurements: 5 cub. ft. 532 cub. in. = 5 cub. ft. (432 + 96 + 4) cub. in. = 5 cub. ft. 3' 8" 4".

35. Multiplication. Note that two linear dimensions multiplied together produce square or superficial values. A square measurement and a linear measurement multiplied together give a cubic value—

$$\begin{aligned} 1 \text{ ft.} \times 1 \text{ in.} &= 1 \text{ ft.} \times 1 \text{ linear prime} \\ &= 1 \text{ ft.} \times 1\frac{1}{12} \text{ ft.} = 1\frac{1}{12} \text{ sq. ft.} \\ &= 1 \text{ square prime} = 12 \text{ sq. in.} \end{aligned}$$

$$\begin{aligned} 1 \text{ ft.} \times 1\frac{1}{12} \text{ in.} &= 1 \text{ ft.} \times 1 \text{ linear second} \\ &= 1 \text{ ft.} \times \frac{1}{12^2} \text{ sq. ft.} = 1\frac{1}{144} \text{ sq. ft.} \\ &= 1 \text{ square second} = 1 \text{ sq. in.} \end{aligned}$$

A linear prime multiplied by a linear prime
= 1 square second—

$$\text{i.e. } 1' \times 1' = 1'' \text{ (square second).}$$

A linear prime multiplied by a linear second
= 1 square third—

$$\text{i.e. } 1' \times 1'' = 1''' \text{ (square third).}$$

NOTE. A linear prime is denoted in the same way as a square prime, but this should not confuse the student, because the first term makes the remainder of the expression clear; i.e.

$$5 \text{ ft. } 7', 5 \text{ sq. ft. } 7', 5 \text{ cub. ft. } 7'.$$

EXAMPLE. Find the area of a window 4 ft. 9 in. \times 3 ft. 6 in.

SOLUTION. 4 ft. 9 in. = 4 ft. 9', and 3 ft. 6 in. = 3 ft. 6".

WORKING.

$$\begin{array}{r} 4 \text{ ft. } 9' \\ 3 \text{ ft. } 6'' \\ \hline 14 \text{ sq. ft. } 3' \quad (\text{multiplying } 4 \text{ ft. } 9' \text{ by } 3 \text{ ft.}) \\ 2 \text{ sq. ft. } 4' 6'' \quad (\text{multiplying } 4 \text{ ft. } 9' \text{ by } 6'') \\ \hline 16 \text{ sq. ft. } 7' 6'' = 16 \text{ sq. ft. } 7 \text{ primes } 6 \text{ seconds} \\ = 16 \text{ sq. ft.} + (1\frac{7}{12} + 1\frac{6}{144}) \text{ sq. ft.} = 16\frac{90}{144} \text{ sq. ft.} \\ = 16 \text{ sq. ft. } 90 \text{ sq. in. } \textit{Ans.} \end{array}$$

EXPLANATION. (1) 9 primes \times 3 ft. = 27 sq. primes = 2 sq. ft. 3'. Carry the 2 sq. ft. to the next column. (2) 4 ft. \times 3 ft. = 12 sq. ft., adding the 2 sq. ft. = 14 sq. ft., therefore the first line of working = 14 sq. ft. 3 primes. (3) 9' \times 6" = 54 sq. seconds = (48 + 6) sq. seconds = 4' 6". Carry forward the 4 sq. primes. (4) 4 ft. \times 6 primes = 24 sq. primes, adding 4' from the previous column = (24 + 4) sq. primes = 2 ft. 4'. (5) Add together the lines of working.

EXAMPLE. Find the area of a floor 42 ft. 10 $\frac{1}{2}$ in. by 21 ft. 10 $\frac{1}{2}$ in.

SOLUTION.

Feet	Primes	Seconds		
42	10	6		
21	10	3		
<hr/>				
900	4	6		
35	8	9	0	
	10	7	7	6
<hr/>				
936	11'	10"	7'''	6''''

$$= 936 \text{ sq. ft.} + \left(\frac{11}{12} + \frac{10}{12^2} + \frac{7}{12^3} + \frac{6}{12^4} \right) \text{ sq. ft.}$$

$$\begin{aligned} &= 936 \text{ sq. ft.} + 11 \times 12 \text{ sq. in.} + 10 \text{ sq. in.} + \frac{7\frac{1}{2}}{12} \text{ sq. in.} \\ &= 936 \text{ sq. ft. } 142\frac{1}{2} \text{ sq. in. } \textit{Ans.} \end{aligned}$$

In practice, this would be considered as 937 sq. ft. Usually, values less than seconds in linear, thirds in square, and fourths in cubic measurements, may be neglected. For building calculations even more approximate answers are usually satisfactory.

EXAMPLE. Find the volume of a concrete lintel 9 ft. 3 $\frac{1}{2}$ in. by 8 $\frac{1}{2}$ in. by 6 $\frac{1}{2}$ in.

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SOLUTION.

$$\begin{array}{r}
 \text{Multiply by } \begin{array}{r} 9 \quad 3 \quad 6 \\ 0 \quad 6 \quad 3 \end{array} \\
 \hline
 4 \quad 7 \quad 9 \quad 0 \\
 \quad 2 \quad 3 \quad 10 \quad 6 \\
 \hline
 \text{Multiply by } \begin{array}{r} 4 \quad 10 \quad 0 \quad 10 \quad 6 \\ 0 \quad 8 \quad 6 \end{array} \\
 \hline
 3 \quad 2 \quad 8 \quad 7 \quad 0 \quad 0 \\
 \quad 2 \quad 5 \quad 0 \quad 5 \quad 3 \quad 0 \\
 \hline
 3 \quad 5' \quad 1'' \quad 7''' \quad 5'''' \quad 3''''
 \end{array}$$

$$\begin{aligned}
 &= 3 \text{ cub. ft.} + \left(\frac{5}{12} + \frac{1}{12^2} + \frac{7}{12^3} \right) \text{ cub. ft.} \\
 &\quad + \left(\frac{5}{12} + \frac{3}{12^2} \right) \text{ cub. in.} \\
 &= 3 \text{ cub. ft.} + \left(\frac{720 + 12 + 7}{1728} \right) \text{ cub. ft.} \\
 &\quad + \frac{720 + 36}{1728} \text{ cub. in.} \\
 &= 3 \frac{749}{1728} \text{ cub. ft.} + \frac{756}{1728} \text{ cub. in.} \\
 &= 3 \text{ cub. ft. } 739 \frac{1}{8} \text{ cub. in.} \\
 &\quad = \text{Approx. } 3 \frac{3}{8} \text{ cub. ft. } \text{ Ans.}
 \end{aligned}$$

When the student is familiar with the method the intermediate steps are not necessary.

36. Division. Divide 16 sq. ft. 90 sq. in. by 3 ft. 6 in.

$$\begin{array}{r}
 3 \text{ ft. } 6' \overline{) 16 \text{ sq. ft. } 9' 6''} \\
 \underline{14 \text{ sq. ft. } 0} \\
 2 \text{ sq. ft. } 7 \quad 6 \\
 \underline{2 \text{ sq. ft. } 7 \quad 6} \\
 0
 \end{array}$$

EXPLANATION. (1) See how many times 3 ft. 6' will go into 16 ft. 7', say four times. (2) Multiply 3 ft. 6' by 4 ft. = 14 sq. ft. (3) Subtract, giving a remainder of 2' 7'. (4) How many times will 3 ft. 6' go into 2' 7' 6''; say 9' times? (5) Multiply 3 ft. 6' by 9' = 2' 7' 6''. (6) Subtract.

There is no remainder, therefore 4 ft. 9 in. is the answer, i.e. 4 ft. 9 in. \times 3 ft. 6 in. = 16 sq. ft. 90 sq. in.

EXAMPLE. 27 cub. ft. of concrete is used for a foundation; the depth is 18 in. and the length is 4 ft. 2 in. Find the breadth.

SOLUTION.

$$\begin{array}{r}
 4 \cdot 2' \\
 1 \cdot 6' \\
 \hline
 4 \cdot 2 \\
 2 \cdot 1 \cdot 0 \\
 \hline
 6 \cdot 3 \cdot 0'' \overline{) 27 \cdot 0' \cdot 0''} \\
 \underline{25 \cdot 0 \cdot 0} \\
 2 \cdot 0 \cdot 0 \\
 \underline{18 \cdot 9 \cdot 0} \\
 5 \cdot 3 \cdot 0 \\
 \underline{5 \cdot 2 \cdot 6 \cdot 0} \\
 0 \cdot 0 \cdot 6 \cdot 0
 \end{array}$$

$4 \cdot 3' \cdot 10'' = 4 \text{ ft. } 3 \frac{5}{8} \text{ in. } \text{ Ans.}$

Values lower than one-twelfth of an inch may be ignored, so that the answer is—

$$4 \text{ ft. } 3 \frac{5}{8} \text{ in.} = \text{Approx. } 4 \text{ ft. } 4 \text{ in.}$$

SIMPLE AND COMPOUND INTEREST

37. When a person lends money he expects to be recompensed for the loan. The recompense, which is called *interest*, varies according to the security offered by the borrower. For instance, the banks will lend money at a low *rate of interest* but they demand security, which may be in the form of deeds for property, etc.; on the other hand, a moneylender will charge a high rate of interest, because in many cases he is uncertain of the return of his money.

When the arrangement is to pay a certain number of pounds each year, for every £100 borrowed, it is known as *simple interest*. Therefore simple interest is a yearly percentage on the borrowed money, which is called the *principal*.

EXAMPLE. A man borrows £1,800 at the rate of 5 per cent per annum. What will he owe: (a) at the end of twelve months; (b) at the end of eight months?

SOLUTION.

$$(a) \text{ Simple Interest} = 5\% \text{ of } \pounds 1800 = \frac{5}{100} \times \frac{1800}{1} = \pounds 90 \text{ at the end of 12 months.}$$

$$\text{Therefore he owes } \pounds 1800 + \pounds 90 = \pounds 1890$$

$$(b) \text{ Simple Interest} = \frac{5}{100} \times \frac{1800}{1} \times \frac{8}{12} = \pounds 60 \text{ at the end of 8 months.}$$

$$\text{Therefore he owes } \pounds 1800 + \pounds 60 = \pounds 1860 \text{ at the end of 8 months}$$

From the foregoing example, it is evident that simple interest = rate per cent \times principal \times time—

$$\text{S.I.} = \frac{P \times r \times T}{100}$$

38. Compound Interest. In the last case, the man owed £1,890 at the end of a year. Now, if he repaid the loan, the owner could lend the money again, but this time he could lend £1,890. Obviously, if the borrower wishes to retain the money for another year, he should pay interest on £1,890, that is on the £1,800 + the added interest. Therefore, at the end of the second year, the interest will be—

$$\frac{5}{100} \text{ of } \frac{1890}{1} = \pounds 94 \text{ 10s.}$$

Therefore, at the end of the second year, he owes—

$$\pounds 1800 + 90 + 94 \frac{1}{2} = \pounds 1984 \text{ 10s.}$$

We could proceed in this manner to find the interest owing after any number of years. Interest accumulated in this way is called *compound interest*. The method of calculation just given is very tedious so we use the formula—

Amount, at the end of T years

$$= P \left(1 + \frac{r}{100} \right)^T$$

where r = rate of interest

and P = principal

EXAMPLE. A builder erects six houses and can sell them for £4,200. If he lets them, the rents, after deducting for rates, depreciation, repairs, etc., will amount to £210 per annum. Which will give the greater financial return at the end of three years: to sell and invest the money at 5 per cent compound interest; or let, and invest the rents at the same rate of interest?

SOLUTION. If he sells, the amount after three years

$$= P \left(1 + \frac{r}{100} \right)^3$$

Therefore

$$A = 4200 \left(1 + \frac{5}{100} \right)^3 = 4200 \times (1.05)^3 \\ = 4200 \times 1.157625 = £4862$$

If he lets, the first year's rents (invested at the end of the first year) after two years will equal

$$210 \left(1 + \frac{5}{100} \right)^2 = 210 \times 1.1025 = £231.525$$

And the second year's rents, after one year, will equal

$$210 \left(1 + \frac{5}{100} \right)^1 = 210 \times 1.05 = £220.5$$

And the third year's rents (which have no added interest) will = £210.

Adding these three sums to the value of the property, we have

$$£4200 + £231.525 + £220.5 + £210 = £4862 \text{ os. } 6d.$$

Therefore, there is an advantage of 6d. by letting the houses; but this advantage would be considerably increased if he invested the rents as he received them, say monthly.

The compound interest formula may also be given as $A = PR^T$, where $R = \left(1 + \frac{r}{100} \right)$. The

value R is called the *growth factor* if $\left(1 + \frac{r}{100} \right)$ is greater than 1, and the *decay factor* if less than 1, as in the case of depreciation. Examples will be given in the chapter on logarithms as they are required in the solutions.

EXERCISE VI (Answers on page 22)

1. Find the amount of money that a man invests, at the rate of $4\frac{1}{2}$ per cent compound interest, if he has £500 at the end of three years.

2. Find the simple interest on £325 7s. 6d. at $4\frac{1}{2}$ per

cent for nine months.

3. Find, by duodecimals, the cost of a block of stone 4 ft. $7\frac{1}{2}$ in. \times 3 ft. 4 in. \times 2 ft. 3 in. at 4s. 4d. per cubic foot.

ANSWERS TO EXERCISE V (page 18)

1. 11 ft. 9 in.
2. $\frac{1}{15}$.
3. 9s. 7d.
4. $11\frac{1}{2}$ minutes.

POWERS AND ROOTS

39. **Involution.** When a number is multiplied by itself, the product is the *square*, or *second power*; that is, 36 is the second power of 6 , and is written 6^2 (read "six squared"). The small number is called the *index* (plural indices), and denotes the power to which the number has to be raised.

In the same way, 6^3 (read "six cubed") = $6 \times 6 \times 6 = 216$. Also, 4^6 (read "four to the sixth power") = $4 \times 4 \times 4 \times 4 \times 4 \times 4 = 4^2 \times 4^2 \times 4^2 = 4^3 \times 4^3 = 4096$.

The process of raising quantities to any given power is called *involution*.

40. **Evolution.** The reverse process to involution is known as *extracting the root*, or *evolution*. The method of denoting evolution is by the sign $\sqrt{\quad}$ (called the radical sign); thus $\sqrt{36}$ (which is read as "the square root of 36") = 6 , because $6 \times 6 = 36$.

When the *cube root* is required, or *any root* other than the square root, a small figure is *added to the sign*; that is, $\sqrt[3]{216}$ (read "the cube root of 216") = 6 ; because $6 \times 6 \times 6 = 216$.

No special name is given after the cube root; that is, $\sqrt[4]{16}$ (read "the fourth root of 16") = 2 ; because $2 \times 2 \times 2 \times 2 = 16$.

To raise a number to any power simply entails multiplication, but to extract the root of a number requires special methods, unless the root is evident, as

$$\sqrt{4} = 2, \quad \sqrt{9} = 3, \quad \sqrt[3]{27} = 3, \text{ etc.}$$

EXAMPLE. Find the square root of 190096.

SOLUTION.

Divisor	Number Square root
	19'00'96(436 Ans.
4	16 . . . <u> </u>
	3 00 ..
83	2 49 ..
	51 96
866	51 96
	<u> </u>

MODERN BUILDING CONSTRUCTION

EXPLANATIONS. (1) Mark off the figures in pairs from the units figure.

(2) Find a number, whose square is *nearly* equal to the first group on the left; in this case it is 4, because $4 \times 4 = 16$.

(3) Place the 4 in the square root, and also under divisor.

(4) Square the 4 and subtract from 19; then bring down the next pair of digits, which will give 300 for the next dividend.

(5) Find a new divisor, by doubling that part of the square root already found; in this case it is 4. Then the first digit of the second divisor will be 8.

(6) Try a number which, when placed after the 8, will give a complete divisor to divide into 300; the complete divisor is then multiplied by this trial number. In this case it is 3; therefore $83 \times 3 = 249$.

(7) Subtract 249 from 300, and bring down another pair of digits.

(8) Double that part of the square root already found, i.e. $43 \times 2 = 86$, and then proceed as before.

EXAMPLE. Find the square root of 258,5664.

RULE. Mark off the pairs of digits, left and right of the decimal point.

SOLUTION.

Divisor	Number	Square root
	2'58-56'64	(16-08 Ans.)
1	1	
	1 58	
26	1 56	
	2 56 64	
	2 56 64	
{ 320		
{ 3208		

Note. When we reach the decimal point in the dividend, we place a decimal point in the square root.

41. Cube Root.

EXAMPLE. Evaluate $\sqrt[3]{41,063,625}$.

To Obtain Divisor	Number	Cube Root
1st divisor = 3		
$30^3 \times 3 = 2700$	$41'063'625$	(345)
$30 \times 3 \times 4 = 360$		27 . . .
$4^3 = 16$		14 063 . . .
2nd divisor = 3076		12 304 . . .
		340^3 \times 3 = 346800
$340 \times 3 \times 5 = 5100$		1 759 625
$5^3 = 25$		1 759 625
		351925

EXPLANATIONS. (1) Mark off in groups of threes from the units column. If the number contains a decimal point, then mark off each way from the decimal point.

(2) Find a number which when cubed will nearly equal the first group on the left; in this case it is 3, because $3^3 = 27$, and 4^3 would be too large.

(3) Place 3 in the root; cube it and subtract from 41.

(4) Bring down the next group to give a new dividend of 14063.

(5) For a new divisor, take that part of the root already found (in this case 3), multiply it by 10, square it, and then multiply by 3, i.e. $(30)^2 \times 3 = 2700$.

Now add to 2700, $30 \times 3 \times$ (a trial number). The trial number is placed in the root. Now square the trial number and add to the quantities already found. In this case the trial number is 4; therefore we have $(30^2 \times 3) + (30 \times 3 \times 4) + 4^3 = 2700 + 360 + 16 = 3076$, which is the new divisor.

(6) Multiply the new divisor by 4 and subtract from 14063.

(7) Bring down the next group 625, and proceed as before. This time the partial root is 34; hence we have, by using 5 as a trial number, $(34 \times 10)^2 \times 3 + (340 \times 3 \times 5) + 5^3 = 351925$. Multiply this quantity by 5 and subtract; there is no remainder, therefore 345 is the cube root.

(8) If there be a remainder, repeat the process as often as is necessary, placing the decimal point in the root as we come to it in the dividend.

For further consideration of evolution, see "Algebra" and "Logarithms," to be dealt with later; but notice that—

The square root of the square root = the 4th root.

" cube " " " " = " 6th root, etc.

If the root cannot be exactly solved, it is called a **SURD**; that is, $\sqrt{2} = 1.414 \dots$, hence $\sqrt{2}$ is a **SURD**.

EXERCISE VII (Answers on page 26)

1. Find the square root of 149,312 to five significant figures.

2. Evaluate $\frac{\frac{3}{4} + \frac{7}{17} \times \frac{8}{11} + \frac{1}{16}}{\frac{1}{10} + \frac{1}{7} \times \frac{8}{11} + \frac{1}{18}}$

3. If 17 men can do a piece of work in 30 days, how long will it take to finish the work, if 9 men leave after working 12 days?

Hint. When 9 men leave, $\frac{3}{8}$ ths of the work remains to be done, therefore 8 men do $\frac{3}{8}$ ths of the work. Also one man does the whole of the work in 30×17 days.

4. A square field has an area of 3 acres 1105 sq. yd. How many yards of fencing will be required to go round the field?

5. A row of houses is 200 yd. long; the roof, from eaves to ridge, is 18 ft. at the front, and 17 ft. at the back. Find (a) the area of the roof surface; (b) the number of slates (Countesses), when 170 slates = a square of 100 sq. ft.; (c) the weight of slates when 1,200 slates weigh 2 tons.

6. Find the cost of painting the walls and ceiling of a room 18 ft. \times 14 ft. \times 10 ft. high, at 2s. 3d. per sq. yd.; not including the door and window, which together equal 4 sq. yd.

7. A floor measures $25\frac{1}{2}$ feet. \times $19\frac{1}{2}$ ft. Find the number of wood blocks, $9\frac{1}{2}$ in. \times $4\frac{1}{2}$ in., required to cover the floor.

ANSWERS TO EXERCISE VI (page 21)

1. £438 4s.
2. £10 19s. 7½d.
3. £7 10s. 3½d.

Chapter III—ALGEBRA (I)

42. ALGEBRA is generalised arithmetic; instead of saying that the area of a *particular* floor is 14 ft. \times 12 ft., we can say that the area of *any* rectangular floor is *length* \times *breadth*, or $L \times B$. Thus the symbols used in algebra are letters, usually from our own alphabet; otherwise the operations used in arithmetic apply equally to algebra. We may let any letter represent any value, or any thing, and it may represent different values in different examples, but it must stand for the *same value* in the *same example*.

The number of cubic feet of brickwork in a wall may be represented by $L \times H \times T$, if the symbols represent feet; but we can put the same formula in even more general terms, thus—

$$\text{Volume} = \text{Length} \times \text{Height} \times \text{Thickness},$$

$$\text{or } V = L \times H \times T.$$

We can select any unit of measurement for L , H , and T (say, inches, feet, or yards); then V will be the cubic value in the same units.

The unit of measurement must be the same for each symbol, in cases of this description. The multiplication sign is usually omitted in algebra; hence—

$$V = LHT$$

EXAMPLES. If $a = 5$, $b = 3$, $x = 4$, and $y = 0$, evaluate (1) $3abx^2$; (2) $4b^2x$; (3) $16x^2y$.

SOLUTION. Substitute the values; then—

$$(1) = 3 \times 5 \times 3 \times 4^2 = 720 \text{ Ans.}$$

$$(2) = 4 \times 3^2 \times 4 = 144 \text{ Ans.}$$

$$(3) = 16 \times 4^2 \times 0 = 0 \text{ Ans.}$$

because if one factor is zero, the product is zero.

The number before the letters is called the *numerical coefficient*; when the numerical coefficient is unity it is omitted. The small number above the letter is the *index*, and means the same as in arithmetic.

EXAMPLE. The volume of a sphere is given by the formula $\frac{4}{3}\pi R^3$.

Find the volume of a concrete dome when $R = 5$ ft. and $\pi = \frac{22}{7}$; the dome is half a sphere.

$$V = \frac{1}{2} \times \frac{4}{3}\pi R^3 = \frac{1}{2} \times \frac{4}{3} \times \frac{22}{7} \times 5 \times 5 \times 5 = \frac{5500}{21}$$

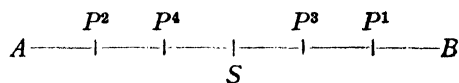
$$= 262 \text{ cub. ft. approximately.}$$

Note. The factors can be arranged in any order, i.e. $\frac{1}{2} \times \frac{4}{3}\pi R^3 = \frac{4}{3}R^3\pi \times \frac{1}{2}$, or $3abx = 3xab$.

43. A *simple expression* has only one term:

$3mnx$. A *compound expression* has more than one term $3mnx + 4ab$, and the terms are connected by + or -. These signs have the same meaning as in arithmetic, but extended slightly; in arithmetic we subtract lesser quantities from greater, i.e. $14 - 6 = 8$. In algebra we sometimes subtract greater quantities from lesser, and have a minus, or *negative*, answer, i.e. $6a - 8a = -2a$; $-4a - 3a = -7a$. Quantities connected by the signs + and - are called *positive*, instead of plus, and *negative*, instead of minus. Any term which has no sign in front is understood to be positive, i.e. $5a$ means + $5a$.

This idea of negative quantities can be applied to arithmetical calculations. Consider the case of a man who owes £25 and someone owes him £22; after a settlement he still owes £3; that is, $\pounds 22 - \pounds 25 = -\pounds 3$. Or, consider the displacement of a point P ; imagine that P starts from S , along a straight line AB , as shown.



The point first moves from S a distance of 5 ft. to the right, then 12 ft. to the left, then 10 ft. to the right, and finally 6 ft. to the left. Hence its final position is 3 ft. to the left of S . Now if we consider displacements to the right as positive, and those to the left as negative, we have $+5 - 12 + 10 - 6 = -3$.

Like terms are those which contain the same letters; $5ab$, $3ab$, ab , $17ab$ are all like terms. Like terms may be combined, that is, $5ab + 3ab - ab + 17ab = 24ab$, because a has the same value throughout, and so has b ; therefore $a \times b$ gives the same product in every term. If we let $a \times b = x$, then we have $5x + 3x - x + 17x = 24x$.

Hence, for like terms, we add together, or subtract, the coefficients.

EXAMPLE. Add together $3a + 6a - 8a + 2a - 3a$.

We can rearrange the terms as follows—

$3a + 6a + 2a - 8a - 3a$, which equals $11a - 11a = 0$, hence the positive values equal the negative values.

If we assume a value for a , say 3, then we have—

$$(3 \times 3) + (6 \times 3) + (2 \times 3) - (8 \times 3) - (3 \times 3)$$

$$= 9 + 18 + 6 - 24 - 9 = 33 - 33 = 0.$$

MODERN BUILDING CONSTRUCTION

Note. The terms may be rearranged in any convenient order (*Commutative Law*). The student should think of the positive and negative signs as part of the term which follows the sign, and move both term and sign together.

Consider the following. Solve $4b + 3b - 2b = 20$.

This example is known as a simple equation, and to *solve* it we have to find the value of b , which is called the *unknown* quantity. By combining the terms which contain b , we have $7b - 2b = 5b$; therefore $5b = 20$.

But we know that $5 \times 4 = 20$; therefore b must equal 4.

Note that a and a^2 are *unlike* terms, because if $a = 3$, then $a^2 = 9$; therefore they cannot be combined; $3a$, $4b$, $3c$, $4x$, $2m$ are all unlike terms.

A multiplication or division sign does *not* divide an expression into terms, i.e. $abc \times xy = abcxy$, which is one term. Hence multiplication and division must be performed before addition and subtraction, unless it is clearly indicated to the contrary.

Thus, $a + b \times c - x \div y = a + bc - \frac{x}{y}$; or, if we assume numerical values for the algebraic symbols, $12 + 7 \times 5 - 6 \div 3 = 12 + (7 \times 5) - (\frac{6}{3}) = 12 + 35 - 2 = 45$.

SIMPLE EQUATIONS

44. An equation is a statement that two quantities are equal, and the two quantities are connected by the *sign of equality* =. We will now consider the rules governing equations.

AXIOMS

(1) *If we add equals to equals, the sums are equal.*

(2) *If we subtract equals from equals, the remainders are equal.*

(3) *If we multiply equals by equals, the products are equal.*

(4) *If we divide equals by equals, the quotients are equal.*

These axioms can easily be verified by arithmetical examples—

(I) $3 + 5 = 6 + 2$, that is, both sides = 8.

Adding equals to each side, then $3 + 5 + 4 = 6 + 2 + 4$, then both sides = 12.

(2) Subtracting equals from each side, then $3 + 5 - 4 = 6 + 2 - 4$, then both sides = 4.

(3) Multiplying both sides by equals, then $4(3 + 5) = 4(6 + 2)$, then both sides = 32.

(4) Dividing both sides by equals, then $\frac{3 + 5}{4} = \frac{6 + 2}{4}$, then both sides = 2

Now, apply these rules to algebraic quantities

(I) $4x - 6 = x + 8$.

Adding 6 to each side, then $4x - 6 + 6 = x + 8 + 6$, therefore $4x = x + 8 + 6$. Hence we can see that the 6 has been transferred to the other side, and its sign has been changed.

(2) Subtracting x from each side of the new equation, then $4x - x = x - x + 8 + 6$, therefore $3x = 14$; this time the x has been transferred to the other side, with its sign changed.

(3) Dividing both sides of the new equation by 3, then $\frac{3x}{3} = \frac{14}{3}$, therefore $x = \frac{14}{3}$; this time the 3 has been transferred to the other side, and has become a divisor.

Hence we can see that any term may be transferred from one side to the other, but we must change its sign.

The process is called *transposing* the terms, and is the first step in *solving an equation*. Transpose the *unknown* quantities to one side, and the *known* quantities to the other.

EXAMPLE. $5x - 17 + 3x - 5 = 6x - 7 - 8x + 115$

SOLUTION.

Transposing, $5x + 3x - 6x + 3x = 115 - 7 + 17 + 5$

Collecting, $10x = 130$

Dividing both sides by 10, $\therefore x = \frac{130}{10} = 13$ Ans.

EXAMPLE. A rectangular joist has a bending moment of $\frac{WL}{4}$, where $L = 120$ in., $W = 1,280$ lb. The moment of resistance of the beam = $\frac{fbd^2}{6}$, where $f = 1,200$ lb., $d = 9$ in. Find the breadth of the joist.

SOLUTION. Bending moment = moment of resistance.

$$\therefore \frac{WL}{4} = \frac{fbd^2}{6}$$

Transposing, $\frac{WL \times 6}{4 \times f \times d^2} = b$. (Note. f and d^2

multiply on one side, hence when they are transposed they become divisors.)

Substituting the known values—

$$\therefore \frac{1280 \times 120 \times 6}{4 \times 1200 \times 9 \times 9} = b$$

$$\therefore \frac{64}{27} = b, \therefore b = 2.4 \text{ in. Ans.}$$

EXAMPLE. A builder acquires a building site of 1 acre 440 sq. yd., and decides to erect three types of

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houses—cottages, parlour houses, and villas, twelve of each type. He apportions the ground as follows: twice as much for a villa as for a parlour house, and $1\frac{1}{2}$ times as much for a parlour house as for a cottage. Find the amount of ground for each type of house.

SOLUTION.

Let x be the amount of ground allotted to each cottage.

Then $1\frac{1}{2}x$ is the amount of ground allotted to each house.

And $2(1\frac{1}{2}x)$ is the amount of ground allotted to each villa.

$$\therefore \text{Total amount of ground required for one of each type} = x + 1\frac{1}{2}x + 3x = 5\frac{1}{2}x$$

$$\therefore \text{Total amount of ground required for twelve of each type} = 12 \times 5\frac{1}{2}x = 66x$$

$$\therefore 66x = 1 \text{ acre } 440 \text{ sq. yd.} = 5,280 \text{ sq. yd.}$$

$$\therefore x = \frac{5280}{66}, \therefore x = 80 \text{ sq. yd.}$$

$$\therefore \text{The ground allotted to each} \left. \begin{array}{l} \text{Cottage} = 80 \text{ sq. yd.} \\ \text{House} = 120 \text{ sq. yd.} \\ \text{Villa} = 240 \text{ sq. yd.} \end{array} \right\} \text{Ans.}$$

SUMMARY OF RULES FOR SOLVING EQUATIONS

- (1) Clear of fractions, by multiplying both sides by the L.C.M. of the denominators.
- (2) Transpose the unknown values to one side and the known values to the other side.
- (3) Collect the terms on each side.
- (4) Divide both sides by the coefficient of the unknown quantity.

BRACKETS

45. Brackets are used to group the expressions for convenience of working, or to make clear

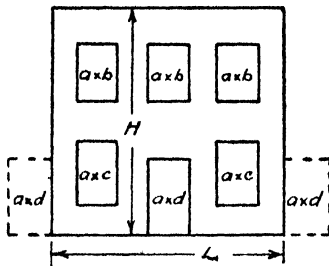


FIG. 5

the meaning of the expression. Fig. 5 shows the elevation of the brickwork for the front of a house. If we have to find the quantity of brickwork, we can do the work in two ways: we can first find the area of the front, and then subtract the openings, then multiply by the

thickness, if it be uniform; or we can find the volume of the front and then subtract the volumes of the openings. We will first adopt the former method—

$$\begin{array}{ll} \text{Area of front} & = L \times H \\ \text{,, ,, upper windows} & = 3(ab) \\ \text{,, ,, lower windows} & = 2(ac) \\ \text{,, ,, doorway} & = a \times d \end{array}$$

If all the dimensions are in feet, then the area of brickwork will be $LH - 3ab - 2ac - ad$ square feet, or we can add the openings together and then subtract—

$$\therefore \text{area} = LH - (3ab + 2ac + ad) \quad (1)$$

Hence we have bracketed the openings for convenience, but we have had to alter the signs of the terms inside the bracket.

RULES

- (1) We can insert or remove brackets as required, and if the bracket is preceded by a + sign, the signs inside the brackets REMAIN UNCHANGED.
- (2) If the bracket is preceded by a - sign, all the signs inside the brackets MUST BE CHANGED.
- (3) If any factor is common to ALL the terms inside the bracket, the common factor may be removed and placed in front of the bracket.

The application of the last rule simplifies the above calculation, because a is common to every term inside the bracket; hence we have

$$LH - a(3b + 2c + d) \quad (2)$$

which shows that when a bracket is preceded by a factor, every term inside the bracket must be multiplied by the factor when we remove the brackets. The same thing applies to a divisor,

$$\text{i.e. } (ab + cd + ef) \div a = \frac{ab}{a} + \frac{cd}{a} + \frac{ef}{a}.$$

Let us again consider the house front, but this time with the addition of the two dotted wings $a \times d$; we will take the volumes this time, when the brickwork = t feet thick.

$$\begin{aligned} \text{Then, } LHt - 3abt - 2act - adt + 2adt \\ = t \{ LH - 3ab - 2ac - ad + 2ad \} \\ = t \{ LH - a(3b + 2c + d - 2d) \} \end{aligned}$$

Note. $+d - 2d = -d$; therefore the expression equals -

$$t \{ LH - a(3b + 2c - d) \}$$

If we assume values for the algebraic symbols

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as follows, we can now find the number of cubic feet numerically—

$$\begin{aligned} & \frac{2}{3} \{20 \times 20 - 3\frac{1}{2} (3 \times 5 + 2 \times 6 - 7)\} \\ &= \frac{2}{3} \{400 - 3\frac{1}{2} (20)\} = \frac{2}{3} (400 - 70) \\ &= \frac{2}{3} \times 330 = \underline{247\frac{1}{2} \text{ cub. ft.}} \quad \text{Ans.} \end{aligned}$$

The above example has shown that we may have brackets inside brackets. The following is the order in which they are inserted: (), { }, []; and they are removed in the same order.

EXERCISE VIII (Answers on page 29)

$$a = 3, b = 2, c = 4, x = 1, y = 5, n = 0$$

- Find the value of $bc + ax + bcy - cn$.
- What is the numerical difference between $3b$ and b^2 ?
- $(2ab - c)(c + xy + n)$.
- $\frac{1}{2}(ab + bc) + \frac{1}{4}(ax - ny)$.
- Remove the brackets and simplify the following expression; then find the value—
 $-2a - [3x + \{3c - (4y + 3x + 2a)\}]$

ANSWERS TO EXERCISE VII (page 22)

- 12·219.
- $\frac{131}{153}$.
- $38\frac{1}{2}$ days. Total time $50\frac{1}{2}$ days.
- 500 yd.
- (a) 21,000 sq. ft., (b) 35,700 slates, (c) $59\frac{1}{2}$ tons.
- £10 14s.
- 1,728.

ADDITION OF UNLIKE TERMS

46. The student is now familiar with addition and subtraction of like terms. The addition of expressions containing *unlike terms* will now be explained.

Add together $4m + 3n + 5x$; $-2m - 8x + 3n$; $m - n + x$. Arrange the expressions in lines, as in arithmetic, but arrange the terms so that the *like terms* are in the *same vertical columns*. Then add the columns together—

$$\begin{array}{r} 4m + 3n + 5x \\ -2m + 3n - 8x \\ m - n + x \\ \hline 3m + 5n - 2x \end{array}$$

The first column is $+4m - 2m + m$, which equals $3m$ (that is, $+4 - 2 + 1 = 3$), therefore 3 is the *algebraic sum* of the coefficients of m , and is the numerical coefficient of the answer.

Repeat the process for the other columns.

If the negative quantities are greater than the

positive quantities, then we prefix the negative sign, as in the last column, i.e.—

$$+5 - 8 + 1 = -2.$$

When arranging the expressions preparatory to adding them together, we should arrange them in a regular order, either in a descending or ascending order of the powers of the letters. For example—

15, \sqrt{x} , x , x^2 , x^3 , x^4 , etc., is arranged in ascending order; and

a^3 , a^2 , a , \sqrt{a} , $\sqrt[3]{a}$, 6, etc., is arranged in descending order.

EXAMPLE. Add together—

$$\begin{aligned} & \frac{1}{2}x^3 - 2x^2y - \frac{3}{4}y^3; \frac{3}{4}x^2y - \frac{1}{2}xy^2 + 2y^3; \\ & -\frac{3}{4}x^3 + xy^2 + \frac{1}{2}y^3 \end{aligned}$$

SOLUTION.

$$\begin{array}{r} \frac{1}{2}x^3 - 2x^2y \qquad \qquad \qquad - \frac{3}{4}y^3 \\ \qquad \qquad \frac{3}{4}x^2y - \frac{1}{2}xy^2 \qquad \qquad \qquad + 2y^3 \\ -\frac{3}{4}x^3 \qquad \qquad \qquad + xy^2 \qquad \qquad \qquad + \frac{1}{2}y^3 \\ \hline -x^3 - \frac{1}{2}x^2y + \frac{1}{2}xy^2 + \frac{1}{2}y^3 + \frac{1}{2}y^3 \quad \text{Ans.} \end{array}$$

This arrangement is in descending powers of x and ascending powers of y . The fractional coefficients are added together as in arithmetic; for instance, in the first column—

$$+ \frac{1}{2} - \frac{3}{4} = -\frac{1}{4} = -1$$

SUBTRACTION OF UNLIKE TERMS

47. The subtraction of unlike terms is simplified by applying the following rule.

RULE. *Change the sign of every term to be subtracted and proceed as in addition.*

The rule may be considered as an illustration of the rule for the removal of brackets, because to subtract $3x - 2y - z$ from $4x - 3y + 5z$ may be written $4x - 3y + 5z - (3x - 2y - z)$; which, on removal of the brackets, becomes $4x - 3y + 5z - 3x + 2y + z = x - y + 6z$.

Arranging the terms for subtraction, we have

$$\begin{array}{r} 4x - 3y + 5z \\ 3x - 2y - z \\ \hline \end{array}$$

Subtracting, $x - y + 6z$ Ans

The changing of the signs is done mentally; but, to make it clear to the student, we will write the lower expression with its signs changed—

$$\begin{array}{r} 4x - 3y + 5z \\ -3x + 2y + z \\ \hline \end{array}$$

Adding, $x - y + 6z$ Ans.

BUILDING CALCULATIONS

EXAMPLE. From $\frac{1}{2}a^3 - \frac{1}{3}ab - \frac{2}{3}b^3$ take $-\frac{3}{4}a^3 + ab - b^3$.

SOLUTION.

$$\begin{array}{r} \frac{1}{2}a^3 - \frac{1}{3}ab - \frac{2}{3}b^3 \\ -\frac{3}{4}a^3 + ab - b^3 \\ \hline 2a^3 - \frac{1}{4}ab - \frac{1}{3}b^3 \quad \text{Ans.} \end{array}$$

EXPLANATION. Change the sign of the bottom coefficient and add to the top coefficient, $+\frac{3}{4} + \frac{1}{2} = 2$. Prefix 2 to a^3 for the answer to the first column. Repeat for the other columns.

MULTIPLICATION

48. Multiplication, as explained in arithmetic, is a form of repeated addition. Therefore, in the multiplication of simple expressions, or *monomials*, as $2xy \times a$, we have to consider that $2xy$ is taken a times; and if $a = 3$, then the expression = $2xy + 2xy + 2xy = 6xy$; or, $3 \times 2xy$, which is the same as $2 \times 3xy$ or $2axy$.

Again $6mn \times 3ab$ means $(6 \times m \times n) \times (3 \times a \times b)$; or, if we substitute the following values $(6 \times 7 \times 2) \times (3 \times 4 \times 5)$.

These factors may be arranged in any order (Commutative Law), therefore $(6 \times 7 \times 2) \times (3 \times 4 \times 5) = 6 \times 3 \times 7 \times 2 \times 4 \times 5$, which, on returning to the algebraic symbols, = $6 \times 3 \times m \times n \times a \times b = 18mnab$.

Hence, to find the product of two or more monomials, we multiply the numerical coefficients together, and prefix the product to the algebraic symbols.

In dealing with *indices* we apply the following rule.

RULE. To find the product of the same letters, we add together the indices: i.e.—

$$a^2 \times a^3 = a^{2+3} = a^5 \quad (\text{Index Law}).$$

EXAMPLE. Find the product of $3a^2b$ and $2a^3b^2$.

SOLUTION.

$$3a^2b \times 2a^3b^2 = 3 \times a \times a \times b \times 2 \times a \times a \times a \times b \times b$$

which, if we rearrange

$$= 3 \times 2 \times (a \times a \times a \times a \times a) \times (b \times b \times b) = 6 \times a^5 \times b^3 = 6a^5b^3 \quad \text{Ans.}$$

49. If there are more than two terms, the answer is the *continued product*, but the method is exactly the same, i.e.—

$$\begin{aligned} 3a^2b \times 2ab^2 \times 3b^3c \\ = (3 \times 2 \times 3) \times (a^2 \times a) \times (b \times b^2 \times b^3) \times c \\ = 18a^3b^5c. \quad \text{Ans.} \end{aligned}$$

Note. The intermediate line should be performed mentally.

50. RULE. To multiply a compound expression by a simple expression, we multiply every term in the compound expression by the simple expression, and add the products together.

$a(x + y)$ means $(x + y)$ taken a times; if $a = 3$, then—

$$\begin{aligned} (x + y) + (x + y) + (x + y) \\ = x + y + x + y + x + y \\ = x + x + x + y + y + y = 3x + 3y \end{aligned}$$

Therefore, returning to the algebraic symbols $a(x + y) = ax + ay$.

ARITHMETICAL ILLUSTRATION

$$3(8 - 6) = 3 \times 2 = 6, \text{ also } (3 \times 8) - (3 \times 6) = 24 - 18 = 6$$

51. Geometrical Illustration of Multiplication. The area of a rectangle is the product of two

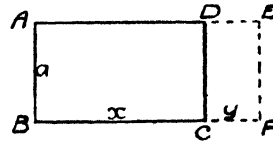


FIG. 6

adjacent sides. Therefore in Fig. 6 the area of $ABCD = a \times x$, and the area of $DCFE = a \times y$; therefore area of $ABFE = ax + ay$, or $a(x + y)$; therefore $a(x + y) = ax + ay$.

In Fig. 7, area $ABCD = a \times x$, and area

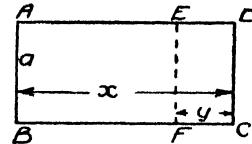


FIG. 7

$ABFE = a \times x - a \times y$, or $a(x - y)$, therefore $a(x - y) = ax - ay$.

EXAMPLE. Simplify $x^2y^2(6x^3yz - 7xy^3z^2)$.

SOLUTION. The expression

$$\begin{aligned} = x^2y^2 \times 6x^3yz - x^2y^2 \times 7xy^3z^2 \\ = 6x^5y^3z - 7x^3y^5z^2 \end{aligned}$$

52. Compound Expressions.

(I) $(m + n)(x + y)$ means $(x + y)$ taken $m + n$ times; that is, $(x + y)$ taken m times + $(x + y)$ taken n times; that is, $\{m(x + y)\} + \{n(x + y)\}$, which equals $(mx + my) + (nx + ny) = mx + my + nx + ny$.

Fig. 8 shows the geometrical illustration of the above. Area of $ABCD =$ area of four separate

MODERN BUILDING CONSTRUCTION

rectangles = $AGKE + EKHD + GBFK + KFCH = a \times c + a \times d + b \times c + b \times d$
 thus $(a + b)(c + d) = ac + ad + bc + bd$.

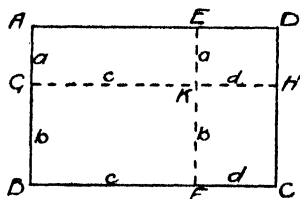


FIG. 8

- (2) $(m - n)(x + y)$
 $= \{m(x + y)\} - \{n(x + y)\}$
 $= (mx + my) - (nx + ny)$
 $= mx + my - nx - ny$
- (3) $(m + n)(x - y)$
 $= \{m(x - y)\} + \{n(x - y)\}$
 $= (mx - my) + (nx - ny)$
 $= mx - my + nx - ny$
- (4) $(m - n)(x - y)$
 $= \{m(x - y)\} - \{n(x - y)\}$
 $= (mx - my) - (nx - ny)$
 $= mx - my - nx + ny$

These results should be carefully noted ; in (4) we have—

$$\begin{aligned} (+m) \times (+x) &= +mx \\ (+m) \times (-y) &= -my \\ (-n) \times (+x) &= -nx \\ (-n) \times (-y) &= +ny \end{aligned}$$

RULES OF SIGNS

The product of two terms with the same signs is positive.

The product of two terms with different signs is negative—

$$\begin{aligned} \text{i.e. } (+) \times (+) &= +, (-) \times (-) = +, \\ (+) \times (-) &= - \end{aligned}$$

EXAMPLE. Find the product of $-am^2 + 3amn^2 - 9an^4$, and $-am - 3an^2$.

SOLUTION.

$$\begin{array}{r} -am^2 + 3amn^2 - 9an^4 \\ -am - 3an^2 \\ \hline a^2m^3 - 3a^2m^2n^2 + 9a^2mn^4 \\ 3a^2m^2n^2 - 9a^2mn^4 + 27a^2n^6 \\ \hline a^2m^3 \qquad \qquad \qquad + 27a^2n^6 \\ \hline \therefore \text{Ans.} = a^2m^3 + 27a^2n^6 \end{array}$$

EXPLANATION. Multiply every term in the top expression by each term separately of the bottom expression, prefixing the correct sign to each partial product. Add together the partial products.

If the terms have fractional coefficients, the coefficients are multiplied together as in arithmetic. For example—

$$\begin{aligned} \frac{3}{4}a^2x \times \frac{1}{2}ax &= \frac{3}{4} \times \frac{1}{2} \times a^2 \times a \times x \times x \\ &= \frac{3}{8}a^3x^2 \end{aligned}$$

53. There are four cases of multiplication of expressions with two terms (*binomial expressions*) which should be specially noted—

- (1) $(a + 3)(a + 2) = a^2 + 3a + 2a + 6 = a^2 + 5a + 6$
- (2) $(a - 3)(a - 2) = a^2 - 3a - 2a + 6 = a^2 - 5a + 6$
- (3) $(a + 3)(a - 2) = a^2 + 3a - 2a - 6 = a^2 + a - 6$
- (4) $(a - 3)(a + 2) = a^2 - 3a + 2a - 6 = a^2 - a - 6$

Note. (a) The product, or answer, has three terms (*trinomial expression*).

(b) The first term is the product of the first terms of each expression; i.e. $a \times a = a^2$.

(c) The third term is the product of the second terms, with the correct sign prefixed; i.e. $3 \times 2 = 6$.

(d) The middle term is the algebraic sum of the product of the two inner terms, and the product of the two outer terms. Hence the coefficient of the middle term, or the answer, is the sum of the numerical terms; i.e. —

- In case (1) it is $+3$ and $+2 = +5$
 „ „ (2) „ -3 „ $-2 = -5$
 „ „ (3) „ $+3$ „ $-2 = +1$
 „ „ (4) „ -3 „ $+2 = -1$

This enables us to write down the product on inspection by omitting the middle line of working.

EXAMPLE. Find the product of $3n + 7$ and $2n - 3$.

SOLUTION.

$$\begin{array}{|c|c|} \hline & \text{3rd term} \\ \hline \text{1st term} & \\ \hline (3n + 7) & (2n - 3) \\ \hline \end{array} = 6n^2 + 5n - 21$$

EXERCISE IX (Answers on page 31)

- From $3a + 2b + 5c$ take $-7a + 11b - 10c$.
- Find the value of $(2x + 3y)(2x - 3y) - 4x^2 + 9y^2$.
- Find the product of $2ab - 3c$ and $2ab + 3c$.

4. Find the product of $27n^3 - 36mn^2 + 48mn^2 - 64m^3$ and $3n + 4m$.
 5. Multiply together $\frac{3}{4}a^3 + ab + \frac{3}{8}b^3$ and $\frac{1}{4}a - \frac{1}{4}b$.

ANSWERS TO EXERCISE VIII (page 26)

1. 51.
 2. 2.
 3. 72.
 4. $7\frac{1}{4}$.
 5. $4y - 3c = 8$.

DIVISION

54. Division is a reverse process to multiplication, hence the same rules apply.

$x \div y = \frac{x}{y}$; this cannot be simplified until

we substitute numerical values for x and y .

$x \div x = \frac{x}{x} = 1$, because the values cancel.

This example shows the application of the index law: "Subtract the indices for the division of similar letters," i.e. $\frac{x^3}{x^2} = x^{3-2} = x$.

EXAMPLE. $\frac{12a^2b^3c^3}{2ab^2c} = 6a^{2-1} \times b^{3-2} \times c^{3-1} = 6abc^2$.

55. To divide a compound expression by a simple expression, divide each term of the compound expression by the simple expression separately, and add together the quotients.

EXAMPLE. Divide $6x^2y^2 + 3xy$ by xy .

SOLUTION. $\frac{6x^2y^2 + 3xy}{xy} = \frac{6x^2y^2}{xy} + \frac{3xy}{xy} = 6xy + 3$

EXAMPLE. $9a - 12b + 3c \div -3$.

SOLUTION. $\frac{9a}{-3} - \frac{12b}{-3} + \frac{3c}{-3} = -3a + 4b - c$.

(Note the application of the rule of signs to the middle term.)

56. Long Division. Method of dividing a compound expression by a compound expression—

1. Arrange both expressions in ascending or descending order, that is, according to the powers of some common letter.

2. Divide the first term of the dividend by the first term of the divisor, and place the answer as the first term of the quotient.

3. Multiply the whole of the divisor by this part of the quotient, and subtract from the dividend.

4. Repeat the operations, bringing down the terms from the dividend as required, for the new dividends.

EXAMPLE. Divide $24a^3 - 65ab + 21b^3$ by $8a - 3b$.

SOLUTION.

$$\begin{array}{r} 8a - 3b \overline{) 24a^3 - 65ab + 21b^3} \\ \underline{24a^3 - 9ab} \end{array}$$

$$\begin{array}{r} -56ab + 21b^3 \\ \underline{-56ab + 21b^3} \end{array}$$

EXPLANATION. (1) $8a$ into $24a^3$ goes $3a$ times. (2) Multiplying $(8a - 3b)$ by $3a$ gives $24a^3 - 9ab$. (3) Subtract, by changing the signs and proceeding as in addition. (4) Bring down $21b^3$ to complete the new dividend, and repeat the process.

Fractional Coefficients.

EXAMPLE. Divide $\frac{1}{8}x^3 - \frac{1}{4}x^2y + \frac{3}{8}xy^2 - 27y^3$ by $\frac{1}{8}x - 3y$.

SOLUTION.

$$\begin{array}{r} \frac{1}{8}x - 3y \overline{) \frac{1}{8}x^3 - \frac{1}{4}x^2y + \frac{3}{8}xy^2 - 27y^3} \\ \underline{\frac{1}{8}x^3 - \frac{3}{8}x^2y} \phantom{+ \frac{3}{8}xy^2 - 27y^3} \\ -\frac{3}{8}x^2y + \frac{3}{8}xy^2 \\ \underline{-\frac{3}{8}x^2y + 9xy^2} \\ \phantom{-\frac{3}{8}x^2y +} \frac{3}{8}xy^2 - 27y^3 \\ \underline{\phantom{-\frac{3}{8}x^2y +} \frac{3}{8}xy^2 - 27y^3} \end{array}$$

FORMULAE

57. We have worked several algebraic equations in the preceding articles. When equations are of general application, instead of being applicable to a particular case only, we speak of them as formulae.

The area (A) of any rectangular surface is given by length (L) \times breadth (B); therefore, $A = LB$ is a formula.

If a number (N) be divided by a divisor (D), giving a quotient (Q) and leaving a remainder (R), we have $\frac{N}{D} = Q + \frac{R}{D}$, which is also a formula.

The solution of formulae is usually a matter of finding one of the values, which is unknown; to do this, we transfer all the known values to one side of the equation, and the unknown value (or values) to the other side. The student should make himself proficient in finding the value of any letter in terms of the other letters. For instance, it is required to find the time (T) in the simple interest formula

$$A = P + \frac{PRT}{100}$$

Transposing, we have

$$A - P = \frac{PRT}{100} \therefore \frac{100(A - P)}{PR} = T$$

The mental process is: (1) subtract P from both sides; (2) multiply both sides by 100; (3) divide both sides by P and R .

EXAMPLE. The approximate depth of an arch is given by the formula $D = C\sqrt{R}$. Find the depth of a brick arch when $C = .4$ and $R = 12\frac{1}{2}$ ft.

SOLUTION.

$D = C\sqrt{R} \therefore D = .4\sqrt{12.25} = .4 \times 3.5 = 1.4$ ft. say two bricks deep.

MODERN BUILDING CONSTRUCTION

EXAMPLE. Find N in terms of the other letters in the formula $\frac{N}{D} = Q + \frac{R}{D}$. Also substitute the values and find the numerical value of N , when $D = 25$, $Q = 10$, $R = 6$.

SOLUTION.

$$\frac{N}{D} = Q + \frac{R}{D} \therefore N = D \left(Q + \frac{R}{D} \right) = DQ + R$$

$$\therefore N = 25 \times 10 + 6 = \underline{256 \text{ Ans.}}$$

HIGHEST COMMON FACTOR OF SIMPLE EXPRESSIONS

58. The definition of the H.C.F. for algebraic expressions is the same as for arithmetic. *The H.C.F. of a number of terms, or expressions, is the greatest term, or expression, which divides into them without a remainder.* (See Art. 15.)

The H.C.F. of x^6, x^3, x^4, x^2 is x^2 .

The H.C.F. of $8a^2x^2, 6abx^2y, 10a^3b^4x^3y^2$ is $2ax^2$, because 2 is the greatest numerical value which will divide into 8, 6, and 10 without a remainder; a is the highest power of a which will divide into a^2, a , and a^3 ; also x^2 is the highest power of x which will divide into x^2, x^2 , and x^3 ; therefore $2ax^2$ is the H.C.F., because b and y do not occur in all the expressions, and cannot be in the H.C.F.

Harder Cases. (This article should be studied again, later in the course, because of its difficulty.)

59. When we cannot factorise, we adopt the method of long division.

Thus, find the H.C.F. of $11x + 2x^3 - 5x^2 + 7$ and $4x^3 + 25x - 11x^2 + 7$.

Arrange both expressions in descending order, and divide the lesser into the greater.

$$\begin{array}{r} A \qquad \qquad \qquad B \\ 2x^3 - 5x^2 + 11x + 7 \quad 4x^3 - 11x^2 + 25x + 7(2) \\ \underline{4x^3 - 10x^2 + 22x + 14} \end{array}$$

$$R = -x^2 + 3x - 7$$

Now divide the remainder (R) into the expression A ; but we can multiply either of the expressions by any factor, to simplify the division, without altering the result, therefore multiply R by -1 .

$$\begin{array}{r} x^2 - 3x + 7 \quad 2x^3 - 5x^2 + 11x + 7(2x) \\ \underline{2x^3 - 6x^2 + 14x} \end{array}$$

$$R_1 = x^2 - 3x + 7$$

Now divide the second remainder (R_1) into the first remainder (R).

$$\begin{array}{r} x^2 - 3x + 7 \quad x^2 - 3x + 7(1) \\ \underline{x^2 - 3x + 7} \end{array}$$

There is no remainder after this operation.

Therefore the last divisor, $x^2 - 3x + 7$, is the H.C.F. of the two expressions A and B .

Note. Any factor of one expression, which is not a factor of the other expression, may be removed at any stage of the working, because the removed factor cannot be in the H.C.F., as it is not common to both expressions; from this we can multiply by any value to remove fractions or inconvenient numbers

The several quotients which were obtained in the last example are not required; therefore it is easier to combine the various operations as follows: find the H.C.F. of the two expressions A and B .

$$\begin{array}{r} \begin{array}{cc} A & B \\ 2a^3 - 3a^2 - 9a + 5 & 2a^4 - a^3 - 10a^2 - 11a + 8 \\ \underline{2a^3 - a^2 - 16a + 8} & \underline{2a^4 - 3a^3 - 9a^2 + 5a} \end{array} \quad \begin{array}{l} \text{Sub-} \\ \text{tract} \\ R \\ R_2 \times \\ (-a) \end{array} \\ R_2 \quad -2a^3 + 7a - 3 & 2a^3 - a^3 - 16a + 8 \\ R_3 \times (-a) \quad -2a^3 + a & \underline{2a^3 - 7a^2 + 3a} \\ \hline \text{Divide by } 3)6a - 3 & \begin{array}{l} 6a^3 - 19a + 8 \\ \underline{6a^3 - 21a + 9} \\ 2a - 1 \end{array} \\ \begin{array}{l} R_4 \quad 2a - 1 \\ R_5 \quad 2a - 1 \end{array} & \begin{array}{l} R_2 \times \\ (-3) \\ R_5 \end{array} \\ \hline \text{No remainder} & \end{array}$$

Therefore $2a - 1$ is the H.C.F. of A and B , which was evident before the final division.

The H.C.F. of three expressions, A, B , and C , is found by finding the H.C.F. of any two of them, and then finding the H.C.F. of the H.C.F. so found and the third expression.

LOWEST COMMON MULTIPLE OF SIMPLE EXPRESSIONS

60. The L.C.M. of several algebraic expressions is the expression of lowest dimensions which is divisible by each of the expressions, without leaving a remainder.

Thus, the L.C.M. of x^6, x^3, x^4 , and x^2 is x^6 , because x^6 is the lowest power of x into which all the terms will divide.

Again, the L.C.M. of $7a^4b, 8ab^5, 2a^2b^3 = 56a^4b^5$, because 56 is the least number divisible by 7, 8, and 2; a^4 is the lowest power of a divisible by a^4, a , and a^3 ; and b^5 is the lowest power of b divisible by b, b^5 , and b^3 . Hence the L.C.M. consists of factors which represent the L.C.M. of the numerical coefficients, and the highest power of each letter contained in the expressions.

61. To find the L.C.M. of more difficult expressions, we first find the H.C.F. of the expressions; then, if the expressions are A and B , we have

$$A = m \times \text{H.C.F.}$$

$$B = n \times \text{H.C.F.}$$

and

Then the L.C.M. = $m \times n \times \text{H.C.F.}$
 and $A \times B = m \times \text{H.C.F.} \times n \times \text{H.C.F.}$
 $= (m \times n \times \text{H.C.F.}) \times \text{H.C.F.}$
 $= \text{L.C.M.} \times \text{H.C.F.}$

That is, the product of the expressions = the product of the L.C.M. and H.C.F.; therefore $A \times B = L \times F$, where L = the L.C.M., and F = the H.C.F.

$$\therefore \frac{A \times B}{F} = L$$

EXERCISE X (Answers on page 33)

1. Simplify $5a^3(3a^2 - 4a + 1) \div a^3$.
2. Divide $20a^3 - 13a^2 - 23a + 10$ by $4a - 5$.
3. $V = \frac{1}{2}\pi R^3$ is the formula for the volume of a sphere. Find the volume of a semicircular dome (half a sphere), when $R = 5$ ft., and $\pi = 3\frac{1}{7}$.
4. A formula for the flow of sewage when flowing full bore is: $V = 50\sqrt{\frac{dH}{L + 50d}}$, where V = velocity in feet per second; d = diameter of pipe in feet; L = length of pipe in feet; and H = head, or fall of water in feet. Find H when $V = 4$ ft. per second in a 6 in. pipe, 100 ft. long.

ANSWERS TO EXERCISE IX (page 28)

1. $10a - 9b + 15c$.
2. 0.
3. $4a^2b^2 - 9c^2$.
4. $81m^4 - 250m^4$.
5. $\frac{2}{3}a^3 - \frac{1}{3}b^3$.

FRACTIONS

62. *Cancelling.* We can apply our knowledge of arithmetic to illustrate algebraic fractions; $\frac{3}{4}$ of anything means that we have divided something into four equal parts, and we are taking three of those parts. Similarly $\frac{a}{b}$ of anything means that we have divided something into b equal parts, and we are taking a of those parts.

The first process, when working fractions, is to reduce the fraction to its lowest terms; that is, divide both numerator and denominator by every factor which is common to both, in other words, by the H.C.F.; this process is called *cancelling*.

EXAMPLE. $9a^2b^4c \div 3ab^3c$
 $= \frac{9a^2b^4c}{3ab^3c} = 3a^1b^1$

Rules for Multiplication. (1) *Cancel where possible.* (2) *Multiply together all the numerators for a new numerator. Multiply together all the denominators for a new denominator.*

Rules for Division. *First invert the divisor and then proceed as in multiplication.*

EXAMPLE. Simplify $\frac{a^2}{8b} \times \frac{36c^2d^2}{81ab} \div \frac{15acn^5}{27b^2n^3m}$

SOLUTION. Re-arranging, we have

$$\frac{a^2}{8b} \times \frac{36c^2d^2}{81ab} \times \frac{27b^2n^3m}{15acn^5}$$

Cancelling and multiplying, we have

$$\frac{c^2d^2m}{10n^2} = \text{Ans.}$$

Rules for Addition and Subtraction. (1) *Simplify each fraction separately.* (2) *Find the lowest common denominator for all the fractions, for a new denominator; that is, find the L.C.M. of the denominators.* (3) *Express all the fractions with the new denominator.* (4) *Find the algebraic sum of the numerators.*

EXAMPLE. Simplify $\frac{7a}{8} + \frac{a}{12} - \frac{a}{4}$

SOLUTION

$$\frac{7a}{8} + \frac{a}{12} - \frac{a}{4} = \frac{21a + 2a - 6a}{24} = \frac{17a}{24} \text{ Ans.}$$

EXPLANATION. (1) 24 is the L.C.M. of 8, 12, and 4, and is therefore the common denominator. (2) 8 into 24 goes three times, therefore $7a \times 3 = 21a =$ new numerator for the first fraction. (3) Repeat for the other fractions. (4) Collect the numerators for 17a.

EXAMPLE. Simplify $\frac{x-2y}{2x} + \frac{x+7y}{8x} - \frac{x-5y}{4x}$

SOLUTION. With a common denominator, the fractions equal

$$\frac{4(x-2y) + x + 7y - 2(x-5y)}{8x}$$

$$\frac{4x - 8y + x + 7y - 2x + 10y}{8x}$$

$$= \frac{3x + 9y}{8x} = \frac{3(x + 3y)}{8x} \text{ Ans.}$$

Complex Fractions. These may be solved as in arithmetic. Multiply the extremes for a new numerator and the means for a new denominator, and cancel where possible. The following cases should be specially noted.

(1) $\frac{\frac{1}{x}}{\frac{1}{y}} = 1 \div \frac{x}{y} = 1 \times \frac{y}{x} = \frac{y}{x}$

(2) $\frac{x}{\frac{1}{y}} = x \div \frac{1}{y} = x \times y = xy$

(3) $\frac{\frac{1}{x}}{\frac{1}{y}} = \frac{1}{x} \div \frac{1}{y} = \frac{1}{x} \times \frac{y}{1} = \frac{y}{x}$

Chapter IV—ALGEBRA (2)

FACTORS

63. ONE of the most difficult operations in algebra, for the beginner, is *factorising*; that is, splitting up an expression into factors.

In arithmetic we know that the factors of 12 may be 6×2 , 3×4 , or 12×1 ; similarly, in algebra many expressions can be resolved into different factors. The process is systematic guesswork, but there are several aids, with which the student must be familiar; the rest depends upon practice.

In Art. 45 it was shown that, when a factor is common to all the terms in an expression, the common factor may be removed and placed outside brackets, i.e.

$$5a^5 - 10a^3b^2 - 15a^3b^3 = 5a^3(a^2 - 2b^2 - 3b^3)$$

EXPLANATION. (1) 5 is a factor of every term. (2) a^3 is a factor of every term, (3) b is not contained in every term, therefore it is not a *common* factor, thus the common factor is $5a^3$. (4) Take the factor $5a^3$ out of each term and enclose the remainder in brackets.

We should re-arrange the terms in the expression, if the re-arrangement would assist the factorising. Examine the terms for some common letter; for example, factorise $6x^2 - my - 2mx + 3xy$; re-arrange into groups containing a common factor, $6x^2 + 3xy - 2mx - my = (6x^2 + 3xy) - (2mx + my) = 3x(2x + y) - m(2x + y)$.

The expression now means that $(2x + y)$ has to be taken $(3x - m)$ times (see Art. 52), therefore the expression equals $(3x - m)(2x + y)$.

64. It was shown in Art. 53 that the products of *binomial expressions* can be written down by inspection, thus

$$\begin{aligned} \text{Case (1)} \quad & (a + 4)(a + 2) = a^2 + 6a + 8 \\ \text{,, (2)} \quad & (a - 4)(a - 2) = a^2 - 6a + 8 \\ \text{,, (3)} \quad & (a + 4)(a - 2) = a^2 + 2a - 8 \\ \text{,, (4)} \quad & (a - 4)(a + 2) = a^2 - 2a - 8 \end{aligned}$$

We now come to the reverse operation of selecting the factors, or components, of *trinomial expressions*. From the above trinomial expressions we can see that for Case (1) we require—

(a) Two factors which, when multiplied together, will equal $+a^2$, i.e. $+a \times +a = a^2$; therefore a is the first term in the required binomial expressions.

(b) Two factors which, when multiplied together, will equal the third term, i.e. $+8$. Now we have solutions, $+8 \times +1 = +8$; $-8 \times -1 = +8$; $+4 \times +2 = +8$; and $-4 \times -2 = +8$.

(c) Two numbers which, when added together, will give the coefficient of the middle term, i.e. $+6$, but the two factors required for (b) are the same as the two numbers required for (c), therefore our selection is simplified. The factors cannot be 8 and 1, so they must be 4 and 2; and they cannot be -4 and -2 , because we require $+6$; therefore the factors must be $+4$ and $+2$. Thus the binomial expressions are $(a + 4)$ and $(a + 2)$.

EXAMPLE. Factorise $x^2 - 18x + 45$.

SOLUTION. This is similar to Case (2). The first term of each binomial factor must be x . The last term may be $+9$ or $+5$; -9 or -5 ; $+3$ or $+15$; -3 or -15 ; but the selected numbers must give -18 as their sum; therefore we select -3 and -15 , and the answer is $(x - 3)(x - 15)$.

In both Case (1) and Case (2) our selection is simplified further if we notice that if the coefficient of the middle term is negative, then the second terms in the binomial factors are both negative. If the middle term is positive, then the factors are both positive.

EXAMPLE. Factorise $n^2 + 3n - 40$ (Case (3)).

SOLUTION. In this case we require two numbers, such that their product = -40 and their sum = $+3$.

They must be of opposite signs (rule of signs), therefore we have $+8$ and -5 , or -8 and $+5$; but the sum of $+8$ and -5 is $+3$, therefore the factors are $(n + 8)$ and $(n - 5)$.

EXAMPLE. Factorise $a^2 - 4a - 12$ (Case (4)).

SOLUTION. In this case the second terms in the binomial expressions must give -12 as the product, and -4 as the sum, and they must be of opposite signs

$$\begin{aligned} -6 \times +2 &= -12 \\ -6 + 2 &= -4 \end{aligned}$$

Therefore the factors are $(a - 6)$ and $(a + 2)$.

HINT. In all these cases we are finding two numbers, say A and B , whose sum and product are given. Now A cannot be a factor of the product, if A has a factor which is not contained in the product.

65. When the first term of the trinomial expression has a *coefficient which is not unity*, the selection is more difficult, and often requires several trials, unless the student has had considerable mathematical experience.

BUILDING CALCULATIONS

EXAMPLE. Factorise $6a^2 - 31a + 35$.

SOLUTION. Arrange as follows for the first attempt

$$\text{Trial: } \begin{array}{|c|c|} \hline 6 & 7 \\ \hline 3 & a - 5 \\ \hline 2 & 5 \\ \hline & 3 \\ \hline \end{array} \begin{array}{|c|c|} \hline 1 & 5 \\ \hline 2 & a - 7 \\ \hline 3 & \\ \hline & \\ \hline \end{array}$$

The product of the $\left\{ \begin{array}{l} -7a, \text{ or } -14a, \text{ or } -21a \\ -5a, \text{ or } -10a, \text{ or } -15a \end{array} \right.$ inner terms may be

The product of the $\left\{ \begin{array}{l} -30a, \text{ or } -42a \\ -15a, \text{ or } -21a \\ -10a, \text{ or } -14a \end{array} \right.$ outer terms may be

Now select one of the *inner products* and one of the *outer products*, such that their sum will be $-31a$.

We will select $-21a$ (which is the product of -7 and $3a$), and $-10a$ (which is the product of $2a$ and -5), therefore the factors are $(2a - 7)(3a - 5)$.

66. An expression which is the *difference of two squares*, i.e. $x^2 - y^2$, is easily factorised, and has many important applications. If we multiply together $x + y$ and $x - y$, we find that the middle term of the trinomial expression disappears, $x^2 + xy - xy - y^2 = x^2 - y^2$.

Hence, to factorise the *difference of two squares*, we have to take the square root of the first term, *plus* the square root of the second term, and *multiply by* the square root of the first term, *minus* the square root of the second term.

EXAMPLE. Factorise $49 - 100x^2$.

SOLUTION. The square root of $49 = 7$, and the square root of $100x^2 = 10x$; therefore the expression $= (7 + 10x)(7 - 10x)$

EXAMPLE. Evaluate $37^2 - 19^2$.

SOLUTION. $37^2 - 19^2 = (37 + 19)(37 - 19)$
 $= 56 \times 18 = 1008$ Ans.

The method may be extended to compound quantities

$$\begin{aligned} & (5a + 2b)^2 - (3a - b)^2 \\ &= \{(5a + 2b) + (3a - b)\} \{(5a + 2b) - (3a - b)\} \\ &= (5a + 2b + 3a - b)(5a + 2b - 3a + b) \\ &= (8a + b)(2a + 3b) \end{aligned}$$

67. The *sum and difference of two cubes* are also important for practical application, and should be memorised

$$\begin{aligned} x^3 + y^3 &= (x + y)(x^2 - xy + y^2) \\ x^3 - y^3 &= (x - y)(x^2 + xy + y^2) \end{aligned}$$

The student should test these results by division, i.e. $(x^3 - y^3) \div (x - y)$.

EXAMPLE. Evaluate $25^3 - 12^3$.

SOLUTION. $25^3 - 12^3 = (25 - 12)(625 + 300 + 144)$
 $= 13 \times 1069 = 13,897$ Ans.

68. Find the H.C.F. and L.C.M. of $6x^5 - 6x^2y^3$, $(x^2 - y^2)^2$, $4x^2y + 4xy^2$, and $3x^4 + 3xy^3$.

$$(a) \quad 6x^5 - 6x^2y^3 = 6x^2(x^3 - y^3) = 6x^2(x + y)(x - y)$$

$$(b) \quad (x^2 - y^2)^2 = (x - y)(x + y)(x - y)(x + y)$$

$$(c) \quad 4x^2y + 4xy^2 = 4xy(x + y)$$

$$(d) \quad 3x^4 + 3xy^3 = 3x(x^3 + y^3) = 3x(x + y)(x^2 - xy + y^2)$$

The highest factor common to all the four expressions, is $(x + y)$, therefore the H.C.F. is $(x + y)$, and the L.C.M. is $12x^2y(x + y)^2(x - y)^2(x^2 - xy + y^2)$.

EXERCISE XI (Answers on page 37)

1. Factorise $(x^4 - 1)$, and $(x^6 - 1)$.

2. Find the factors of (a) $x^2 + 5xy + 6y^2$; (b) $n^2 - 21n + 108$; (c) $130 + 31mn + m^2n^2$; (d) $72a^2 - 145a + 72$.

3. Evaluate $(434)^2 - (166)^2$.

4. Simplify $\frac{2n}{9m} \times \frac{3y}{5x} + \frac{x}{5y} \times \frac{2m}{3n} - \frac{4n}{9m} \div \frac{8x}{27y}$

ANSWERS TO EXERCISE X (page 31)

1. $15a^3 - 20a^2 + 5a$.

2. $5a^2 + 3a - 2$.

3. $261\frac{1}{2}$.

4. $\frac{4}{5}H = \sqrt{\frac{5H}{125}} \therefore H = 1.6$ ft.

INDICES

69. The following is a summary of the *Index Laws* :-

(I) $x^m \times x^n$ means x taken m times \times x taken n times $= x^{m+n}$.

Example. $x^3 \times x^2 = (x \times x \times x)(x \times x) = x^5$.
 $x^m \div x^n$ means x taken m times \div x taken n times $= x^{m-n}$.

Example. $x^3 \div x^2 = \frac{x \times x \times x}{x \times x} = x^{3-2} = x$.

(2) $(x^m)^n$ means x taken m times, and then the whole taken n times $= x^{m \times n} = x^{mn}$.

Example. $(x^3)^2 = x^3 \times x^3$
 $= (x \times x \times x)(x \times x \times x) = x^6$.

(3) $(abc \dots)^n = a^n b^n c^n \dots$

Example. $(abc)^3 = abc \times abc \times abc$
 $= a \times a \times a \times b \times b \times b \times c \times c \times c$
 $= a^3 b^3 c^3$.

MODERN BUILDING CONSTRUCTION

$$(4) \left(\frac{abc \dots}{pqr \dots} \right)^n = \frac{a^n b^n c^n \dots}{p^n q^n r^n \dots}$$

Example. $\left(\frac{ab}{pq} \right)^3 = \frac{ab \times ab \times ab}{pq \times pq \times pq} = \frac{a^3 b^3}{p^3 q^3}$

70. **Involution** means the raising of an expression to any power. There are several rules (Index Laws) by which we can write down the powers by inspection, but they can also be found by repeated multiplication.

The *Rule of Signs* requires careful consideration; we have seen, by the Index Law, that $(x^3)^2 = x^6$; but by the rule of signs $(-x^3)^2 = -x^3 \times -x^3 = +x^6$, which is the same result.

Hence, the square of any expression, whether positive or negative, is POSITIVE.

Again $(x^3)^3 = x^3 \times x^3 \times x^3 = x^9$

And $(-x^3)^3 = -x^3 \times -x^3 \times -x^3 = x^6 \times -x^3 = -x^9$

Hence we can see from the rule of signs that—

(1) An even power of a quantity must be positive.

(2) An odd power of a quantity will have the same sign as the quantity.

Rules for Involution.

(1) Raise the coefficient by arithmetic and prefix the proper sign.

(2) Multiply the index of each factor of the expression, by the index of the required power.

Notes. (1) Any power of 1 = 1. (2) The first power of any quantity is the quantity itself.

Examples. $(3xy^2)^3 = 9x^3y^6$
 $(3xy^2)^3 = 27x^3y^6$

If the expression is in the form of a fraction, we raise both numerator and denominator.

Examples. $\left(\frac{1}{3a^2} \right)^3 = \frac{1}{27a^6}$
 $\left(\frac{3a^2}{2b^3} \right)^5 = \frac{243a^{10}}{32b^{15}}$

71. The square of a binomial expression can be written down by inspection. By multiplication

$$(x + y)^2 = (x + y)(x + y) = x^2 + 2xy + y^2$$

$$(x - y)^2 = (x - y)(x - y) = x^2 - 2xy + y^2$$

RULES

(1) The square of the SUM of any two quantities is equal to the sum of their squares PLUS twice their product.

(2) The square of the DIFFERENCE of any two quantities is equal to the sum of their squares MINUS twice their product.

Example. $(2x^3 \pm 3y^2)^2$
 $= 4x^6 \pm 2(2x^3 \times 3y^2) + 9y^4$
 $= 4x^6 \pm 12x^3y^2 + 9y^4$

Note. \pm means plus or minus, and in this case infers two different examples.

Numerical Examples

$$(1003)^2 = (1000 + 3)^2$$

$$= 1000^2 + 2 \times 1000 \times 3 + 3^2$$

$$= 1,000,000 + 6000 + 9$$

$$= 1,006,009 \text{ Ans.}$$

$$(97)^2 = (100 - 3)^2$$

$$= 100^2 - 2 \times 100 \times 3 + 3^2$$

$$= 10,000 - 600 + 9$$

$$= 9,409 \text{ Ans.}$$

72. **Geometrical Illustrations.** Fig. 9 shows a square $EBJG$, the sides of which are $a + b$

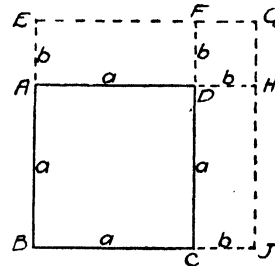


FIG. 9

and $a + b$, hence the area of the square is $(a + b)^2$; but this area consists of the square $ABCD$, the square $FDHG$, and the two rectangles $EADF$ and $DCJH$, which may be stated as $a^2 + b^2 + 2(ab)$.

$$\therefore (a + b)^2 = a^2 + 2ab + b^2$$

Fig. 10 shows a square $ABCD$, the sides of which are a and a , hence the area is a^2 ; but

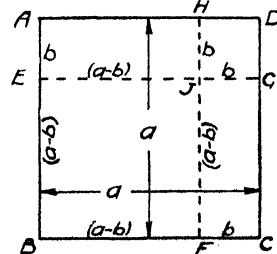


FIG. 10

this area consists of the square $EBFJ$, the rectangle $AEGD$, and the rectangle $HFCD$ less.

the square $HJGD$, which may be stated as $(a - b)^2 + 2ab - b^2$.

$$\therefore a^2 = (a - b)^2 + 2ab - b^2$$

Therefore transposing, we have

$$a^2 - 2ab + b^2 = (a - b)^2$$

73. The rules for the squaring of binomial expressions can be extended to expressions containing more than two terms.

$$\begin{aligned} (x + y + z)^2 &= \{(x + y) + z\}^2 \\ &= (x + y)^2 + 2 \times (x + y) \times z + z^2 \\ &= x^2 + 2xy + y^2 + 2xz + 2yz + z^2 \\ &= x^2 + y^2 + z^2 + 2xy + 2xz + 2yz \end{aligned}$$

RULE FOR SQUARING ANY MULTINOMIAL EXPRESSION. Add together the squares of each term of the expression PLUS TWICE the product of each term into each term which follows it.

(Note that *plus* means algebraic addition; that is, according to the rule of signs.)

Examples.

$$(1) (x - y + z)^2 = x^2 + y^2 + z^2 - 2xy + 2xz - 2yz$$

$$(2) (a + b + c + d)^2 = a^2 + b^2 + c^2 + d^2 + 2ab + 2ac + 2ad + 2bc + 2bd + 2cd$$

$$\begin{aligned} (3) (a - b)^4 &= \{(a - b)^2\}^2 = (a^2 - 2ab + b^2)^2 \\ &= a^4 + 4a^2b^2 + b^4 - 2 \times a^2 \times 2ab \\ &\quad + 2a^2b^2 - 2 \times 2ab \times b^2 \\ &= a^4 + 4a^2b^2 + b^4 - 4a^3b + 2a^2b^2 \\ &\quad - 4ab^3 \\ &= a^4 - 4a^3b + 6a^2b^2 - 4ab^3 + b^4 \end{aligned}$$

Note the descending order of a and the ascending order of b .

The *cubes of binomial expressions* may be written down by inspection.

$$\begin{aligned} (x + y)^3 &= (x + y)(x + y)(x + y) \\ &= x^3 + 3x^2y + 3xy^2 + y^3 \end{aligned}$$

EXPLANATION. (1) First term cubed. (2) Second term cubed. (3) Add three times the first term squared multiplied by the second term. (4) Add three times the first term multiplied by the second term squared.

$$(x - y)^3 = x^3 - 3x^2y + 3xy^2 - y^3$$

Note that we have the same arrangement, but the signs are according to the rule of signs.

These two cases can be extended in the same way that we extended the squares.

HINTS. When n is even $x^n - y^n$ is exactly divisible by $(x + y)$ or $(x - y)$, but $x^n + y^n$ is not. When n is

odd, $x^n - y^n$ is exactly divisible by $(x - y)$, and $x^n + y^n$ by $(x + y)$.

74. **Evolution** is the reverse process to involution, and presents no difficulty if we can guess the factors; the previous work will often suggest the solution, by reversing the process.

RULES FOR SIMPLE EXPRESSIONS

(1) Find the square root of the coefficient by arithmetic.

(2) Divide the index of each factor of the expression, by the index of the proposed root.

Notes. (1) The square root of a positive quantity may be negative or positive, i.e. $-a \times -a = +a^2$ and $+a \times +a = +a^2$.

$$\therefore \sqrt{a^2} = \pm a$$

(2) We cannot have an *even* root of a negative quantity, i.e. $\sqrt{-25}$ is an *imaginary* quantity.

(3) An *odd* root of a quantity has the same sign as the quantity.

Referring to Index Law (2), we know that $(x^3)^3 = x^9$.

$$\therefore \sqrt[3]{x^9} = x^3 = x^3$$

Hence, to find any root of any power, we divide the index of the power by the index of the root required.

The Index Laws apply equally to fractional indices, $x^m \times x^n = x^{m+n}$, where m and n are any values,

$$\therefore x^{\frac{1}{2}} \times x^{\frac{1}{2}} = x^{\frac{1}{2} + \frac{1}{2}} = x^1$$

$$\text{or } x^{\frac{p}{q}} \times x^{\frac{p}{q}} = x^{\frac{p}{q} + \frac{p}{q}} = x^{\frac{2p}{q}}$$

and $x^{\frac{p}{q}} \times x^{\frac{p}{q}} \times x^{\frac{p}{q}} = x^{\frac{p}{q} + \frac{p}{q} + \frac{p}{q}} = x^{\frac{3p}{q}}$, etc.

Therefore, if we take q number of factors, we have

$$(x^{\frac{p}{q}})^q = x^{q \times \frac{p}{q}} = x^p, \text{ that is } (x^{\frac{p}{q}})^3 = x^{\frac{p}{q} \times 3} = x^p.$$

Hence, if we take the cube root of x^3 , we have $\sqrt[3]{x^3} = x^1$.

Examples.

$$(1) a^{\frac{1}{2}} = \sqrt{a}. \quad (2) a^{\frac{1}{3}} = \sqrt[3]{a}. \quad (3) a^{\frac{1}{5}} = \sqrt[5]{a}.$$

$$(4) m^{\frac{a}{2}} \times m^{\frac{1}{3}} = m^{\frac{a}{2} + \frac{1}{3}} = m^{\frac{3a+2}{6}} = \sqrt[6]{m^{3a+2}}$$

$$\begin{aligned} (5) 3x^{\frac{1}{2}}y^{\frac{1}{3}} \times 4x^{\frac{1}{3}}y^{\frac{1}{2}} &= 12x^{\frac{1}{2} + \frac{1}{3}}y^{\frac{1}{3} + \frac{1}{2}} = 12x^{\frac{5}{6}}y^{\frac{5}{6}} \\ &= 12 \times \sqrt[6]{x^5} \times \sqrt[6]{y^5} \end{aligned}$$

According to Index Law (1) $\frac{a^m}{a^n} = a^{m-n}$. Now, if $m = n$, then we have $\frac{a^m}{a^n} = a^{m-n} = a^0$; but by cancelling, $\frac{a^n}{a^n} = \frac{1}{1} = 1$; hence $a^0 = 1$.

MODERN BUILDING CONSTRUCTION

Since $a^{-n} \times a^n = a^{-n+n} = 1$; then, by transposing, $a^n = \frac{1}{a^{-n}}$; and $a^{-n} = \frac{1}{a^n}$.

Simple Illustration. $a \times b = 1$, $\therefore b = \frac{1}{a}$, and $a = \frac{1}{b}$. Therefore if n is any fraction

$$a^{\frac{1}{n}} = \frac{1}{a^{-\frac{1}{n}}}, \text{ and } a^{-\frac{1}{n}} = \frac{1}{a^{\frac{1}{n}}}.$$

Hence, any factor may be transferred from numerator to denominator, or vice versa, by changing the sign of the index.

Examples.

$$(1) 27^{-\frac{2}{3}} = \frac{1}{27^{\frac{2}{3}}} = \frac{1}{\sqrt[3]{27^2}} = \frac{1}{\sqrt[3]{(3^3)^2}} \\ = \frac{1}{\sqrt[3]{3^6}} = \frac{1}{3^2} = \frac{1}{9}$$

$$(2) \frac{3x^{-2}}{5y^{-1}y} = \frac{3y}{5x^2y} = \frac{3}{5x^2}$$

$$(3) \sqrt{64a^6b^2} = 8a^3b. \quad (4) \sqrt{\frac{81x^4}{36y^6}} = \frac{9x^2}{6y^3} = \frac{3x^2}{2y^3}$$

$$(5) \sqrt[3]{27x^6y^3z^3} = 3x^2yz. \quad (6) \sqrt[3]{-\frac{27a^9}{64y^6}} = -\frac{3a^3}{4y^2}$$

$$(7) \sqrt[4]{a^8b^{12}} = a^2b^3 = a^2b^3.$$

SURDS

75. A *surd* is a root which does not work out exactly; that is, the answer can be given only approximately, i.e.

$$\sqrt{2} = 1.414213 \dots$$

$$\sqrt{3} = 1.73205 \dots$$

Algebraic terms with fractional indices are also surds. The algebraic laws of combination are applicable to surds, as to other algebraic symbols.

Numerical surds can be worked out sufficiently accurately for practical purposes; we seldom use more than four figures in our calculations, hence 2.449 is sufficiently accurate for $\sqrt{6}$.

Quantities which are surds are termed *irrational*, other quantities are termed *rational*.

When the denominator of a fraction is a surd, it is often convenient to rationalise it, i.e.

$$\frac{7}{\sqrt{3}} = \frac{7 \times \sqrt{3}}{\sqrt{3} \times \sqrt{3}} = \frac{7\sqrt{3}}{3}$$

This simplifies the working, because it is easier to multiply by $\sqrt{3}$ than to divide by $\sqrt{3}$.

A surd may be changed to a different order

$$\sqrt[3]{5} = 5^{\frac{1}{3}} = 5^{\frac{2}{6}} = \sqrt[6]{5^2}$$

Hence, we can bring surds of different orders to the same order.

Example. Find which is the greatest of $\sqrt[3]{6}$, $\sqrt[4]{10}$, $\sqrt[5]{5}$.

The L.C.M. of 3, 4, and 5 is 60, hence the surds may be expressed as

$$\sqrt[3]{6} = 6^{\frac{1}{3}} = 6^{\frac{20}{60}} = \sqrt[60]{6^{20}}$$

$$\sqrt[4]{10} = 10^{\frac{1}{4}} = 10^{\frac{15}{60}} = \sqrt[60]{10^{15}}$$

$$\sqrt[5]{5} = 5^{\frac{1}{5}} = 5^{\frac{12}{60}} = \sqrt[60]{5^{12}}$$

$$\therefore \sqrt[5]{5} \text{ is the greatest.}$$

76. The root of a quantity is equal to the product of the roots of the factors of the quantity, i.e.

$$\sqrt{15} = \sqrt{3} \times \sqrt{5}$$

$$\sqrt{50} = \sqrt{25} \times \sqrt{2} = 5\sqrt{2}$$

Multiplication and division of surds

$$\sqrt{x} \times \sqrt{y} = \sqrt{xy}$$

Proof. Let $\sqrt{xy} = m$, then $m = \sqrt{x} \times \sqrt{y}$

$$\therefore m^2 = \sqrt{x} \times \sqrt{y} \times \sqrt{x} \times \sqrt{y}$$

$$= \sqrt{x} \times \sqrt{x} \times \sqrt{y} \times \sqrt{y}$$

$$\therefore m^2 = x \times y$$

$$\therefore m = \sqrt{xy}$$

The proof may be extended to show that $\sqrt[n]{x} \times \sqrt[n]{y} = \sqrt[n]{xy}$, or that $\sqrt[n]{x} \times \sqrt[n]{y} = \sqrt[n]{xy}$.

Hence, we have $\frac{\sqrt{xy}}{\sqrt{y}} = \sqrt{x}$, or $\frac{\sqrt[n]{xy}}{\sqrt[n]{y}} = \sqrt[n]{x}$,

because $\frac{\sqrt[n]{xy}}{\sqrt[n]{y}} = \frac{\sqrt[n]{x} \times \sqrt[n]{y}}{\sqrt[n]{y}}$, and $\sqrt[n]{y}$ cancels.

77. *Like surds* are surds having the same quantity under the root sign, i.e. $4\sqrt{3}$, $6\sqrt{3}$, $\frac{1}{2}\sqrt{3}$ are like surds, and may be collected.

Unlike surds cannot be collected.

Hence, to add together several surds, we must first make them *like* surds, then add together the coefficients.

Example. Evaluate $7\sqrt{5} - \sqrt{20} + 3\sqrt{45}$.

First bring the surds to the same root quantity, i.e. make them *like* surds.

$$\begin{aligned}\sqrt{20} &= \sqrt{5 \times 4} = \sqrt{5} \times \sqrt{4} = 2\sqrt{5} \\ 3\sqrt{45} &= 3\sqrt{9 \times 5} = 3 \times \sqrt{9} \times \sqrt{5} \\ &= 3 \times 3 \times \sqrt{5} = 9\sqrt{5}\end{aligned}$$

Therefore the expression becomes $7\sqrt{5} - 2\sqrt{5} + 9\sqrt{5} = 14\sqrt{5}$.

Compound Surds. To multiply together compound surds, we proceed as for ordinary algebraic expressions,

$$\begin{aligned}(1) (3\sqrt{a} - 5) \times 2\sqrt{a} \\ &= 3\sqrt{a} \times 2\sqrt{a} - (5 \times 2\sqrt{a}) \\ &= 6a - 10\sqrt{a}\end{aligned}$$

$$(2) (\sqrt{a+b} - 1) \times \sqrt{a+b} \\ = a + b - \sqrt{a+b}$$

$$\begin{aligned}(3) (\sqrt{x} + \sqrt{y})(\sqrt{x} - \sqrt{y}) \\ = x + \sqrt{xy} - \sqrt{xy} - y = x - y\end{aligned}$$

SQUARE ROOT OF COMPOUND EXPRESSIONS

78. When we cannot factorise a compound expression, we proceed as follows to find the square root.

Find the square root of $25a^2b^2 - 12ab^3 + 16a^4 + 4b^4 - 24a^3b$.

First arrange the expression in descending powers of a .

Divisor	Dividend	Root
$4a^2$	$16a^4 - 24a^3b + 25a^2b^2 - 12ab^3 + 4b^4$	$(4a^2 - 3ab + 2b^2)$
$8a^2 - 3ab$	$-24a^3b + 25a^2b^2$ $-24a^3b + 9a^2b^2$	
$8a^2 - 6ab + 2b^2$	$16a^2b^2 - 12ab^3 + 4b^4$ $16a^2b^2 - 12ab^3 + 4b^4$	

EXPLANATION. (1) Find the square root of the first term, in this case $4a^2$, and place it as the first term in the root. (2) Square $4a^2$ and subtract from $16a^4$. (3) Double the first term of the root, for the first term of the second divisor. (4) See how many times $8a^2$ will go into $-24a^3b = -3ab$; place $-3ab$ in the root, and also use it to complete the divisor. Multiply the complete divisor by $-3ab$, and subtract, bringing down the terms as required. (5) For the third divisor, double the root already found, thus giving $8a^2 - 6ab$. For the third term of the root, divide $8a^2 - 6ab$ into the new dividend, thus giving $2b^2$, and add to the third divisor. (6) Multiply the complete divisor by $2b^2$, and subtract. (7) If there should be any remainder, continue the process.

Note. Compare the above explanation with Article 40.

Fractional Terms. An expression containing fractional terms is dealt with in the same way, but it requires the application of the rules given for fractions (see Article 62). To arrange the terms in descending order may require care. For instance, if the expression contains x^2 , x , $6, \frac{3}{x^2}$, then x^2 is the highest term and $\frac{3}{x^2}$ is the lowest term.

EXAMPLE. Arrange the following expression in descending order: $4 + \frac{1}{a^2} + 2a + a^3 + 7a^2 + \frac{8}{a^3} + \frac{5}{a}$

The arrangement is

$$a^3 + 7a^2 + 2a + 4 + \frac{5}{a} + \frac{1}{a^2} + \frac{8}{a^3}$$

EXAMPLE. Find the square root of $\frac{a^2}{b^2} + \frac{10a}{b} + 25$.

$$\frac{a^2}{b^2} + \frac{10a}{b} + 25 \left(\frac{a}{b} + 5 \right)$$

$$\frac{a^2}{b^2}$$

$$\frac{2a}{b} + 5 \qquad \frac{10a}{b} + 25$$

$$\frac{10a}{b} + 25$$

EXERCISE XII (Answers on page 42)

1. If $\sqrt{2} = 1.414$ and $\sqrt{3} = 1.732$, find the value of
(a) $\frac{5}{2\sqrt{3}}$; (b) $\frac{10\sqrt{2}}{3\sqrt{3}}$
2. Find the square root of $9a^2 + 12ab + 4b^2$, and $x^2 + 4xy - 2xz + 4y^2 - 4yz + z^2$.
3. Multiply together $2\sqrt[3]{5} \times 3\sqrt[3]{5} \times 4\sqrt[3]{5}$.
4. Evaluate, from the values given in Question 1,
 $\frac{7\sqrt{3}}{2\sqrt{5}} \div \frac{8\sqrt{6}}{3\sqrt{15}}$

ANSWERS TO EXERCISE XI (page 33)

1. (a) $(x^2)^2 - 1 = (x^2 + 1)(x^2 - 1) = (x^2 + 1)(x + 1)(x - 1)$.
(b) $(x^2)^2 - 1 = (x^2 + 1)(x^2 - 1) =$ sum and difference of two cubes.
2. (a) $(x + 2y)(x + 3y)$.
(b) $(n - 9)(n - 12)$.
(c) $(26 + mn)(5 + mn)$.
(d) $(8a - 9)(9a - 8)$.
3. 160,800.
4. $\frac{4m^2x^2 - 41n^2y^2}{30mnxy}$.

Chapter V—ALGEBRA (3)

SIMULTANEOUS EQUATIONS

79. WHEN we have more than one unknown quantity, we require more than one equation to find the solution, and we speak of the equations as *simultaneous*. Consider the following example.

A builder purchases 1,000 stocks and 1,000 red facing bricks for £11. He makes a further purchase of 750 stocks and 250 reds for £5 5s. What is the price of each kind per thousand?

Let x stand for 1,000 stocks.

And y „ „ 1,000 reds.

Then $x + y = £11 = 220s.$. . . (1)

And $\frac{3}{4}x + \frac{1}{4}y = £5\frac{1}{2} = 105s.$. . . (2)

We require the *same coefficient* for either x or y in both equations; therefore multiply equation (2) by $\frac{4}{3}$ to make x unity.

Then (2) becomes $\frac{4}{3} \times \frac{3}{4}x + \frac{4}{3} \times \frac{1}{4}y = \frac{4}{3} \times 105$

$\therefore x + \frac{1}{3}y = 140s$. . . (3)

Now subtract equation (3) from equation (1), and we have

$$x + y = 220$$

$$x + \frac{1}{3}y = 140$$

$$\frac{2}{3}y = 80s., \therefore y = 120s$$

But $x + y = 220s. \therefore x = 220 - 120 = 100s.$

\therefore Stocks cost £5 per thousand.

And reds cost £6 per thousand.

General Method of Solving Simultaneous Equations. (1) Clear of fractions and simplify as far as possible.

(2) Make the coefficient of one unknown the same in both equations, by multiplying all the terms in one equation by the same quantity.

(3) Add, or subtract, one equation to, or from, the other; thus *eliminating* one unknown quantity.

(4) Solve the remaining simple equation, by finding the value of the other unknown.

(5) Substitute the solution in either of the original equations, to find the remaining unknown.

Find the value of a and b in the equations.

$$\frac{a-1}{3} = \frac{1}{4}(b+1) \quad \dots \quad (1)$$

$$\frac{2a-3}{5} + \frac{2b-13}{7} = 0 \quad \dots \quad (2)$$

To clear of fractions, bring both sides of the equation to the same denominator, then equation (1) becomes $\frac{4a-4}{12} = \frac{3(b+1)}{12}$.

Now multiply both sides by 12, then $4a-4 = 3b+3$.

Transposing, $4a-3b = 7$. . . (1)

In the same way equation (2) becomes $14a-21+10b-65=0$.

$\therefore 14a+10b = 86$. . . (2)

Making the coefficient of a the same in both equations, we have

$$28a - 21b = 49 \quad \dots \quad (3) = (1) \times 7$$

$$28a + 20b = 172 \quad \dots \quad (4) = (2) \times 2$$

Subtracting (3) from (4)

$$41b = 123, \therefore b = \frac{123}{41} = 3$$

Substituting the value of b in equation (1)

$$4a - 3 \times 3 = 7, \therefore 4a = 16, \therefore a = 4$$

$$\therefore b = 3 \text{ and } a = 4 \text{ Ans.}$$

In the solution of simultaneous equations it is often an advantage to substitute the value of one unknown in terms of another unknown.

EXAMPLES. 1. Solve the simultaneous equations—

$$x + y = 17 \text{ and } \frac{x}{2} = \frac{y}{3}$$

SOLUTION. In equation (2) $x = \frac{2}{3}y$
Substituting this value of x in equation (1)

Then $\frac{2}{3}y + y = 17 \therefore 1\frac{2}{3}y = 17 \therefore y = 17 \times \frac{3}{5} = \frac{51}{5} = 10\cdot2.$

$\therefore x = 17 - 10\cdot2 = 6\cdot8 \therefore x = 6\cdot8 \text{ and } y = 10\cdot2. \text{ Ans.}$

2. Two numbers added together = 90, and $\frac{1}{3}$ of the smaller number equals $\frac{1}{4}$ of the larger number. Find the numbers.

SOLUTION. Let x be the smaller number and y the larger number.

Then $x + y = 90$

and $\frac{1}{3}x = \frac{1}{4}y \therefore x = \frac{3}{4}y$

Then $\frac{3}{4}y + y = 90 \therefore 1\frac{3}{4}y = 90 \therefore y = 63$

$\therefore x = 90 - 63 = 27 \therefore x = 27 \text{ and } y = 63. \text{ Ans.}$

$$3. \frac{3x-1}{2y+1} = 4 = \frac{2x+2}{y+2}$$

SOLUTION. (1) $3x-1 = 4(2y+1) = 8y+4$
 $\therefore 3x-8y = 5$

(2) $2x+2 = 4(y+2) = 4y+8$
 $\therefore 2x-4y = 6$

Multiply (2) by 2 and subtract

$$\begin{array}{r} 4x-8y = 12 \\ 3x-8y = 5 \\ \hline x = 7 \end{array}$$

Substituting in (2) $14-4y = 6 \therefore 14-6 = 4y$
 $\therefore y = \frac{8}{4} = 2$
 $\therefore x = 7$ and $y = 2$. Ans.

80. When we have three unknowns, we use three equations to find the unknown quantities

$$2x - 2y + z = -5 \quad \cdot \quad \cdot \quad (1)$$

$$3x + y + 2z = -2 \quad \cdot \quad \cdot \quad (2)$$

$$x + y + 2z = 4 \quad \cdot \quad \cdot \quad (3)$$

First remove one unknown from any two of the equations, proceeding as in the last example.

Multiplying equation (3) by 2, we have

$$2x + 2y + 4z = 8$$

Subtracting eq. (1) $2x - 2y + z = -5$

$$\hline 4y + 3z = 13 \quad (4)$$

Now eliminate the *same* unknown from equation (2), and either equation (1) or (3).

Using equation (3) again, and multiplying by 3, we have

$$3x + 3y + 6z = 12$$

Subtracting eq. (2) $3x + y + 2z = -2$

$$\hline 2y + 4z = 14 \quad (5)$$

Now eliminate one unknown from equations (4) and (5).

Multiplying equation (5) by 2, we have

$$4y + 8z = 28$$

Subtracting eq. (4) $4y + 3z = 13$

$$\hline 5z = 15 \therefore z = 3$$

Substituting z in either equation (4) or (5), say (4), we have $4y + 9 = 13$, $\therefore y = 1$.

Substituting the values of y and z in any of the original equations, say (3), we have $x + 1 + 6 = 4$, $\therefore x = -3$.

Therefore $\left. \begin{array}{l} x = -3 \\ y = 1 \\ z = 3 \end{array} \right\}$ are the required values.

QUADRATIC EQUATIONS

81. The solution of equations, which we have considered so far, have only contained the first power of the unknown quantities. When the

unknown is of the second power, the equation is a *quadratic*.

The student should be familiar with the form of a quadratic equation from the chapters on factors, involution, and evolution. When the equation can be factorised, the work is considerably simplified.

Solve the equation $x^2 + 2x = 8$.

Transposing all the terms to one side, we have $x^2 + 2x - 8 = 0$.

Factorising, $(x + 4)(x - 2) = 0$.

Now if the product of two quantities is zero, then one of the quantities must be a zero quantity.

Assuming that $(x + 4)$ is the zero factor, that is, $x + 4 = 0$, then, $x = -4$.

Again, if $(x - 2)$ is the zero factor, then $x = 2$, therefore the solution is $x = -4$ or 2 .

Test the correctness of these values by substituting

(1) $(-4)^2 + 2 \times (-4) = 8$, $\therefore 16 + (-8) = 8$.

(2) $2^2 + 2 \times 2 = 8$.

When solving quadratic equations we have two answers, from the rule of signs. In practical examples we can often ignore one of the solutions by common-sense reasoning; for instance, the simplest form of quadratic is shown in the equation

$$A = \frac{2}{7}R^2$$

where A = area of circle, and R = radius.

Then, if the area is $28\frac{2}{7}$ sq. ft., we have

$$28\frac{2}{7} = \frac{2}{7}R^2, \therefore R^2 = \frac{198 \times 7}{7 \times 22} = 9$$

Now, taking the square root of each side, we have $R = \pm 3$; but we know that R cannot be a negative quantity, therefore we ignore -3 .

82. **Completing the Square.** When the factors are not easily seen, we apply the method known as *completing the square*. This method is really re-arranging the equation, so that it can be factorised by taking the square root of each side.

A plumber used 160 sq. ft. of sheet lead to line the inside of a cylindrical vat. If the height was 8 ft., what was the diameter of the base?

The circumference of the vat = $2 \times \frac{2}{7}R \times R$, where R is the radius of the base.

Therefore the cylindrical surface (without bottom) = $8 \times 2 \times \frac{2}{7}R \times R$.

The area of the bottom = $\frac{2}{7}R^2$. Using the symbol π for $\frac{2}{7}$, then the total area = $\pi R^2 + 16\pi R$.

$$\therefore \pi R^2 + 16\pi R = 160$$

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Making the coefficient of R^2 unity, by dividing every term by π , we have $R^2 + 16R = \frac{160}{\pi}$.

Now make the left-hand side a *perfect square* by adding *half the coefficient of R squared*, then we have $R^2 + 16R + (8)^2 = \frac{160}{\pi} + (8)^2$, because we must add the same quantity to both sides.

We can now take the square root of each side, because $R^2 + 16R + (8)^2 = (R + 8)^2$, therefore we have

$$R + 8 = \sqrt{\frac{160}{\pi} + 64} = \sqrt{114.92} = \pm 10.72$$

$$\therefore R = \pm 10.72 - 8$$

But we can ignore -10.72 .

$$\therefore R = 10.72 - 8$$

$$= 2.72 \text{ ft.}, \therefore \text{diameter} = 5.44 \text{ ft.}$$

The general method of solving a quadratic equation is as follows—

(1) Transpose the terms, if necessary, so that the unknown quantities are on one side of the equation and the numerical values on the other side.

(2) Make the coefficient of the second power *unity and positive*, by dividing throughout by the coefficient of the second power.

(3) *Add to both sides the square of half the coefficient of the first power*, that is, make the left-hand side a *perfect square*.

(4) Extract the square root of both sides.

(5) Solve the resulting simple equation.

The reason for rule (3) is shown in the following examples of perfect squares—

$$(x + n)^2 = x^2 + (2n)x + n^2$$

$$(x - n)^2 = x^2 - (2n)x + n^2$$

In both cases we see that the coefficient of x is twice the square root of the third term, i.e. $n \times 2$. Also see Art. 85A.

EXAMPLE. Solve $\frac{7}{12}x - x^2 + \frac{1}{12} = 0$.

SOLUTION. Transpose, so that $-x^2$ is the first term and $\frac{1}{12}$ is on the other side of the equation; hence, we have, $-x^2 + \frac{7}{12}x = -\frac{1}{12}$.

Multiply by -1 to make the coefficient of $-x^2$ positive.

$$\text{Then, } x^2 - \frac{7}{12}x = \frac{1}{12}.$$

$$\text{Complete the square, } x^2 - \frac{7}{12}x + \left(\frac{7}{12}\right)^2 = \frac{1}{12} + \frac{49}{144}$$

Extracting the square root

$$x - \frac{7}{12} = \sqrt{\frac{121}{144}} = \pm \frac{11}{12}$$

$$\therefore x = \pm \frac{11}{12} + \frac{7}{12} = \frac{11+7}{12} = 1\frac{1}{2}$$

$$\text{or } \frac{-11+7}{12} = \frac{-4}{12} = -\frac{1}{3} \quad \left. \vphantom{\frac{11+7}{12}} \right\} \text{Ans.}$$

$(x - 1\frac{1}{2})(x + \frac{1}{3})$ are the factors of the expression.

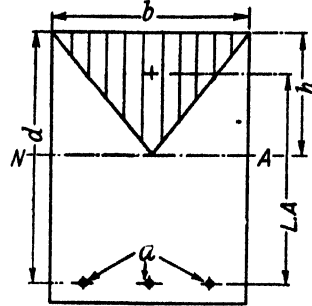


FIG. 10A

EXAMPLE. Fig. 10A shows the section of a reinforced concrete beam. Find the depth of the neutral axis, h , given the following values: $d = 20$ in., $b = 10$ in., $a = 2$ sq. in. = area of steel reinforcement.

$$\text{The formula is } \frac{2a}{hb} = \frac{h}{18(d-h)}$$

SOLUTION.

$$\frac{2 \times 2}{h \times 10} = \frac{h}{18(20-h)} \quad \therefore \frac{4}{10h} = \frac{h}{360-18h}$$

$$\therefore 4(360-18h) = 10h \times h$$

$$\therefore 1440 - 72h = 10h^2$$

$$\therefore 10h^2 + 72h = 1440 \quad \therefore h^2 + 7.2h = 144$$

$$\therefore h^2 + 7.2h + (3.6)^2 = 144 + (3.6)^2$$

$$\therefore h + 3.6 = \sqrt{156.96}$$

$$\therefore h + 3.6 = 12.53 \quad \therefore h = 8.93 \text{ in. Ans.}$$

EXAMPLE. Two pipes together can fill a tank in six minutes. One pipe can fill the tank in five minutes less time than the other. How long will it take for each pipe to fill the tank separately?

SOLUTION. If it takes the smaller pipe x minutes to fill the tank, then the larger pipe will fill the tank in $x - 5$ minutes.

Then both pipes will fill $\left(\frac{1}{x} + \frac{1}{x-5}\right)$ of the tank in one minute; but this equals one-sixth of the tank, therefore $\frac{1}{x} + \frac{1}{x-5} = \frac{1}{6}$.

Clearing of fractions, by using a common denominator of $x(x-5) \times 6$, we have $6(2x-5) = x(x-5)$; $\therefore 12x - 30 = x^2 - 5x$; $\therefore x^2 - 17x + 30 = 0$; $\therefore (x-15)(x-2) = 0$; $\therefore x-15 = 0$, or $x-2 = 0$; $\therefore x = 15$ or 2 .

But $x = 2$ is impossible; $\therefore x = 15$; \therefore the pipes fill the tank separately in 15 and 10 minutes respectively.

SIMULTANEOUS QUADRATICS

83. The solution of quadratic equations with two unknowns depends very much upon the

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ingenuity of the student. The problems are so varied that no general rule can be given, but the majority of cases will be covered by the following illustrations.

The area of a rectangular plot of ground is 4,800 sq. yd., and a diagonal footpath is 100 yd. long. What is the length of fencing required to enclose the plot?

The student should always illustrate the questions by diagrams, if possible.

The solution of this question requires the application of *Pythagoras's theorem*, which states that: "In a right-angled triangle, the square on the hypotenuse is equal to the sum of the squares on the other two sides." Now the diagonal of the plot, together with two sides, forms a right-angled triangle; therefore, if we call one side x and the other side y , we have

$$x^2 + y^2 = 100^2 = 10,000 \quad (1)$$

Also, the area of the plot will be $x \times y$

$$\therefore xy = 4800 \quad (2)$$

Multiplying equation (2) by 2, we have $2xy = 9600$.

Now add this to equation (1), and we have

$$x^2 + 2xy + y^2 = 9600 + 10,000 \\ = 19,600$$

which makes the left-hand side a perfect square; hence, by extracting the square root of each side, we have

$$x + y = 140 \quad (3)$$

Now subtract $2xy = 9600$ from $x^2 + y^2 = 10,000$

$$\therefore x^2 - 2xy + y^2 = 400$$

This again makes the left-hand side a perfect square; hence, by extracting the square root of each side, we have

$$x - y = 20 \quad (4)$$

Add together equations (3) and (4)

$$\begin{array}{r} x + y = 140 \\ x - y = 20 \\ \hline 2x = 160 \end{array} \therefore x = 80 \text{ yd.}$$

Now subtract these two equations

$$\begin{array}{r} x + y = 140 \\ x - y = 20 \\ \hline 2y = 120 \end{array} \therefore y = 60 \text{ yd.}$$

Therefore the length of fencing required

$$\begin{aligned} &= 2(x + y) \\ &= 2(80 + 60) = 2 \times 140 \\ &= 280 \text{ yd. } \textit{Ans.} \end{aligned}$$

84. Consider the last example again, when the length of fencing and the area of the plot are given, and it is required to find the lengths of the sides; we have

$$2(x + y) = 280, \therefore x + y = 140 \quad (1)$$

$$\text{and} \quad xy = 4,800 \quad (2)$$

Squaring (1), we have $x^2 + 2xy + y^2 = 19,600$

$$\text{Multiplying (2) by 4} \quad 4xy = 19,200$$

$$\text{Subtracting} \quad x^2 - 2xy + y^2 = 400$$

$$\text{Extracting roots, then } x - y = \sqrt{400} = 20$$

$$\text{Adding equation (1)} \quad x + y = 140$$

$$2x = 160$$

$$\therefore x = 80 \text{ yd.}$$

$$\therefore y = 140 - 80 = 60 \text{ yd.}$$

In these examples we can ignore the negative values, but in the algebraic examples we have several values for x and y , as shown in the following. Solve the equations

$$a - b = 8 \quad (1)$$

$$ab = 513 \quad (2)$$

$$\text{Squaring equation (1)} \quad a^2 - 2ab + b^2 = 64$$

$$\text{Multiplying (2) by 4} \quad 4ab = 2052$$

$$\text{Adding} \quad a^2 + 2ab + b^2 = 2116$$

$$\text{Extracting roots} \quad a + b = \pm 46$$

$$\text{Adding equation (1)} \quad a - b = 8$$

$$2a = \pm 46 + 8 \\ = 54 \text{ or } -38$$

$$\therefore a = 27 \text{ or } -19$$

Subtracting equation (1)

$$2b = \pm 46 - 8 = -54 \text{ or } +38$$

$$\therefore b = -27 \text{ or } 19$$

EXAMPLE. The volume of concrete used in a hollow hemispherical dome was 15 cub. yd., the thickness of the concrete was 0.32 yd. Find the outside and inside radii of the dome.

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SOLUTION. Let R = outside radius, r = inside radius, and $\pi = 3.142$.

Then $15 = \frac{\frac{3}{8}\pi(R^2 - r^2)}{2}$

$\therefore \frac{30}{\frac{3}{8}\pi} = R^2 - r^2 = (R - r)(R^2 + Rr + r^2)$

But $R - r = .32$

$\therefore \frac{30}{.32 \times \frac{3}{8}\pi} = R^2 + Rr + r^2 = 22.4$ (1)

Squaring $R - r = .32$, we have

$R^2 - 2Rr + r^2 = .1024$ (2)

Subtracting (2) from (1), then $3Rr = 22.2976$

$\therefore Rr = 7.4325$

$\therefore \begin{matrix} R^2 + Rr + r^2 & = & 22.4 \\ Rr & = & 7.4325 \end{matrix}$

Adding $R^2 + 2Rr + r^2 = 29.8325$

Extracting roots $R + r = 5.46$

And $R - r = .32$

$\therefore \begin{matrix} 2R & = & 5.78, & \therefore R & = & 2.89 \text{ yds.} \\ 2r & = & 5.14, & \therefore r & = & 2.57 \text{ yds.} \end{matrix}$ } *Ans.*

85. If the equations are in the form of

$x^2 + y^2$ (1)

and $x + y$ (2)

we have to square equation (2), and then subtract the result from twice equation (1). We shall thus have $x^2 - 2xy + y^2$, which is a perfect square for $x - y$.

The student will have noticed that we require $x + y$ and $x - y$, and we have to use artifice to arrive at these two results; hence we require the two perfect squares $x^2 + 2xy + y^2$, or $x^2 - 2xy + y^2$ in most cases.

We will work another example to show the various answers obtained when solving quadratics.

Solve the equations

$a^2 + b^2 = 170$ (1)

$ab = 77$ (2)

Multiplying equation (2) by 2 and, adding to equation (1), we have, $a^2 + 2ab + b^2 = 324$.

$\therefore a + b = \pm 18$

Now subtracting $2ab = 154$ from equation (1), we have $a^2 - 2ab + b^2 = 16$.

$\therefore a - b = \pm 4$

Hence, we have

$\left. \begin{matrix} a + b = 18 \\ a + b = -18 \\ a - b = 4 \\ a - b = -4 \end{matrix} \right\} \therefore \begin{matrix} a = 11, -11; 7, -7 \\ b = 7, -7; 11, -11 \end{matrix} \right\} \text{Ans.}$

85A. **Solutions by Formula.** Every quadratic can be reduced to the form $ax^2 + bx + c = 0$, where a , b , and c may have any numerical values. Hence the solution of this algebraic arrangement provides a useful formula for general application.

Solution of $ax^2 + bx + c = 0$.

Divide by a , and transpose, then $x^2 + \frac{bx}{a} = -\frac{c}{a}$.

Completing the square, then $x^2 + \frac{bx}{a} + \left(\frac{b}{2a}\right)^2 = \frac{b^2}{4a^2} - \frac{c}{a}$.

$\therefore \left(x + \frac{b}{2a}\right)^2 = \frac{b^2 - 4ac}{4a^2}$. Extracting the

square root, $x + \frac{b}{2a} = \frac{\pm \sqrt{b^2 - 4ac}}{2a}$

$\therefore x = -\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a}$

$\therefore x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

EXERCISE XIII (Answers on page 46)

1. Fig. 11 shows the details of a cotttered bolt, in which we assume the following modes of failure—

(1) $W = \frac{\pi}{4}d^2f_t$. (2) $W = 2btf_s$.

(3) $W = (a^2 - at)f_t$. (4) $W = 2acf_s$.

Find the values of d , a , c , and t , when $W = 10.6$ tons, $\pi = 3.14$, f_t = safe working stress in tension = 6 tons per square inch, f_s = safe working stress in shear = 5 tons per square inch, and $b = 4t$.

Hint. To find the values, solve each equation in turn, and as each value is found, substitute it in the following equations. In equation (2) we have bt , but $b = 4t$; therefore substituting, equation (2) becomes $10.6 = 2 \times 4t^2f_s$.

2. A consignment of 24 yd. of 4 in. and 16 yd. of 6 in. cast-iron drain pipes cost £13 12s.; a second consignment of 30 yd. of 4 in. and 24 yd. of 6 in. cost £18 15s. What was the cost per yard of each size of pipe?

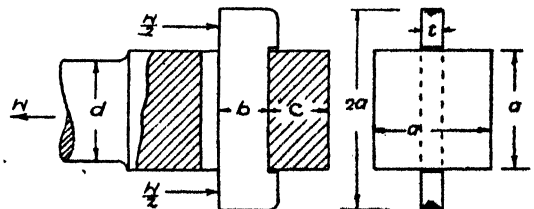


FIG. 11

ANSWERS TO EXERCISE XII (page 37)

1. (a) 1.4434. (b) 2.721.
2. $3a + 2b$ and $x + 2y - z$.
3. 120.
4. 1.6075.

Chapter VI—ALGEBRA (4)

GRAPHIC SOLUTIONS

86. **Plotting a Point.** The various applications of squared paper to everyday problems are too numerous to illustrate in these pages. Once the student understands how to plot a point, many of the applications depend upon common sense. The following examples will show those

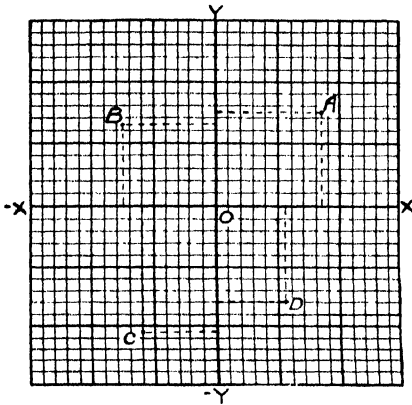


FIG. 12

uses of squared paper which require special knowledge.

The most convenient squared paper is divided in 9 tenths of inches, with every fifth line drawn heavier. Fig. 12 illustrates the various terms applied to the plotting of points. The two lines $-XOX$ and $-YOY$ divide the paper into four spaces, or quadrants. The *first* quadrant is XOY , the *second* $YO-X$, and the *third* $-XO-Y$. The two lines are called the *axis of X*, and the *axis of Y*. The intersection of the axes is the *origin*.

When *plotting a point* we refer to its distances from the axes as its *co-ordinates*. Measurements above or to the right of the origin are *positive*; those below or to the left of the origin are *negative*, as denoted by X and $-Y$.

To find the position of a point in any of the spaces, we require two measurements. The value along X is stated first.

We will consider each small division as representing one unit; then the position of point A is $(8.5, 7.5)$; the position of B is $(-7.5, 6.5)$; $C = (-6, -10.5)$; $D = (5.5, -8)$. Measure-

ments along OX are sometimes called the *abscissae*.

87. **Plotting a Graph.** When we plot a series of points and draw a line through them, the line is called a *graph*. In Fig. 13 are two graphs showing the safe distributed loads that a 10 in. by 6 in. and a 10 in. by 5 in. rolled steel joist will carry for different spans. In this case we

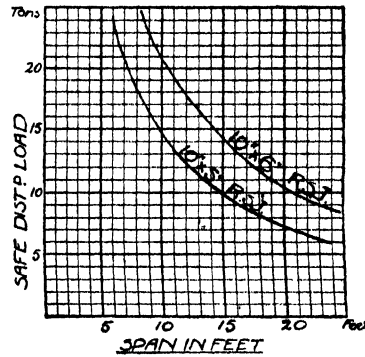


FIG. 13

only require the first quadrant. Along the axis of X we have the span of the joist, in feet; and along the axis of Y we have the value of the safe load, in tons. The points have been plotted from the following table for a 10 in. by 6 in. joist—

Span in feet	8	10	12	16	18	22
Safe load in tons	26.4	21.1	17.6	13.2	11.7	9.6

And for a 10 in. by 5 in. joist—

Span in feet	6	8	10	12	16	18	22
Safe load in tons	24.3	18.2	14.6	12.1	9.1	8.1	6.6

The tabulated values are called *connected variables*.

When we have drawn the graphs by linking up the points, we can read off, or *interpolate*, the intermediate values; for instance, the safe load for a 15 ft. span is 14.1 tons, and the span for a safe load of $10\frac{1}{2}$ tons is 20 ft., in both cases for a 10 in. by 6 in. joist.

The student must exercise care when drawing

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the graph. In this case the graph is a regular curve, and it would not be correct to join up the points by straight lines. Generally, the curve is drawn freehand; but a flexible rule, a piece of cardboard, or a special instrument for the purpose may be used.

88. **Solution of Equations.** This is another important application of squared paper. If we have an equation of the form $y = \frac{1}{2}x + 2$, we understand that x and y are variable quantities, and that the value of y depends upon the value of x . Now, if we assume a series of values for x , we can calculate the corresponding value of y . For instance, when $x = 3$, then $y = \frac{1}{2} \times 3 + 2 = 3\frac{1}{2}$. If we plot a series of values, so that the value of x is along the *axis* of X , and the corresponding values of y along the axis of Y , we shall obtain a graph which is a straight line. This form of graph is known as a *linear graph*, and we know that it represents an equation of the form $y = x$, $y = mx$, or $y = mx + c$, where m and c are constants and x a variable.

To Find the Values of m and c . Fig. 14 shows three graphs A, B, and C. Graph A represents $y = x$; graph B represents $y = \frac{1}{2}x$; and graph C represents $y = \frac{1}{2}x + 1\frac{1}{2}$.

We know that each graph must be a straight line, so we only plot *two* points for each graph.

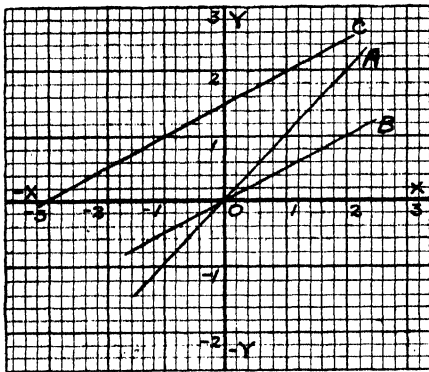


FIG. 14

In each graph we will assume 2 and 0 as the values of x .

GRAPH A. When x is $\begin{array}{|c|c|} \hline 2 & 0 \\ \hline \end{array}$
Then y is $\begin{array}{|c|c|} \hline 2 & 0 \\ \hline \end{array}$

GRAPH B. $\begin{array}{|c|c|c|} \hline x & 2 & 0 \\ \hline y & 1 & 0 \\ \hline \end{array}$

It is often more convenient, when plotting

an equation of the C type, to take the value of y when $x = 0$, and the value of x when $y = 0$.

GRAPH C. $\begin{array}{|c|c|c|} \hline x & 0 & -3 \\ \hline y & 1\frac{1}{2} & 0 \\ \hline \end{array}$

The student will notice that the graphs without the constant c pass through the origin;

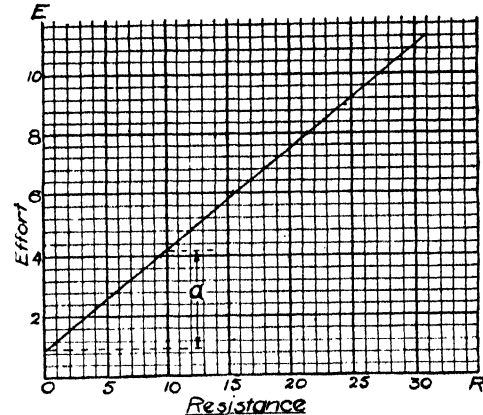


FIG. 15

also that the graphs with the same value of m are parallel to each other, but graph C passes through the Y axis a distance of $1\frac{1}{2}$ above the origin. Hence, we can say that the value m alters the *slope* of the line, and the value c alters its position on the axis of Y . If the intersection with the axis of Y is below the origin, the value of the constant c is negative, i.e. $y = mx - c$.

89. The following table shows the effort required to overcome the resistance applied to a machine. Plot the observed values, which are supposed to follow the law $E = mR + c$, and find the values of m and c .

E	4	5	6	7	8	9	10	11
R	$9\frac{1}{2}$	$12\frac{1}{2}$	$15\frac{1}{2}$	$18\frac{1}{2}$	$21\frac{1}{2}$	$24\frac{1}{2}$	$27\frac{1}{2}$	$30\frac{1}{2}$

Fig. 15 shows the graph plotted from the table. After plotting the points we have to draw the graph, so that it lies *evenly* amongst the points; this corrects the errors made when observing the values.

The value of c can be read at once; it is the distance from O to the intersection of the graph with the Y , or E , axis, i.e. $\cdot 83$. To find the value m , we take a convenient length along the X , or R , ordinates, in this case 10 units, and find the rise (or slope) of the graph, with this horizontal

distance ; in this case it is a , or 3.4 units, along the E ordinates. Then $\frac{3.4}{10} = .34$ is the slope of the graph, and is the value of m .

Therefore the equation is $E = .34R + .83$.

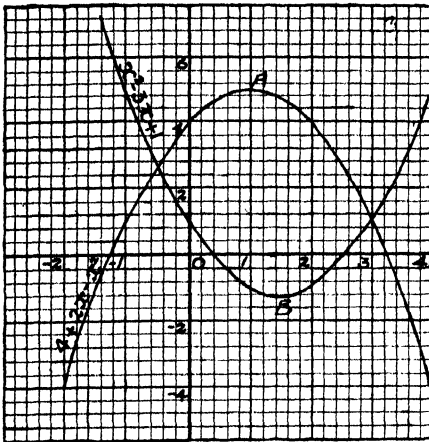


FIG. 16

We can now calculate the value of E for any value of R .

When we require the solution for *simultaneous equations*, we draw the graphs representing the equations, and read the values of x and y at the intersection of the graphs.

90. **Quadratic Equations.** The graph for the second power of x is a parabola. The student should plot graphs representing $y = x^2$, $y = -x^2$, $y = mx^2$, and $y = mx^2 + c$, when he will find that m again influences the slope of the line, and c alters the position of the parabola with regard to the origin.

Suppose it is required to draw the graph of $y = 4 + 2x - x^2$.

It is convenient to tabulate the values as follows—

x	4	3	2	1	0	-1	-2
x^2	16	9	4	1	0	1	4
$2x$	8	6	4	2	0	-2	-4
y	-4	1	4	5	4	1	-4

We assume values for x , and work out the corresponding values of y from the equation. The selections for x sometimes require thought ; but if we select a few as above, we can soon see

which values are of use to guide our selection. We require a good selection at the turning point of the parabola; and also where the parabola crosses the axis of X , because the intersections with the X axis are the roots of the equation. Fig. 16, A , shows the graph ; and we find that the roots are -1.24 and 3.24 , which satisfy the equation $4 + 2x - x^2 = 0$. From this example, the student can see that we have to bring all the values to one side of the equation, so that the other side = zero, then let $y =$ the expression.

Another example. Find the roots of the equation $x^2 - 3x + 1 = 0$, then give the factors of the expression.

The graph is shown in Fig. 16, B , and the roots are .4 and 2.6 ; hence the factors of the expression are $(x - .4)(x - 2.6)$, as near as can be found graphically.

For equations of a higher power than the second, we proceed in the same way.

91. **Maximum and Minimum Values.** The turning point of the parabola, as at A , Fig. 16, shows the *maximum* value of the expression ; the turning point, as at B , shows the *minimum* value of the expression.

Two-graph Method. When we have several equations to solve, it is an advantage to use the

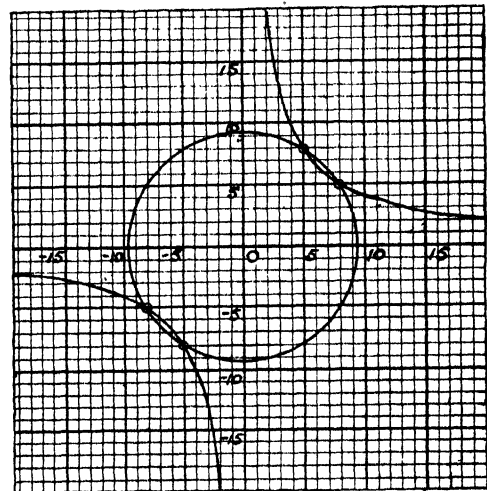


FIG. 17

two-graph method. If $x^2 - 6x + 8 = 0$, then $x^2 = 6x - 8$. Now let $y = x^2$, and $y_1 = 6x - 8$, and plot the two graphs ; one is a parabola and the other a straight line. The parabola is symmetrical about the axis Y , and passes through the origin. The intersection of the

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graphs will give the values of x , which satisfy the equation. If there are several equations, $y = x^2$ will serve for all of them, so that we only require the linear graphs.

92. **Solution of $y = x^n$.** Any graph of the form $y = x^n$ may be plotted as a linear equation, by taking the logarithms of each side, i.e. $\log y = n \log x$. (See Logarithms.)

The graph of $x^2 + y^2 = N$, is a circle. The graph of $xy = N$, is a rectangular hyperbola. For example, solve graphically, the simultaneous equations: (1) $x^2 + y^2 = 89$; (2) $xy = 40$.

The graph for equation (1) is a circle, Fig. 17A. If we assume a value for x , then $y = \sqrt{89 - x^2}$; if we assume a value for y , then $x = \sqrt{89 - y^2}$. Therefore, when $x = 5$, then $y = \sqrt{89 - 25} = \sqrt{64} = 8$; and when $y = -8$, then $x = \sqrt{89 - 64} = \sqrt{25} = 5$. No matter how many values we may plot, the points will all be equidistant from the origin, if both axes are to the same scale; hence the graph is a circle.

The graph for equation (2) is a rectangular hyperbola; hence there are two branches, Fig. 17B. Assuming positive and negative values for x , we have the following table from $y = \frac{40}{x}$.

x	1	2	4	5	8	10	∞	0
y	40	20	10	8	5	4	0	∞

No matter how great we take the value of x , we shall never have y equal to 0, until we get to *infinity* (∞), which of course has no practical meaning. Similarly, when $x = 0$, then $y = \infty$. Hence we have a graph which is always approaching the axes, but never meets them. We only require the intersections of the two graphs for the solutions, so we select more values near the intersections, and we find the solutions are

When $x = 5, 8; -5, -8$. $y = 8, 5; -8, -5$.

Figs. 17A and 17B show the application of graphs to trigonometry. The graph of $\sin x^\circ$ is shown in Fig. 17A by a continuous line and the graph of $\cos x^\circ$ by a broken line. In Fig. 17B the graphs of $\tan x^\circ$ and $\cot x^\circ$ are shown in the same way.

These curves should be drawn to a large scale and studied in connection with Art. 128 in Chapter IX. A table should be compiled

similar to the following, but including more values, especially for $\tan x$ and $\cot x$.

x	0	45	90	135	180	225	270	315	360
$\sin x^\circ$	0	.71	1	.71	0	-.71	-1	-.71	0
$\cos x^\circ$	1	.71	0	-.71	-1	-.71	0	.71	1
$\tan x^\circ$	0	1	∞	-1	0	1	∞	-1	0
$\cot x^\circ$	∞	1	0	1	∞	1	0	-1	∞

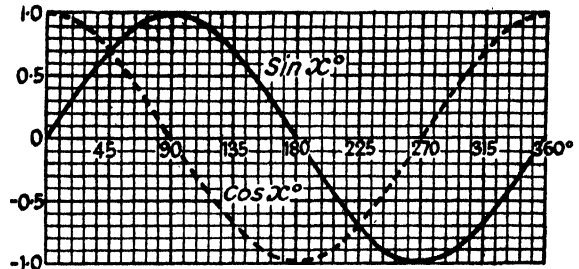


FIG. 17A

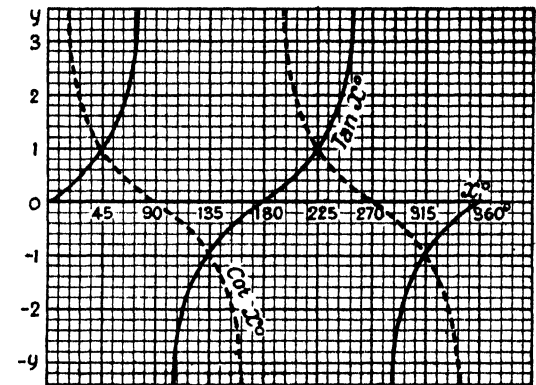


FIG. 17B

SUMMARY

- The graph of $y = mx + c$ is a straight line.
- " " $y = mx^2 + c$ " parabola.
- " " $y = \frac{N}{x}$ " hyperbola.
- " " $y = \sqrt{N - x^2}$ " circle.

ANSWERS TO EXERCISE XIII (page 42)

1. $d = 1\frac{1}{2}$ in. $a = 1.65$, $t = .5$, $c = .64$.
2. 5s. 6d. and 8s. 9d. per yard, respectively.

Chapter VII—ALGEBRA (5)

RATIO

93. FROM previous consideration of arithmetical ratio, the student is familiar with the statement that the ratio of any two values may be expressed as a fraction, which shows their relative magnitude. We cannot compare a length with an area, or a weight with a foot; but we can compare a length with a length, or a weight with a weight.

A ratio and a fraction are governed by the same laws, but we have to distinguish between the two. For instance

$\frac{3 \text{ in.}}{2 \text{ ft.}}$ is a ratio and not a fraction,

but $\frac{3 \text{ in.}}{24 \text{ in.}}$ which = $\frac{1}{8}$, may be regarded as either a ratio or a fraction.

There are two ways of expressing a ratio, i.e.

$$x : y, \text{ or } \frac{x}{y}$$

x is called the *antecedent*, and y the *consequent*.

94. The following rules should be carefully considered.

RULE (1). *A ratio remains unaltered if we multiply, or divide, both antecedent and consequent by the same value.*

$$\frac{x}{y} = \frac{mx}{my}, \text{ and } \frac{x}{y} = \frac{\frac{x}{m}}{\frac{y}{m}} = \frac{mx}{my}$$

RULE (2). *We can compare two or more ratios, by finding a common denominator, and reducing to equivalent fractions.*

If $a : b$ and $c : d$ be the ratios, then

$$\frac{a}{b} = \frac{a \times d}{b \times d}, \text{ and } \frac{c}{d} = \frac{b \times c}{b \times d}$$

Now we can compare the numerators, because both ratios have the same denominators; therefore if ad is $> bc$, evidently the ratio $\frac{a}{b}$ is $> \frac{c}{d}$

RULE (3). *We may express two fractions as a ratio, i.e.*

$$\frac{a}{b} : \frac{c}{d} = \frac{\frac{a}{b}}{\frac{c}{d}} = \frac{ad}{bc} = ad : bc$$

$$\text{or, if } \frac{a}{b} = \frac{c}{d}, \text{ then } \frac{a}{b} \times bd = \frac{c}{d} \times bd$$

$$\therefore ad = cb$$

RULE (4). *We may compound two or more ratios, by finding the product of the fraction representing the ratios, i.e.*

$$\frac{a}{b}, \frac{c}{d}, \frac{e}{f} = \frac{ace}{bdf}$$

95. If the antecedent is $<$ the consequent the ratio is of *less inequality*.

If the antecedent is $>$ the consequent the ratio is of *greater inequality*.

If the antecedent is equal to the consequent the ratio is of *equality*.

If we add equals to antecedent and consequent of a ratio of less inequality, we *increase* the ratio.

If we add equals to antecedent and consequent of a ratio of greater inequality, we *decrease* the ratio.

Numerical Examples. $\frac{3}{4}$ is a ratio of less inequality; adding equals we have $\frac{3+4}{4+4} = \frac{7}{8}$ therefore we have increased the value.

$\frac{2}{1}$ is a ratio of greater inequality; adding equals we have $\frac{2+4}{1+4} = \frac{6}{5} = 1\frac{1}{5}$, therefore we have decreased the value,

$$\therefore \text{ if } a > b, \text{ then } \frac{a}{b} > \frac{a+m}{b+m}$$

$$\text{ and if } a < b, \text{ then } \frac{a}{b} < \frac{a+m}{b+m}$$

96. When two ratios are equal, we may express them as follows: $a : b :: c : d$, or $\frac{a}{b} = \frac{c}{d}$; that is, both ratios work out to the same value of fraction.

The four terms are called *proportionals*; a and d are the extremes, and b and c are the means. *The products of extremes and means are equal, therefore $ad = bc$.*

The first two terms a and b must be of the same kind, and the last two terms c and d must be of the same kind, but the first two terms may be of a different kind than the second two.

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This enables us to find any one of the values if it be unknown, because if $ad = bc$, then

$$a = \frac{bc}{d}, d = \frac{bc}{a}, c = \frac{ad}{b}, \text{ and } b = \frac{ad}{c}.$$

Note. $a : b :: c : d$ reads "a is to b as c is to d."

97. If the mean terms are alike, we have

$$\frac{a}{b} = \frac{b}{c} \text{ or } a : b :: b : c, \therefore ac = b^2$$

then b is the *mean* proportional, and c is the *third* proportional.

(a) If $a : b = c : d$, that is, $\frac{a}{b} = \frac{c}{d}$, then $\frac{a}{b}$ and $\frac{c}{d}$

both equal the same thing, say n ,

$$\therefore a = nb, \text{ and } c = nd$$

(b) If $\frac{a}{b} = \frac{c}{d}$, then $\frac{b}{a} = \frac{d}{c}$; for if $\frac{a}{b} = \frac{c}{d} = n$,

then $\frac{b}{a} = \frac{1}{n}$, and $\frac{d}{c} = \frac{1}{n}$

$$\therefore \frac{b}{a} = \frac{d}{c}, \therefore b : a :: d : c$$

(c) If $\frac{a}{b} = \frac{c}{d}$, then $a \pm b : b = c \pm d : d$; for

if $\frac{a}{b} = \frac{c}{d} = n$, then $a = nb$, and $c = nd$, $\therefore a \pm b$

$= nb \pm b = (n \pm 1)b$, that is, $\frac{a \pm b}{b} = n \pm 1$,

and in the same way $\frac{c \pm d}{d} = n \pm 1$

$$\therefore \frac{a \pm b}{b} = \frac{c \pm d}{d}$$

(d) If $\frac{a}{b} = \frac{c}{d}$, then $a : c = b : d$, or $\frac{a}{c} = \frac{b}{d}$; for

$a = nb$, and $c = nd$, $\therefore \frac{a}{c} = \frac{nb}{nd}$, $\therefore \frac{a}{c} = \frac{b}{d}$, when

all of the terms are of the *same kind*.

(e) If $\frac{a}{b} = \frac{c}{d} = \frac{e}{f} \dots$, then $\frac{a + c + e \dots}{b + d + f \dots}$ is a

ratio of the *same kind*; for $a = nb$, $c = nd$, $e = nf$, etc.,

$\therefore a + c + e = nb + nd + nf = n(b + d + f)$,

$$\therefore \frac{a + c + e \dots}{b + d + f \dots} = n.$$

The *duplicate* ratio of $a : b$ is $a^2 : b^2$.

The *triplicate* ratio of $a : b$ is $a^3 : b^3$.

The *sub-duplicate* ratio of $a : b$ is $\sqrt{a} : \sqrt{b}$.

If $\frac{a}{b} = \frac{c}{d}$, then $\frac{a^2}{b^2} = \frac{c^2}{d^2}$, and $\frac{a^3}{b^3} = \frac{c^3}{d^3}$ because

$$\frac{a}{b} \times \frac{a}{b} = \frac{c}{d} \times \frac{c}{d}, \text{ etc.}$$

VARIATION

98. When one quantity varies as another, we use the sign \propto , i.e. $a \propto b$, which means that the ratio $\frac{a}{b}$ has always the same value. Let this value be denoted by K , then $\frac{a}{b} = K$, $\therefore a = Kb$.

Direct variation is when $a \propto b$.

Inverse variation is when $a \propto \frac{1}{b}$, then

$$a = K \times \frac{1}{b} = \frac{K}{b}.$$

If $a \propto \frac{b}{c}$, then $a \propto$ directly as b , and inversely

as c , and $a = \frac{Kb}{c}$.

a may also vary directly or inversely as the square of another quantity, i.e. $a = Kb^2$, or

$$a = \frac{K}{b^2}.$$

EXAMPLE. The volume of a cylinder varies directly as the square of the radius of the base, and also directly as the height,

$$\therefore \text{Volume} \propto r^2 H, \therefore \text{Volume} = Kr^2 H.$$

Find the value of K , when the base is 4 ft. diam., height = 7 ft., and volume = 88 cub. ft.

$$88 = Kr^2 H, \therefore K = \frac{88}{2^2 \times 7} = \frac{22}{7}$$

Now find the volume, when base = 6 ft. diam., and height = 10 ft.

$$V = \frac{22}{7} \times 3^2 \times 10 = \frac{22 \times 9 \times 10}{7} = \frac{1980}{7} = 282\frac{6}{7} \text{ cub. ft.}$$

EXAMPLE. The strength of a beam varies as its thickness, or breadth; that is, if we have two beams alike in every respect, except thickness, then $W \propto b$. Also $W \propto d^2$, where d is the depth; therefore if the length is constant $W \propto bd^2$. In both cases W varies directly; but when we consider the length, we know that a beam becomes weaker as the length *increases*; that is

$$W \propto \frac{1}{L}$$

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Combining these variations, we have $W \propto \frac{bd^2}{L}$

$$\therefore W = \frac{Kbd^2}{L}$$

This formula gives the breaking strength of a timber beam with a central load, where b and d are inches and L feet.

EXAMPLE. A joist 10 ft. \times 6 in. \times 4 in. breaks with a central load of 43.2 cwt. Find the weight that will break a beam 12 ft. long and 10 in. deep, when $b = \frac{5}{8}d$.

SOLUTION.

$$W = \frac{Kbd^2}{L} = \frac{K \times 4 \times 6 \times 6}{10} = 43.2 \text{ cwt.}$$

$$\therefore K = \frac{43.2 \times 10}{4 \times 6 \times 6} = 3$$

Substituting the value of K for the second joist,

$$W = \frac{Kbd^2}{L}, \text{ we have } W = \frac{K \frac{5}{8}d^3}{L}$$

$$\therefore W = \frac{3 \times 5 \times 10 \times 10 \times 10}{7 \times 12} = \frac{1250}{7} = 178\frac{4}{7} \text{ cwt}$$

SERIES

99. WHEN the successive terms of an expression are found by some regular law it is in *series*.

Progression. When a series of numbers increase, or decrease, by the same quantity, the series is in *arithmetical progression* (A.P.), i.e. 3, 5, 7, 9, 11 form a series in which each successive number is formed by adding 2 to the previous number. The first *term* is 3, and the *common difference* is 2; again 5, 1, -3, -7, -11 have a common difference of -4.

General Statement. If a is the first term, and d the common difference, then the general statement is

$$a, a + d, a + 2d, a + 3d, \text{ etc.}$$

Hence the 1st term is a

2nd " " $a + d$

3rd " " $a + 2d$

The last or n th " " $a + (n-1)d$

$$\therefore l = a + (n-1)d \quad (1)$$

EXAMPLE. Find the sixth and twelfth terms of the series 6, 3, 0, -3.

SOLUTION. Here the first term is 6, and the difference is -3; and for the sixth term, n is 6.

$$\therefore \text{6th term} = a + (n-1)d = 6 + 5(-3) = 6 + (-15) = -9$$

$$\therefore \text{12th term} = a + (n-1)d = 6 + 11(-3) = 6 + (-33) = -27$$

100. To find the sum of n terms of an A.P.

Let the series be $a, a + d, a + 2d, \dots, a + (n-2)d, a + (n-1)d$.

Let the last term be l , then the last but one term is $l - d$, and the last but two term is $l - 2d$.

Hence we can write the series in reverse ways

(1) $a, a + d, a + 2d, a + 3d \dots l - d, l$.

(2) $l, l - d, l - 2d, l - 3d \dots a + d, a$.

Now if S be the sum of the series and we add the two series together, we shall have $2S$,

$$\therefore 2S = (a + l) + (a + l) + (a + l) + \dots + (a + l) + (a + l)$$

for as many times as there are terms.

But there are n terms

$$\therefore 2S = n(a + l), \therefore S = \frac{n}{2}(a + l)$$

But l is the n th or last term, and $l = a + (n-1)d$

$$\therefore S = \frac{n}{2}\{a + a + (n-1)d\}$$

$$\therefore S = \frac{n}{2}\{2a + (n-1)d\} \quad (2)$$

EXAMPLE. A man accepts a salary of £150 per annum with annual increases of £10. Would he have had any financial advantage at the end of ten years, if he had accepted a fixed salary of £180?

SOLUTION.

The first year he had £150, \therefore 1st term = 150

The second year he had £160, \therefore common diff. = 10
 \therefore at the end of 10 years he has received

$$\begin{aligned} \frac{n}{2}(2a + (n-1)d) &= 5(300 + 9 \times 10) \\ &= 5 \times 390 = \text{£}1,950 \end{aligned}$$

If he had accepted £180 per annum, he would have received $180 \times 10 = \text{£}1,800$, therefore he gains £150 by accepting £150 with annual increments, neglecting interest.

101. If three quantities are in A.P. the middle one is the *arithmetical mean* (A.M.).

Let x be the A.M., then a, x, b are in A.P., $\therefore x - a =$ common difference and $b - x =$ common difference, $\therefore x - a = b - x, \therefore x = \frac{a + b}{2}$.

For any number of quantities in A.P., the intermediate terms are the A.Ms. between the first and last. If we have to insert, say, four A.Ms. between 7 and -8, we have six terms in A.P., and the sixth term is -8, the first term is 7.

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Applying the formula $l = a + (n - 1)d$, then
 $-8 = 7 + (6 - 1)d$, $\therefore -8 = 7 + 5d$, $\therefore \frac{-8-7}{5}$
 $= d$, $\therefore d = -3$, \therefore the series is 7, 4, 1, -2, -5, -8.

102. **Geometrical Progression.** A series of the form, 2, 4, 8, 16, etc., that is, $2, 2 \times 2, 2 \times 2^2, 2 \times 2^3$, etc., is called a *geometrical progression*. The general statement is

$$a, a \times r, a \times r^2, a \times r^3, \text{ etc.}$$

Each term is obtained by multiplying the preceding term by some constant factor, i.e. the third term $= (a \times r)r = a \times r^2$, therefore if we divide any term by the preceding one we obtain r , which is the *common ratio*. In any term the index of r is always one less than its position in the series, that is

$$\begin{aligned} \text{The 2nd term} &= ar \\ \text{3rd } &= ar^2 \\ \text{4th } &= ar^3 \\ \text{The last or } n\text{th } &= ar^{n-1} \end{aligned}$$

The geometrical mean (G.M.) is the middle quantity of three terms in G.P. If a and b be the first and last terms and M the G.M., then $\frac{b}{M} = \frac{M}{a}$, and both are equal to the common ratio, $\therefore M^2 = ab$, $\therefore M = \sqrt{ab}$.

103. To find the sum of N terms, let $S =$ sum, then

$$S = a + ar + ar^2 + \dots + ar^{n-2} + ar^{n-1}. \quad (1)$$

Multiplying by r , then

$$Sr = ar + ar^2 + ar^3 + \dots + ar^{n-1} + ar^n. \quad (2)$$

Subtracting (2) from (1), $S - Sr = a - ar^n$,

$$\therefore S(1 - r) = a - ar^n = a(1 - r^n)$$

$$\therefore S = \frac{a(1 - r^n)}{1 - r}$$

(This formula is used when r is less than 1.)

When r is greater than 1 we use the formula $S = \frac{a(r^n - 1)}{r - 1}$, which is obtained by multiplying the first formula, numerator and denominator, by -1 .

EXAMPLE. A builder pays £300 for a consignment of timber; the timber has gone through the hands of four agents before reaching the builder, and each agent had 5 per cent profit. What was the original cost?

SOLUTION. Let a be the first cost, r the common ratio, and l the last term; then number of terms $= 5$, because the fourth agent was the last seller.

$$\begin{aligned} \text{Then } l = ar^{n-1} &= a(1.05)^4, \therefore a = \frac{300}{(1.05)^4} = \frac{300}{1.215} \\ &= \text{£}247 \text{ nearly. } \text{Ans.} \end{aligned}$$

104. **Harmonical Progression.** When the reciprocals of a series of quantities are in A.P., then the quantities themselves are in *harmonical progression*; that is, if a, b, c be in H.P., then $\frac{1}{a}, \frac{1}{b}, \frac{1}{c}$ are in A.P.

$$\begin{aligned} \therefore \frac{1}{c} - \frac{1}{b} &= \frac{1}{b} - \frac{1}{a}, \therefore \frac{b-c}{bc} = \frac{a-b}{ab} \\ \therefore \frac{a-b}{b-c} &= \frac{ab}{bc} = \frac{a}{c} \\ \therefore \frac{a}{a-b} &= \frac{c}{b-c} \text{ or } \frac{a-b}{a} = \frac{b-c}{c} \\ \therefore a:c &= a-b : b-c \end{aligned}$$

The harmonical mean between two quantities a and b , is given by H.M. $= \frac{2ab}{a+b}$. We have seen that the A.M. $= \frac{a+b}{2}$, and the G.M. $= \sqrt{ab}$, or $G^2 = ab$.

105. An important link between these series, is that the G.M. of two quantities is the G.M. between their A.M. and H.M.

If a and b be the two quantities and A, G , and H their arithmetical, geometrical, and harmonical means respectively, then

$$A \times H = \frac{a+b}{2} \times \frac{2ab}{a+b} = ab = G^2$$

$$\text{hence } G = \sqrt{A \times H}$$

There is no general formula for finding the sum of a series in H.P. It is usually an advantage to solve H.P. questions by inverting and treating as in A.P.

Chapter VIII—LOGARITHMS

106. **Definitions.** For easy and rapid calculations logarithms are indispensable. There is no difficulty in understanding their use, but practice is necessary to become familiar with the various operations.

The log of a *number* (N) is the *index* to which a *base* must be raised to equal the *number*.

If $a^x = N$, then x is the log of N , to the base a , and is written $x = \log_a N$.

Numerical illustration: $4^3 = 64$, therefore 3 is the log of 64 to the base 4.

107. **Common Logarithms.** From the above explanation, any base may be used, but for the convenience of tabulating we use the base 10, and call them *common logs*. Hence we have $10^x = N$, in place of the above; we omit the base and write $x = \log N$, or $\log N = x$.

Integral, or "Whole" Number, Logs—

1,000 = 10^3 , ∴ 3 is the log of 1,000	
100 = 10^2 , ∴ 2 " " 100	
10 = 10^1 , ∴ 1 " " 10	
1 = 10^0 , ∴ 0 " " 1	
·1 = $\frac{1}{10} = 10^{-1}$, ∴ -1 " " ·1	
·01 = $\frac{1}{100} = 10^{-2}$, ∴ -2 " " ·01	
·001 = $\frac{1}{1000} = 10^{-3}$, ∴ -3 " " ·001	

The student will notice that the numbers have descended in sub-multiples of 10, and the logs have descended in units, so that $3 = \log 1,000$, and $-3 = \log \frac{1}{1000}$.

$a^0 = 1$ for all values of a , therefore $\log 1 = 0$. (See Indices, Art. 74.)

$a^1 = a$ for all values of a , therefore the log of the base = 1.

108. **Characteristic and Mantissa.** We saw that $\log 1,000 = 3$ and $\log 100 = 2$; but we have a large range of numbers between 100 and 1,000, from 101 to 999, and these are provided for by adding a decimal fraction to the integral log, i.e.

Log 100 = 2
∴ 101 = 2 + a fraction
∴ 999 = 2 + a larger fraction
∴ 1,000 = 3

The integral part is called the *characteristic*.
The fractional part is called the *mantissa*.

109. The *characteristic* depends upon the *number of digits* in the number; that is

356 has 3 digits, therefore the characteristic is 2.

356,000 has 6 digits, therefore the characteristic is 5.

35 has 2 digits, therefore the characteristic is 1.

For all numbers greater than unity, the characteristic is one less than the *number of digits* contained in the integral part of the number, and is *positive*.

When the number is less than unity, i.e. a fraction, we have *negative* characteristics

Log .456 = -1 + a fraction.
∴ .00456 = -3 + the same fraction.
∴ .0000456 = -5 + the same fraction.

That is, the characteristic is *one more* than the number of *cyphers* between the decimal point and the first significant figure, and is *negative*.

110. The *mantissa* is the same for all numbers having the same significant figures, and is positive, i.e. the mantissa for 35,600 is the same as for .00356, because

$$\begin{aligned} \log 35,600 &= \log (3.56 \times 10^4) \\ &= \log 3.56 + \log 10^4 \end{aligned}$$

$$\begin{aligned} \text{and } \log .00356 &= \log (3.56 \times 10^{-3}) \\ &= \log 3.56 + \log 10^{-3} \end{aligned}$$

This enables us to tabulate the values of the mantissae for all numbers; and we shall now proceed to read these values from the Board of Education mathematical tables, published at one penny, and which may be obtained from H.M. Stationery Office, Adastral House, Kingsway, London, W.C.2. We can get tables in which the mantissae have been calculated up to seven figures, but four-figure tables are sufficient for our purposes. Only a small portion of the table is included here, but it is sufficient to explain its use.

111. **To Find the Logarithm of a Number.** Find the log of 156.

The number has three digits, therefore the characteristic is 2. To find the mantissa we look for the first two significant figures 15 down

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the left-hand column, then travel horizontally until we arrive in the column under the *third* significant figure 6, and read the value, which is 1931.

Note that all the mantissae are decimal fractions.

$$\begin{aligned} \therefore \cdot 1931 & \text{ is the mantissa} \\ \therefore \text{Log } 156 & = 2 \cdot 1931 \\ \text{Log } 156,000 & = 5 \cdot 1931 \\ \text{Log } \cdot 156 & = -1 + \cdot 1931 = \bar{1} \cdot 1931 \\ \text{Log } \cdot 000156 & = -4 + \cdot 1931 = \bar{4} \cdot 1931 \end{aligned}$$

To distinguish the *negative* characteristic from the *positive* mantissa, we place the negative sign *over* the characteristic, and call it *bar* 4.

112. NUMBER WITH FOUR FIGURES. Find the log of 1,006.

The characteristic = 3; the mantissa for 10 = 0000, for 100 = 0000. Now we have to consider the fourth digit. We turn to the right-hand series from 1 to 9 until we arrive at 6, then read down this column until we are opposite 10 (which is the first value given), and find that the number given is 26. This value is added to that part of the mantissa already found for the first *three* digits, therefore we have

$$\begin{array}{r} \cdot 0000 \\ 26 \text{ from difference column} \\ \hline \cdot 0026 = \text{complete mantissa} \\ \therefore \text{Log } 1,006 = 3 \cdot 0026 \\ \text{Log } \cdot 001006 = \bar{3} \cdot 0026 \end{array}$$

113. There are two sets of values given in the difference column; from 100 to 104 we read the top values; from 105 to 109 we read the bottom set of values, therefore

$$\begin{aligned} \text{Log } 1,045 & = 3 \cdot 0191 \text{ (adding 21)} \\ \text{Log } 1,055 & = 3 \cdot 0232 \text{ (adding 20)}. \end{aligned}$$

114. RULES. (1) To multiply two factors together, we add the indices, therefore we add together the logs of the factors.

(2) To divide one value by another value, we subtract the indices, therefore we subtract the logs of the two values.

(3) To raise a value to any power p , we multiply the index of the value by p , therefore we multiply the log of the value by p .

(4) To find the root r of a value, we divide

the index of the value by r , therefore we divide the log of the value by r .

These rules may be summarized as follows. By using logs

Multiplication becomes addition, or $\log (mn) = \log m + \log n$.

Division becomes subtraction, or $\log \frac{m}{n} = \log m - \log n$.

Involution becomes multiplication, or $\log (m^n) = n \log m$.

Evolution becomes division, or $\log \sqrt[n]{m} = \frac{\log m}{n}$.

115. Multiplication. For multiplication, add together the logs of the factors, which will give the *log* of the required product.

Find the product of $13 \cdot 42 \times 1765 \times \cdot 006214$.

Let the product be x , then $\log x = \log 13 \cdot 42 + \log 1765 + \log \cdot 006214 = 1 \cdot 1278 + 3 \cdot 2467 + \bar{3} \cdot 7934$.

$$\begin{array}{r} 1 \cdot 1278 \\ 3 \cdot 2467 \\ \hline \bar{3} \cdot 7934 \end{array}$$

$$2 \cdot 1679 = \log \text{ of product.}$$

Notice that we carry 1 to the characteristic column, therefore we add together $1 + 1 + 3 - 3 = 2$.

We must now think in the reverse order from the method for finding logs; $2 \cdot 1679$ is a log for which we require the number.

The mantissa $\cdot 1679$ represents the *significant figures* in the product.

The characteristic 2 represents the *number of figures* in the integral part of the product, that is, the characteristic *fixes the decimal point*.

For convenience the tables include antilogs, that is, the corresponding numbers are given for the logs. Turning to the antilog table, we find on reading down the first column that $\cdot 16$ represents the number 1,445. Under 7, which is the third figure of the log, the number increases to 1,469. The fourth figure of the log is in the right-hand *difference* column, and under 9 we find the value is given as 3. Add together 1,469 and 3, and we have 1,472 for the required significant figures. The characteristic is 2, which is one less than the number of figures in the *integral part* of the number. Hence the number is 1472.

$$\therefore 13 \cdot 42 \times 1765 \times \cdot 006214 = 147 \cdot 2 \text{ Ans.}$$

BUILDING CALCULATIONS

MATHEMATICAL TABLES—LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4 9	13 17	21	26 30	34 38	24 28	32 37		
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4 8	12 15	19	23 27	31 35	22 26	30 33		
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3 7	11 14	18	21 25	28 32	20 24	27 31		
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3 7	10 13	16	20 23	26 30	19 22	25 29		
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3 6	9 12	15	18 21	24 28	17 20	23 26		
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3 6	9 11	14	17 20	23 26	16 19	22 25		
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3 5	8 11	14	16 19	22 24	15 18	21 23		

MATHEMATICAL TABLES—ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0 0	1 1	1 1	1 1	1 1	1 2	2 2	2 2	2 2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0 0	1 1	1 1	1 1	1 1	1 2	2 2	2 2	2 2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0 0	1 1	1 1	1 1	1 1	1 2	2 2	2 2	2 2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0 0	1 1	1 1	1 1	1 1	1 2	2 2	2 2	2 2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0 1	1 1	1 1	1 1	1 1	2 2	2 2	2 2	2 2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0 1	1 1	1 1	1 1	1 1	2 2	2 2	2 2	2 2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0 1	1 1	1 1	1 1	1 1	2 2	2 2	2 2	2 2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0 1	1 1	1 1	1 1	1 1	2 2	2 2	2 2	2 2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0 1	1 1	1 1	1 1	1 1	2 2	2 2	2 3	2 3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0 1	1 1	1 1	1 1	1 1	2 2	2 2	2 3	2 3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0 1	1 1	1 1	1 1	1 1	2 2	2 2	2 3	2 3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0 1	1 1	1 1	2 2	2 2	2 2	2 3	2 3	2 3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0 1	1 1	1 1	2 2	2 2	2 2	2 3	2 3	2 3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0 1	1 1	1 1	2 2	2 2	2 3	2 3	2 3	2 3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0 1	1 1	1 1	2 2	2 2	2 3	2 3	2 3	2 3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0 1	1 1	1 1	2 2	2 2	2 3	2 3	2 3	2 3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0 1	1 1	1 1	2 2	2 2	2 3	2 3	2 3	2 3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0 1	1 1	1 1	2 2	2 2	2 3	2 3	2 3	2 3

116. Division. Divide 834.2 by 1,764. Let the quotient be x , then $\log x$

$$= \log 834.2 - \log 1,764$$

$$= 2.9213 - 3.2465$$

Subtract the mantissa, giving .6748.

Subtract the characteristics, i.e. $2 - 3 = -1$

$$\therefore \log x = \bar{1}.6748$$

From the table of antilogs we get the value 4,730. The characteristic is $\bar{1}$, which corresponds to no cyphers between the decimal point and the first significant figure.

$$\therefore \frac{834.2}{1764} = .473 \text{ Ans.}$$

EXAMPLE. Evaluate $\frac{3256 \times .1426 \times 1.341}{.00421 \times 3.24 \times 675.400}$

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SOLUTION.

$$\begin{aligned} \log x &= \log 3256 + \log .1426 + \log 1.341 \\ &= (\log .00421 + \log 3.24 + \log 675.400) \\ &\quad \begin{array}{r} 3.5127 \\ 1.1541 \\ 0.1274 \\ \hline \end{array} \quad \begin{array}{r} 3.6243 \\ 0.5105 \\ 5.8296 \\ \hline \end{array} \end{aligned}$$

$$\begin{array}{ll} \text{Adding} &= 2.7942 \\ &\underline{3.9644} \end{array} \quad \begin{array}{ll} \text{Adding} &= 3.9644 \end{array}$$

$$\text{Subtracting} = \bar{2}.8298 \quad \text{Antilog} = .06757 \text{ Ans}$$

117. Involution and Evolution. Example. Evaluate 217^3 .

To raise a number to a given power, we multiply the log of the number by the given power, and find the antilog,

$$\begin{aligned} \therefore \log x &= 3 \times \log 217 \\ &= 3 \times 2.3365 = 7.0095 \\ \text{antilog} &= 1.022 \end{aligned}$$

but a characteristic of 7 gives eight figures before the decimal point,

$$\therefore 217^3 = 10,220,000 \text{ Ans.}$$

EXAMPLE. Evaluate $\sqrt[3]{217}$.

SOLUTION. Note that $\sqrt[3]{217} = 217^{\frac{1}{3}}$, hence we divide the log of 217 by 3.

$$\begin{aligned} \therefore \log x &= \frac{\log 217}{3} = \frac{2.3365}{3} = .7788 \\ \text{Antilog} &= 6.009, \therefore \sqrt[3]{217} = 6.009 \text{ Ans.} \end{aligned}$$

118. Negative Characteristic and Positive Mantissa. Find the fifth root of .00763.

$$\begin{aligned} \text{Let } x &= \sqrt[5]{.00763}, \text{ then } \log x = \frac{\log .00763}{5} \\ &= \frac{\bar{3}.8825}{5}. \text{ This is the same as } \frac{\bar{3}}{5} + \frac{.8825}{5} \end{aligned}$$

We cannot divide -3 by 5 , and still have a whole number, so we make the negative characteristic divisible by 5 , i.e. make it -5 . Then we have $\frac{-5}{5} = -1$. But although the log consists of two parts, the two parts together have a definite value; hence if we alter one part, we must compensate by altering the other part. When we altered -3 to -5 , we took 2 away from the characteristic, therefore we must add 2 to the mantissa, thus

$$\text{Log } x \text{ now equals } \frac{\bar{5} + 2.8825}{5}, \text{ which} = \bar{1}.5765$$

$$\therefore \text{Log } x = \bar{1}.5767 \quad \therefore \text{Antilog} = .3771$$

$$\therefore \sqrt[5]{.00763} = .3771 \text{ Ans.}$$

119. Negative Logarithm. When we have in the course of the work a negative logarithm, i.e. -3.4616 , not 3.4614 , and it interferes with the working, we can easily convert the mantissa to a positive one.

$-3.4614 = -4 + 4 - 3.4614$; we have not altered the value of the whole, because $-4 + 4 = 0$, then $-4 + (4 - 3.4614) = -4 + .5386 = \bar{4}.5386$.

To reverse the process add -1 to the mantissa and $+1$ to the characteristic.

EXAMPLES. (1) Convert $\bar{1}.8451$ to a negative logarithm.

$$\begin{aligned} \bar{1}.8451 &= -1 + .8451 \\ \text{add } -1 \text{ to the mantissa, then } -1 + .8451 &= -.1549 \\ \text{add } +1 \text{ to the characteristic, then} \\ \bar{1}.8451 &= -0.1549. \text{ Ans.} \end{aligned}$$

(2) Find the value of n in the equation $(.8)^n = .7$.

$$\begin{aligned} n \log .8 &= \log .7 \\ \therefore n &= \frac{\log .7}{\log .8} = \frac{\bar{1}.8451}{\bar{1}.9031} = \frac{-0.1549}{-0.0969} = 1.6 \\ \therefore (.8)^{1.6} &= .7. \end{aligned}$$

(3) A machine costs $\pounds 750$ and depreciates 10 per cent in value every year. What is its value after 8 years?

$$\begin{aligned} A &= PR^n = 750R^8, \text{ and } R = (1 - \frac{10}{100}) = \frac{90}{100} \\ \therefore \log A &= \log 750 + 8 \log .9 = 2.8751 + 8 \times \bar{1}.9542 \\ &= 2.5087 \quad \therefore \text{antilog} = \pounds 322.6. \text{ Ans.} \end{aligned}$$

(4) What is the value of $\pounds 590$ after 14 years at $2\frac{1}{2}$ per cent compound interest?

$$\begin{aligned} A &= PR^n = 590 \left(1 + \frac{2.5}{100}\right)^{14} = 590 \times 1.025^{14} \\ \therefore \log A &= \log 590 + 14 \log 1.025 \\ &= 2.7709 + 14 \times 0.0107 = 2.9207 \\ \text{Antilog} &= \pounds 833.2. \text{ Ans.} \end{aligned}$$

EXERCISE XIV (Answers on page 58)

1. Find, by logs, the products of the following; (a) 17.654×3.765 ; (b) 34.593×16.34 ; (c) $.00375 \times .06542$.

2. Evaluate: (a) $32.76 \div 5.206$; (b) $\frac{17.5}{276.8}$; (c) $\frac{.2179}{.08576}$

3. Find the cube root of $\frac{359.6 \times .862}{125.4}$

4. Find the value of $\frac{\sqrt[3]{172500}}{\sqrt[6]{.01}}$

5. Find the value of P , when $P = \frac{(806300t)^{2.10}}{L.D}$
 $L = 4.5, D = 36, t = .325$.

Chapter IX—TRIGONOMETRY

120. **Measurement of Angles.** If a line revolves about one of its ends, in a plane, then the space that it moves through is an *angle*. In Fig. 18 the line OA revolves about O , until the end A arrives at A_1 , then AOA_1 is an angle. The line may continue to revolve until it completes one revolution and arrives at its original position; it has then gone through an angle of 360° , i.e. a circle. If it still continues until it arrives at A_1 again, it has passed through an angle of $360 + \alpha$ degrees.

In building calculations we are seldom concerned with angles greater than 360° , hence we generally use the *sexagesimal method* of measuring angles. The circle is divided into four quadrants of $90^\circ = 90$ degrees each, which are right angles. A degree is divided into 60 *minutes*, and a minute is divided into 60 *seconds*. If the angle is 60 degrees, 30 minutes, 30 seconds, it is written $60^\circ 30' 30''$.

121. **The Radian.** The second method of measuring angles is important for mathematical calculations, and is called the *circular, or radian, method*. If we draw a circle with the compass set to, say, 2 in. radius, and then cut off this distance across the circle to cut the circumference in two places, we have a chord which subtends 60° at the centre of the circle. Therefore a chord equal to the radius, in any circle, subtends an angle of 60° at the centre. Now, if the chord were bent round the circumference, instead of being straight, evidently it will come inside the 60° angle; it will be found to be 57.3° nearly, and is called a *radian*, which is the *unit of circular measure*. Hence, the angle subtended at the centre of a circle, by an *arc* equal in length to the radius, is a *radian*. (See Art. 134.)

122. **Trigonometrical Ratios.** In any triangle the sum of the three angles = 180° . If one angle of the triangle is a right angle, then the other two angles together = 90° , and one angle is the *complement* of the other; so that, if one angle = θ , then the other angle = $90^\circ - \theta$.

If we draw any right-angled triangle, Fig. 19, and draw a line parallel to AC , to form a second ΔDBE , we have two similar triangles. Measure the sides of these two triangles, and for the large triangle let base = a , hypotenuse = b , and perpendicular = c ; and for the small triangle

let base = x , hypotenuse = y , and perpendicular = z .

$$\text{Then } \frac{a}{b} = \frac{x}{y}, \frac{b}{c} = \frac{y}{z}, \text{ and } \frac{b}{a} = \frac{y}{x}; \text{ and for any}$$

arrangement we choose, we shall find that the ratio for *corresponding* sides of each triangle has always the same value, no matter what the lengths of the sides may be. The student should

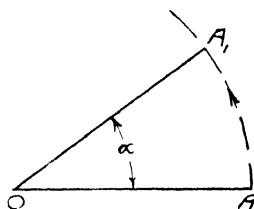


FIG. 18

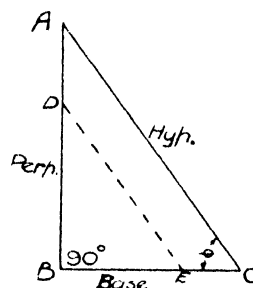


FIG. 19

draw several pairs of similar right-angled triangles, to test the truth of this statement.

123. The ratios between the various sides have been given special names, and if we let the angle at $C = \theta$, we have

- (1) $\frac{\text{Perp.}}{\text{Hyp.}} = \text{Sine } \theta$, abbreviated to $\sin \theta$.
- (2) $\frac{\text{Base}}{\text{Hyp.}} = \text{Cosine } \theta$, $\cos \theta$.
- (3) $\frac{\text{Perp.}}{\text{Base}} = \text{Tangent } \theta$, $\tan \theta$.

Inverting these three ratios, we have

- (4) $\frac{\text{Hyp.}}{\text{Perp.}} = \text{Cosecant } \theta$, abbreviated to $\text{cosec } \theta$.
- (5) $\frac{\text{Hyp.}}{\text{Base}} = \text{Secant } \theta$, $\sec \theta$.
- (6) $\frac{\text{Base}}{\text{Perp.}} = \text{Cotangent } \theta$, $\cot \theta$.

These ratios are known as the *trig. ratios*, and so long as θ has the same value, the value of the ratio is constant, whatever the lengths of the sides may be.

The values of the ratios have been tabulated

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for all angles up to 90° . A portion of the table is shown below to illustrate the method of using it.

124. **Reading Trigonometrical Tables.** To read the Board of Education tables, as reproduced, we first find the angle, for which we require the ratio, in the first vertical column under *degrees*. Then travel horizontally until we arrive under the heading of the required ratio, and read the given value. For instance, to find $\sin 4^\circ$, travel horizontally from 4 in the *degrees* column until

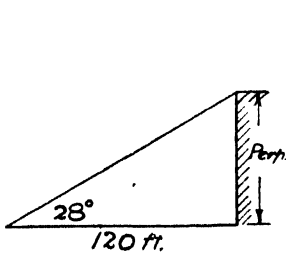


FIG. 20

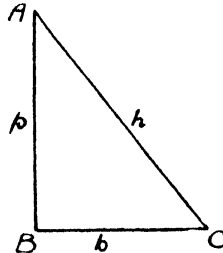


FIG. 21

we arrive at the *sine* column, where we are given the value $\cdot 0698$. The cosine of $4^\circ = \cdot 9976$, the tangent of $4^\circ = \cdot 0699$. In every case the values are given to four places of decimals.

125. When we require the ratios for angles greater than 45° , we turn to the last vertical column, and read from the bottom upwards; notice particularly that the values of the ratios are also read from the bottom. Therefore the sine column, for angles up to 45° , becomes the cosine column for angles over 45° .

EXAMPLE. A raking shore is 25 ft. long, and it has to make an angle of 72° with the ground. What height will it reach above the ground?

SOLUTION. The student should make a sketch to illustrate each problem. The two sides we have to consider are the hypotenuse and the perpendicular, therefore the ratio required is the sine:

$$\therefore \frac{\text{Perpendicular}}{\text{Hypotenuse}} = \sin 72^\circ$$

From the tables we find that $\sin 72^\circ = \cdot 9511$

$$\begin{aligned} \therefore \text{perpendicular} &= \text{hypotenuse} \times \cdot 9511 \\ &= 25 \times \cdot 9511 = \underline{23\cdot 78 \text{ ft.}} \quad \text{Ans.} \end{aligned}$$

EXAMPLE. An observer finds that the angle of elevation of the top of a building is 28° , at a point 120 ft. from the base of the building. Find the height of the building (Fig. 20).

SOLUTION.

$$\frac{\text{Perpendicular}}{\text{Base}} = \tan 28^\circ$$

$$\begin{aligned} \therefore \text{Perpendicular} &= \text{base} \times \tan 28^\circ \\ &= 120 \times \cdot 5317 = 63\cdot 8 \text{ ft.} \end{aligned}$$

$$\therefore \text{the height of the building} = \underline{63\cdot 8 \text{ ft.}} \quad \text{Ans.}$$

EXAMPLE. A roof of 40° pitch has a span of 30 ft. 2 in. What is the length of a common rafter, when the ridge is 2 in. thick?

SOLUTION. In this case the secant would be the most convenient ratio, but the B. of E. tables do not give this ratio, therefore we must use the cosine.

$$\frac{\text{Base}}{\text{Hypotenuse}} = \cos 40^\circ, \therefore \frac{\text{Base}}{\cos 40^\circ} = \text{hypotenuse}$$

$$\therefore \frac{15}{\cdot 766} = \text{hypotenuse} = 19\cdot 58$$

$$\therefore \text{Common rafter} = \underline{19\cdot 5 \text{ ft.}} \quad \text{Ans.}$$

MATHEMATICAL TABLES

Angle		Chord	Sine	Tangent	Co-tangent	Cosine			
Degrees	Radians								
0°	0	0	0	0	∞	1	1.414	1.5708	90°
1	$\cdot 0175$	$\cdot 017$	$\cdot 0175$	$\cdot 0175$	57.2900	$\cdot 9998$	1.402	1.5533	89
2	$\cdot 0349$	$\cdot 035$	$\cdot 0349$	$\cdot 0349$	28.6363	$\cdot 9994$	1.389	1.5359	88
3	$\cdot 0524$	$\cdot 052$	$\cdot 0523$	$\cdot 0524$	19.0811	$\cdot 9986$	1.377	1.5184	87
4	$\cdot 0698$	$\cdot 070$	$\cdot 0698$	$\cdot 0699$	14.3007	$\cdot 9976$	1.364	1.5010	86
5	$\cdot 0873$	$\cdot 087$	$\cdot 0872$	$\cdot 0875$	11.4301	$\cdot 9962$	1.351	1.4835	85
6	$\cdot 1047$	$\cdot 105$	$\cdot 1045$	$\cdot 1051$	9.5144	$\cdot 9945$	1.338	1.4661	84
7	$\cdot 1222$	$\cdot 122$	$\cdot 1219$	$\cdot 1228$	8.1443	$\cdot 9925$	1.325	1.4486	83
8	$\cdot 1396$	$\cdot 140$	$\cdot 1392$	$\cdot 1405$	7.1154	$\cdot 9903$	1.312	1.4312	82
9	$\cdot 1571$	$\cdot 157$	$\cdot 1564$	$\cdot 1584$	6.3138	$\cdot 9877$	1.299	1.4137	81
			Cosine	Co tangent	Tangent	Sine	Chord	Radians	Deg.

BUILDING CALCULATIONS

126. We have already stated that the second three ratios are the inversions, or reciprocals, of the first three, that is

$$\begin{aligned} \text{Ratio (1)} \times \text{ratio (4)} &= \sin C \times \text{cosec } C \\ &= \frac{p}{h} \times \frac{h}{p} = 1 \text{ (Fig. 21)} \end{aligned}$$

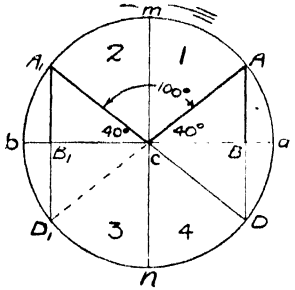


FIG. 22

Similarly, cosine \times secant = 1, that is

$$\cos C \times \sec C = \frac{b}{h} \times \frac{h}{b} = 1$$

$$\text{Also } \tan C \times \cot C = \frac{p}{b} \times \frac{b}{p} = 1$$

From this, we have

$$\sin C = \frac{1}{\text{cosec } C}, \text{ cosec } C = \frac{1}{\sin C}$$

$$\cos C = \frac{1}{\sec C}, \sec C = \frac{1}{\cos C}$$

$$\tan C = \frac{1}{\cot C}, \cot C = \frac{1}{\tan C}$$

127. **Angles Greater than 90°.** When two angles together = 180°, then one is the *supplement* of the other. In Fig. 22 angle bcA_1 = angle acA , $\therefore \angle acA_1$ is the supplement of acA , and $\sin acA = \frac{AB}{cA} = \frac{A_1B_1}{cA_1}$, $\therefore \sin acA = \sin acA_1$; hence the sine of an angle is the same as for its supplement.

Therefore $\sin (180^\circ - 40^\circ) = \sin 40^\circ$, or $\sin 140^\circ = \sin 40^\circ$.

Similarly, $\sin (180^\circ - 30^\circ) = \sin 30^\circ$; and generally, $\sin (180^\circ - \theta) = \sin \theta$.

We should consider any angle greater than 90° with regard to its positive or negative signs, but for the purposes of building calculations these

may be neglected. The following table gives the signs for the ratios in the various quadrants.

Quadrant . . .	1	2	3	4
Sine	+	+	-	-
Cosine	+	-	-	+
Tangent	+	-	+	-

The radius, or revolving line, is positive. Horizontal lines to the right of mn are positive, and to the left of mn negative. Vertical lines above ab are positive, and below ab negative.

128. **Values of Important Ratios.** The most important of the ratios may be tabulated from Fig. 23 and Fig. 24. If the angle $C = 60^\circ$ and the base = 1 unit, then the hypotenuse = 2 units, \therefore the perpendicular $AB = \sqrt{2^2 - 1^2} = \sqrt{3}$. If $C = 45^\circ$, then the base and perpendicular are equal in length, and the hypotenuse

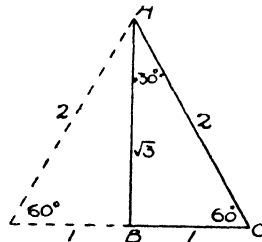


FIG. 23

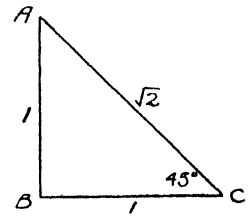


FIG. 24

= $\sqrt{2}$ units when the sides = 1 unit. The following table gives the various values—

Degrees.	0	30	45	60	90	120	135	150	180°
Sine	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0
Cosine	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{\sqrt{2}}$	$-\frac{\sqrt{3}}{2}$	-1
Tangent	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞	$-\sqrt{3}$	-1	$-\frac{1}{\sqrt{3}}$	0

The values for 0°, 90°, and 180° have only theoretical importance. (See Art. 92.)

Note. $\sqrt{2} = 1.414$, $\sqrt{3} = 1.732$.

EXAMPLE. A surveyor requires to find the width of a river (Fig. 25). He measures off a line AB , along one bank, 300 ft. long. From B he finds the angle subtended by an object C on the opposite bank equals 56° , and the same object from A subtends 28° . What is the width of the river ?

MODERN BUILDING CONSTRUCTION

SOLUTION. From Fig. 25, $\frac{p}{x} = \tan 56^\circ$, $\therefore p = x \tan 56^\circ$; also $\frac{p}{300-x} = \tan 28^\circ$, $\therefore p = (300-x) \tan 28^\circ$
 $\therefore x \tan 56^\circ = (300-x) \tan 28^\circ$
 $\therefore 1.4826x = .5317(300-x) = 159.51 - .5317x$
 $\therefore 2.0143x = 159.51$, $\therefore x = 79.18$

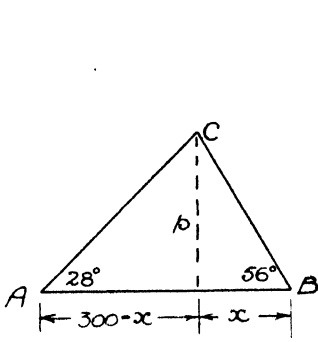


FIG. 25

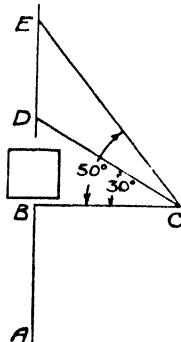


FIG. 26

But $\frac{p}{x} = \tan 56^\circ$, $\therefore p = 79.18 \times 1.4826 = 117.4$ ft. = distance across river. *Ans.*

EXAMPLE. A building is 45 ft. wide and a gable, 2 bricks thick, forms an isosceles triangle with base angles of 36° . How many rods of reduced brickwork does the gable contain?

SOLUTION. The height of the triangle (gable) is found by the ratio of $\tan 36^\circ$,

$$\therefore \frac{\text{Height}}{22.5 \text{ ft.}} = \tan 36^\circ = .7265$$

$$\therefore \text{Height} = 16.35 \text{ ft.}$$

$$\therefore \text{Area of } \Delta = \frac{16.35 \times 45}{2} = \frac{735.75}{2} \text{ sq. ft.}$$

$$\text{Rods of brickwork} = \frac{735.75 \times 4}{2 \times 272 \times 3} = 1.803 \text{ rods. } \underline{\text{Ans.}}$$

EXAMPLE. A surveyor requires to continue a straight line AB, on the far side of a house (Fig. 26). He sets off a line BC = 100 yd., at right angles to AB, and at C he sights two points D and E on the far side of the house. Angle BCD = 30° , angle BCE = 50° . What are the lengths of CD and CE, so that A, B, D, and E will lie in one straight line?

SOLUTION.

$$\frac{100}{CD} = \cos 30^\circ = .866, \therefore CD = \frac{100}{.866}$$

$$\therefore CD = 115.47 \text{ yd.}$$

$$\frac{100}{CE} = \cos 50^\circ = .6428$$

$$\therefore CE = 155.57 \text{ yd. } \underline{\text{Ans.}}$$

EXAMPLE. A raking shore is 30 ft. long and the foot has to be 12 ft. out from the face of the wall. What are the angles for the foot and head cuts?

SOLUTION.

$$\frac{12 \text{ ft.}}{30 \text{ ft.}} = \cos \theta = .4$$

Find, from the tables, the angle corresponding to $\cos = .4$. The nearest value is 66° , which is sufficiently accurate for the foot cut. The head cut = $90^\circ - 66^\circ = 24^\circ$ *Ans.*

EXAMPLE. A plot of ground ABCD, Fig. 27, has to be divided into three equal parts for building purposes. Find the frontage along BC for each part, that is, find the lengths x, y, and z.

SOLUTION.

$$\text{Area (1)} = a \times x + \frac{x^2 \tan \theta}{2}, \text{ and } \tan \theta$$

$$= \frac{10}{30} = \frac{1}{3}$$

The height *mn* of the $\Delta mnD = x \tan \theta$.

$$\therefore \Delta = \frac{x \times x \tan \theta}{2} = \frac{x^2 \tan \theta}{2}$$

$$\therefore \text{Area (1)} = 16x + \frac{x^2}{6}, \text{ and this}$$

$$= \frac{1}{3}A \text{ (total area)}$$

$$\text{And } A = \frac{26 + 16}{2} \times 30 = 630 \text{ sq. yd.}$$

$$\therefore \text{Area (1)} = 210 = 16x + \frac{x^2}{6}$$

Solving the quadratic equation $x = 11.7$ yd.

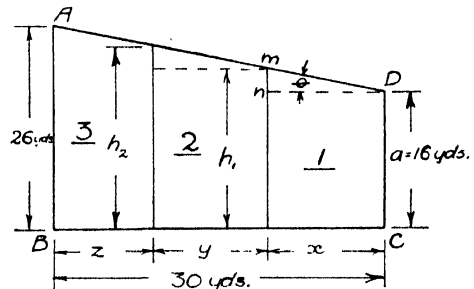


FIG. 27

$$\text{Therefore } h_1 = 16 + x \tan \theta = 16 + \frac{11.7}{3} = 16 + 3.9 = 19.9 \text{ yd.}$$

$$\text{Area (2)} = 210 = 10.9y + \frac{y^2 \tan \theta}{2}$$

$$= 10.9y + \frac{y^2}{6}$$

$$\therefore y^2 + 119.4y = 1260$$

$$\therefore y = 9.75 \text{ yd.}$$

$$\therefore h_2 = 19.9 + y \tan \theta$$

$$= 19.9 + \frac{9.75}{3} = 23.15 \text{ yd.}$$

$$\text{And } z = 30 - (x + y) = 8.55 \text{ yd.}$$

ANSWERS TO EXERCISE XIV (page 54)

1. (a) 66.45; (b) 565200; (c) 0.0002453
2. (a) 6.292; (b) 0.05895; (c) 2.541
3. 1.129
4. 139.8
5. 4,536,000,000

TRIGONOMETRICAL IDENTITIES AND SOLUTION OF TRIANGLES

120. EUCLID I, 47, proves that $c^2 = a^2 + b^2$ in a right-angled triangle (Fig. 28). If we divide both sides by c^2 , then

$$\frac{c^2}{c^2} = \frac{a^2}{c^2} + \frac{b^2}{c^2} = \left(\frac{a}{c}\right)^2 + \left(\frac{b}{c}\right)^2$$

$$= (\sin A)^2 + (\cos A)^2$$

$\therefore \sin^2 A + \cos^2 A = 1$ (1)

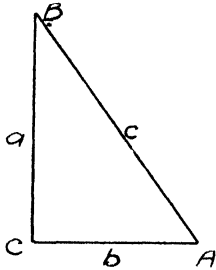


FIG. 28

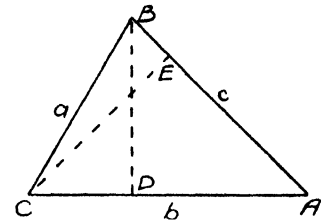


FIG. 29

(The index is written before the angle, and we read sine squared $A + \cos$ squared $A = 1$.)

If we divide by b^2 , we have

$$\tan^2 A + 1 = \sec^2 A$$
 (2)

Repeating again for a^2 , then

$$1 + \cot^2 A = \operatorname{cosec}^2 A$$
 (3)

$$\tan A = \frac{a}{b} = \frac{a}{c} \div \frac{b}{c} = \frac{\sin A}{\cos A}$$
 (4)

$$\cot A = \frac{b}{a} = \frac{b}{c} \div \frac{a}{c} = \frac{\cos A}{\sin A}$$
 (5)

130. **Right-angled Triangles.** Fig. 28 shows the usual method of denoting the *six parts* of a triangle. If we know any three of these parts (including one side), we can determine the other parts.

(1) Given $\angle A$ and side c .

SOLUTIONS.

$$B = 90^\circ - A; \frac{a}{c} = \sin A, \therefore a = c \sin A$$

$$\frac{b}{c} = \cos A, \therefore b = c \cos A$$

(2) Given a and b

SOLUTIONS

$$c^2 = a^2 + b^2, \therefore c = \sqrt{a^2 + b^2}$$

$$\frac{a}{b} = \tan A; \text{ read value of } A \text{ from tables, then } B = 90^\circ - A.$$

(3) Given a and c .

SOLUTIONS.

$$b = \sqrt{c^2 - a^2}; \frac{a}{c} = \sin A$$

$$B = 90^\circ - A$$

131. **Solutions of Triangles.** In Fig. 29

$$BD = c \sin A, \text{ because } \frac{BD}{c} = \sin A$$

$$\text{also } BD = a \sin C, \therefore c \sin A = a \sin C$$

$$\therefore \frac{c \sin A}{ca} = \frac{a \sin C}{ca}, \therefore \frac{\sin A}{a} = \frac{\sin C}{c}$$

Also, we can prove that $\frac{\sin A}{a} = \frac{\sin B}{b}$, by dropping a perpendicular CE on to AB .

Then $CE = b \sin A$, and $CE = a \sin B$

$$\therefore b \sin A = a \sin B, \therefore \frac{\sin A}{a} = \frac{\sin B}{b}$$

$$\text{Hence } \frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}; \text{ and } \frac{\sin A}{\sin B} =$$

$$\frac{a}{b}; \frac{\sin B}{\sin C} = \frac{b}{c}; \frac{\sin A}{\sin C} = \frac{a}{c}; C = 180^\circ - (A + B)$$

$$B = 180^\circ - (A + C); A = 180^\circ - (B + C).$$

132. When the angle A is acute, as in Fig. 30, it is proved in geometry that

$$BC^2 = AB^2 + AC^2 - 2AB \cdot AD$$

$$\text{also that } AC^2 = AB^2 + BC^2 - 2AB \cdot BD$$

$$\therefore a^2 = c^2 + b^2 - 2cx$$

$$\text{and } b^2 = c^2 + a^2 - 2cy$$

$$\text{but } x = b \cos A, \text{ and } y = a \cos B$$

$$\therefore a^2 = b^2 + c^2 - 2bc \cos A$$

$$\text{and } b^2 = a^2 + c^2 - 2ac \cos B$$

Also, it may be proved that $c^2 = a^2 + b^2 - 2ab \cos C$.

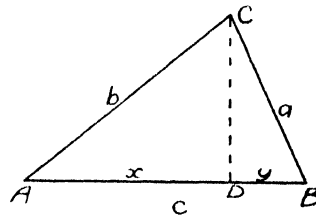


FIG. 30

Hence we can find the \cos of any angle when the *sides* are given, for

$$2bc \cos A = b^2 + c^2 - a^2$$

$$\therefore \cos A = \frac{b^2 + c^2 - a^2}{2bc}, \text{ etc.}$$

MODERN BUILDING CONSTRUCTION

The above formulae can be proved for any form of triangle, through the further propositions on the extensions of Pythagoras' Theorem, in Geometry. Lack of space prevents the proofs being given here.

133. SOLUTIONS (Fig. 30). (1) Given three sides, $a = 3''$, $b = 2.5''$, $c = 3.5''$.

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc} = \frac{2.5^2 + 3.5^2 - 3^2}{2 \times 2.5 \times 3.5} = 0.5429$$

\therefore From Tables $A \simeq 57^\circ$

$$\sin B = \frac{b \sin A}{a} = \frac{2.5 \times .8387}{3} = 0.699$$

\therefore From Tables $B \simeq 44\frac{1}{2}^\circ$

$$\text{Then } C = 180^\circ - (A + B) = 180 - (57 + 44\frac{1}{2}) = 78\frac{1}{2}^\circ.$$

(2) Given two sides and included angle, $b = 2''$, $c = 2.5''$, $A = 40^\circ$.

$$a^2 = b^2 + c^2 - 2bc \cos A$$

$$\therefore a^2 = 2^2 + 2.5^2 - 2 \times 2 \times 2.5 \times .766 = 2.59$$

$$\therefore a = \sqrt{2.59} = 1.61''$$

$$\sin B = \frac{b \sin A}{a} = \frac{2 \times .6428}{1.61} = .8$$

\therefore From Tables $B \simeq 53^\circ$

(3) Given two angles and one side, $B = 42^\circ$, $C = 54^\circ$, $a = 3''$

$$A = 180 - (B + C) = 180 - (42 + 54) = 84^\circ$$

$$b = \frac{a \sin B}{\sin A} = \frac{3 \times .6691}{.9945} = 2''$$

$$c = \frac{a \sin C}{\sin A} = \frac{3 \times .809}{.9945} = 2.45''$$

(4) Given two sides and the angle opposite to one side, $a = 2''$, $b = 3''$, $A = 40^\circ$. (This is the ambiguous case with two solutions.)

$$\sin B = \frac{b \sin A}{a} = \frac{3 \times .6428}{2} = 0.9642$$

\therefore From Tables $B \simeq 75^\circ$ $\therefore C = 65^\circ$

$$c = \frac{a \sin C}{\sin A} = \frac{3 \times .9063}{.6428} = 4.23''$$

Second solution = 105° , 35° , and $1.8''$.

HINTS. (1) Make sketches to illustrate the given data. (2) Solve smallest angle first. (3) Do not use cos formula more than once.

134. Degrees and Radians. Angular measurement in radians is called *circular measure*, and is usually denoted by a small index c . It has been shown that a radian $\simeq 57.3^\circ$. This is stated more accurately as 57.295° , or $57^\circ 17.7'$, or $57^\circ 17' 45''$. \therefore 1 radian, or 1^c , = 57.295° .

It is often necessary to convert from one unit

to the other, and the fundamental relation is

$$\pi^c = 180^\circ, \text{ because } \frac{180^\circ}{57.295^\circ} = 3\frac{1}{7} = \pi.$$

Conversion tables may be obtained but the following should be memorized—

$$2\pi^c = 360^\circ, \pi^c = 180^\circ, \frac{1}{2}\pi^c = 90^\circ, \frac{1}{4}\pi^c = 45^\circ.$$

$$\frac{3}{4}\pi^c = 120^\circ, \frac{1}{3}\pi^c = 60^\circ, \frac{1}{6}\pi^c = 30^\circ.$$

135. Regular Polygons. The areas of inscribed and circumscribing polygons may be readily obtained by the use of radians.

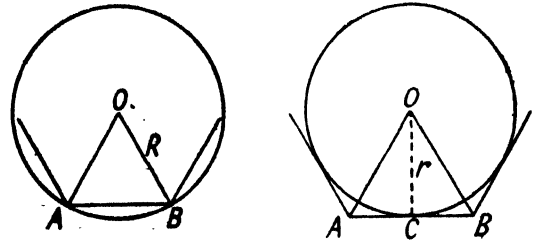


FIG. 31

(1) Let the inscribed polygon have n sides, as shown by AB in Fig. 31. Then the angle $AOB = \frac{2\pi^c}{n}$.

$$\text{The area of the } \triangle AOB = \frac{1}{2}R^2 \sin\left(\frac{2\pi}{n}\right)$$

$$\therefore \text{the area of the polygon} = \frac{1}{2}nR^2 \sin\left(\frac{2\pi}{n}\right)$$

(2) If the polygon circumscribes the circle, then side AB touches the circle at C , and OC is the radius r of the circle. Again angle $AOB = \frac{2\pi^c}{n}$, $\therefore \angle AOC = \frac{\pi^c}{n}$,

$$\therefore AC = r \tan\left(\frac{\pi}{n}\right)$$

$$\therefore \text{area of } \triangle AOB = OC \times AC = r^2 \tan\left(\frac{\pi}{n}\right)$$

$$\therefore \text{area of polygon} = nr^2 \tan\left(\frac{\pi}{n}\right)$$

(3) The area can also be obtained when the side AB is given.

$$\text{Let } AB = a, \text{ then } OC = \frac{a}{2} \cot\left(\frac{\pi}{n}\right)$$

$$\therefore \triangle AOB = \frac{1}{2} \times AB \times OC = \frac{1}{4}a^2 \cot\left(\frac{\pi}{n}\right)$$

$$\therefore \text{area of polygon} = \frac{1}{4}na^2 \cot\left(\frac{\pi}{n}\right)$$

Chapter X—MENSURATION

136. MENSURATION is that branch of mathematics which deals with the areas of surfaces and the volumes of solids. It has been shown, in arithmetic, that the area of rectangular surfaces is given by the product of two adjacent sides.

The area of a parallelogram is not the product of its sides unless it is rectangular.

Fig. 32 shows a rhomboid, $ABCD$, and a rectangle $AEFD$. These two figures have the same area, because the triangle ABE is identical with the $\triangle DCF$; therefore, if we add the

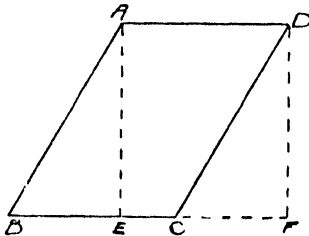


FIG. 32

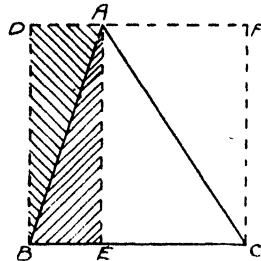


FIG. 33

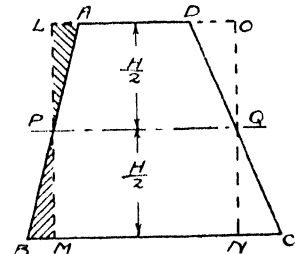


FIG. 34

remaining portion $AECD$ to each triangle, then area $ABCD = \text{area } AEFD$.

Hence we have the rule: *The area of a parallelogram is the product of base and perpendicular height.*

$$A = B \times H$$

Therefore *parallelograms on the same base and between the same parallels are equal in area.*

137. **Area of Triangle.** Fig. 33 shows that the area of a triangle is equal to half that of a parallelogram when they are on the same base and between the same parallels.

Because AB is the diagonal of $DBEA$, $\therefore \triangle DBA = \triangle ABE$. In the same way $\triangle AEC = \triangle ACF$,

$$\therefore \triangle ABE + \triangle AEC = \frac{1}{2} DBCF$$

$$\therefore \text{area of triangle} = \frac{B \times H}{2}$$

138. The area of **any irregular figure with straight sides** can be found by dividing it up into triangles, then calculating the area of each triangle, and adding together their respective areas.

139. Fig. 34 shows a *trapezium* $ABCD$, which is the usual section for a retaining wall, or, if it is inverted, for a trench. The definition for a trapezium is that two sides only are parallel.

The area is the product of *half the sum of the parallel sides and the perpendicular distance*

between them; i.e. it is equal to an equivalent rectangle, for $LMNO$ is a rectangle, $\triangle ALP = \triangle PBM$, $\triangle DQO = \triangle QNC$; but $\triangle PBM$ and $\triangle QNC$ have been cut off the trapezium, and $\triangle ALP$ and $\triangle DQO$ have been added to the remainder of the trapezium to form the rectangle; hence area of trapezium = area of rectangle.

$$\therefore \text{Area of trapezium} = \frac{AD + BC}{2} \times H$$

EXAMPLE. Fig. 35 is the plan of a field plotted from the following survey notes.

	To N	
	700	
	600	150 to C
350 to E	500	
	350	250 to B
250 to D	150	
	100	200 to A
	From S	

MODERN BUILDING CONSTRUCTION

SOLUTION. Calculating the various sections, we have

△ <i>NFC</i>	=	7,500	sq. yd.
△ <i>NGE</i>	=	35,000	"
△ <i>SKA</i>	=	10,000	"
△ <i>SJD</i>	=	18,750	"
Trapezium <i>KHBA</i>	=	56,250	"
" <i>JGED</i>	=	105,000	"
" <i>HFCB</i>	=	50,000	"
Total = 282,500 sq. yd.			

∴ Area = 58 ac., 1 rd., 18 sq.p., 25½ sq.yd.

The student is advised to plot the figure, and then calculate the areas.

140. Areas of Regular Polygons. To find the area of regular polygons, we may triangulate, or we may calculate by the aid of trigonometry.

Fig. 36 is a regular hexagon with 4 in. side. We may consider the area as six times the area

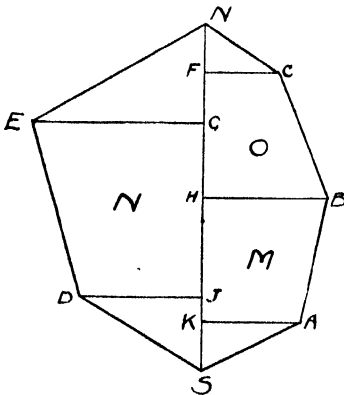


FIG. 35

of the $\triangle OAB$, which is 2 in. \times y . Now y is the perpendicular of a right-angled triangle,

$$\therefore \frac{y}{2} = \tan 60^\circ$$

$$\therefore y = 2 \tan 60^\circ = 2 \times 1.7321 = 3.4642$$

$$\therefore \text{area of one } \triangle = \frac{4 \times 3.4642}{2}$$

$$\therefore \text{area of hexagon} = \frac{6 \times 4 \times 3.4642}{2} = 41.5704 \text{ sq. in.}$$

Suppose it is required to find the angle OAB for any polygon with N sides. A circle contains 360° , therefore the angle $AOB = \frac{360}{N}$; but any

triangle contains 180° in its three angles, ∴

$$\angle OAB + \angle OBA = 180 - \frac{360}{N}, \text{ also } \angle OAB =$$

$$\angle OBA, \therefore \angle OBA = \frac{180 - \frac{360}{N}}{2}, \therefore \text{if the poly-}$$

gon be an octagon, we have $\angle OBA$

$$= \frac{180 - \frac{360}{8}}{2} = \frac{135}{2} = 67\frac{1}{2}^\circ$$

THE CIRCLE

141. To Find the Length of the Circumference.

If we take the diameter of any circle and bend it round the circumference, we find that it goes round $3\frac{1}{2}$ times, i.e.

$$\frac{\text{Circum.}}{\text{Diam.}} = 3\frac{1}{2}, \therefore \text{Circum.} = 3\frac{1}{2} \times \text{diam.}$$

This value of $3\frac{1}{2}$ is not quite accurate, but it is sufficiently accurate for practical purposes; the

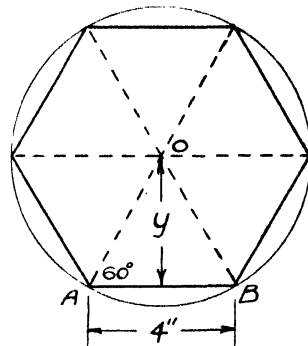


FIG. 36

decimal equivalent is $3.14159\dots$, but 3.142 is the approximate equivalent generally used for building calculations. In all calculations involving the circle and sphere we have to use this value, hence we use the symbol π (pronounced "pie") for convenience.

142. Area of Circle. We may find the area, approximately, by cutting the circle into a number of small equal sectors, and laying them side by side as shown (half only) in Fig. 37. The figure so built up is practically a parallelogram, therefore the area is

$$\frac{\text{Circumference}}{2} \times \text{radius}$$

$$\text{But } \frac{\text{Circumference}}{2} = \frac{3\frac{1}{2} \times \text{diameter}}{2} = 3\frac{1}{2} \text{ radius}$$

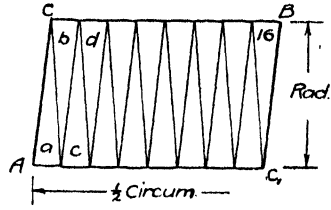
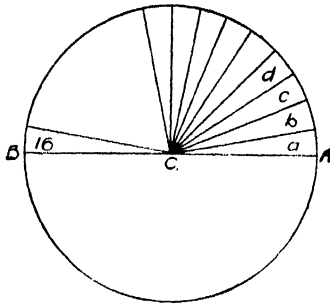


FIG. 37

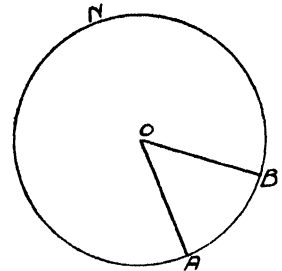


FIG. 38

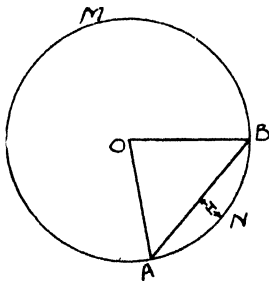


FIG. 39

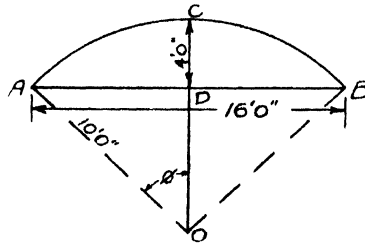


FIG. 40

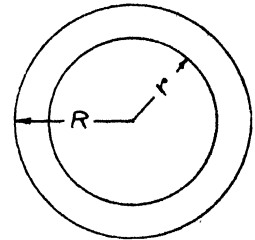


FIG. 42

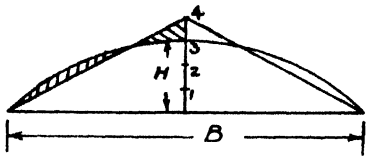


FIG. 41

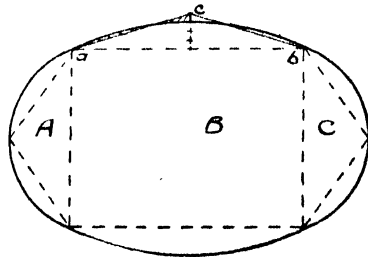


FIG. 43

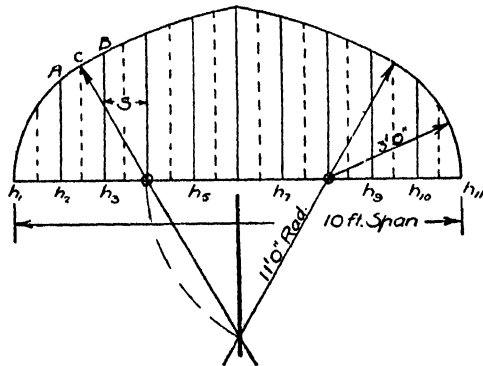


FIG. 44

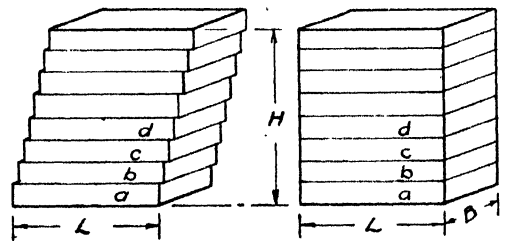


FIG. 46

MODERN BUILDING CONSTRUCTION

$$\begin{aligned} \therefore \text{area of circle} &= 3\frac{1}{2} \times R \times R \\ &= \pi R^2 = \frac{\pi}{4} D^2 \text{ or } .7854 D^2 \end{aligned}$$

143. Arc of Circle. The length of an arc of a circle is found by considering it as a fraction of the circumference. We must know the angle subtended by the arc, at the centre of the circle.

If we require the length AB in Fig. 38, we require to know the $\angle AOB$; if this angle be θ , then the arc = $\frac{\theta}{360}$ of the circumference; if θ be 60° , then the arc = $\frac{60}{360} = \frac{1}{6}$ of the circumference = $\frac{1}{6} 2\pi R$.

144. Sector of Circle. The sector AOB , Fig. 38, can be found in the same way; that is, the area of the sector = $\frac{\theta}{360}$ of the area of the circle.

If $\theta = 45^\circ$, then sector = $\frac{45}{360} \times \pi R^2 = \frac{1}{8} \pi R^2$.

The large or major sector $OANB$ is the remainder of the circle, i.e. $\frac{315}{360} \pi R^2 = \frac{7}{8} \pi R^2$.

145. Segment of Circle. To find the area of the segment ABN in Fig. 39, we first require the angle AOB ; then from the area of the sector $OANB$ we subtract the area of the $\triangle OAB$. The major segment AMB is the remainder of the circle. An approximate formula for small segments is $\frac{H^3}{2C} + \frac{2}{3} CH$, where C is the chord AB .

EXAMPLE. Find the area of the panel ABC in Fig. 40. Span = 16 ft., rise = 4 ft.

SOLUTION. The radius of the arc may be found by

$$\begin{aligned} &\frac{1}{2} \left(\frac{\frac{1}{2} \text{span}^2}{\text{rise}} + \text{rise} \right) \\ &= \frac{1}{2} \left(\frac{16^2}{4} + 4 \right) = \frac{1}{2} (20) = 10 \text{ ft.} \end{aligned}$$

Angle $AOD = \theta$, then $\frac{16}{10} = \sin \theta$

$$\therefore \theta = 54^\circ \text{ nearly, } \therefore \angle AOB = 108^\circ$$

But area of circle = πR^2 , \therefore area of sector = $\frac{108}{360} \pi R^2$
 $= \frac{3}{10} \times \pi \times 10^2 = 94\frac{2}{7} \text{ sq. ft.}$

But area of $\triangle AOB = AD \times DO$

$$\therefore \triangle AOB = 8 \times 6 = 48 \text{ sq. ft.}$$

$$\therefore \text{Area of panel} = 94\frac{2}{7} - 48 = 46\frac{2}{7} \text{ sq. ft. } \text{Ans.}$$

146. Areas of Small Segments. The areas of surfaces bounded by small arcs, whether of circle, ellipse, parabola, or any curve, so long as it is *continuous in one direction*, may be found by drawing an equivalent triangle, as in Fig. 41.

The triangle is $\frac{1}{3}$ the height of the segment; then
 area of segment = area of $\triangle = \frac{\frac{1}{3} H \times B}{2}$.

This rule is accurate for the arc of a parabola, but approximate for other curves.

147. Fig. 42 shows the *annulus*, the area of which is given by $\pi R^2 - \pi r^2 = \pi (R^2 - r^2)$

$$= \pi (R + r) (R - r)$$

148. Ellipse. The area of an ellipse is derived from that of a circle, but instead of *radius*

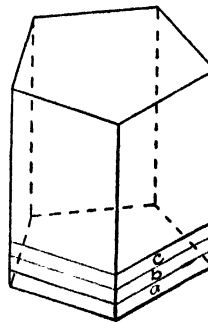
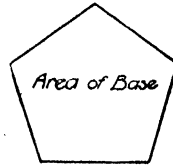


FIG. 45

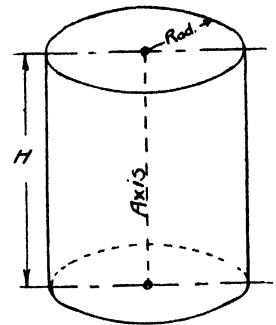


FIG. 47

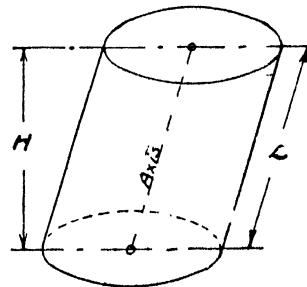


FIG. 48

squared, we find the product of half the major axis and half the minor axis, therefore area of ellipse

$$= \pi \left(\frac{1}{2} \text{major axis} \times \frac{1}{2} \text{minor axis} \right)$$

$$= .7854 D \times d$$

where D and d are the axes.

149. This rule will not apply to the oval, or to the three-centred arch; Fig. 43 shows one method of finding the area of either an ellipse or an oval. Cut off a convenient series of small arcs (Art. 146); then find the sum of the separate areas.

An approximate formula for the perimeter of an ellipse is

$$P = \pi \left(\frac{D+d}{2} \right)$$

150. Areas of Irregular Figures. (a) *Mid-ordinate Method.* (1) Draw the figure, either

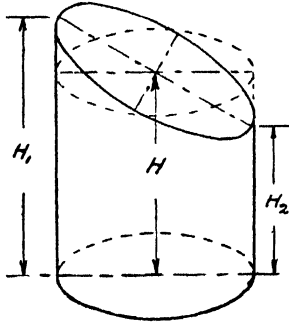


FIG. 49

full size or to some convenient scale. (2) Make some convenient line the *base*, and divide it into any number of equal parts. (3) At the centre of each space erect lines at right angles to the base. (These lines, which are *mid-ordinates*, are shown dotted in Fig. 44.) (4) Add together the lengths of all the mid-ordinates, find the average length, and multiply by the length of the base, or multiply the total length of the ordinates by the width of one strip.

(b) *Simpson's Rule.* (1) Divide the base into an even number of equal parts. (2) Erect ordinates (*h*), at each point of division; then $\frac{1}{3}$ Space (sum of end ordinates + twice odd ordinates + four times even ordinates) =

$$\frac{1}{3} S \{ h_1 + h_{11} + 2(h_3 + h_5 + h_7 + h_9) + 4(h_2 + h_4 + h_6 + h_8 + h_{10}) \}$$

Substituting the values, and noting that $S = 1$ ft., then

$$\begin{aligned} & \frac{1}{3} \{ 0 + 2(13.2 \text{ ft.}) + 4(15.2 \text{ ft.}) \} \\ & = \frac{1}{3} (26.4 + 60.8) \\ & = 29.1 \text{ sq. ft. area.} \end{aligned}$$

The easiest method of finding the sum of the ordinates is to mark them off continuously on a

strip of paper, and then measure the total length. If the figure is drawn to scale, the actual dimensions must be taken, and not the scale measurements, otherwise the conversion is liable to confuse the student. In Fig. 44 we could have found the area of half the figure by reasons of symmetry.

(c) *The Squared Paper Method* is to draw the figure on squared paper. Then count all the full squares, and add all the part squares which are more than half a square, and neglect the part squares which are less than half a square. The student must note carefully what area each square represents, if the figure is drawn to scale.

(d) *Planimeter Method.* The planimeter is an instrument which registers the area when a needle is traced along the bounding line of the figure.

SOLIDS

151. **Right Prisms.** The volumes of rectangular solids have already been considered.

Volume = length \times breadth \times thickness, i.e. $V = LBT$.

Solids which have their *axes at right angles to the base*, and have the same section throughout their length, are called *right prisms*. The base may have any number of sides, and the sides may be of different lengths.

Fig. 45 shows the base and a pictorial view of a pentagonal prism. It will easily be seen that

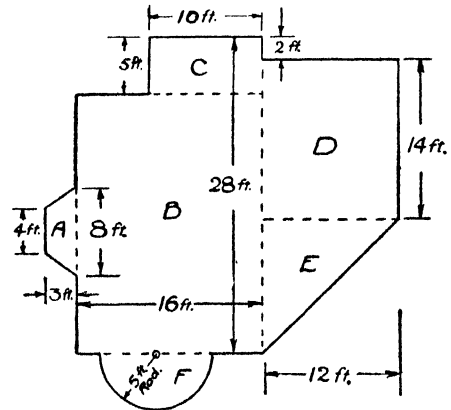


FIG. 50

the volume is the area of the base multiplied by the height, for if we consider the solid as built up of a number of thin slabs *a, b, c*, etc. (say 1 in. thick), then the volume of each slab is (area of base \times 1) cub. in., and if the solid consists

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of eight such slabs, that is, 8 in. high, then the volume = 8 times the volume of one slab,

$$\therefore V = A \times H.$$

152. **Oblique Prisms.** When the axis is not at right angles to the base, the solid is *oblique*; the volume is then

Area of base \times *perpendicular height.*

For if we consider the prism, Fig. 46, as built up of a large number of thin slabs *a, b, c, d,* etc., then the volume of the prism is equal to the

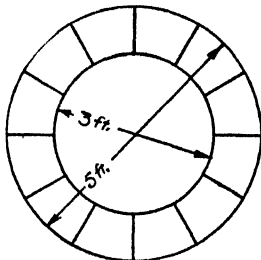


FIG. 51

volumes of the slabs. But the volume of each slab is *area of base* \times *thickness*, and the *thickness of each slab* \times the *number of slabs* = the vertical height of the prism,

$$\therefore V = A \times \text{perpendicular height}$$

153. **Areas of Surfaces.** The *areas* of surfaces of prisms are found by adding together the areas of all the separate faces. The surface areas of right prisms are the product of *perimeter of base* and *height*. If we consider the pentagonal prism in Fig. 45, and assume the length of side of base as $1\frac{1}{2}$ in., and 8 in. for the height, then the surface area is $(5 \times 1\frac{1}{2} \text{ in.}) \times 8 \text{ in.} = 60 \text{ sq. in.}$ Add to this area the areas of base and top.

154. **Cylinders.** A cylinder is a special case of the prism, in which the base is a circle. The calculations for volume and area involve the same principles (see Fig. 47).

$$\text{Area of base} = \pi R^2.$$

$$\therefore \text{Volume} = \text{base} \times \text{height} = \pi R^2 H.$$

The curved surface is the perimeter of the base \times height = $2\pi RH$, \therefore total area = $2\pi RH + 2\pi R^2 = 2\pi R(H + R)$.

155. **Oblique Cylinder.** Vol. = base \times vertical height.

Surface of Oblique Cylinder (Fig. 48). It is necessary to find the perimeter of the section at right angles to the axis, and multiply by

the length of the axis. This also applies to the surface area of the oblique prism.

The student must distinguish between *oblique cylinder* and *right cylinder "cut obliquely."* A section at right angles to the axis of an oblique cylinder is an ellipse, and a section at right angles to the axis of a right cylinder is a circle.

Fig. 49 shows a right cylinder *cut obliquely* at one end; this solid is called a truncated cylinder.

Volume = base \times average height

$$= \pi R^2 \left(\frac{H_1 + H_2}{2} \right) = \pi R^2 H$$

Area of curved surface

$$= 2\pi R \times \left(\frac{H_1 + H_2}{2} \right) = 2\pi RH$$

Area of base = πR^2 ,

Area of top = π ($\frac{1}{2}$ major axis \times $\frac{1}{2}$ minor axis)

Volume of hollow cylinder, or pipes

$$= (\pi R^2 - \pi r^2)L = L \pi (R^2 - r^2)$$

$$= L \pi (R + r)(R - r) \text{ (see Art. 152).}$$

EXERCISE XV (Answers on page 69)

1. Find the area of the given floor (Fig. 50).

Hint. The dotted lines show the method, calculate the separate parts and then add together.

2. Fig. 51 is the elevation of a bull's eye window opening, the stones are bonded 9 in. and $13\frac{1}{2}$ in. alternately. Find the volume of the stone, and the cost at 6s. 6d. per foot cube.

Hint. Find the area of the face, then multiply by the average depth.

3. Find the weight of stone in an elliptical arch, 25 ft. span, 10 ft. rise, 1 ft. deep, and 1 ft. 6 in. thick. Stone = 140 lb. per cub. ft. Assume that both soffit and extrados are ellipses.

156. **Volume of Pyramid.** A pyramid is a solid having a base and three or more triangular sides. The sides meet at a point called the apex.

Fig. 52 shows a square pyramid, and Fig. 53 shows the same pyramid placed inside a cube which is twice the height of the pyramid, with the base of the pyramid lying in the face *BCDE* of the cube. If we imagine the cube divided into two equal parts along the plane *FGHJ*, then the apex of the pyramid will be at the centre of this plane.

The student will readily see that if we placed a similar pyramid in every face of the cube, we should have six similar pyramids which would just fill the cube. Hence one pyramid would equal one-sixth of the cube, that is, one-third of half the cube.

But half of the cube = base $\times h$, \therefore pyramid = $\frac{1}{3}$ of base $\times h$, that is, the volume of a pyramid = $\frac{\text{base} \times \text{height}}{3}$

157. **Cone.** When the base is a circle, as in Fig. 54, the "pyramid" is called a *cone*, and volume = $\frac{\text{base} \times \text{height}}{3} = \frac{\pi r^2 H}{3}$; therefore the volume = one-third that of a circumscribing cylinder.

The surface area = $\frac{2\pi R \times L}{2} = \pi RL$, because the perimeter of the base = $2\pi R$; therefore total area = $\pi RL + \pi R^2 = \pi R(L + R)$, where L is the *slant height* of the cone.

Fig. 55 shows the method of finding L when

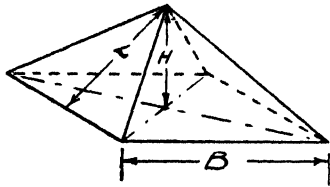


FIG. 52

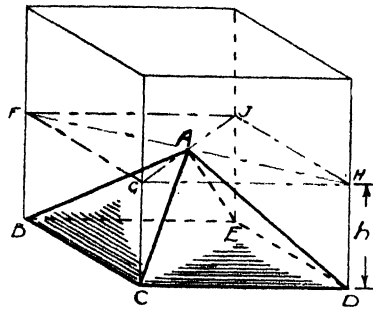


FIG. 53

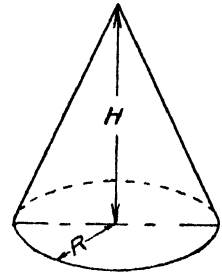


FIG. 54

H and B are given. From the right-angled triangle, we have

$$H^2 + x^2 = L^2, \therefore L = \sqrt{H^2 + x^2}$$

and $H = \sqrt{L^2 - x^2}$

158. The surface area for all pyramids is the area of the base plus the area of all the triangular faces. Hence, for a *regular pyramid*, if N = number of sides of base, a = length of base edge, and L = slant height of pyramid, then sloping surfaces = $\frac{N \times a \times L}{2}$, but $N \times a$ = perimeter of base, therefore total area

$$= \frac{\text{perimeter of base} \times L}{2} + \text{area of base}$$

159. **Frusta of Cone and Pyramid.** When a pyramid or cone is cut, or truncated, by a plane parallel to the base, the resulting solid is a *frustum*.

Fig. 56 shows the frustum of a hexagonal pyramid. The sloping surfaces consist of a number of trapeziums (see Art. 139). The area of

a trapezium is *half the sum of the parallel sides* \times the *perpendicular distance between them*.

$$\therefore \text{Area} = \left(\frac{N \times a + N \times b}{2} \right) \times L$$

where N = the number of sides to the pyramid.

$$\therefore \text{Area} = \frac{1}{2} L N (a + b) + \text{base} + \text{top}.$$

$N \times a$ and $N \times b$ become $2\pi r$ and $2\pi R$ in a cone, therefore sloping surface of cone frustum = $\frac{1}{2} L (2\pi r + 2\pi R) = \frac{1}{2} L \times 2\pi (r + R) = L\pi (r + R)$

The volume of a frustum is given by $\frac{1}{3} H (A_1 + A_2 + \sqrt{A_1 A_2})$, where A_1 is the area of the top and A_2 is the area of the base; or we can calculate the volume of the whole pyramid,

and subtract the volume of the small pyramid which has been cut away. (See also Art. 169.)

160. **Circular Anchor Ring** (*Guldinus' Theorem*). This solid is in the form of a ring. The solid may be imagined as a long bar, of any section, bent into a circle; hence the volume of the ring is equal to the volume of the rod before bending.

If the rod be circular in section (Fig. 57), the length will be $2\pi R$, where R is the radius to the centre of gravity of the section, and the area of the section will be πr^2 , therefore

$$\text{Volume} = \pi r^2 L = \pi r^2 \times 2\pi R = 2\pi^2 r^2 R$$

$$\begin{aligned} \text{The area of the surface} &= \text{circumference of section} \times L \\ &= 2\pi r \times 2\pi R = 4\pi^2 r R \end{aligned}$$

EXAMPLE. Find the volume and surface area of the ring shown in Fig. 57, when $R = 10\frac{1}{2}$ in. and $r = \frac{1}{4}$ in.

SOLUTION. Vol. = $2\pi^2 r^2 R$ \therefore log V. = log 2 + 2 log π + 2 log r + log R = 0.3010 + 2 \times 0.4972 + 2 \times 1.0314 = 2.2108 \therefore Antilog = 162.5 cub. in. Ans.

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$$\begin{aligned} \text{Surface} &= 4\pi^2 r R \therefore \log S = \log 4 + 2 \log \pi + \log r \\ &\quad + \log R \\ &= 0.6021 + 0.9944 + 1.942 + 1.0314 \\ &= 0.5699 \therefore \text{Antilog} = 371.5 \text{ sq. in. } \textit{Ans.} \end{aligned}$$

EXAMPLE. Fig. 58 shows the section of a blocking course for a circular tower. Find the weight of the stone, when the inside diameter = 10 ft., and the stone weighs 156 lb. per foot cube.

SOLUTION. The centre of gravity is 5.2 in. from the inside face, and the area of the section

$$= \frac{8 + 12}{2} \times 18 = 10 \times 18,$$

Mean radius = 60 + 5.2 = 65.2 in.



FIG. 55

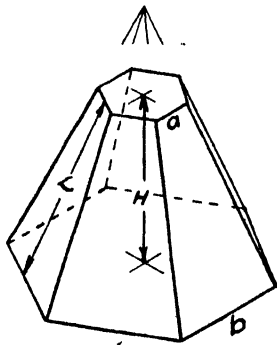


FIG. 56

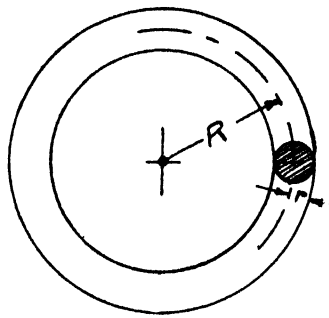


FIG. 57

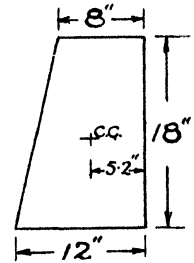


FIG. 58

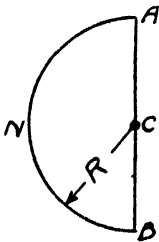


FIG. 59

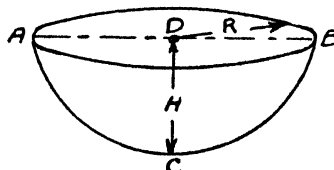


FIG. 60

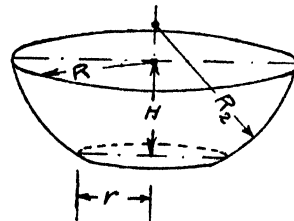


FIG. 61

$$\begin{aligned} \therefore \text{Volume} &= (10 \times 18) \times (2 \times 3.14 \times 65.2) \text{ cub. in.} \\ \therefore \text{Wt.} &= \frac{10 \times 18 \times 2 \times 3.14 \times 65.2 \times 156}{12 \times 12 \times 12} \\ &= 6,653 \frac{1}{2} \text{ lb.} \end{aligned}$$

161. The Sphere. A perfectly round ball is called a *sphere*. If radial lines be drawn from the centre, in any direction, to the surface, they will be of equal length. If the semicircle *ANB*, Fig. 59, rotates about *AB*, then the semicircle will trace out the spherical surface, the area of which is $4\pi R^2$, and the volume is $\frac{4}{3}\pi R^3$.

These values are found by applying *Guldinus' Theorem*. In the first case find the centre of gravity of the arc *ANB*, and in the second case

find the centre of gravity of the area of the semicircle *ANB*.

When a sphere is cut by a plane passing through its centre, it is divided into two hemispheres. If the plane does not pass through the centre, the sphere is divided into *segments*. Any section through a sphere is a circle.

162. Segment of Sphere. The volume of a *segment* of a sphere, Fig. 60, is $\frac{1}{6}\pi H(H^2 + 3R^2)$, where *R* is the radius *AD*, of the plane surface.

Area of curved surface = $\pi(R^2 + H^2)$.

163. Zone. If we cut away the top portion

of a segment, by a plane parallel to the plane surface, the curved surface is a *zone* (Fig. 61), and the *volume* of the frustum

$$= \frac{1}{6}\pi H(H^2 + 3R^2 + 3r^2)$$

Area of curved surface = $2\pi R_2 H$, where R_2 = radius of sphere.

164. Prismoidal Formula. To find the volume of irregular solids with parallel ends, we can apply *Simpson's rule* (Art. 150), substituting the areas of the sections *A*, *A*₁, etc., for the ordinates. This is equivalent to finding the average cross-section of the solid, and then multiplying by the length.

Solids of this description are called *prismoids* ;

and if the length of a prismoid be divided into six equal lengths, then the volume is

$$\frac{1}{6} S \{A_1 + A_7 + 2(A_3 + A_5) + 4(A_2 + A_4 + A_6)\}$$

where S is the length of one part, and A is the cross-sectional area at the point of division.

We have many important applications of this formula when only three ordinates, or areas, are given, i.e. the areas at the centre and two ends. If these areas are A_1 , A_2 , and A_3 , then the average area = $\frac{1}{6}(A_1 + A_3 + 4A_2)$, and volume

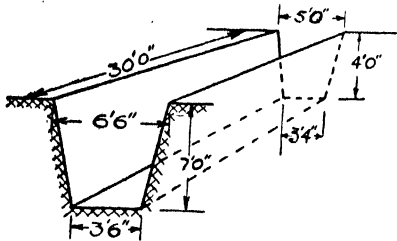


FIG. 62

equals $\frac{1}{6}H(A_1 + A_3 + 4A_2)$, where H is the height or length of the prismoid, and A_2 is the middle area. The formula is true for all solids with parallel ends, which are connected by plane surfaces, and for the frusta of regular solids.

EXAMPLE. Find the volume and surface area of a cone frustum, when height = 12 in., diameter of base and top = 6 in. and 3 in. respectively.

SOLUTION. Vol. = $\frac{h}{6}(A_1 + A_3 + 4A_2)$

$$= 2(9\pi + 2\frac{1}{4}\pi + 4 \times 5.0625\pi)$$

$$= 2\pi(9 + 2.25 + 20.25)$$

$$= 2\pi(32.5) = 65\pi = 204\frac{3}{4} \text{ cub. in. } Ans.$$

Note. The diameter of the middle ordinate

$$= \frac{3 + 6}{2} = 4\frac{1}{2} \text{ in.}$$

$$\text{Surface} = \pi l(R + r) + \pi R^2 + \pi r^2 = \pi l(R + r) + R^2 + r^2$$

$$\text{But } l = \sqrt{12^2 + 1.5^2} = 12.1$$

$$\therefore S = 3.142(12.1 \times 4.5 + 9 + 2.25) = 3.142 \times 65.7 = 206.43 \text{ sq. in. } Ans.$$

The volume of any solid, which does not lend itself to a recognised formula, may be found by displacement, as described in "Experimental Science."

EXERCISE XVI (*Answers below*)

1. Find the amount of earth excavated from the trench shown in Fig. 62. Use the formula $\frac{1}{6}L(A_1 + A_3 + 4A_2)$; find the area at the middle by taking the averages of the end dimensions for breadth and depth.

2. Fig. 63 shows a projecting course in a circular chimney coping; outside diameter of chimney = 12 ft. Find the volume of the block A . Calculate semicircle and rectangle separately.

3. A concrete hemispherical dome 1 ft. thick is 15 ft. outside diameter. Find the weight of the dome when the concrete weighs 112 lb. per foot cube.

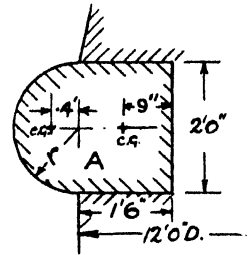


FIG. 63

4. A conical turret 7 ft. high and 12 ft. diameter stands on a cylindrical base of the same diameter and 1 ft. 6 in. deep. Find the weight of lead at 8 lb. per square foot to cover the outside surfaces of cone and cylinder. Add 5 per cent for seams and waste.

ANSWERS TO EXERCISE XV (*page 66*)

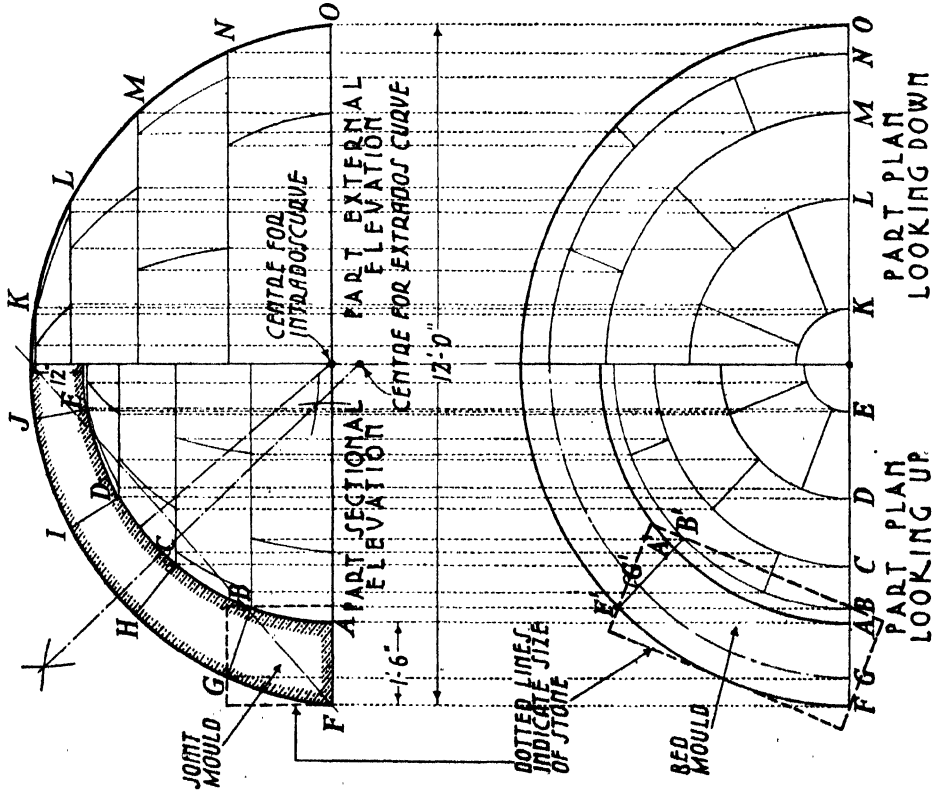
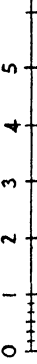
1. 715 $\frac{1}{2}$ sq. ft.
2. £3 16s. 7d.
3. 7,755 lb.

ANSWERS TO EXERCISE XVI (*above*)

1. 762.5 cub. ft.
2. 162.2 cub. ft.
3. 308.5 cwt.
4. 241.5 sq. ft. = 17.2 cwt.

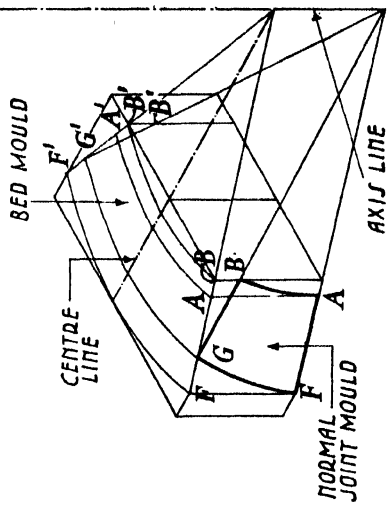
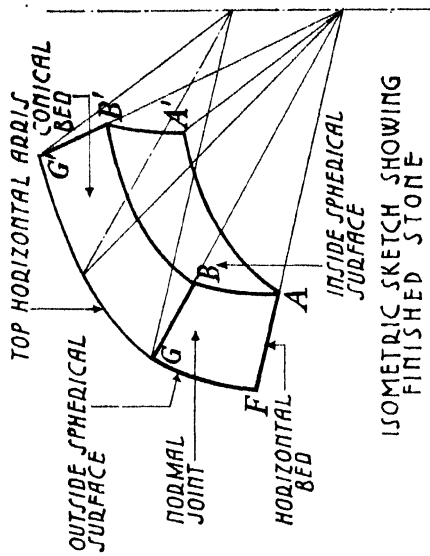
PROJECTIONS FOR A STONE DOME

10 FT.



PART PLAN
LOOKING UP.

PART PLAN
LOOKING DOWN



ISOMETRIC SKETCH SHOWING MOULDS
APPLIED TO STONE
E.G.W.

Builder's Geometry

By RICHARD GREENHALGH, A.I.STRUCT.E.
Honours Medallist in Geometry

Chapter I—DRAWING INSTRUMENTS AND MATERIALS

Introduction. Geometry might be defined as the scientific basis of technical drawing; in fact, practical geometry and technical drawing are often used as interchangeable terms. It is indispensable to the architect who designs the building and to the craftsmen who construct the building. An architect might be able to draw a tracery window without a knowledge of geometry, but he would do so only slowly and inefficiently; so, likewise, a carpenter could cut his roof bevels by trial and error, or by various practical makeshifts, but he would take longer and make a poorer job than if he had a knowledge of geometry. And the same remarks apply to innumerable details and aspects of building construction.

In studying this subject, the student is advised that reading is of little use in itself; the various examples should be drawn out. In this way he will not only better understand the methods given, but he will gain skill and facility with his drawing instruments, and the various principles will be impressed on his mind.

Geometry is often divided into two branches—*plane* geometry and *solid* geometry. Plane geometry treats of geometrical figures, and not with solid objects; it is often termed *geometrical drawing*.

The most difficult part of geometry is solid geometry, which deals with the drawing of objects requiring the use of three dimensions in space. Such branches of building as handrailing, skew arches, and circle-on-circle work require a sound knowledge of solid geometry if they are to be understood thoroughly.

Many craftsmen are somewhat afraid of solid geometry, and look upon it as something very difficult and even mysterious. It is nothing of the kind. In fact, there is hardly another subject in which mere common sense and a little imagination will carry the student so far. But visual imagination, that is, the faculty of picturing the objects in the mind's eye, is a great asset. The ability to draw out a certain problem

is of little use unless the student knows *why* it is done. But when only even a few principles in solid geometry have been thoroughly grasped, the student can apply them with facility to many practical building problems.

The following chapters have been arranged to explain in a progressive manner the principles of geometry most useful to builders and architects. After describing the instruments required

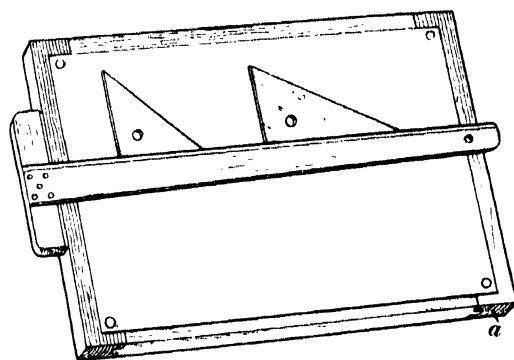


FIG. 1. SMALL BOARD, T-SQUARE, AND SET-SQUARE

and their use, simple geometrical constructions are explained, followed by more difficult applications, chiefly in solid geometry. Other particular applications belonging more strictly to one or other of the various trades are dealt with in their special sections.

DRAWING BOARDS. All drawing boards should be made of soft wood, usually yellow pine, so that the drawing pins can be easily inserted and withdrawn. The size required will vary according to circumstances. For technical school work it is usual to have a board 23 in. by 16 in.; this size will take half imperial paper (22 in. by 15 in.) and leave a margin of half-inch all round. For office work, a larger board, 31 in. by 23 in., to take imperial paper, or a board 42 in. by 29 in., to take double elephant paper, 40 in. by 26½ in., is generally used.

Small boards, say up to half imperial size,

MODERN BUILDING CONSTRUCTION

may be made of 1 in. pine boards, glued together to give the necessary width; two battens, *a*, about $2\frac{1}{2}$ in. wide, as shown in Fig. 1, are tongued and grooved or mortised and tenoned to the ends to prevent warping. Three-ply boards are much used, and these consist of three pine layers, the grain of the centre layer running at right angles to the top and bottom layers to prevent twisting.

For large boards, the best construction is shown in Fig. 2, which shows the back of the board. Here, the pine boards are glued up to the required width, and two battens, *a*, about 3 in. by 1 in., are then screwed to the back to prevent warping. The screws pass through slots in the battens, the slots having slotted washers sunk into the battens; this allows the board

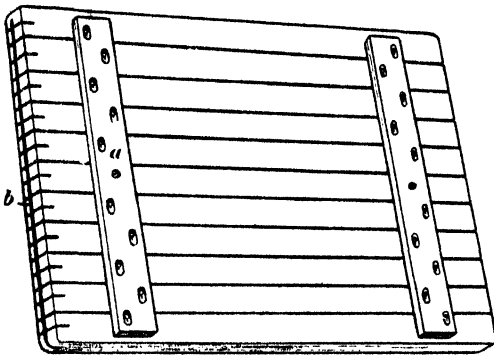


FIG. 2. BACK VIEW OF GOOD TYPE OF DRAWING BOARD

to expand and contract, but at the same time keeps it flat. The back of the board is usually grooved at about 3 in. intervals to nearly half its thickness, so that the screws can easily bend the wood and hold the back of the board tightly to the battens.

One edge (the left-hand edge) of the board is often grooved and fitted with a slightly projecting slip, *b*, of ebony, the strip being sawn through at intervals to allow for contraction of the board. This strip forms a good edge for the stock of the T-square to run against, and it can be easily planed if it gets dented or becomes crooked.

A good drawing board has two chief characteristics: a smooth, *straight* edge for the T-square to slide against, and a reasonably flat surface. It is not essential that the board should be dead square; a draughtsman only uses his T-square against the left-hand edge; vertical lines are drawn with a set-square. If, however, the working edge of the board is not straight, it is impossible to draw parallel horizontal lines.

DRAWING PAPER. There are many varieties of drawing paper, but for ordinary drawings or students' work "cartridge" is generally used. It may be obtained in either rolls or sheets, the chief sizes of the latter having already been given. The rolls are usually 30 yd. long and 30 in. or more in width. Cartridge paper can be obtained in various thicknesses and qualities.

For important work, or where the drawings have to be coloured, a *hand-made paper* is advisable; *Whatman's* is perhaps the best known, but there are many other makes. Hand-made paper is also made in various thicknesses, and with either a "smooth" or a "rough" surface, the latter being the better for coloured drawings.

Bank Detail Paper is a thin, semi-transparent paper; it can be used for drawing large-scale detail views or as a substitute for tracing paper.

Tracing Paper is used chiefly for copying drawings in ink, but it is also employed for large details. *Tracing cloth* has the characteristics of tracing paper, but is more durable and not easily torn; one side is dull and the other glossy, the dull side being used for drawing upon.

Squared paper is sometimes found useful for making sketches, and can be obtained with various sizes of squares, usually $\frac{1}{8}$ in. and $\frac{1}{10}$ in.

Drawing paper is dealt with in more detail in the section on "Architectural Drawing."

DRAWING PINS. Four pins are generally required, one for each corner of the sheet, but for large drawings eight pins are often used. The pins should have a thin and slightly curved head, so that the T-square will pass easily over them. The heads should be rather large, say about $\frac{3}{4}$ in. in diameter.

INDIA-RUBBER. A soft rubber should be used; the hard composition "rubbers" should be avoided. *Ink erasers*, which are made of a hard, gritty composition, can be obtained; they are useful for erasing ink marks, but they should not be used for rubbing out pencil marks, as they injure the surface of the paper. A sharp pen-knife is, however, generally employed for erasing ink lines.

T-SQUARE. The length of the T-square, Fig. 1, should be such that the blade is about an inch longer than the drawing board. Ordinary T-squares are usually made of pear wood; the blade should be tapered and bevelled at the drawing edge, but very cheap makes are made with the blade parallel and without bevel. The blade must be screwed firmly on the stock; it

is not very important that the blade be accurately at right angles to the stock, but the joint must be rigid.

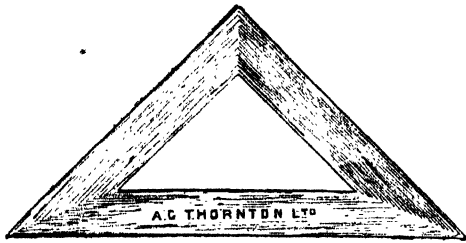


FIG. 3. FRAMED WOODEN SET-SQUARE

The best T-squares are made of mahogany and have an ebony working edge. Some are provided with a celluloid edge, which is very convenient but is easily damaged.

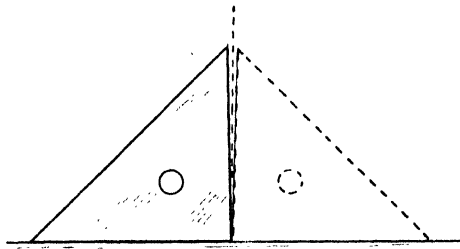


FIG. 4. TESTING RIGHT-ANGLE OF SET-SQUARE

SET-SQUARES. Wooden set-squares, usually made of pear wood, were at one time largely used, but they have been largely displaced by set-squares made of celluloid. If wooden set-

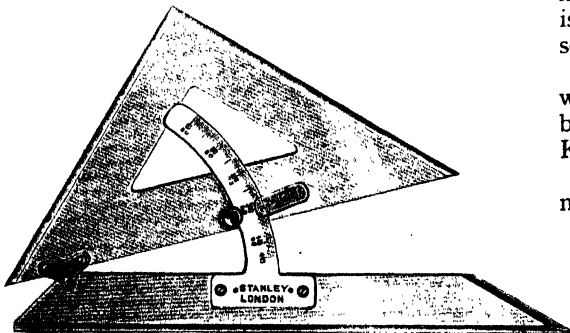


FIG. 5. ADJUSTABLE SET-SQUARE

squares are used they should be framed (see Fig. 3), so that any shrinkage of the wood will have the minimum effect on their accuracy.

The great advantage of celluloid set-squares is that they are transparent and the lines underneath them can be seen.

Two set-squares (a pair) are required, as shown in Fig. 1, one being known as a 45° set-square and the other as a 30° or 60° set-square. A convenient size has a long edge of about 9 in.

Perhaps the most important feature of a set-square is that the right angle should be accurate, and this is tested as shown in Fig. 4. Place the set-square on the T-square and draw a line; then turn the set-square over and draw another line near to the first line. If the two lines are parallel, then the right angle is correct; but if not, then the angle is out of truth by half the small angle between the lines.

A type of set-square now largely used, and which can be highly recommended, is the *adjustable set-square* shown in Fig. 5. It will perform all the functions of both the ordinary set-squares, and of a protractor as well.

The arm is pivoted so that it can be adjusted to any required angle by means of the scale, and fixed in position by the screw. The latter screw is also very handy for lifting and moving the set-square.

PENCILS. It pays to buy good pencils; they work smoothly, are free from grit, and do not break easily. One of the best makes is the Koh-i-Noor.

Pencils are made in various degrees of hardness from 6B to 6H, as follows—

BB, B, HB, F, HB, H, HH.

A HH pencil is satisfactory for most drawings, and a F pencil for writing and lettering. Hexagonal pencils are better than round ones, as they do not roll about the board.

The drawing pencil may be either sharpened to a conical point or to a chisel edge (see Fig. 6). The chisel edge lasts longer and gives finer lines

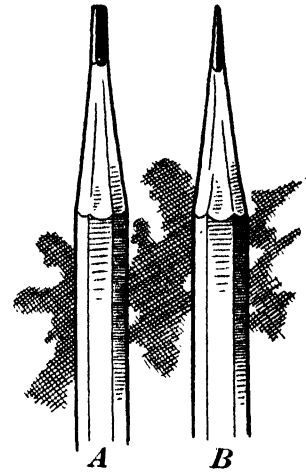


FIG. 6. CHISEL AND CONICAL POINTS

MODERN BUILDING CONSTRUCTION

than the ordinary point, but it is not so convenient to use. The point should not be stumpy, but should be about $1\frac{1}{2}$ in. long.

After sharpening with a penknife, the point should be rubbed up on a piece of fine glass-paper. Most draughtsmen have a strip of glass-paper glued to a small piece of wood for this

moved towards the draughtsman. In Fig. 9 the line is being drawn along the other side of the set-square, and the pencil point is moved away from the draughtsman. It is very bad practice to draw vertical lines by using the T-square against the top or bottom edges of the board.

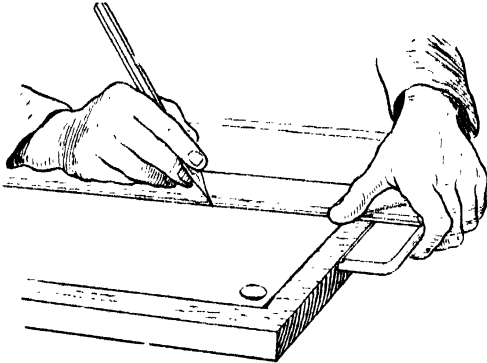


FIG. 7. DRAWING HORIZONTAL LINES

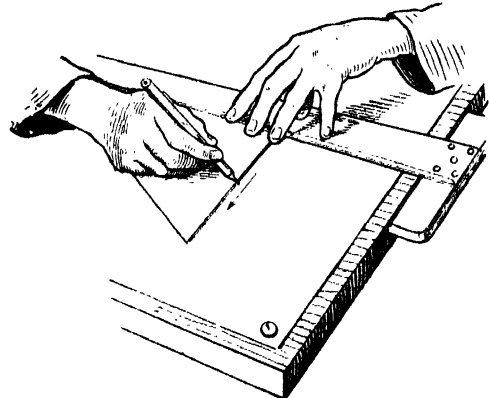


FIG. 9. ALTERNATIVE METHOD

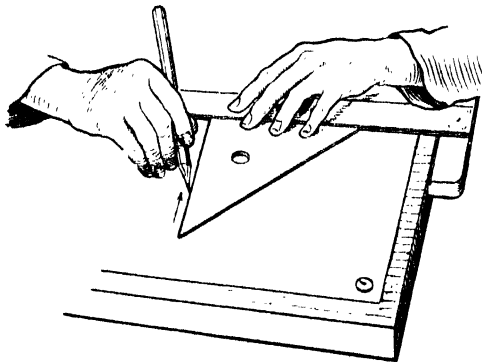


FIG. 8. DRAWING PERPENDICULAR LINES

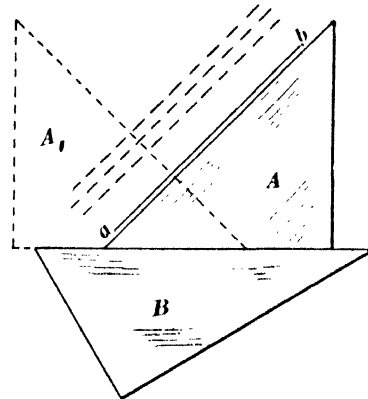


FIG. 10. DRAWING PARALLEL SLANTING LINES

purpose. Small sharpening blocks, containing about a dozen strips of glasspaper pinned together, can be purchased.

Drawing Straight Lines. Horizontal lines are drawn with a T-square, care being taken that it is held firmly to the left-hand edge of the board, as shown in Fig. 7. Vertical lines are drawn by placing a set-square on the T-square, both instruments being then held gently but firmly with the left hand while the line is drawn. Fig. 8 shows a line being drawn along the right-hand side of the set-square, the pencil being

Slanting parallel lines are drawn by using a set-square, as shown in Fig. 10. Suppose one or more lines have to be drawn parallel with *ab*. Place one edge of set-square *A* against *ab*, and then place another set-square *B* or the T-square against another edge of the first set-square. Slide the first set-square forward to the required positions and draw the lines.

Other lines at right angles to the first lines can be drawn by holding the second set-square in position, and turning the first set-square to the position shown at *A*₁.

INSTRUMENTS. It is always advisable for the draughtsman to purchase the best instruments within his means. Good work cannot be done with cheap instruments; the joints of compasses, etc., move jerkily and soon work loose, and the points cannot be adjusted accurately. It is preferable to buy one or two instruments of good quality as required, rather than a case full of inferior make.

The joints should be of the double-jointed kind, that is, where the joints are pivoted and the two parts fit into each other, there should be double slots and tongues. The needle points should be replaceable and should fit tightly where they emerge from the bottom of the leg, so that there will be no play or side movement when in use.

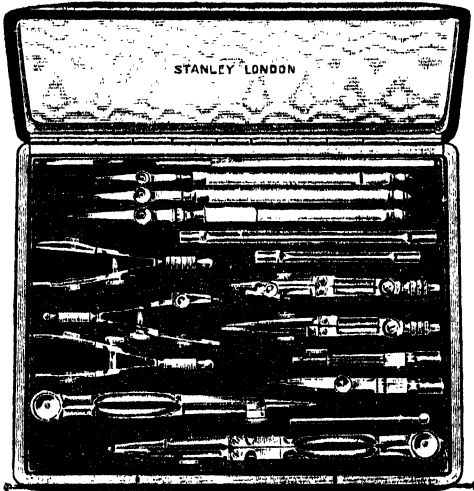


FIG. 11. POCKET CASE OF DRAWING INSTRUMENTS

A pocket case of good quality drawing instruments is shown in Fig. 11.

COMPASSES. Compasses may be obtained in three patterns, the type shown in Fig. 12 being adapted for large circles. When complete with a lengthening bar (top illustration) and a pen (bottom at right), the various parts are known collectively as a *half set*. The lengthening bar is used when drawing very large circles, the compass leg being removed and replaced by the lengthening bar, and then fitted into the lower end of the lengthening bar. The pen leg can be used in place of the pencil leg.

For circles of medium size, say between 1 in.

and 4 in. in diameter, *bow compasses*, as shown in Fig. 13, are the most useful. These compasses have a knob at the top, and the points

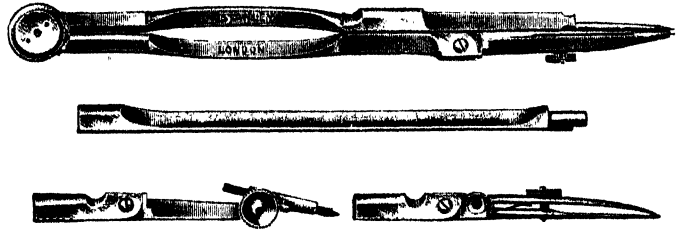


FIG. 12. HALF SET OF COMPASSES

are not detachable, so separate instruments are required for pencil and ink.

Spring-bow compasses, a good pattern of which

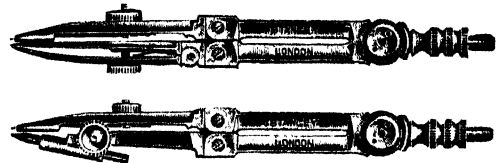


FIG. 13. BOW COMPASSES

is shown in Fig. 14, are used for very small circles. They are usually supplied in sets of three: pencil, pen, and divider points, but the latter are of little use.

Using Compasses. To use a pair of compasses efficiently requires a fair amount of practice. Two rules should be observed. First, put as little pressure as possible on the point; and, secondly, always keep the legs as upright as possible. If these two rules are followed, an unsightly hole will not be made in the paper, thus also tending to make further curves inaccurate when struck from this centre. The top of the compasses should be held lightly between the thumb and first and second fingers, as shown in Fig. 15.

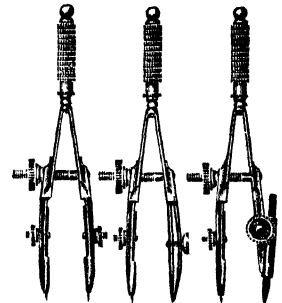


FIG. 14. SPRING-BOW COMPASSES

The young draughtsman should try to handle and adjust the compasses with one hand, as shown in Fig. 16, which shows the compasses being set to inscribe a circle in a triangle.

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Practice will soon enable the student to adjust his compasses in this manner.

DIVIDERS. These are not very necessary, as compasses can generally be used instead, but they are looked upon as part of a draughtsman's equipment. The points should be kept very fine and

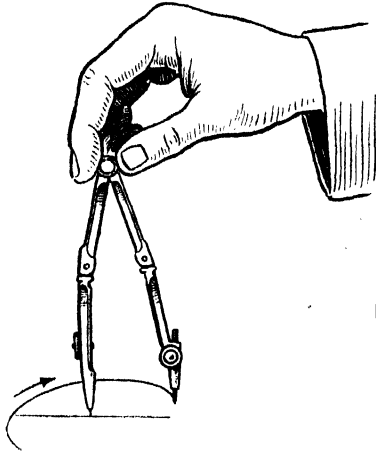


FIG. 15. METHOD OF USING COMPASSES

sharp, and the knuckle should work smoothly. When setting the dividers to a required length, there is a tendency to jerk the points a little over or under the required setting, and therefore some dividers are provided with a *hair adjustment*, as shown in Fig. 17. This means that one leg is jointed near the middle or

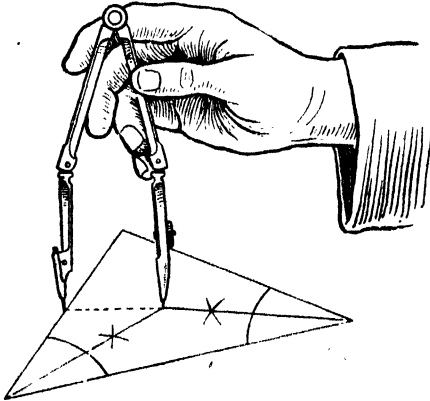


FIG. 16. SETTING THE COMPASSES

near one end, and the lower part can be adjusted a little by turning a screw, as shown. It is a rather unnecessary refinement.

FRENCH CURVES. Curved lines which are not

parts of circles and which cannot be drawn freehand are usually drawn by the aid of French curves, a typical example of which is shown in Fig. 18. Many varieties of shapes can be purchased in either wood or celluloid, the latter being preferable. Some draughtsmen make their own from a sheet of celluloid, which can be cut with a penknife and glass-papered to a smooth edge.

When using French curves, care must be exercised or "kinks" will show in the curves drawn. The French curve should be adjusted to at least three points on the required curve, and it is often advisable first to sketch the line freehand. As the line is drawn, the French curve is moved about to successive positions,

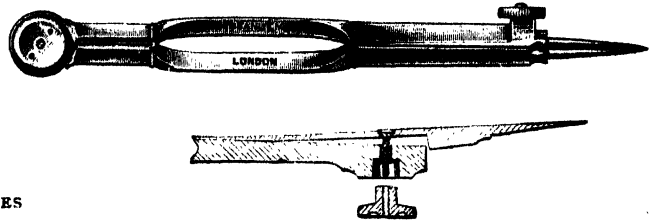


FIG. 17. HAIR DIVIDERS AND SECTION THROUGH LEG

and should always be adjusted so that part of it coincides with a portion of the curve already drawn.

Flexible curves may also be obtained for drawing curved lines, but they are not much used.

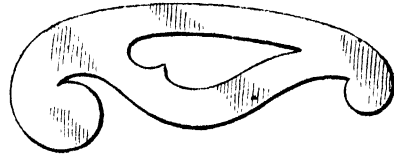


FIG. 18. FRENCH CURVE

PROTRACTORS. The instrument used for measuring or setting out angles is known as a protractor. It is usually a semicircle of celluloid with the degrees marked round its arc, but is sometimes a complete circle as shown in Fig. 19. Protractors are also sometimes made of wood, metal or ivory, but celluloid is the best material because it is transparent. Rectangular protractors, as shown in Fig. 20, are also made. In setting out an angle, the base of the protractor is adjusted to the line, with the middle point of the base over the spot from which the angle has to be drawn; a point is then marked off at the rim of the protractor.

SCALE OF CHORDS. A scale of chords is also used for setting out angles, and is often found marked on rules.

follows: Draw a line (Fig. 22) and describe an arc with AB (Fig. 21) as radius. Now set the compass from A to 20 (the chord of 20°)

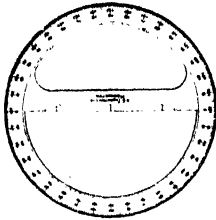


FIG. 19. CIRCULAR PROTRACTOR

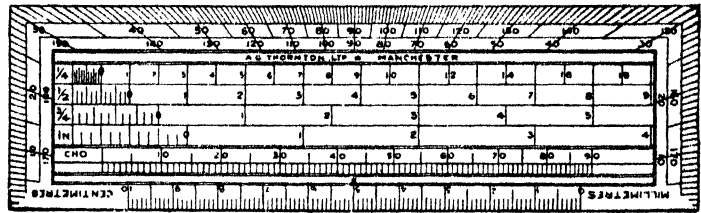


FIG. 20. RECTANGULAR PROTRACTOR

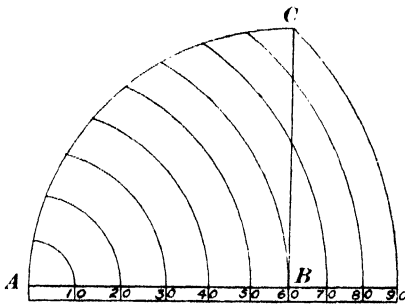


FIG. 21. CONSTRUCTING A SCALE OF CHORDS

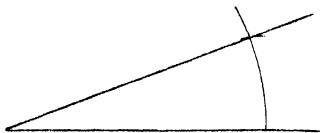


FIG. 22. SETTING OUT ANGLE WITH SCALE OF CHORDS

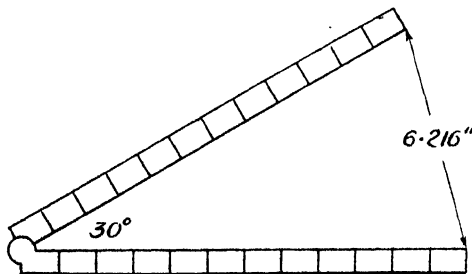


FIG. 23. SETTING OUT ANGLE WITH RULE

To construct a scale of chords, draw a quadrant ABC (Fig. 21) and divide the arc AC into nine equal parts. With A as centre turn these points down on to AB (produced).

To set out any angle, say 20° , proceed as

on the scale of chords and cut off the arc to this length.

A scale of chords is shown on the rectangular protractor in Fig. 20.

Setting Out Angles with Rule. The table below gives the values of the chords of a number of angles; that is, the figures in the centre column give the ratio of the chords to the radii of the various angles, the radius in each case being unity. If the radius is taken as 12 units, say inches, the chord will then be 12 times the size given in the centre column; therefore the figures in the last column are 12 times those in the centre column.

The latter figures can be used for setting out any angle with a 2 ft. rule. Thus, in Fig. 23, the inside corners of the ends of the rule are adjusted (as nearly as possible) to 6.216 in., as given opposite 30° in the table, and the legs of the rule thus make an angle of 30° .

TABLE FOR SETTING OUT ANGLES WITH RULE

Degrees	Chord	Chord at 12 in.
5	0.087	1.044
10	0.174	2.088
15	0.261	3.132
20	0.347	4.164
25	0.433	5.196
30	0.518	6.216
33½	0.577	6.924
35	0.601	7.212
40	0.684	8.208
45	0.705	9.180
50	0.845	10.140
55	0.923	11.076
60	1.000	12.000
65	1.075	12.900
70	1.147	13.764
75	1.218	14.616
80	1.286	15.432
85	1.351	16.212
90	1.414	16.968

Chapter II—PLANE GEOMETRY

PRELIMINARY DEFINITIONS AND CONSTRUCTIONS

LINES. A *straight line* is a line describing the shortest distance between two points. *Parallel lines* are such that if produced indefinitely they would never meet.

CIRCLE. A *circle* is a plane figure having a boundary, or *circumference*, which is equidistant at all points from a given point called the *centre*. A *chord* (see Fig. 24) is a line drawn across the circle, and the *diameter* may be said to be the largest chord. A *segment* is the figure enclosed between an *arc* and a chord. A *sector* is the part of a circle enclosed between two radii

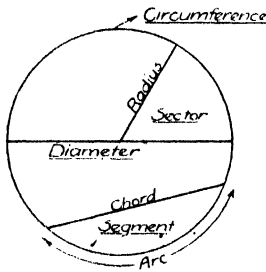


FIG. 24. PARTS OF A CIRCLE

and an arc. A *tangent* is a line that just touches a circle or other curve.

ANGLES. An *angle* is the amount of angular space between two lines, or, in other words, it is the magnitude of rotation that one line must make to coincide with the other. If one line stands on another line, Fig. 25, so that the adjacent angles are equal, then the two angles are *right angles*. The unit of angular measurement is a *degree*, and is the ninetieth part of a right angle. There are four right angles or 360° in a circle. An angle less than a right angle is termed an *acute angle*; an *obtuse angle* is greater than a right angle.

TRIANGLES. A triangle is a figure bounded by three straight lines. An *equilateral* triangle has all its sides (and angles) equal. In an *isosceles* triangle, two sides (and angles) are equal. A *scalene* triangle has all its sides of different lengths.

Beginning a Drawing. It is first necessary to pin the drawing paper to the board. Insert the top left-hand drawing pin. Adjust the drawing paper so that its top edge is level, as given by the T-square; stretch the paper towards the diagonally opposite corner, and insert the bottom right-hand drawing pin. Pull the paper towards

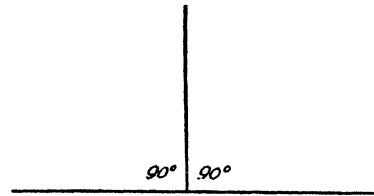


FIG. 25. RIGHT ANGLES

the other two corners, and insert the other two pins.

Some draughtsmen use a back sheet under the drawing paper, particularly if the board is pitted with drawing-pin holes; this sheet then prevents the pencil bumping into any crevices in the board, and enables the compasses to be used with greater ease if the leg happens to come over a pin hole.

Care should always be taken to keep the drawing instruments clean. Before using the set-squares, they should be rubbed on a sheet of clean paper until they fail to make a mark. The back of the T-square should be well cleaned; in fact, on elaborate drawings, some draughtsmen fold over the drawing paper for about a half-inch at the left-hand side, so that the T-square will not rub the lines of the drawing.

In beginning a large drawing or when making several drawings on a big sheet, care should be exercised at the start in placing the drawings, so that when finished the work will be evenly balanced on the paper.

Bisecting a Line. If a line is of definite length, say, 3 in., the easiest way to divide it into two equal parts is obviously to apply a scale. Where the line is of uncertain length, the draughtsmen generally use the method given in Fig. 26. Adjust the dividers or compasses as near as can be guessed to half the line, and mark off the distance from each end *A* and *B* of the line,

thus giving two points a and b close together. The centre of the short distance between these two points can then be judged with considerable accuracy.

The geometrical method given in most text-books is shown in Fig. 27. Adjust the compasses to rather more than half the length of the line, and describe arcs as shown from each end A and B of the line. Draw a line through the points C and D where these arcs intersect each other. The line CD bisects the given line.

Bisecting an Angle. Let ABC be any angle. With B as centre and any radius, describe an

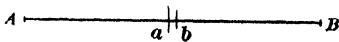


FIG. 26. BISECTING A LINE BY TRIAL

arc cutting the lines at D and E . With the latter points as centres, and compasses set to any length greater than half the arc, describe two small arcs intersecting in a point

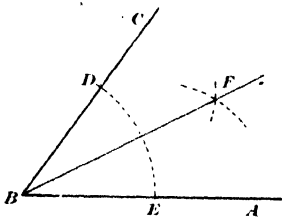


FIG. 28. BISECTING AN ANGLE

F . A line from B through F bisects the given angle.

Dividing a Line. The method of dividing a line into any number of equal parts is shown in Fig. 29. Assume that the line AB has to be divided into seven equal parts. Draw any line AC , making an angle with AB . Set off seven equal spaces with the dividers along AC . Join the last point 7 to B , and draw lines parallel with $7B$ from the other points. The line AB will thus be divided into seven equal portions.

Length of Curved Line. The easiest way of finding the length of an irregular curved line is shown in Fig. 30. Set the dividers to a small length, and step out this length from one end a until the other end b is reached. The number of repeats is then set out along a straight line, as

shown in (B). If there is part of a division left over, as bc , the dividers are set to this bit and transferred to (B).

Another method is shown in Fig. 31. A straight line is marked on a piece of tracing paper C . The latter is then adjusted over the

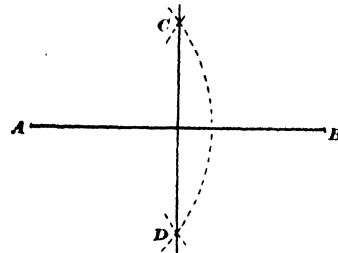


FIG. 27. BISECTING A LINE

curved line, so that one end A of the straight line coincides with a , and a sharp point, as a divider leg, is pricked through A into a . The tracing paper is swivelled about until the straight

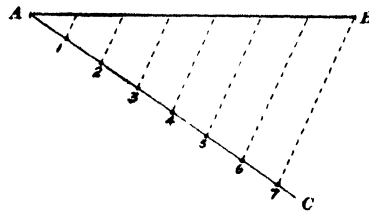


FIG. 29. DIVIDING A LINE INTO EQUAL PARTS

line on the tracing paper lies approximately in the same direction as a short portion of the curved line; really, the line on the tracing paper coincides with the chord of the small curved arc $a1$. The divider point, or pricker, is then pricked through the tracing paper at point 1, and the tracing paper is again swivelled to lie in the same direction as a second short portion of the curved line. The illustration shows the tracing paper adjusted to a third short arc. The operation is repeated until the end of the curved line is reached, when the true length, or stretch-out, will be shown on the straight line. The advantage of the tracing paper method is that the steps can be readily made short or long, according to the "quickness" or "flatness" of the curve being measured.

To Draw a Right Angle. Of course, the usual method for the draughtsman when drawing a

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right angle is to use a set-square, and for the practical man a try-square, but if these instruments are not available other methods must be adopted.

In setting out large angles, say, when setting out the corner of a building or making a builder's square (a large wooden square for setting out buildings, etc.) what is known as the 3 : 4 : 5 rule

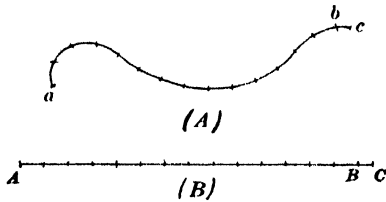


FIG. 30. OBTAINING LENGTH OF CURVED LINE

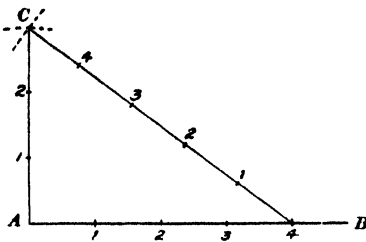


FIG. 32. CONSTRUCTING A RIGHT ANGLE, 3 : 4 : 5 RULE

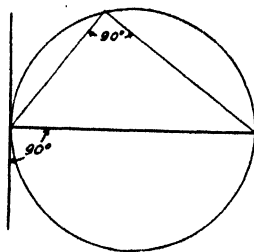


FIG. 34. ANGLE IN SEMICIRCLE

is often used. Suppose a line has to be drawn perpendicular to AB from the point A , Fig. 32. Set out 4 units (say, 4 ft.) from A along AB . From point 4 strike out 5 units and from A strike out 3 units, thus giving point C . Then CAB is a right angle. This method can conveniently be performed by means of any tape measure. The beginning of the tape is held at

A , and the 8 ft. mark at point 4; if the tape is held at the 3 ft. mark and pulled taut, point C will be located.

The 3 : 4 : 5 rule is based on a well-known theorem in Euclid, which states: *In a right-*

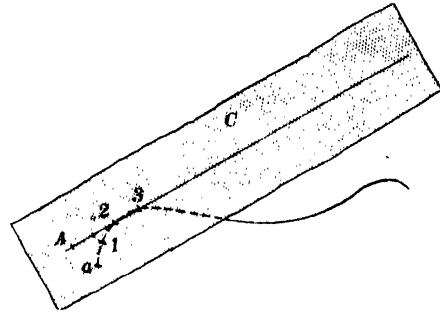


FIG. 31. TRACING-PAPER METHOD

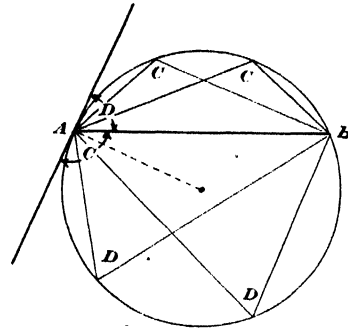


FIG. 33. ANGLES IN SEGMENTS

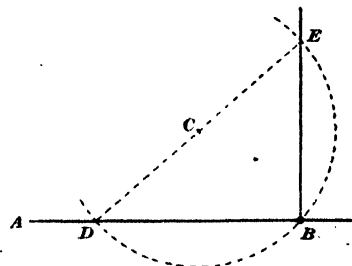


FIG. 35. CONSTRUCTING A RIGHT ANGLE, USING COMPASSES

angled triangle, the square on the hypotenuse is equal to the sum of the squares on the other two sides. Thus, if a right-angled triangle has the two short sides 6 in. and 8 in. long respectively, the squares on these two sides are 36 sq. in. and 64 sq. in. respectively. Therefore, the square on the hypotenuse must be $36 + 64 = 100$ sq. in.; that is, the hypotenuse is 10 in. long.

This theorem relating to the squares on the sides of a right-angled triangle, besides being of use in drawing right angles, is much used for many kinds of simple problems involving the finding of the length of the hypotenuse of a right-angled triangle. Thus, assume that a roof has a span of 22 ft. and a rise of 8 ft. The half-span would be the base of a right-angled triangle having the rise, 8 ft., of the roof as perpendicular, and the slope of the roof as hypotenuse. The length of the slope of the roof would thus be $\sqrt{11^2 + 8^2} = \sqrt{121 + 64} = \sqrt{185} = 13.7$ ft. Of course, problems of this kind can always be solved geometrically by drawing the base and perpendicular of the right-angled triangle to scale, and then scaling off the length of the hypotenuse.

Angles in Segments. A useful and well-known geometrical principle is illustrated in Fig. 33. AB is the chord of a circle dividing the circle into two unequal segments. If several triangles are formed on the chord and with their apexes on the arc, then all the upper angles of these triangles are equal to each other. Further, if a tangent to the circle is drawn through one end of the chord, then the *angle between the chord*

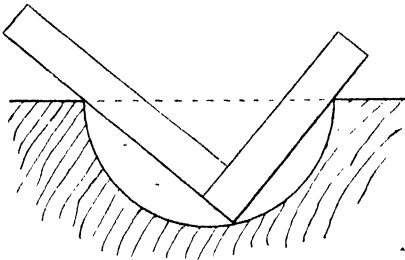


FIG. 36. USE OF TRY-SQUARE TO TEST SEMICIRCLE

and the tangent is always equal to the angle in the opposite segment of the circle. Thus, in Fig. 33, all angles C are equal, and all angles D are equal. These statements should be proved by drawing out the figure and measuring the angles with a protractor.

A particular case of the above theorem is shown in Fig. 34. Here the segments are equal, that is, they are semicircles; and as the angle between the chord and the tangent is a right angle, it follows from the above rule that *the angle in the semicircle is a right angle*. The principle is often made use of in drawing a right angle, as shown in Fig. 35.

Let it be required to draw a line at right angles to a line AB from a point B in it. Select

a point in a position as C , and with C as centre describe an arc passing through B and cutting the line AB in another point D . Join DC , and produce to cut the arc in E . Join BE , which will be found to be at right angles to AB . The correctness of this construction is obvious, as the angle DBE is the angle on the diameter of a circle and must, therefore, be a right angle.

Another application of the principle that the angle in a semicircle is a right angle is illustrated in Fig. 36, where a try-square is shown being used to test the accuracy of a semicircular sinking in a piece of wood or stone.

CIRCLES AND ARCS

Circle Through Three Points. Let A , B , and C , Fig. 37, be the three points, which may be

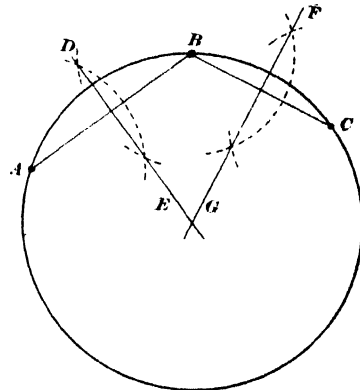


FIG. 37. DRAWING CIRCLE THROUGH THREE GIVEN POINTS

placed anywhere except in a straight line. Bisect AB by the line DE ; then any point on DE is equidistant from A and B . Similarly,

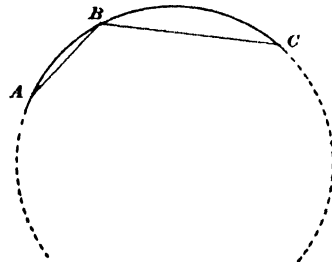


FIG. 38. GIVEN AN ARC, TO COMPLETE THE CIRCLE

bisect BC by FG , and any point on FG must be equidistant from B and C . The intersection of the two bisectors will thus be equidistant

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from all three points and must therefore be the centre of the required circle.

The above problem is really the same as circumscribing a triangle by a circle, and is also identical with the problem of completing a circle when only an arc is given. For example, let the given arc be as shown in Fig. 38. Choose any three points as *A*, *B*, and *C* on the arc.

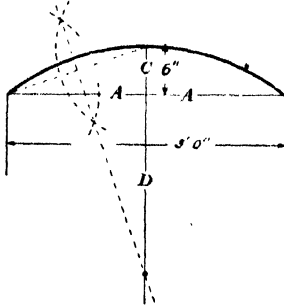


FIG. 39. OBTAINING RADIUS OF SEGMENTAL ARCH

Then bisect the lines joining the points, as already explained.

Segmental Arch. An application of the previous problem is when a segmental arch has to

$$D = \frac{A \times B}{C}$$

therefore,

$$D = \frac{2 \times 3}{1} = 6 \text{ in.}$$

In the case of an arch, one chord is divided into two equal parts *A*, Fig. 39, and therefore

$$D = \frac{A \times A}{C} = \frac{A^2}{C}$$

When *D* is obtained, the diameter can be

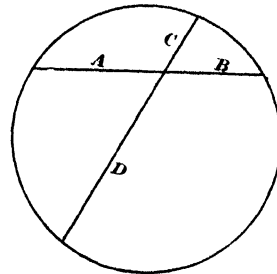


FIG. 40. INTERSECTING CHORDS

obtained by adding *C*; the radius is found by halving the diameter.

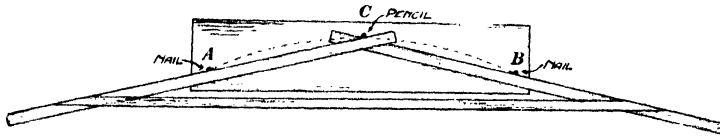


FIG. 41. DRAWING "FLAT" ARC

be drawn to a given span and rise. Let the span be 3 ft. and the rise 6 in., as shown in Fig. 39. Set out the dimensions to a suitable scale, say, 1 in. to a foot. Join the top of the rise with one end of the span, and bisect the line so formed. Where this bisector cuts the centre line of the arch will be the centre from which the arch curves are struck. Of course, if the centre line was not available, a bisector could be drawn at the other side of the arch, and the required centre would be at the intersection of the bisectors.

The above result can be checked by calculation, using the following rule: *If two chords intersect, then the product of the two parts of one chord is equal to the product of the two parts of the other chord.* Thus, in Fig. 40, $A \times B = C \times D$. It follows from this that, if any three of the lengths are known, the other length can be calculated. Thus, if *A* is 2 in., *B* is 3 in., and *C* is 1 in., then

This method of obtaining the radius of an arch when the span and rise are given, is often summed up in the following rule: *Square half the span, divide by rise, add rise, and divide by two.*

Apply this rule to the arch given in Fig. 39.

$$\begin{aligned} \text{Squaring half rise} & \quad \frac{3}{2} \times \frac{3}{2} = \frac{9}{4} \\ \text{Dividing by rise} & \quad \frac{9}{4} \div \frac{1}{2} = \frac{9}{2} \\ \text{Adding rise} & \quad \frac{9}{2} + \frac{1}{2} = 5 \\ \text{Dividing by 2} & \quad 5 \div 2 = 2\frac{1}{2} \text{ ft.} \end{aligned}$$

The radius of the soffit is therefore 2 ft. 6 in., which length may be checked by measuring Fig. 39 to scale.

Flat Arcs. Sometimes an arch has a very "flat" curve, that is, its rise is small compared to its span. In this case, the radius is very long, and in some cases the centre may be so far away as to be inaccessible. Under these circumstances, the flat curve can be drawn, as shown in Fig. 41, by means of a triangular

frame. The principle of this method is that the angles in the same segment of a circle are always equal.

Suppose a curve has to be drawn through the three points *A*, *B*, and *C* on the board shown in Fig. 41. Drive nails a little into the board at *A* and *B*. Make a triangular frame as shown from three strips of wood, the angle at the apex being equal to the angle *ACB*. Then, holding a pencil against the apex of the frame, glide the legs of the frame against the two nails. The required curve will thus be traced on the board.

Circle in Triangle. Let *ABC*, Fig. 42, be a triangle in which it is required to inscribe a circle. Bisect one of the angles, as *BAC*. Then, any point on the bisector *AD* must be equidistant from the sides *AB* and *AC*. Similarly, any point on the bisector *BE* must be equidistant from *AB* and *BC*. Therefore the point of intersection *F* of these two bisectors must be equidistant from the three sides of the triangle, and must consequently be the centre of the required circle. If desired, the radius of the circle may be obtained by dropping a perpendicular (as *FG*) from the point *F* on to any side of the triangle.

Of course, the above explanation is not necessary merely to solve the problem, but is necessary to understand and remember the construction, and to apply the same method to other problems.

Trefoil and Quatrefoil. A trefoil is shown in Fig. 43 and consists of three equal and tangential circles, circumscribed by a larger circle. Each small circle will clearly occupy a sector equal to one-third of the circle and having an angle of 120° . Draw *AB* and *AC* with the 30° set-square, and draw *AD* vertically. The centre of

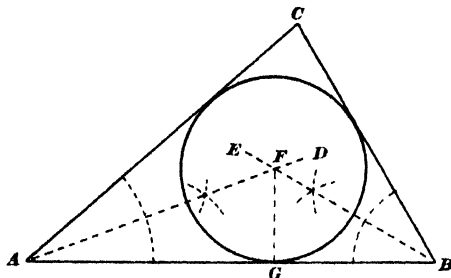


FIG. 42. INSCRIBING CIRCLE IN TRIANGLE

the top circle clearly lies on *DA* produced. Complete the triangle *ABC*, and bisect an angle, as *ACB*. The bisector will cut *DA* produced in

the centre of the required small circle. The other two centres are then easily obtained and the trefoil completed.

It should be observed that this problem chiefly

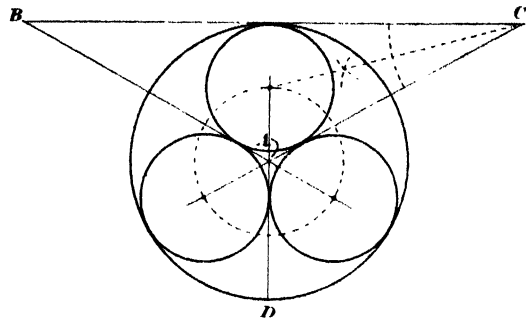


FIG. 43. CONSTRUCTING A TREFOIL

consists in drawing a circle in the triangle *ACB*, as already explained in connection with Fig. 42.

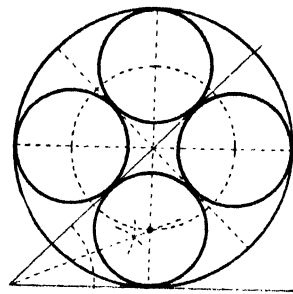


FIG. 44. CONSTRUCTING A QUATREFOIL

A *quatrefoil* is shown in Fig. 44. It is drawn by first dividing the large circle into four sectors.

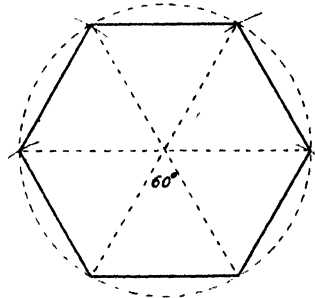


FIG. 45. DRAWING A HEXAGON

A small circle is then inscribed in one sector by first drawing the surrounding triangle. The

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quatrefoil is completed in the same manner as for the trefoil.

Similar figures with a larger number of small circles can be drawn out in the same way.

POLYGONS

A polygon is a plane figure bounded by a number of straight lines. A triangle may be

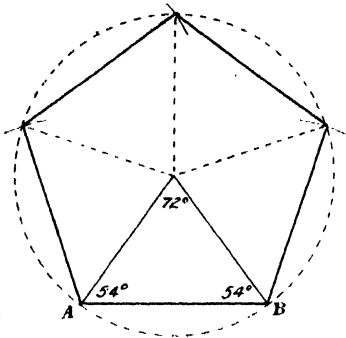


FIG. 46. DRAWING A POLYGON

considered to be a three-sided polygon, and a *quadrilateral* is a polygon with four sides.

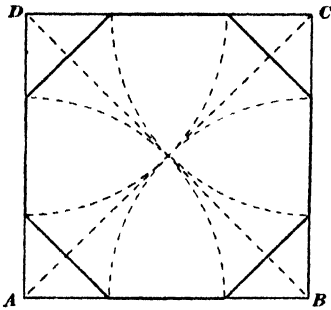


FIG. 47. DRAWING OCTAGON IN SQUARE

Usually, the term is only applied to figures of five or more sides, as follows—

Pentagon has 5 sides.	Octagon has 8 sides.
Hexagon " 6 "	Nonagon " 9 "
Heptagon " 7 "	Decagon " 10 "

Polygons may be either *regular*, that is, the

sides (and angles) are equal; or *irregular*, that is, with unequal sides and angles.

Regular Hexagon. Suppose it is required to draw a regular hexagon of $1\frac{1}{2}$ in. side. Describe a circle of $1\frac{1}{2}$ in. radius, Fig. 45, and then step off the radius round the circle. If this is done accurately, the compasses will just go round six times. Join the points thus obtained.

If diagonals are drawn, it will be seen that the angles between them at the centre are each 60° , and another method of finding the points on the circumference would, therefore, have been to use the 60° set-square.

Regular Pentagon. Assume that a pentagon of $1\frac{1}{2}$ in. side is required. Draw AB $1\frac{1}{2}$ in. long, Fig. 46. Now, the triangle between AB and the centre of the circle contains 180° , and the apex angle is $360 \div 5 = 72^\circ$; therefore the base angles at A and B must be $(180 - 72) \div 2 = 54^\circ$. Set out these angles at A and B , thus locating the centre of the circumscribing circle. Draw the circle, and step off AB round the circumference. If the draughtsmanship is accurate, the length AB will just go round five times. Join the points thus obtained, and the pentagon is completed.

Octagon in Square. A woodworker often requires to convert a square length of timber to octagonal form. Let $ABCD$, Fig. 47, be the square section. Draw the diagonals. With each corner of the square as centre, and a half diagonal as radius, describe arcs as shown. Draw across each corner to the points thus obtained on the sides.

Irregular Polygons. It is usually best to consider irregular polygons to be built up of triangles. Thus an irregular pentagon could be drawn if we were given the lengths of the sides and two of its diagonals, which would split the pentagon into three triangles. Instead of the lengths of the two diagonals, it would suffice if two of the angles were given. All surveying problems depend on triangulation, because any shape can be divided into triangles (of course only approximately if one or more of the sides are curved), and the shape of any triangle is precisely determined when the lengths of its three sides are known—or of course, one side and two angles, or two sides and one angle.

Chapter III—CONIC SECTIONS

The Four Sections. A cone may be cut by a plane in four ways: (1) by a plane parallel to the base, when the section is a *circle*; (2) by a plane at a less inclination than the generator, when the section is an *ellipse*; (3) by a plane parallel to the generator, when the section is a *parabola*; (4) by a plane of greater inclination

ellipses, these methods being divided into two classes, those for drawing *true* ellipses and those for drawing *approximate* curves. A true ellipse has a different curvature at every point, whereas an approximate ellipse is made up of a number of circular arcs joined tangentially.

Axis and Foci. An ellipse has two diameters,

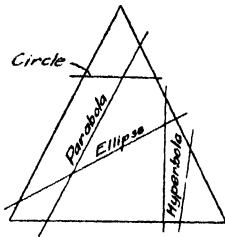


FIG. 48. SECTIONS OF CONE

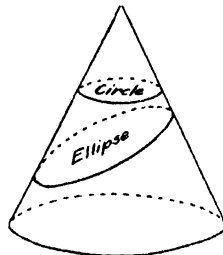


FIG. 49. CIRCLE AND ELLIPSE

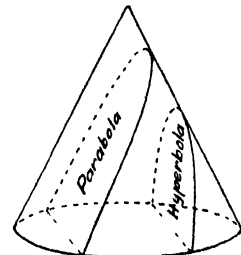


FIG. 50. PARABOLA AND HYPERBOLA

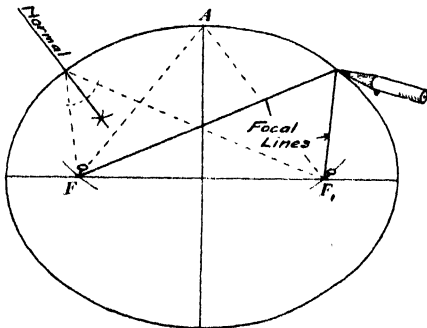


FIG. 51. STRING METHOD

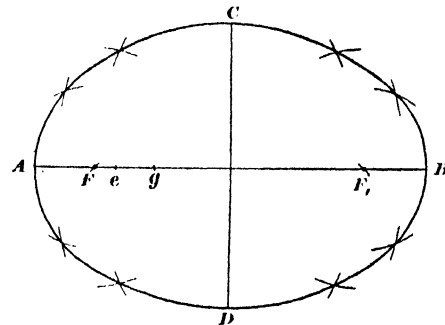


FIG. 52. GEOMETRICAL METHOD

than the generator, when the section is a *hyperbola* (see Figs. 48, 49, and 50).

Of the three latter sections, the ellipse is the most used in building work; the parabola is used to a slight extent for arches, moulding, and in structural mechanics; the hyperbola is sometimes used in the outline of Greek mouldings.

The conic sections will now be dealt with from the point of view of plane geometry, but will be dealt with later as the sections of solid bodies.

ELLIPSE

True and Approximate Ellipses. There are at least a score of different methods of drawing

or *axes*, the larger one being called the *major axis* and the smaller one being termed the *minor axis*. If half of the major axis is taken in the compasses, and this distance is then struck off from one end of the minor axis on to the major axis, Fig. 51, two points, known as *foci*, are obtained. The lines from the foci to any point on the curve are known as *focal lines*. If the angle between the focal lines is bisected, the bisector is said to be *normal* to the curve.

DRAWING AN ELLIPSE (STRING METHOD). A practical method of drawing a true ellipse is by means of a piece of string, as shown in Fig. 51. This method depends on the following well-known property of the ellipse: *The sum of any*

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pair of focal lines is constant and is equal to the length of the major axis.

Let it be required to draw an ellipse having a major axis of 4 in. and a minor axis of $2\frac{1}{2}$ in. Draw the axes as shown in Fig. 51, and obtain the foci by striking off 2 in. from A on to the major axis. Insert small nails or drawing pins at F , F_1 , and A . Tie a piece of thin string to F , pass the string over the top of A , and bring the string down to F_1 , where it is again tied.

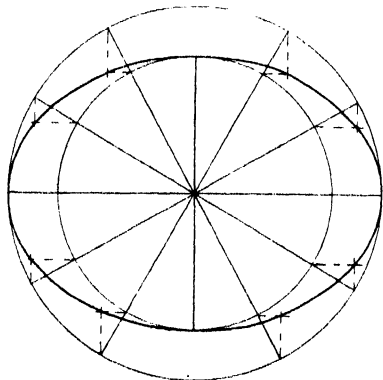


FIG. 53. THE EASIEST METHOD

axis in the compasses, and again describe arcs with the foci as centres. Four points on the ellipse are thus located, and further points on the curve can be located by repeating the process for other points, as g , on the major axis.

In this method it will be observed that the sum of the two lengths taken in the compasses is equal to the length of the major axis.

Perhaps the easiest geometrical method is that shown in Fig. 53. Describe circles on the major

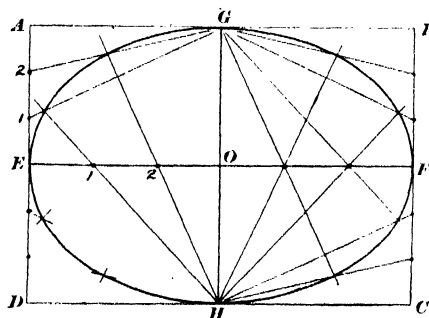


FIG. 54. ELLIPSE IN RECTANGLE

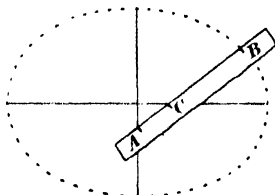


FIG. 55. TRAMMEL METHOD

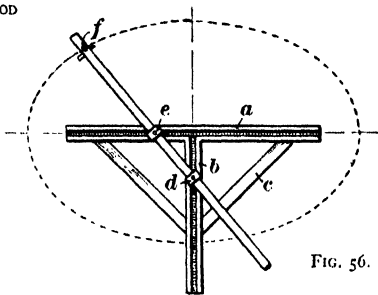


FIG. 56. A SIMPLE TRAMMEL

Now remove the pin at A and, pressing a pencil against the inside of the loop of string, glide the pencil round. An ellipse will thus be traced.

It will be seen, in this method, that the length of string represents the sum of the focal distances and is constant. This is the reason why half the major axis is struck off from A to obtain the foci; these two radii must together equal the major axis.

GEOMETRICAL METHOD. Fig. 52 shows a geometrical method of drawing an ellipse, the principle being the same as for the string method. Draw the axes AB and CD , and find the foci F and F_1 . Divide the major axis into two parts, as at the point e . Take one part, as Ae , in the compasses, and strike out arcs with the foci as centres. Now take the remainder of the major

and minor axes. Draw a number of radial lines. Where each radial line cuts the outer circle draw a vertical line, and where the radial line cuts the inner circle draw a horizontal line to intersect the vertical line. The intersection is a point on the elliptic curve required. A number of such points are obtained, and the curve is then drawn freehand through them.

ELLIPSE IN RECTANGLE. Fig. 54 shows another method of drawing an ellipse when the two axes are given. The containing rectangle $ABCD$ is first drawn through the extremities of the axes EF and GH . Divide EA into a number of equal parts, and divide EO into a similar number of equal parts. Draw radial lines from G to the division points on EA , and draw other radial lines from H through the points on EO .

to intersect the first radial lines. Two points on the quarter curve are thus given. The construction is repeated for the other quarters.

TRAMMEL METHOD. This practical method of drawing an ellipse depends on another property of the ellipse. Take a piece of paper, at least equal to the length AB of half the major axis, as shown in Fig. 55, and mark on it the length BC of half minor axis. Now move the paper so that point A glides on the minor axis while

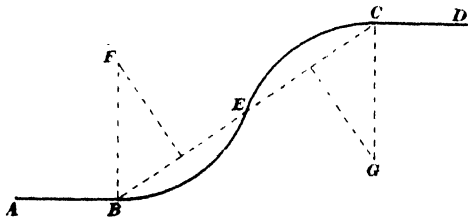


FIG. 57. TANGENTIAL PATHS

point C glides on the major axis. The point B will thus describe the ellipse. It is usual to mark against B in a number of positions, and then draw a freehand curve through the points thus obtained.

THE TRAMMEL. The *trammel* is an instrument for drawing ellipses, and can either be purchased or home-made. A type that can be made by any woodworker is shown in Fig. 56. Two pieces of grooved wood, a and b , are halved together at the centre, the joint being stiffened by means of four angle braces c . The *trammel bar* is a strip of wood arranged so that two pegs, d and e , can be adjusted along its length and secured where desired. The end of the bar is arranged to carry a pencil f . Part of the trammel bar is shown enlarged at the left-hand side.

To use the trammel, the peg d is set at a distance from the pencil equal to half the required major axis, and the peg e is similarly set for the half minor axis. The trammel bar is then moved so that the peg d slides along the minor axis, and the peg e travels along the major axis, the pencil thus tracing out the ellipse.

This method of striking an ellipse can also be used by the plasterer to run an elliptical moulding, say on an arch, the mould, or *horse*, taking the place of the pencil.

TANGENTIAL ARCS. An important rule to bear in mind when dealing with problems involving circles in contact, or curves made of tangential arcs, is as follows: *If two circles touch each other,*

then the line joining their centres passes through the point of contact.

Suppose two straight paths, AB and CD , have to be joined tangentially by a curved path between the point B and C .

Join B to C and bisect BC , giving point E . Bisect BE by a line at right angles, and draw a line at right angles to AB from B . These two lines meet at F , which is the required centre for the arc BE . The centre G is similarly obtained. If the two centres F and G are joined, it will be seen that line FG passes through the junction of the two arcs.

SIMPLE APPROXIMATE ELLIPSE. Set out the major and minor axes to the required dimensions, as shown in Fig. 58, and describe circles on each half of the major axis. Mark the radius of these circles from the top of the minor axis, and join the point A thus obtained to the centre B of one of the circles. The point C , where the bisector of AB cuts the centre line, gives the centre for the top part of the ellipse. Note that CB produced passes through the junction of the two arcs.

ARCHES

Elliptical Brick Arch. If a true elliptical curve were used for a brick arch, every brick (or pair of bricks) would be of different shape, and would require a separate pattern to cut or

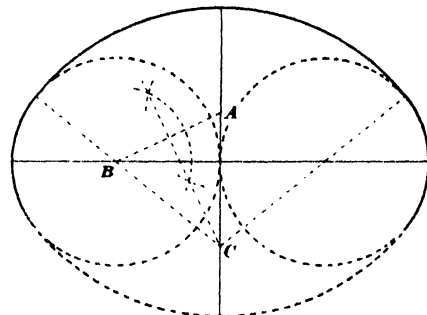


FIG. 58. SIMPLE APPROXIMATE ELLIPSE

mould it. For small arches, the method given in the previous example would be fairly satisfactory, and only two patterns, or *templets*, would be necessary, because there are only two curvatures in the arch.

For larger or better work, a closer approximation to the true curve is desirable, and the method shown in Fig. 59 is often adopted. First, obtain two points on the true curve, as shown at the left-hand side of the illustration. To do this construct the rectangle $AEDF$ on

MODERN BUILDING CONSTRUCTION

half the major axis. Divide AF and AE into three equal parts. Draw radial lines $1D$ and $2D$. Make EC equal to DE , and draw radial lines from C through points 1_1 and 2_1 to meet the first radial lines. Two points, 1^1 and 2^1 , on the true curve are thus obtained.

The problem now is to draw a series of tangential arcs through $D2^11^1A$. Bisect 2^1D by a line; the intersection H of the bisector, with the centre line, gives the centre from which the portion 2^1D of the curve is struck.

Join 2^1H . Bisect 1^12^1 . Then the intersection I of the bisector with 2^1H is the second centre, from which arc 2^11^1 is described.

A slight difficulty occurs with the third and last centre. Join 1^1I , and the point j , where this line cuts AE , is approximately the third centre. This centre may be adjusted a little from j , so that the curve joins the jamb and the arc 1^12^1 with the best effect. If desired, this last centre may be geometrically obtained more accurately as follows. With I as centre and $I1^1$ as radius, describe the arc 1^1K , so that it cuts a horizontal line IK . Join KA and produce to cut the arc at L . The intersection M of LI with AE gives the centre required.

The right-hand half of the curve can be easily

required, as there are three different shapes of arch stones (voussoirs). If a more accurate arch were required, the same geometrical prin-

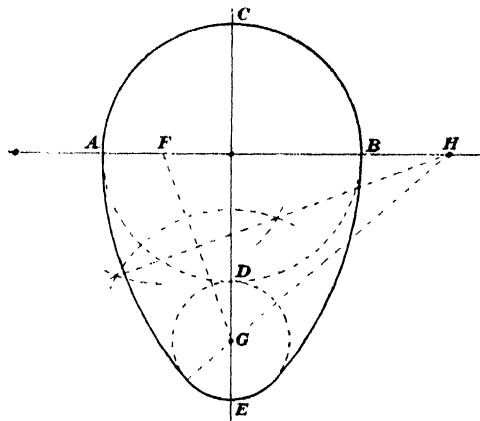


FIG. 60. CONSTRUCTING AN OVAL

ciples could be adapted to give an arch struck from seven or more centres.

OVAL. The word *oval* is often used as being the same as ellipse; thus, a carpenter speaks of oval wire nails, when the nails are really elliptical in section. Oval means egg shaped; that is, an oval is narrower at one end than at the other, whereas an ellipse is symmetrical about its minor axis.

Fig. 60 shows the method of drawing an oval when the width and length are given. Describe a circle on the width AB . The vertical diameter of the circle is CD . Make CE equal to the large diameter given. Draw a semicircle on DE . We have thus got the curves of the top and bottom of the oval, and tangential connecting arcs are now required.

Mark off AF equal to the radius DG of the smaller circle. Bisect GF . The point H where the bisector cuts AB produced is the centre of the connecting arc. With H as centre and HA as radius describe the arc. This arc will join the smaller circle on HG produced.

Tudor Arch. The method of drawing a Tudor, or four-centred, arch when the span only is given is shown in Fig. 61. Divide the span into four equal parts; draw two tangential circles

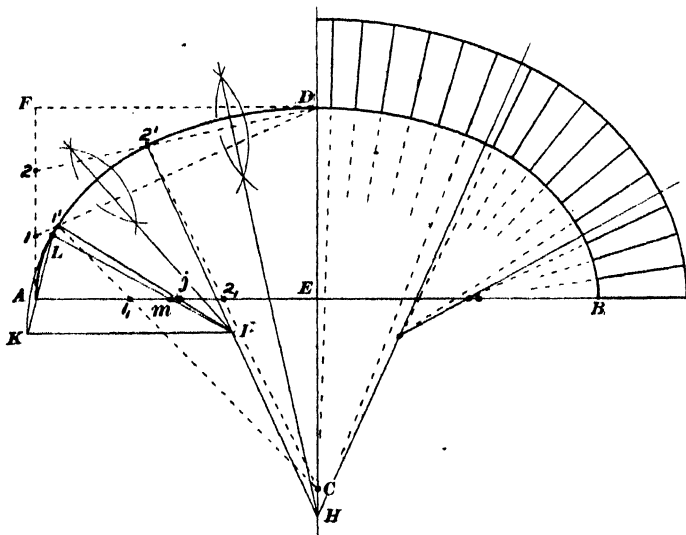


FIG. 59. APPROXIMATE ELLIPTICAL ARCH, USING THREE TEMPLATES

duplicated. The extrados curve is struck from the same centres as the soffit curve.

In order to make this five-centred arch from shaped bricks or stones three templates would be

with centres on the springing; and construct a square below the middle half of the span. Draw the diagonal AB , and produce to cut the small circle at C . With A as centre and AC as radius draw the arc CD . Finish the drawing as shown.

Gothic Arches. Three types of Gothic, or pointed, arches are given in Fig. 62. Assume that the span AB and rise CD are given (top diagram). Join A to D , and bisect AD by a line at right angles to it. This bisector cuts the springing line at E , from which centre the arch

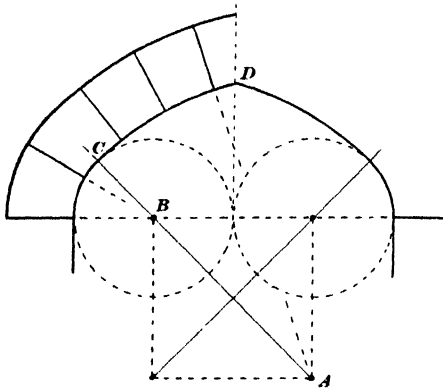


FIG. 61. DRAWING TUDOR ARCH

curves are struck. When this centre falls outside the span, the arch is said to be an *acute*, or *lancet*, arch.

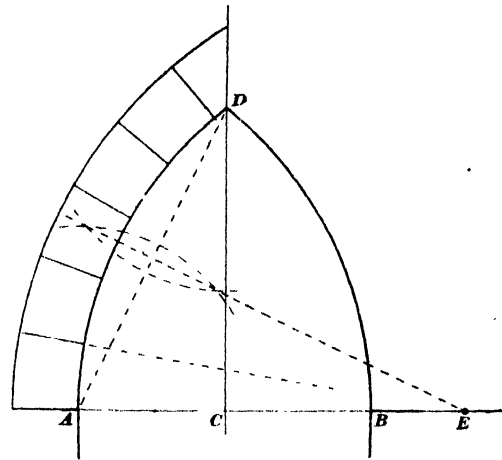
If the arch curves are struck from the extremities of the span, an *equilateral* arch results, so called because the springing points and the apex form the corners of an equilateral triangle.

When the centres are within the span the arch is called a *drop* arch. Notice that in this type the joints between the voussoirs may, if preferred, converge to the centre of the span; both methods are shown in the drawing.

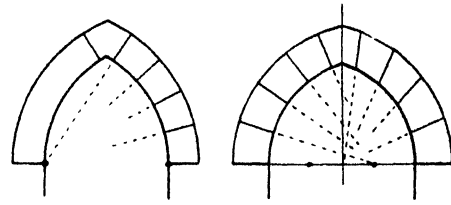
Ogee Arch. Let the span be AB , Fig. 63, and let the rise be CD . With C as centre, describe a semicircle on the span. Joint AD , cutting the semicircle in E . Draw from C through E to meet a horizontal line drawn through D , thus giving point F . With F as centre, and FD as radius, draw the arc DE .

Parabolic Arch. The method of drawing a parabola is shown at the left-hand side of Fig. 64, the two half parabolas shown forming an arch. Let AB be the axis and assume that the curve has to pass through point C . Complete the

rectangle $ABCD$. Divide AD into a number of equal parts, and draw lines parallel to the axis through the division points. Divide CD into



LANCET ARCH



EQUILATERAL ARCH

DROP ARCH

FIG. 62. THREE TYPES OF GOTHIC ARCHES

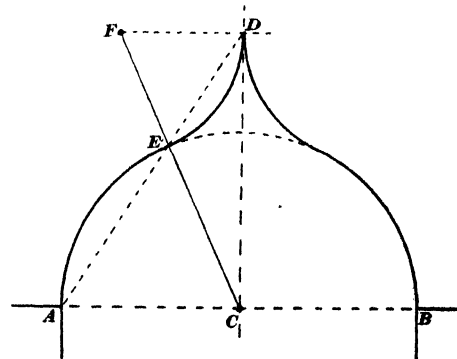


FIG. 63. OGEE ARCH

the same number of equal parts, and draw radial lines to point A . Three intermediate points on the parabolic curve are thus obtained, and the curve is then drawn freehand.

TANGENT AND NORMAL TO PARABOLA. Let it be

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required to draw a tangent and normal through the point *E*, Fig. 64. Let fall a perpendicular *EF* from *E* to the axis *GB*. Make *GH* equal

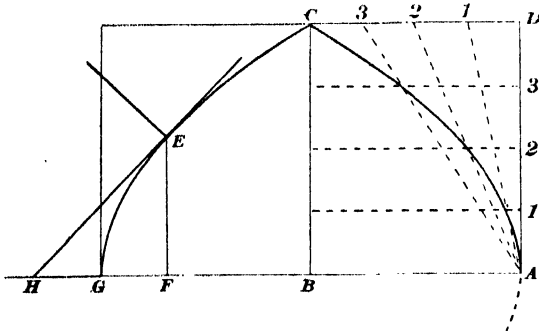


FIG. 64. DRAWING PARABOLIC ARCH

to *GF*. Then a line from *H* passing through *E* is tangential to the curve.

A line at right angles to the tangent from *E* gives the normal at that point. This construction could be repeated to determine the joint lines of a parabolic arch.

LOCI

Locus of a Point. The *locus* of a point means the *path* described by the point as it is moved ; thus, an ellipse is the locus of a point which moves so that the sum of its distances from two fixed points (called the *foci* of the ellipse) is constant.

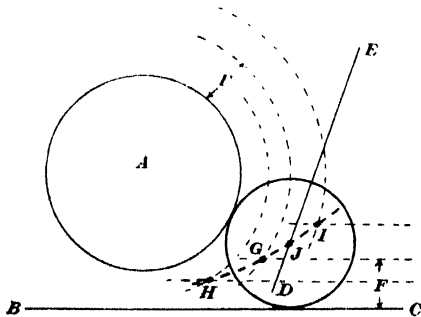


FIG. 65. USE OF LOCUS TO SOLVE A PROBLEM

Fig. 65 shows a circle, centre *A*, a line *BC*, and another line *DE*. Suppose it is required to draw a circle having its centre on *DE* and touching *BC* and the given circle.

Draw a line parallel to *BC* and an arc concentric with the given circle, the distances *F* being equal. The point *G*, where the arc and line intersect, is obviously equidistant from the given line and the given circle, and a circle could be drawn with this point as centre to touch the given circle and line.

Obtain other points, as *H* and *I*, in a similar manner. Then a line drawn through these points is the locus of a point that moves, so that it is always equidistant from circle *A* and line *BC*. The locus cuts the line *DE* at *J*, and this is the centre from which the required circle can be drawn.

A practical problem where a locus is required is shown in Fig. 66, where a circle has to be

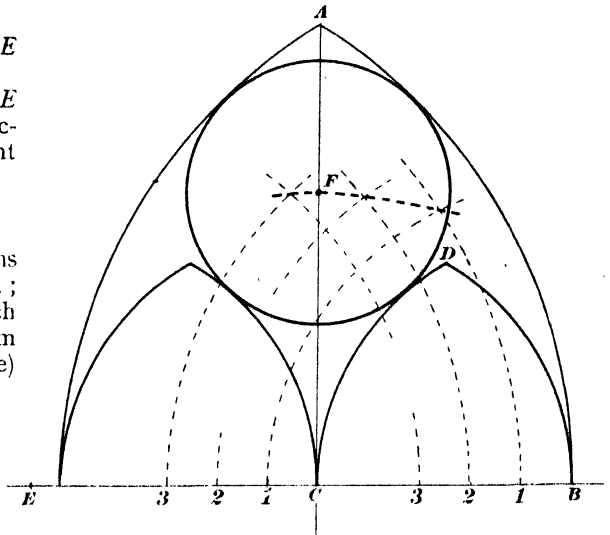


FIG. 66. USE OF LOCUS IN DRAWING TRACERY WINDOW

fitted into a tracery window, so that it is underneath the large Gothic head and over the two small lights.

It is obvious that the required circle will have its centre on the centre line of the window, and that the centre will also be equidistant from the arcs *AB* (centre *E*) and *CD* (centre *B*). Draw a locus, as shown, through points equidistant from these two arcs. The locus cuts the centre line at *E*, the centre of the circle required.

Chapter IV—MOULDINGS

THE geometrical methods of drawing a number of the common mouldings used in building work are shown in Figs. 67-91. *Roman* mouldings are usually made up of arcs of circles, but *Grecian* mouldings are often made up of elliptic or parabolic curves.

of a circle, as in Fig. 72 ; or it may be composed of a quarter of an ellipse, arranged either as in Fig. 73 or as in Fig. 74.

OVOLO AND ECHINUS. The ovolo moulding in Fig. 75 is a quadrant of a circle. The echinus moulding, shown in Fig. 76, is somewhat similar to an ovolo, and is often used at the top of

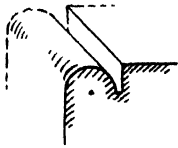


FIG. 67 BEAD

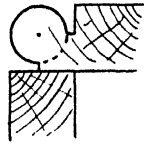


FIG. 68 RETURN BEAD



FIG. 69. REEDING



FIG. 70. FLUTING



FIG. 71. FLUTING TO COLUMN

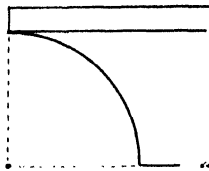


FIG. 72. CAVETTO

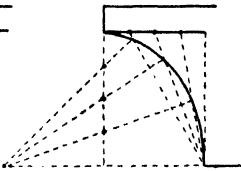


FIG. 73. CAVETTO, ELLIPTICAL

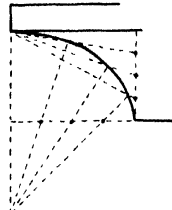


FIG. 74. CAVETTO, ELLIPTICAL

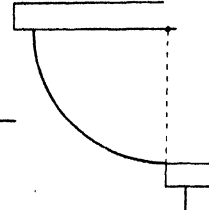


FIG. 75 OVOLO

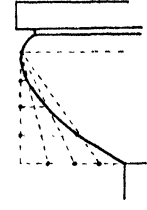


FIG. 76. ECHINUS, PARABOLIC

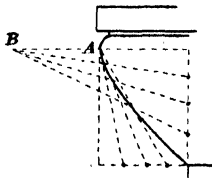


FIG. 77. ECHINUS, HYPERBOLIC

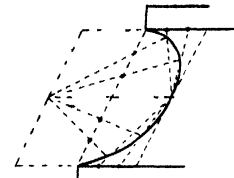


FIG. 78. SCOTIA, ELLIPTICAL

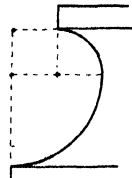


FIG. 79. SCOTIA

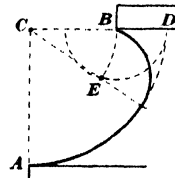


FIG. 80. SCOTIA

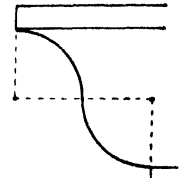


FIG. 81. OGEE (CYMA RECTA)

GEOMETRICAL CONSTRUCTION OF MOULDINGS

moulding is simply a semicircle in section, as shown in Fig. 67. The *return bead* is three-quarters of a circle, Fig. 68. *Reeding*, Fig. 69, consists of a number of semicircles separated by small quirks, or fillets. *Fluting*, Fig. 70, is the reverse of reeding. The fluting to the column in Fig. 71 consists of half (approximate) ellipses struck from three centres.

CAVETTO. This is a moulding having a concave curve, which may be formed of either a quadrant

of a circle, as in Fig. 72 ; or it may be composed of a quarter of an ellipse, arranged either as in Fig. 73 or as in Fig. 74. The curve may be either parabolic, Fig. 76, or hyperbolic, Fig. 77. In the latter case, the points on the curve are obtained by two sets of radial lines. The distance *AB* can be made any convenient length ; the position of point *B* determines the character of the curve.

SCOTIA. A scotia is a concave moulding and may be in the form of a simple inverted cavetto ; see Fig. 72. An undercut scotia, made of a half

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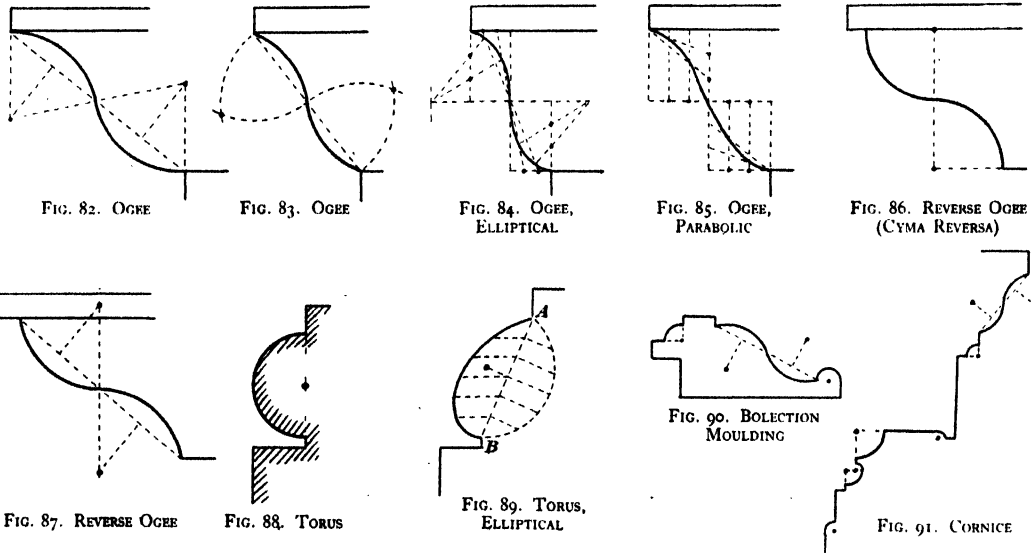
ellipse, is shown in Fig. 78. The simple undercut type, shown in Fig. 79, is made up of two quadrants.

The general construction for a scotia, to be drawn between two points *A* and *B*, is shown in Fig. 80. A vertical line from *A*, and a horizontal line from *B*, locate the centre *C* of the lower curve. With *C* as centre and *CA* as radius, describe the quadrant *AD*. With *B* as centre and *BD* as radius, draw the dotted semi-

circle at right angles to *AB*. The horizontal ordinates shown are then drawn equal in length to the first ordinates, thus locating points on the curve. This method of drawing elliptic curves can be applied to other elliptic mouldings.

A *bolection* moulding as used for panelled framing is shown in Fig. 90, and Fig. 91 shows the section of a cornice. The centres of the curves are indicated.

In drawing curves made up of tangential arcs,



GEOMETRICAL CONSTRUCTION OF MOULDINGS

circle shown. With *C* as centre and *CB* as radius, draw an arc from *B*, cutting the dotted notice that the point of junction always lies on semicircle in *E*. Then *E* is the centre from which the remainder of the scotia is struck.

OGEE. The ogee, or *cyma recta*, moulding is shown in its simplest form in Fig. 81, where it is composed of two quadrants. Two other methods for use where the width is greater than the height, Fig. 82, and where the width is less than the height, Fig. 83, are also given. Fig. 84 is an elliptical ogee, and Fig. 85 is a parabolic ogee.

Two methods of drawing a reverse ogee, or *cyma reversa*, are shown in Figs. 86 and 87.

OTHER MOULDINGS. Two examples of *torus* mouldings, suitable for the top edge of skirting boards, etc., are shown in Figs. 88 and 89. In drawing the latter, which is elliptical, an arc is first described on *AB*, and ordinates are drawn

the line joining the centres from which the arcs are struck.

ENLARGING AND REDUCING MOULDINGS

The obvious method of enlarging a figure is simply to draw the new figure by increasing the lines in the required proportion. Thus, if the small moulding, *A*, Fig. 92, has to be enlarged to twice its size, *OB* would be made twice the size of *Ob*, and the other sides enlarged in the same proportion.

If, however, after drawing the large moulding, radial lines as shown dotted are drawn, it will be found that corresponding radial lines in the two figures bear the same proportion to each other as the sides of the two mouldings; thus *Oc* is half *OC*. Points on the curve can also be plotted in this way; thus, *OD* is twice *Od*. This is called the *radial method* of enlarging or reducing figures.

Fig. 93 shows how to draw a moulding two-thirds the size of a given moulding. Draw radial lines from each corner of the figure to any point O . Take any radial line as OA , and divide it so that Oa is two-thirds its length. From a draw ab parallel to AB , and complete

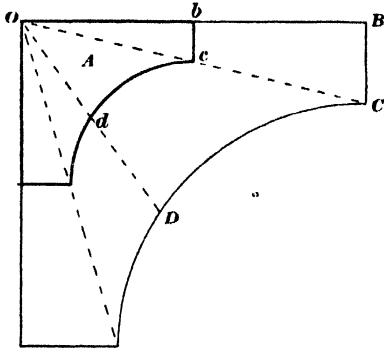


FIG. 92. ENLARGING A FIGURE

the figure by drawing all the lines of the required figure parallel to the corresponding lines of the given figure. Note that the extremities of the curves, or even points on the curves themselves, can be obtained by drawing lines as shown dotted.

A variation of the method is to set off two-thirds of each projector, and join up the points.

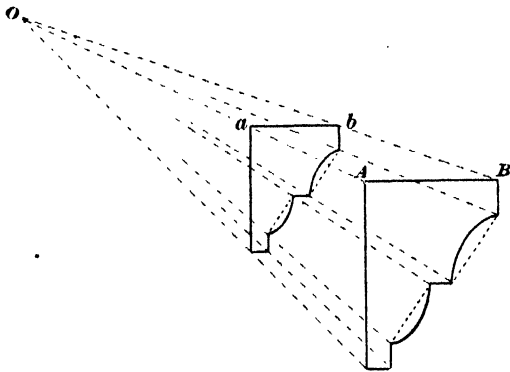


FIG. 93. REDUCING A MOULDING

Reducing in One Direction. It is sometimes required to reduce a figure in one direction only. Thus, Fig. 94 gives a bracket as often used on the sides of cut strings in staircases. Where the string winds round the turn at the

end of a well, the ends of the steps become less, though maintaining the same rise, and the brackets must be compressed, as it were, in length, while the vertical dimensions remain the same. A number of vertical lines, or ordinates, are drawn on the given bracket from points

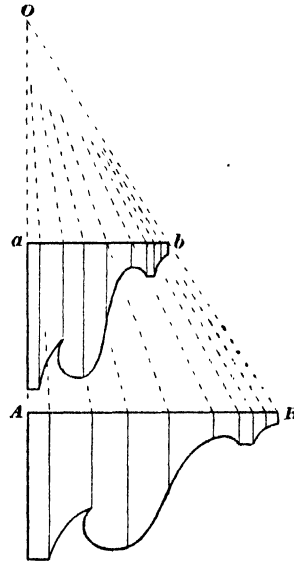


FIG. 94. DIMINISHED STAIR BRACKET

on its curve; draw radial lines to any point O from the top points of these lines, and draw a line ab , equal to the required compressed length of the bracket, between the extreme radial lines and parallel to AB . Drop ordinates from the points where the radial lines cut ab , and make these ordinates equal to those on the original bracket.

Join the lower ends of the ordinates to give the required diminished bracket.

Linear, Superficial, and Cubic Sizes. There is much confusion about the relative sizes of objects. The following is a useful theorem to remember: *The surface areas and volumes of similar figures are respectively proportional to the squares and cubes of their linear dimensions.*

The truth of this theorem can be easily seen by comparing two cubes, one of 1 in. side and the other of 2 in. side. The second cube is obviously twice the linear size of the first; each surface of big cube is clearly four times the area of a side of the small cube; and eight of the little cubes would make up the volume of the big cube.

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To take a practical example, suppose there are two boxes, not necessarily cubes, but of any shape, yet similar in shape, and let one edge of one box be 2 ft. long and the corresponding edge of the other box 6 ft. long; that is, one box is three times the linear size of the other box.

Then the amount of paint required for the large box, as compared with the small box, will be—

$$6^3 : 2^3 = 36 : 4 = 9 : 1$$

That is, one box requires nine times as much paint as the other.

The timber required will be in the proportion of—

$$6^3 : 2^3 = 216 : 8 = 27 : 1$$

That is, the large box requires twenty-seven times as much timber to make it as the small one.

SPIRAL CURVES

Scrolls and Volutes. The forms of spiral curves mostly used in builder's work are *scrolls* and *volute*s. These curves are made up of circular arcs described about an *eye*, or *evolute*. Fig. 95 shows a spiral having a triangular eye. Produce the sides as shown by dotted lines. With point 1 as centre and radius 13, describe the arc 3A in the exterior angle of the triangle. With 2 as centre and 2A as radius, draw a second arc. The third arc is drawn with 3 as centre; and so on with points 1, 2, 3 again as centres.

It will be seen that this spiral is the same as would be described by the end, 3, of a piece of string wrapped round the triangle and then unwound. The small triangle is said to be the evolute of the spiral. This evolute is the figure containing the centres from which the spiral curve is struck; that is, it is the locus of the centres. Conversely, the spiral is often termed the *involute* of the locus of the centres; that is, it is the curve described by the end of a piece of string unwound from the eye.

The eye can be any kind of polygon, but it is usually a square, as shown in Fig. 96.

Another kind of eye is shown in Fig. 97, and is itself in the form of a spiral. Note that the lines *ab* and *cd* are at right angles, but are not inclined at 45°.

Curtail Step. Fig. 98 shows a method of

drawing a curtail step as the bottom of a flight of stairs. The tread is divided into eight equal parts, and the eye is a square drawn on one of these parts. The spiral end consists of three arcs, joining tangentially, and described consecutively from points 1, 2, and 3 as centres.

Handrail Scroll. This construction, Fig. 99, is based on the method given in Fig. 97. Various proportions can be adopted for the distances *ab*, *bc*, *cd*, and *de*. In the drawing the proportions are 1 : 2½ : ¾ : ½, and these proportions give a pleasing scroll. Points *c* and *e* are joined, and the other axis is drawn from *d* at right angles to *ce*. The evolute is then continued from *e* by drawing vertical and horizontal lines, to cut the axes of the evolute.

Note that the outer curve requires seven centres, but that the inner curve joins the outer curve when describing the arc from the third centre *e*.

Ionic Volute. There are several methods of drawing this volute, which forms part of the capital of the Ionic column, but perhaps the best known is Goldman's method, which is shown in Fig. 100. The largest diameter *ab* is known as the *cathetus*, and is nine times the radius *ac* of the eye, and also nine times the width *bd* of the fillet.

Draw the square 1, 2, 3, 4 as shown, the sides being equal to *ac*; this square is shown enlarged at the right-hand side. Connect *a* to 2 and 3. Trisect *a1* in points 5 and 9, and describe the two small concentric squares shown, thus giving twelve centres.

Begin with centre 1, and describe arc *b1*¹, meeting 12 produced. With 2 as centre and 21¹ as radius, draw arc 1¹2¹. Similarly, use 3 and 4 as centres, and then 5, 6, 7, and 8 as centres; continue with 9, 10, 11, and 12 as centres. If accurately drawn, the last arc with 12 as centre should join on to the eye.

The inner curve for the fillet should now be described. Draw *be* at right angles to *bc* and equal to *a1*. Join *e* to *c*. Draw a line from *d* at right angles to *bc*, intersecting *ec* in *f*. Set off length *df* on each side of *a*, thus giving points *f*¹. Trisect *af*¹ and draw the concentric dotted squares. The twelve centres for the fillet are thus obtained. Begin with centre *f*¹ and proceed as for the outer curve.

Great care is needed to draw this volute accurately. Note that the eye is one-eighth the total height of the volute, and is placed on the fifth division from the top.

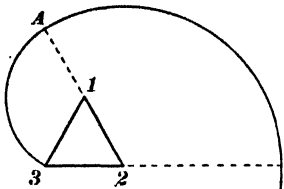


FIG. 95. SPIRAL HAVING TRIANGULAR EVOLUTE

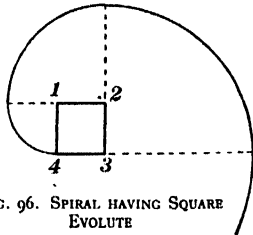


FIG. 96. SPIRAL HAVING SQUARE EVOLUTE

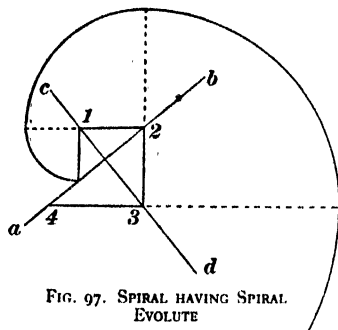


FIG. 97. SPIRAL HAVING SPIRAL EVOLUTE

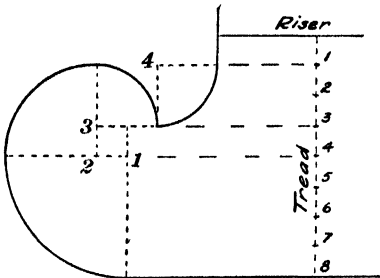


FIG. 98. CURTAIL STEP

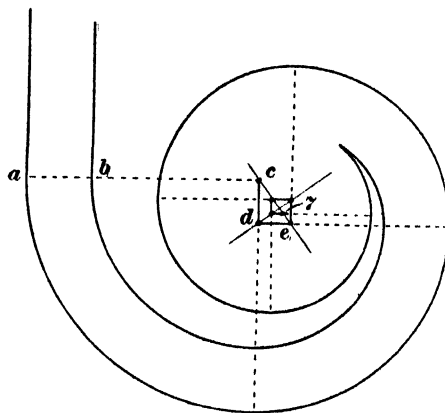


FIG. 99. HANDRAIL SCROLL

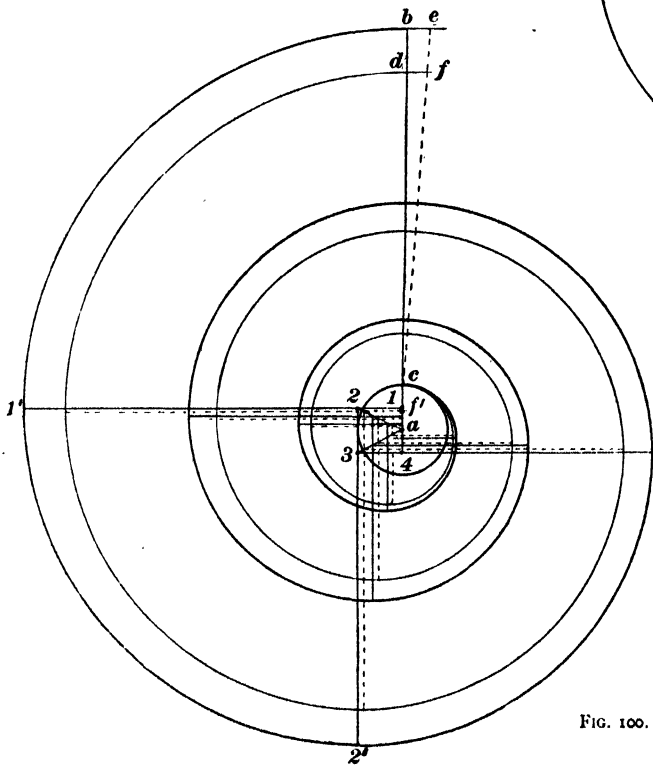
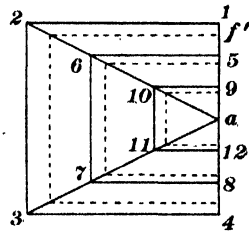


FIG. 100. IONIC VOLUTE



SPIRAL CURVES

Chapter V—SOLID GEOMETRY

ORTHOGRAPHIC PROJECTION

Plan and Elevation. The ordinary kind of technical drawing is *orthographic* projection, meaning *right-angled* projection, and is simply the usual

All solid objects have three dimensions, which are usually termed length, width, and thickness; in the case of a house the three dimensions are, however, spoken of as the length, width (or

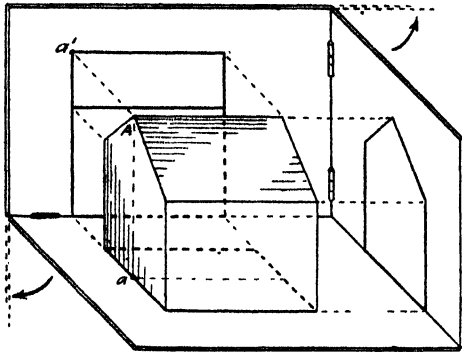


FIG. 101. METHOD OF OBTAINING PROJECTIONS

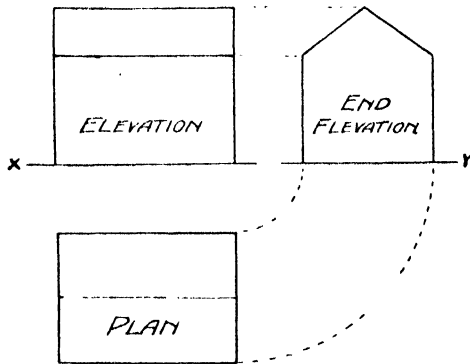


FIG. 102. PROJECTIONS OF HOUSE

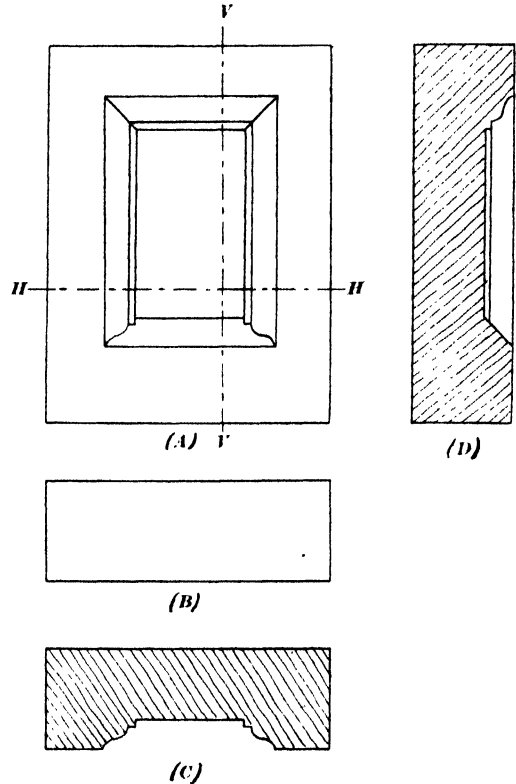


FIG. 103. VARIOUS VIEWS OF A PANELLED BLOCK

method of drawing by means of plans and elevations.

Fig. 101 shows how plans and elevations are projected. A *plan* is a kind of bird's-eye view; more strictly it is a view obtained by projecting the object on to a horizontal plane. (A *plane* is any flat surface.)

An *elevation* is the view as seen from the front, or as projected on to the vertical plane.

The projectors, or imaginary lines, joining the object to its project are *always at right angles to the plane of projection.*

depth), and height. The elevation of the small house given in Fig. 101 only shows the length and height of the house, and another view, as either the plan or the end elevation, is required to give the width. It is thus clear that two projections are required to show the dimensions and shape of a solid object.

Ground Line. The junction of the planes of projection is called the *ground line*, and is usually marked with the letters *X Y*. When the required views have been projected on to the planes, the planes are supposed to be hinged, as shown, and

rotated backwards until they all lie flat. The views will thus be as shown in Fig. 102. It will be noticed that all the projectors are at right angles to XY .

LETTERING. It is customary in solid geometry to adopt a certain system of lettering. Thus the actual point in Fig. 101 is given by the capital letter A ; the plan is shown by a small italic letter a ; and the elevation by a small italic letter with a dash at the top, as a' .

Sections. When the internal parts of an object

out, and this setting out usually consists merely of two full-size sections of the article to be made.

PROJECTIONS OF LINES

In order to understand the application of solid geometry to practical problems, it is first advisable to consider the solid geometry of lines and planes without any relation to practical work.

Fig. 104 is a pictorial view showing a number of lines differently situated with regard to the horizontal and vertical planes of projection; the

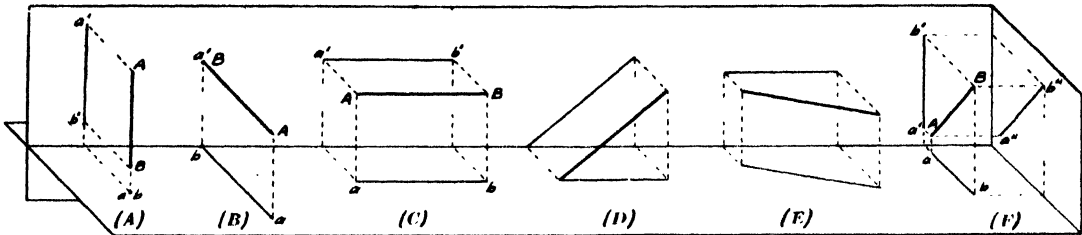


FIG. 104. METHOD OF PROJECTING PLANS AND ELEVATIONS OF LINES

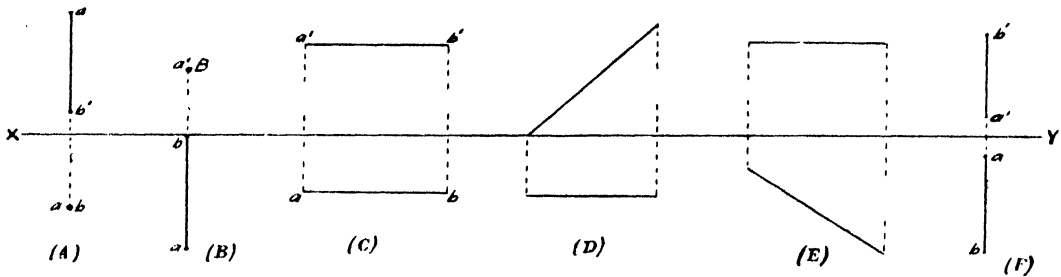


FIG. 105. PLANS AND ELEVATIONS OF LINES SHOWN IN FIG. 101

require to be shown, the object is imagined to be cut through, and the cut surface thus exposed is termed a *section*. Thus, in Fig. 103, the elevation (A) and plan (B) of a panelled block of stone, or wood, are shown. These views give the length, width, and thickness of the stone, but the depth of the panel and the shape of the mouldings, cannot be shown without a section. The block is, therefore, assumed to be cut through horizontally by a plane HH , the upper portion of the block removed, and the cut portion exposed, as shown at (C). Similarly, a vertical section on VV is shown at (D). From these two views, all the measurements of the block can be obtained. In view (D), the edges of the moulding in the distance are shown, and this view is, therefore, part edge elevation and part section, and is known as a *sectional elevation*.

Joiners' work before being made is usually set

plans and elevations of these lines are shown in Fig. 105.

At (A) is shown a vertical line. Its plan is a point, and its elevation is a vertical line equal in length to the actual line.

In (B) the line is horizontal and at right angles to the vertical plane; its true length is given in plan.

The true length of the line in (C) is given in both plan and elevation.

In (D) the line is parallel to the vertical plane, but inclined to the horizontal plane. The elevation gives the true length of the line, but the plan length is shorter than the actual line. Similarly, in (E), the elevation is shorter than the actual length, because the line is inclined to the vertical plane.

The line in (F) is inclined to both planes of projection, and therefore the plan and the elevation are each shorter than the line; but as

MODERN BUILDING CONSTRUCTION

this line is parallel to the end vertical plane, its projection thereon will exhibit its true length.

True Length of Oblique Line. The lines so far dealt with have been parallel to one or other of the planes of projection, and therefore their true length and inclinations can be obtained directly from plan or elevation. In Fig. 106, however, is shown the pictorial view of a line inclined to both the horizontal and vertical planes, and the projections do not give either the true length or the true inclination of the line. For example, the plan ab and the elevation $a'b'$ in Fig. 107 are shorter than the actual length of the line.

To find the *true length*, the line and its projectors are imagined to be hinged about the plan until the line lies flat on the horizontal plane. To show this construction on the drawing paper, draw lines at right angles to the plan ab , Fig. 107,

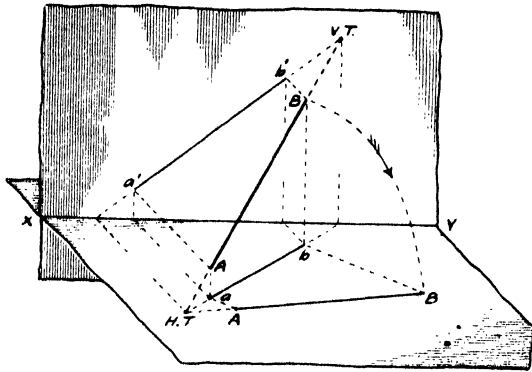


FIG. 106. PICTORIAL VIEW SHOWING METHOD OF OBTAINING TRUE LENGTH AND INCLINATION OF OBLIQUE LINE

and make these lines (projectors) equal in length to the heights of a' and b' above XY , thus giving points A and B . The length AB is then the true length of the line.

Another method is to revolve the line into the vertical plane, by drawing projectors at right angles to $a'b'$, and making them equal to the distances of the points below XY . If the true lengths as found by these two different methods are measured, they will be found to be equal.

Inclinations of Line. When a line is revolved into a plane of projection, as shown in Figs. 106 and 107, not only the true length is given, but also the *true inclination* of the line to that plane. Produce the plan to meet AB produced, and the angle between the lines is the inclination of the line to the horizontal plane. Similarly, the angle

between the elevation and the rabatment $A'B'$ of the line is the inclination of the line to the vertical plane.

Traces of Lines. The point where a line, or a

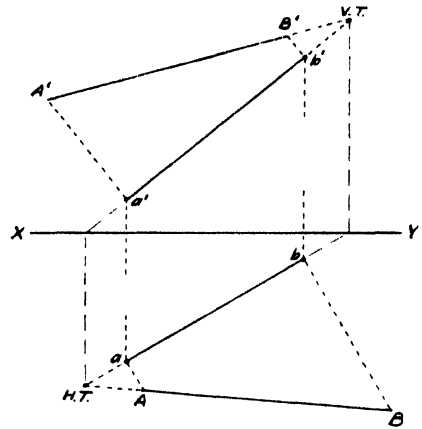


FIG. 107. OBTAINING TRUE LENGTH, ETC., OF LINE SHOWN IN FIG. 103

line produced, penetrates a plane is known as the *trace* of the line on that plane. Thus, in Figs. 106 and 107, HT is the horizontal trace, and VT is the vertical trace.

The problem just given is perhaps the most important in solid geometry. The student should

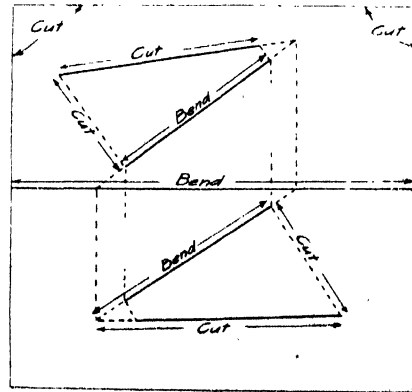


FIG. 108. MAKING PAPER MODEL

not only be able to draw it out—he must *understand* it. It is advisable to make a paper model as shown in Fig. 108.

This problem occurs in many building examples; for example, finding the length of a hip rafter.

Chapter VI—PLANES

FIG. 109 shows a number of planes placed in various positions regarding the H.P. and V.P. At (A) the plane is placed vertical. The line where it intersects the horizontal plane is

This true angle can, however, be obtained by assuming that a cone, with its axis in the V.P., fits under the plane so that the plane lies on the sloping surface. The base angle of this

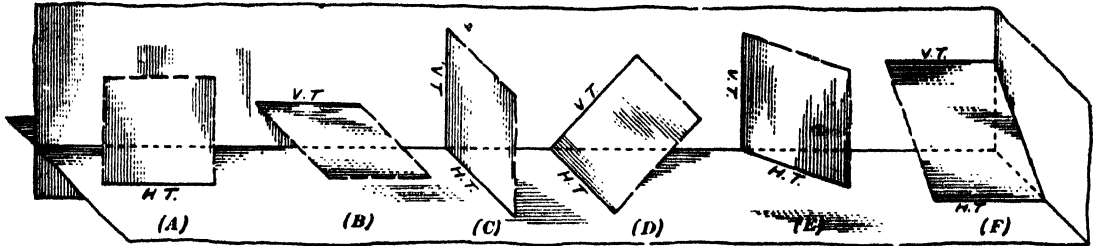


FIG. 109. PICTORIAL VIEW SHOWING TYPES OF PLANES

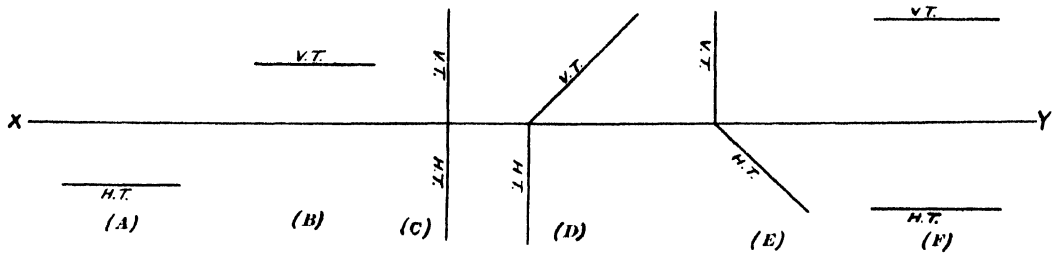


FIG. 110. PLANS AND ELEVATIONS OF PLANES SHOWN IN FIG. 109

known as its *horizontal trace*, or H.T. The plane (B) is horizontal and has only a *vertical trace*, V.T.

Plane (C) is perpendicular to both planes of projection and both traces are at right angles to *XY*. An inclined plane is shown at (D); the angle between V.T. and *XY* gives the inclination of the plane. Similarly, the angle between H.T. and *XY* of the vertical plane (E) gives the inclination to the vertical plane of projection.

The plane at (F) is inclined to both planes of projection, but its traces are parallel to *XY*; its inclination can be obtained from its trace on the end plane.

Oblique Plane. When a plane has both traces inclined to *XY* as shown in Fig. 111, the true inclination of the plane to the H.P. is *not* given by the angle between the V.T. and *XY*.

cone then gives the inclination of the plane to the H.P.

Let H.T. and V.T., Fig. 112, be the traces of a given plane of which the inclination to the H.P. is required. With compass point at any point *a* on *XY* draw a semicircle just touching H.T.; this is the base of the required cone. From *a* draw a vertical line *ab* to the V.T.; this vertical line is then the axis of the cone. Join *b* to an end *c* of the semicircle, and the angle *bca* is the required inclination of the oblique plane.

Inclination to V.P. The true inclination of an oblique plane to the V.P. is obtained by assuming the cone to have its base in the V.P., as in Fig. 113. Thus, in Fig. 114, draw the semicircle, *cc*, touching the V.T., and draw the axis *ab*. Join *bc*, and *bca* gives the true angle between the oblique plane and the V.P.

MODERN BUILDING CONSTRUCTION

Angle Between Traces. In finding the inclination to the H.P., Fig. 112, it is not usual to draw the whole semicircle, but to draw a line, as aC , at right angles to the H.T. and then turn this line to lie on XY . This modified construction of course gives the same results.

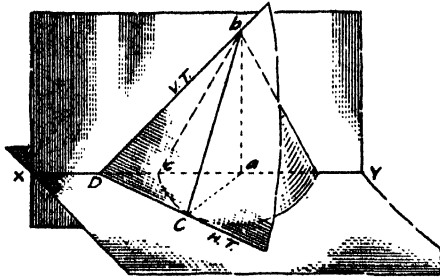


FIG. 111. SHOWING METHOD OF OBTAINING INCLINATION OF PLANE

If the oblique plane is considered to be hinged at its H.T. and revolved over into the H.P., the line Cb (which represents where the cone touches the underside of the oblique plane) will fall at right angles to H.T. as shown at CB . Join BD , and the angle CBD is the true angle between the traces. Note also that BD equals Db .

Fig. 112 should be cut out and folded into

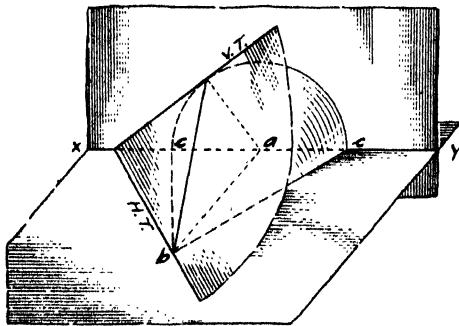


FIG. 113. SHOWING INCLINATION TO V.P.

position to make a small paper model as described in the previous chapter.

Intersection of Oblique Planes. Fig. 116 shows two oblique planes intersecting in a line AB . This intersection is shown in plan aB and elevation $A'b'$ in Fig. 115.

The true length and inclination to H.P. of

the intersection is obtained by hinging the triangle BaA about Ba until it falls flat in the H.P. To draw out this operation, draw aA' at right angles to aB and make it equal to aA . Join $A'B$, which gives the true length of the

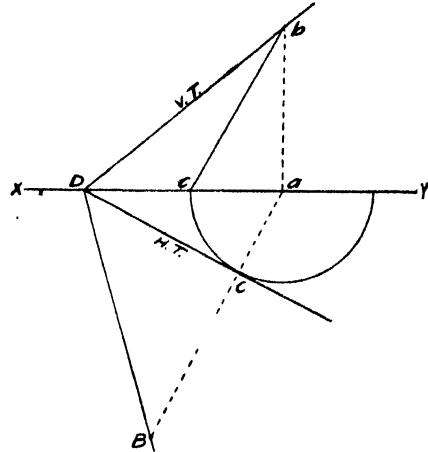


FIG. 112. OBTAINING INCLINATION OF PLANE SHOWN IN FIG. 111

intersection, and $A'Ba$ is the inclination of the intersection to the H.P. This problem is the same as finding the length and bevels of a hip rafter, and as already given in Fig. 106.

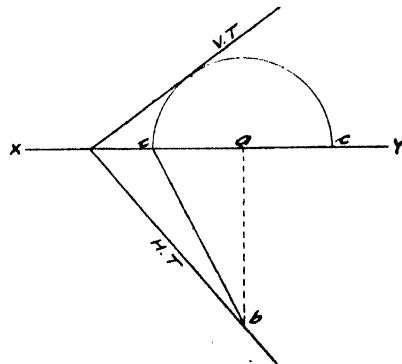


FIG. 114. OBTAINING INCLINATION TO VERTICAL PLANE

Dihedral Angle. The angle between two planes is known as a *dihedral angle*; it is the angle between two lines, one in each plane and at right angles to the intersection. This principle is shown applied in Fig. 116. Revolve the two oblique planes into H.P., as explained for Fig. 112; see also Fig. 115. Select two points

C and C' equidistant from B , and draw lines CD and $C'D'$ at right angles to the BA_1 and BA_2 , respectively. With D and D' as centres and DC , $D'C'$ as radii cut the plan of the intersection in point C_1 . Join C_1D and C_1D' ;

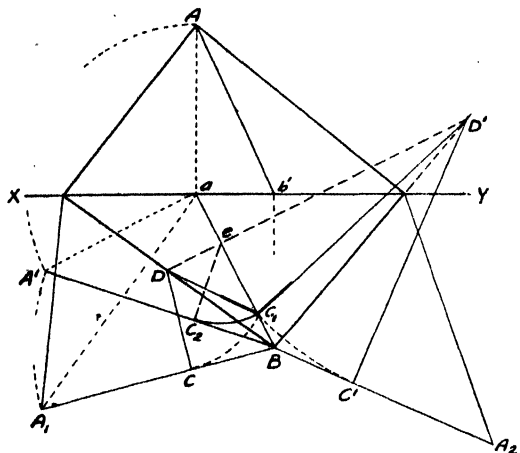


FIG. 115. INTERSECTION AND DIHEDRAL ANGLE BETWEEN TWO OBLIQUE PLANES

then the angle DC_1D' is the dihedral angle required. This dihedral angle is the angle required by a carpenter in bevelling, or backing, the top edge of a hip rafter; it is also the angle of the tiles required over the hip.

Another, and more usual, method of finding the dihedral angle is also shown in Fig. 115. The two oblique planes are cut through by a plane at right angles to the intersection. This plane will, in edge view, be a line ec_2 at right angles to the intersection, and intersects the H.P. in the line DD' . The latter line is considered as a hinge, and the triangle formed under the oblique planes is turned down into the H.P. This is done by describing the arc C_2c_1 with e as centre, and then joining DC_1 and C_1D' . In order to understand this important problem clearly, a paper model should be made, as already explained for other problems.

ROOF BEVELS

Roof bevels can be obtained geometrically, as will be now explained, or by means of the steel square. To understand thoroughly the use of the latter, however, a knowledge of the

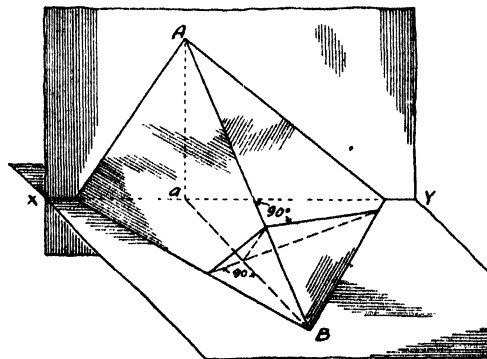


FIG. 116. METHOD OF OBTAINING DIHEDRAL ANGLE

geometrical methods is necessary. Some workmen obtain their lengths and bevels by various practical expedients, such as stringing lines and using measuring rods, but these methods are inefficient and out of date. If carpenters were expert mathematicians, perhaps the best method would be by the use of trigonometry; no drawing instruments would be required and

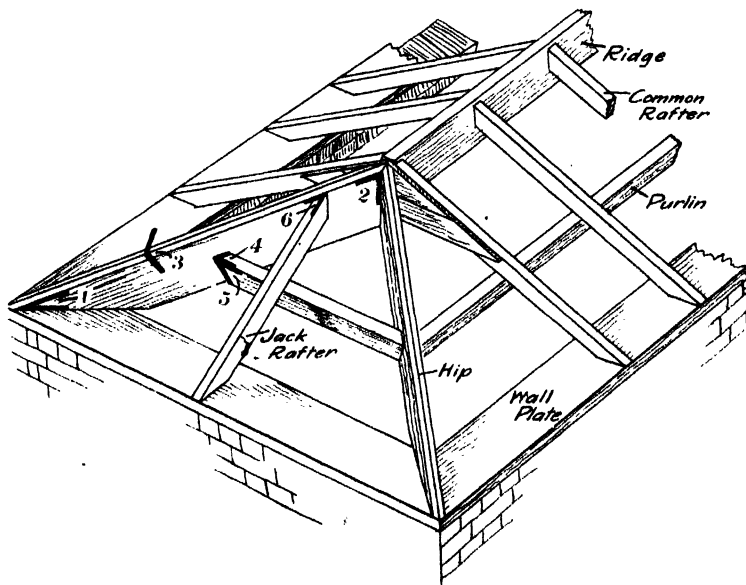


FIG. 117. SKETCH OF HIPPED ROOF (TIMBERS EXAGGERATED)

MODERN BUILDING CONSTRUCTION

the results would be very accurate. But even if this too abstruse method were used, a

common rafters are taken direct from the elevation. If the three surfaces have the same slope, the plans of the hips will bisect the angles between the walls.

Consider the hip to be hinged about its plan, until it lies level; thus, cC is made equal to the height of the ridge, and C is joined to B . Angle 1 is the foot cut, and BC is the true length of the hips.

Find the dihedral angle, that is, the backing angle for the top edge of the hip, as follows. Draw EF at right angles to Bc . Make GH_1 equal to GH , which is drawn at right angles to BC , and join H_1E and H_1F . Then EH_1F is the backing angle. (This construction was explained in connection with Fig. 115.)

Jack Rafters and Purlins.

Imagine one side of the roof to be hinged about the eaves line AA until it is in a level position. This gives the top bevel 6 for the jack rafters, and also for the edge cut for the top of the

hip. The side bevel for the jack rafters is the same as the top (plumb) bevel of the common rafters. Angle 4 is the top cut for the purlin.

The side cut 5 of the purlin is obtained by turning up the side of the purlin. Thus, the distance W is made equal to the width of the purlin, and kK is drawn at right angles to the plan lines of the purlin, when 5 gives the bevel required.

Applying the Bevels. In practice, hips are often not "backed," the hip being kept down the right amount, about $\frac{1}{2}$ in., so that the roof boarding or battens can be nailed to the outside top edges of the hips. But it is a better job to back the hips, as the backing gives a better seating for the boards or battens. In any case the method of obtaining the backing angle is usually required in order to find the internal angle of the hip tiles; if the tiles have a slightly less angle than the backing angle, all the better, for the hip tiles will then fit better where their edges bear on the slates, etc. Of course, the backing angle can be planed off the top edge of the hip before the top and bottom cuts are sawn, the backing angle EH_1F being applied

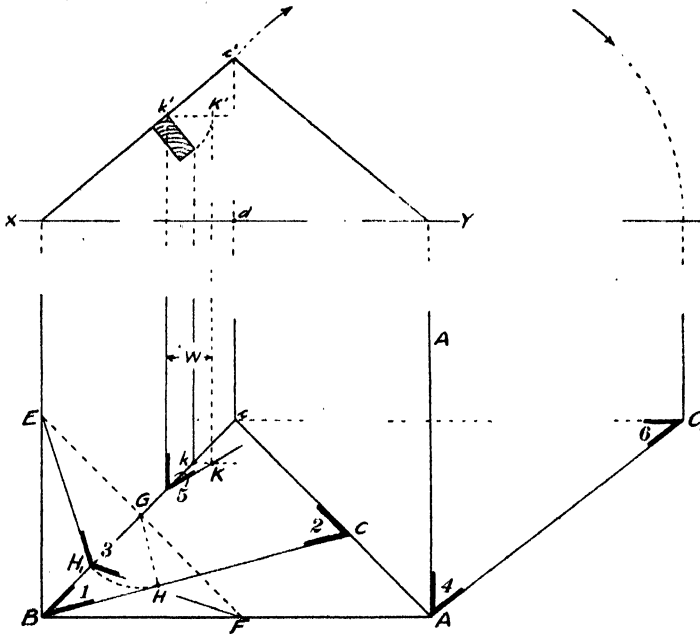


FIG. 118. BEVELS FOR HIPPED ROOF

knowledge of the solid geometry of roof bevels would still be required.

Fig. 117 shows a sketch of a hipped roof; the sizes of the timbers are exaggerated to show the joints clearly. There are various methods of forming the joints at the top and bottom of the hips and at the feet of the common rafters. But if the student can find the bevels for the construction shown, he can easily deal with any variations.

In erecting a hipped roof, the wall plates and ridge are first placed in position, together with a few common rafters to help to support the ridge. Then the *hips* are cut and erected. The *purlins* are cut and nailed to the hips, and the remaining rafters, including the short rafters butting against the hip and termed *jack rafters*, are fixed.

If the preceding problems have been understood, the methods of obtaining roof cuts and lengths should be easily grasped.

Hips. Fig. 118 shows the plan and elevation of a hipped roof. Note that the XY line represents the top of the wall plate, and that the hips and ridge are shown by their top centre lines. The top and bottom bevels of the

to the square end; or the dihedral angle can be tested from the side of the hip by setting a joiner's bevel to the angle BH_1F in Fig. 118.

But usually the hip is first cut to the length and bevels shown in Fig. 118. The top cut, like the bottom cut, is sawn square through the plank, and, for the top edge cuts, when they are as shown in Fig. 117, half the thickness of the hip is gauged down the sides of the hip from the sawn end, the two edge cuts then being sawn to these lines. Sometimes the hips are forked over the end of the ridge, in which case the gauging distances can be obtained from a plan of the junction.

If an angle tie is used to tie the wall plates together at the foot of the hip rafter, the latter being then notched over the tie, the shape of the notch can be obtained by drawing the tie in position in the triangle BcC , Fig. 118, because this triangle gives the true length and bevels of the hip. If a dragon piece is used at the foot of the hip, to connect the angle tie to the corner junction of the wall plates, its dimensions could also be obtained in the same manner.

Irregular Plans. Suppose $ABCD$, Fig. 119, is the plan of an irregular building that has to be covered with a hipped roof. If the four roof slopes all have the same inclination to the horizontal, then the plans of the hips will bisect the angles between the walls in plan. The hip plan lines meet at ef . This line could be taken as the plan of the ridge; but, if so, the ridge would be out of level, or the roofs $ABfe$ and $CDef$ would have to be twisted, and the slates would not lie flat. The usual method is to form a small lead flat, by drawing eg parallel to AB , gh parallel to BC , and he parallel to CD . Note that the triangular roof surface ADe must be a plane (out of twist) surface, because a plane can always be made to pass through three given points.

To understand this statement clearly, imagine any plane surface to be rotated about a line joining any two points in the plane; the plane could be stopped in its rotation by any point, not lying in the hinge line, and the three points referred to then fix the plane in position. If the plane is required to pass through four points, then the fourth point must obviously be specially placed to allow the plane to contain it.

There are really many ways of arranging the roof for irregular buildings of the type illustrated in Fig. 119: (1) as shown, using a lead flat, the

top and bottom of all roof planes being level; (2) using a sloping ridge as ef , the eaves all being level; (3) having a level ridge as plan ef , and twisting the front and back surfaces; (4) taking eh as the ridge and putting a hip at hB ; this would give the front surface as $BAeh$, which would be twisted; (5) as in (4) but putting a valley at eB ; (6) keeping a level ridge and having sloping eaves on two sides.

Fig. 119 also gives the true lengths and bevels of the hips, the backing angle for hip HC , and

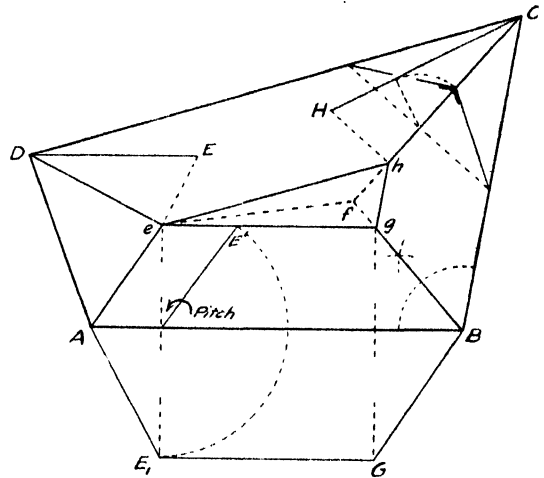


FIG. 119. ROOFING IRREGULAR PLAN

the true shape and bevels for jack rafters of the front slope.

Other Roofs. There are many other shapes of roof, depending on the plans of the buildings to be covered, but if the principles underlying the geometrical constructions given have been understood, these principles can be applied to any roof. The chief principle is to revolve any inclined plane or line until it lies horizontally, when its true shape will be seen. Thus, in the last example, the front roof surface is revolved about the line AB , the hip DE is revolved about its plan, and the triangle containing the dihedral angle at its apex is revolved about its base. The bevels for valley rafters, and the purlins and rafters supported by them, should also present no difficulty as valley rafters are similar from a geometrical point of view to hip rafters.

Roof bevels are also dealt with in the sections on "Carpentry" and "Roof Coverings."

Chapter VII—SECTIONS

Section of Prism. Fig. 120 shows the plan and elevation of a triangular prism, the ends being equilateral triangles. It should be observed that the height in elevation is not equal to the length ac , but equal to the perpendicular height bB of the triangular end.

Imagine the prism cut by a vertical plane as shown, and that it is required to determine the true shape of the section made by this plane. Draw $x'y'$ parallel to HT and project the section def as shown. Points d' and f' will be on $x'y'$,

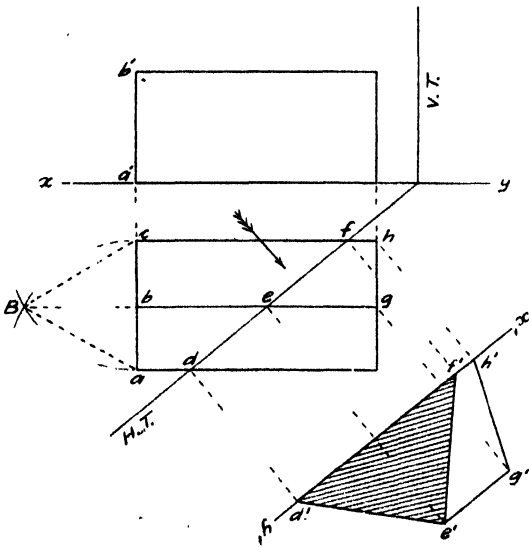


FIG. 120. PROJECTIONS OF TRIANGULAR PRISM

and e' will be the height of the prism above $x'y'$. The triangle $d'e'f'$ will then be the true shape of the section, because it is the projection of the section on a vertical plane placed parallel to the plane that cuts the prism.

If the points $g'h'$ are also projected as shown, a view of one portion of the prism, as seen in the direction of the arrow, is given; this combined view is termed a *sectional elevation*, because it gives the section and also the view of part of the prism.

Section of Cylinder. In Fig. 121 a cylinder is shown standing on one end. This cylinder is

cut by an inclined plane, of which the vertical trace VT only is given. To obtain the true shape of the section of the cylinder by this plane, draw projectors at right angles to VT . The true section will be an ellipse, of which $a'b'$ will give the length of the major axis, and the

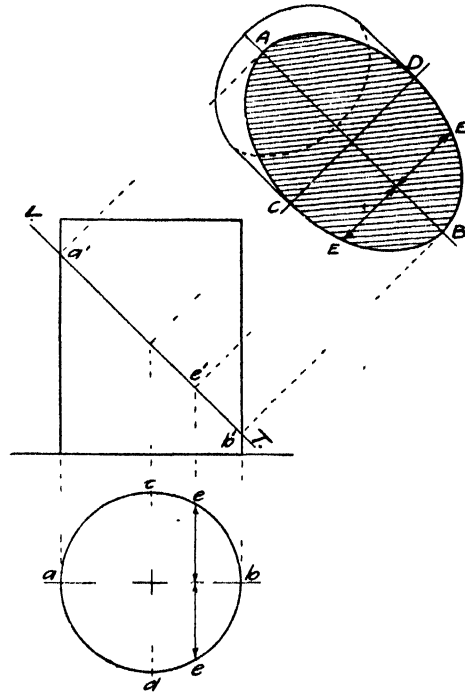


FIG. 121. PROJECTIONS OF CYLINDER

diameter cd of the cylinder will be the minor axis. Points A, B, C, D are thus located. Intermediate points can be obtained by selecting any point as e' on VT , and projecting down to obtain ee on plan. The length ee is then transferred to give EE ; note that the portions between arrows are equal to each other.

As the true section has been obtained by projecting from the given elevation, the section is a plan view looking obliquely upwards, and the complete view is a *sectional plan*. Note, therefore, that a sectional plan is projected from a given elevation, as in the last problem, and a

sectional elevation is projected from the given plan.

Conic Sections. The methods of drawing the conic sections by means of plane geometry

half slices drawn in elevation, as shown at $f'g'$. Note that the portions between arrows are equal.

The true section parallel to the generator can also be projected as done for the elliptical section; this section is a parabola. A hyperbolic section is also given.

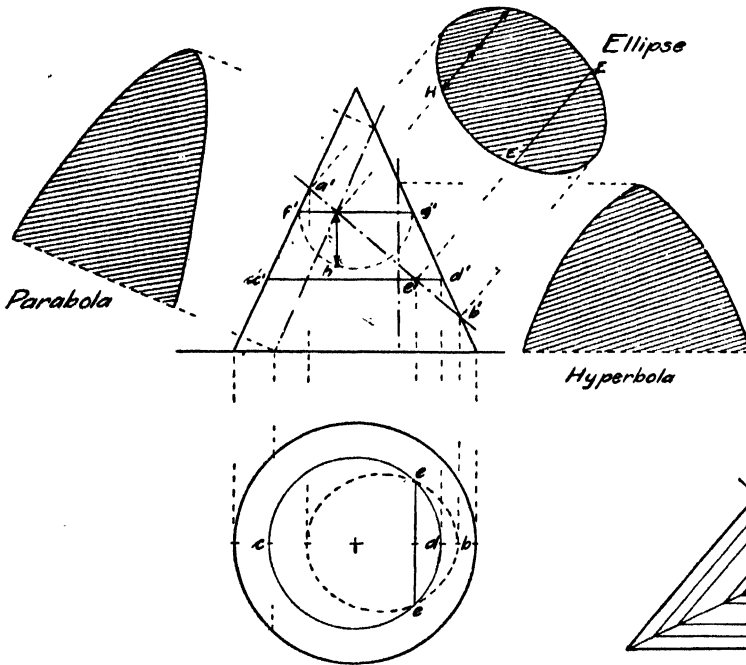


FIG. 122. PROJECTION OF CONIC SECTIONS

MOULDINGS

Mitres in Curved Mouldings. When a straight moulding meets a curved moulding of similar section,

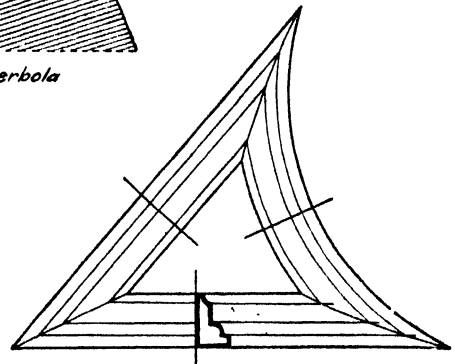


FIG. 123. OBTAINING SHAPES OF CARVED MITRE

have been already explained, so we will now consider them from the point of view of solid geometry, and project them from their section planes.

The horizontal section of a cone is obviously a circle, as the base of the cone, Fig. 122.

Let $a'b'$ be the vertical trace of an inclined plane cutting the cone. The section will be an ellipse. The plan of the section can be obtained by taking horizontal slices, as $c'd'$, of the cone. These slices will be circles in plan. The widths of the inclined section $a'b'$, and the horizontal slice $c'd'$, will be the same where the two sections cross at e' , and will be equal to ee . EE on the section is, therefore, made equal to ee . Other points on the true section could be obtained in a similar manner, and the curve drawn freehand through the points. The plan of the section is also an ellipse, and can be drawn, as shown dotted.

In drawing the true section, the plan of the cone could be dispensed with, and horizontal

a curved mitre results, as shown in Fig. 123. This type of mitre occurs when curved rails are used in panelled framing and doors. The shape of the mitre is obtained by simply drawing an elevation of the mouldings; the points where the arrises meet are located on the mitres.

Mouldings of Unequal Width. Suppose a moulding A , Fig. 124, has to be mitred to a moulding B of similar design, but smaller width. Draw the elevation of the moulding A and the mitre. From the points on the mitre, draw the arrises of the narrow moulding, and then make the corresponding parts of the section of the narrow moulding equal in thickness to those of the given section A ; thus the respective dimensions c and d are equal.

True Shapes of Mitres. Fig. 125 gives the elevation A and edge plan B of a piece of moulding. The moulding is cut at 45° in plan at C , and the elevation C' of this cut is the true section of the moulding. The true shape of the

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oblique cut is shown at *D*, and is obtained by revolving the cut end until it is parallel to the vertical plane.

The other end of the moulding is cut by a plane inclined at 45° , and the true shape of this cut end is shown at *E*; note that *t* is the thick-

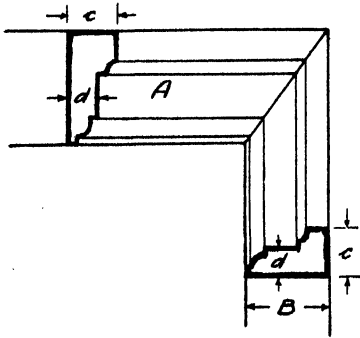


FIG. 124. MOULDINGS OF UNEQUAL WIDTH

ness of the moulding. The plan of this cut end can also be projected as shown at *F*.

Raking Mouldings Over Square Plan. Suppose a room has a sloping ceiling, and a cornice and picture moulding run round the room (see Fig. 126). If a projection, such as a pilaster or a chimney breast, occurs in the wall, the cornice or picture moulding down the sides of the projection should follow the pitch of the ceiling. These side mouldings are known as *raking mouldings*, and require to be of a different section to the level moulding, in order to give a correct mitred joint at the junctions.

Let *A*, Fig. 127, be the section of the level moulding, and assume the raking moulding to mitre into it is inclined at 30° .

Select a number of points on the given section and draw lines at 30° from the points. These lines then represent the raking moulding in

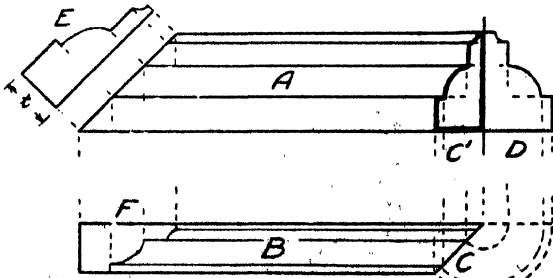


FIG. 125. TRUE SHAPES OF MITRES

elevation, and a cross-section of the moulding is required. Draw *AB* at right angles to the

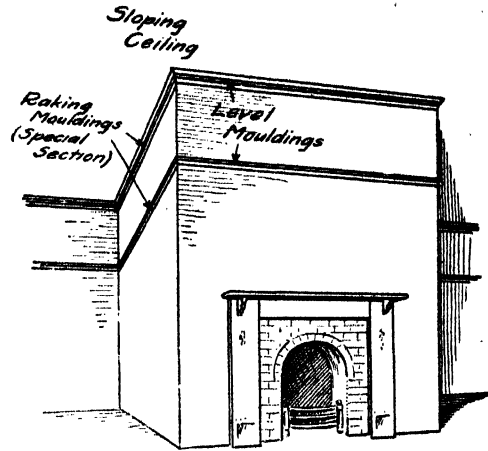


FIG. 126. EXAMPLE OF RAKING MOULDINGS

rake, and make the distances $o'1'$, $o'2'$, $o'3'$, etc., equal to the distance $o1$, $o2$, etc. Draw projectors from points $1'$, $2'$, etc., to meet the corresponding elevation lines. Points on the outline of the raking section are thus obtained, and when joined give the required section.

Sash Bars. In Fig. 128 is given the section of the moulded sash bars of a greenhouse. The glazed roof is made up of a number of sashes which fit into rebates in the sash bars, or rafters. These bars are required to mitre into a ridge.

Lines drawn at the correct pitch from points in the sash-bar section give the elevation of the sash bar, and the required section is completed

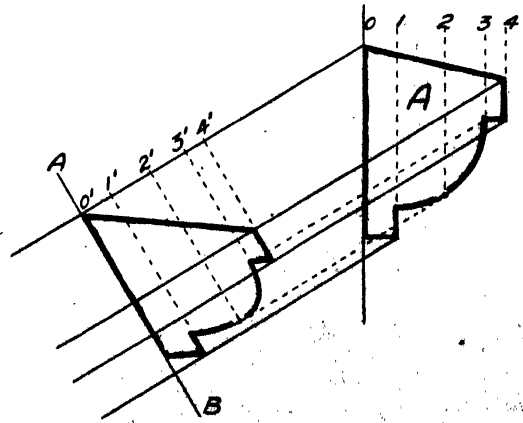


FIG. 127. OBTAINING SECTION OF RAKING MOULDING

after the manner described for the previous example.

Raking Moulding Over Obtuse Angle. A level moulding *A* has to mitre correctly into a raking moulding inclined at, say, 40° , the angle between the mouldings in plan being, say, 120° . In plan the mouldings are the same thickness, and the mitre bisects the angle between them. Draw lines from the selected points in the section to give the elevation *a'*, and draw these lines in

they might be either plaster or stone. If of wood, a length of raking moulding of the section obtained geometrically would be prepared either by hand or on a moulding machine. For the example shown in Fig. 129, the level moulding (ordinary section) would first be cut to the mitre line given in plan. The back of the raking moulding can then be marked to the bevel given in elevation, and cut as near as can be judged to the plan bevel; probably the raking

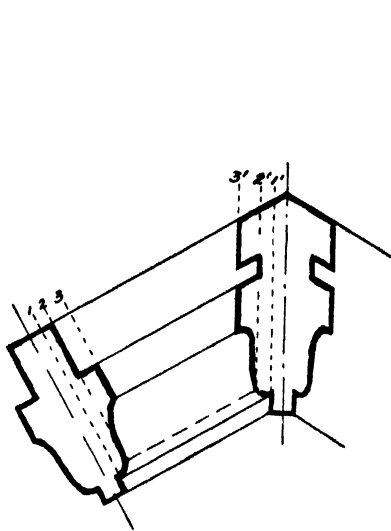


FIG. 128. OBTAINING RIDGE TO FIT SASH BAR

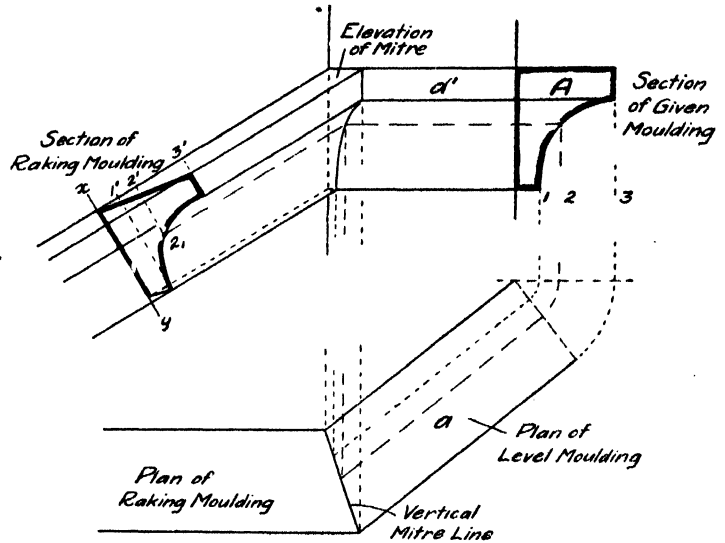


FIG. 129. RAKING Moulding OVER OBTUSE ANGLE

plan at *a*. From the point where the plan lines intersect the mitre, project upwards to meet the corresponding elevation lines. Points on the elevation of the mitre are thus located.

Draw lines in elevation to represent the raking moulding meeting this mitre. Obtain a section of the raking moulding, by drawing *xy* at right angles to the rake, and setting off the points *1'*, *2'*, *3'* equal to *1*, *2*, *3* at *A*. Complete the required section of the raking moulding by projecting from *1'*, *2'*, etc., to meet the elevation lines of the raking moulding and drawing through the points thus obtained. Note that more points, as *2₁*, on the curve could be located if required.

Practical Work. The raking mouldings illustrated would probably be made of wood, but

piece could be held up approximately in position to mark the bevels. An edge bevel, for applying to the upper edge of the raking piece, could be obtained geometrically, but this procedure is hardly worth the trouble.

If the raking moulding is of plaster, a length could be run on a plank and, when set, cut and jointed into position almost as if it were timber. Short lengths of plaster raking mouldings, say round a shallow chimney breast or pilaster, are often moulded in position, by using straight-edges and mitreing tools, between the two ends of the level mouldings already in position, this method being performed without obtaining the section of the raking moulding.

Raking mouldings are also dealt with in the section on "Masonry."

Chapter VIII—PICTORIAL DRAWINGS

Isometric Projection. In the ordinary method of drawing by means of plan and elevations, two views are required to show the dimensions of a

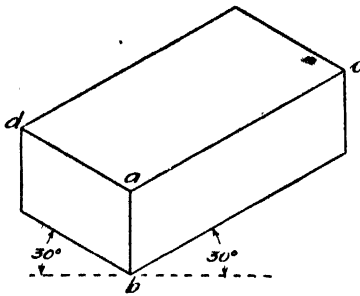


FIG. 130. ISOMETRIC VIEW OF BRICK

solid object, but there are several methods of drawing a pictorial, or "solid," view on which all the dimensions of the solid object can be shown. One of the best known of these methods is *isometric projection*.

Fig. 130 shows an isometric drawing of a

manner, which is the usual way, the drawing is said to be a *conventional isometric projection*. There is also another kind of isometric drawing known as *pure isometric projection*.

Let Fig. 131 be the plan of a cube poised on the corner in which the three lower edges meet. The upper edges *ab*, *ac*, and *ad* meet in the highest point *a*. As these three edges are equally inclined to the horizontal plane, the angles between them will be equal, that is, 120° , and can all be drawn with the 30° set-square. Also, as the lines *ac* and *ad* slope down equally from *a*, the diagonal *cd* must be a level line. Imagine the face *aced* to be rotated about this level line as hinge until the face is level. During this rotation, point *e* will describe a path *eE* in plan at right angles to *cd*, and at the finish of the rotation *cE* will be at 45° to *cd* and will be the *true length* of the edge of the cube. The plan length *ce* is shorter than the actual length and is known as the *isometric length*. If, therefore, a scale is used, by setting up the actual length on a 45° line, as in Fig. 132, and projecting

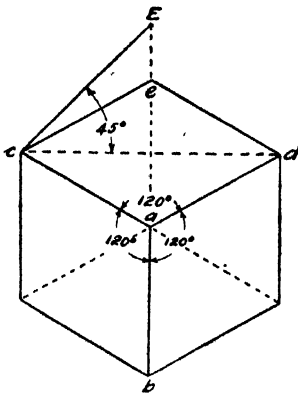


FIG. 131. PURE ISOMETRIC PROJECTION

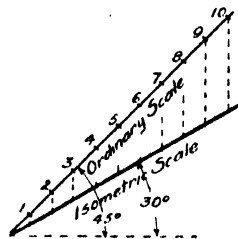


FIG. 132. ISOMETRIC SCALE

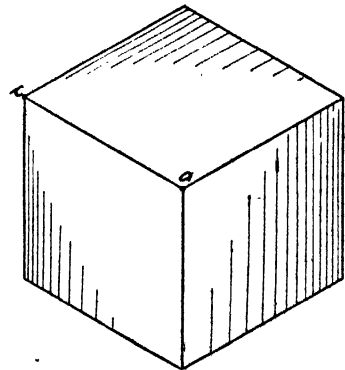
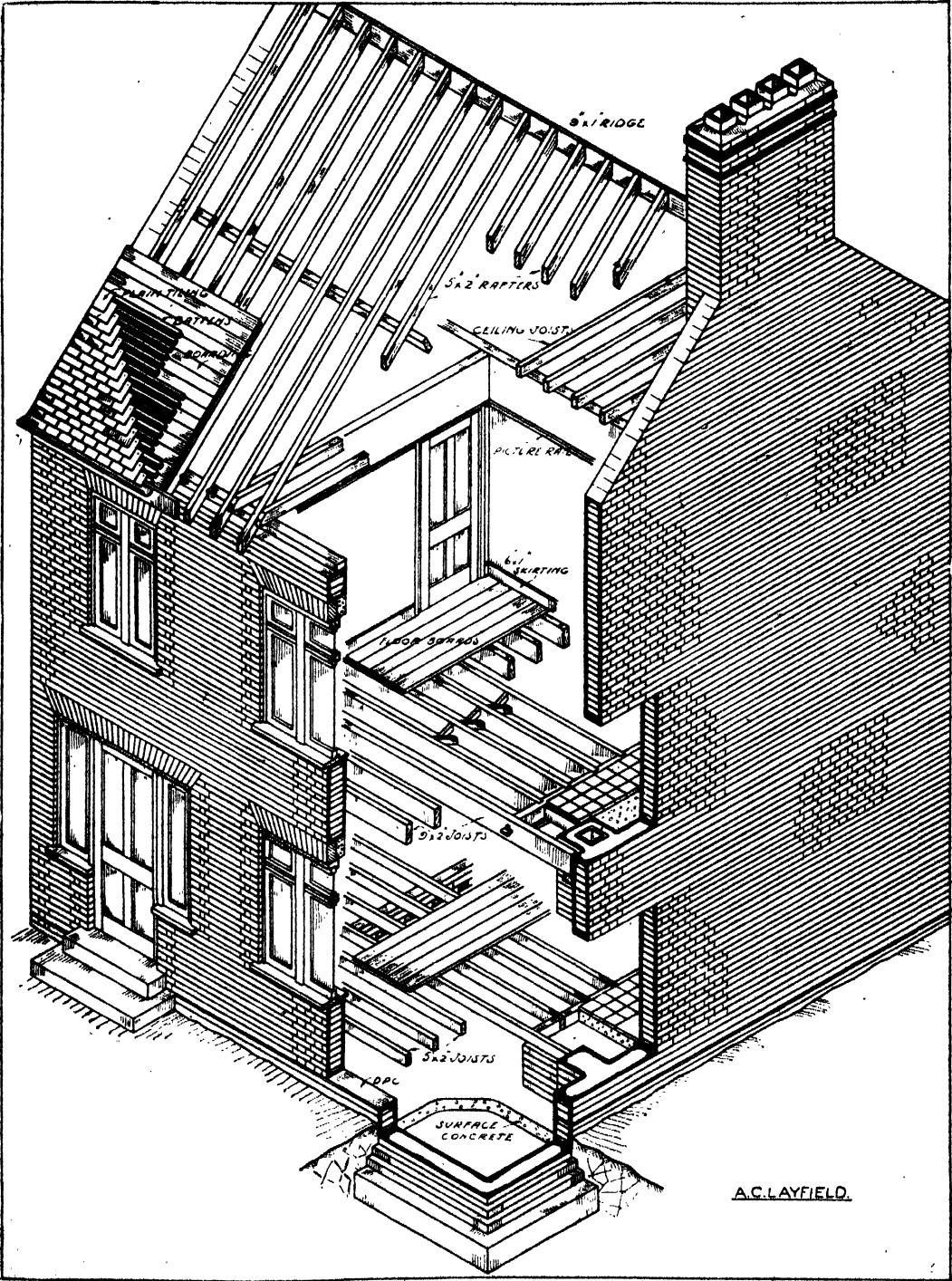


FIG. 133. CONVENTIONAL ISOMETRIC

brick. Note that there are three sets of parallel lines, all of which can be drawn with a 30° set-square. The dimensions of the object are measured (either full size or to any desired scale) along these lines; thus, *ab* gives the thickness of the brick, *ac* is the length, and *ad* the width. When the dimensions are measured in this

down on to a 30° line, the latter forms an *isometric scale*. Note, therefore, that a pure isometric drawing is simply an ordinary projection on a plane, the object being placed so that its right-angled corners are equally inclined to the plane of projection. Such a pure isometric projection is shown in Fig. 131, but if the actual



ISOMETRIC DRAWING SHOWING THE CONSTRUCTION OF A SMALL HOUSE

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length of edge is set off, thus ac , Fig. 133, is made equal to cE , Fig. 131, then Fig. 133 gives an enlarged but similar view of the cube and is a conventional "isometric." For practical purposes this conventional view serves as well as the pure isometric view, and has the advantage

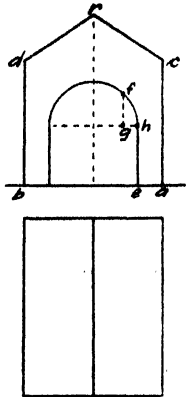


FIG. 134. ELEVATION AND PLAN OF A BUILDING

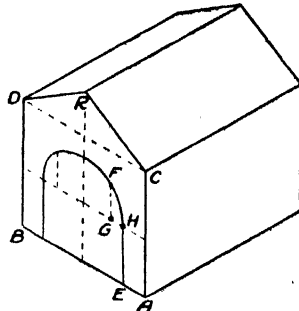


FIG. 135. ISOMETRIC VIEW OF BUILDING

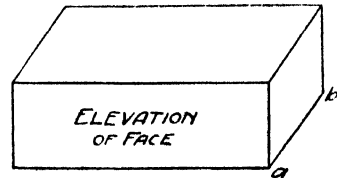


FIG. 136. OBLIQUE PROJECTION

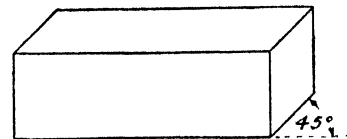


FIG. 136A. PICTORIAL PROJECTION

that dimensions can be at once scaled off the drawing.

Isometric Views. Suppose it is required to draw a (conventional) isometric view of the small building given in plan and end elevation in Fig. 134. Draw AB , Fig. 135, at 30° and equal to ab , Fig. 134. Erect perpendiculars AC and BD equal to corresponding lines in Fig. 134. Draw the centre line and set out height of ridge R ; join CR and DR , and complete the outline of building as shown.

To draw the archway, set out springing and height in Fig. 135 as given in Fig. 134. Make AE equal to ae . Points at the springing and centre of arch are thus located. Additional points on the curve may be obtained by selecting points as f in the elevation, Fig. 134, and then transferring the horizontal and vertical distances hg and gf to Fig. 135.

The student should examine the numerous isometric views given in other sections, such as "Joinery."

OBLIQUE PROJECTIONS

In ordinary projection the projectors are at right angles to the plane of projection, but in *oblique projection* the projectors are inclined to the plane of projection. If any plane figure is placed parallel to a plane, and the figure is pro-

jected by oblique parallel lines on to the plane, then the projection will be the same as the figure. Thus, to draw the oblique projection, Fig. 136, of a brick, the front face is drawn the same shape as the actual brick. The angle and length of the side lines ab , etc., will depend on the slope of the

oblique projectors, and can be made any angle or length. This projection in Fig. 136 obviously gives a distorted view, and it is therefore usual to draw the side lines with a 45° set-square and to half scale, as shown in Fig. 136A; this particular variety of oblique projection is often

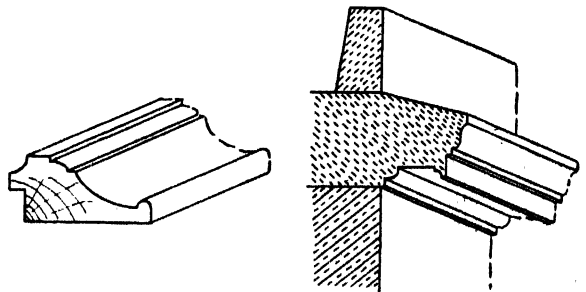


FIG. 137. OBLIQUE PROJECTIONS

termed *pictorial projection*. (Of course, this distinction is quite arbitrary, as all views giving a pictorial effect—isometric and perspective, for example, are pictorial projections.) It will be noticed that the side edges of the brick in Fig. 136A appear too short, and it might be better to make these lines a larger proportion than half scale, say two-thirds, but the dimensions could not then be so readily scaled off.

Oblique projection is particularly suitable for drawing objects of which the front face is composed largely of slanting lines and curves and the side lines are parallel to each other. Thus, the bolection moulding and cornice in Fig. 137 are converted from sections to oblique projections by drawing the edge lines, or arrises, at any angle or length to give a suitable appearance.

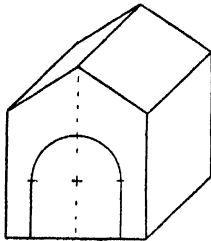


FIG. 138. PICTORIAL PROJECTION

A pictorial projection of the small building already shown in isometric is shown in Fig. 138. This pictorial projection is made by first reproducing the front of the building exactly as given in the elevation, Fig. 134, and then drawing the side lines of the building at 45° and to half scale.

Planometric Drawing. It may be that there are changing fashions in scaled pictorial drawings, but it seems probable that new and better

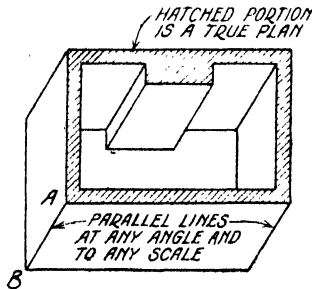


FIG. 139. SIMPLE PLANOMETRIC DRAWING

methods of drawing are devised for particular purposes. Isometric drawing was the first type of scaled pictorial drawing. Then it apparently became the fashion to use oblique (pictorial) projection, though in these last few years isometric projection seems to have been more popular than pictorial projection.

A new method of scaled pictorial projection, which has only been devised during the past few years, is *planometric* drawing. Fig. 139 shows a simple illustration of this method. The

hatched portion shows the actual plan, to any scale, of a small building. This plan is then turned into a planometric view, by simply drawing sloping lines, as *AB* from the corners, and completing as shown. The lines *AB* may be drawn at any angle and to any scale.

It will be seen that planometric drawing is really a form of oblique projection, but whereas in ordinary pictorial projection we first select the elevation or elevational section and then draw our oblique lines, in planometric drawing we first select the plan of the object. The principle is the same.

Planometric drawing is particularly suitable for showing heating installations and similar work. Most of the pipes run horizontally, and both lengths and angles can be taken directly from a planometric drawing.

Axonometric Drawing. This method of drawing (which is sometimes called *axiometric* drawing) is somewhat similar to planometric drawing.

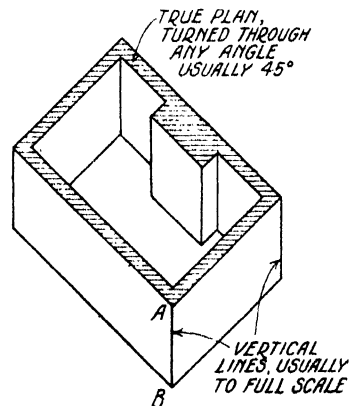


FIG. 139A. AXONOMETRIC DRAWING

and may, indeed, be said to be an improved variation. The actual plan is taken and turned through an angle, usually 45. Vertical lines, as *AB* (Fig. 139A), are then drawn from the corners to represent actual vertical edges. The scale for the vertical lines is usually the same as for the plan.

This method of drawing is coming more into use, and deservedly so. It is easily drawn, can be readily scaled, and does not appear very distorted. It has been more used on the Continent than in this country, but is now coming more into use here. For architects' scaled pictorial drawings it is probably the best method. An elaborate axonometric view of an hotel, designed by Otto Zollinger, is shown in Fig.

MODERN BUILDING CONSTRUCTION

139B. If the view is turned sideways, it will be seen that the roof is a true plan.

It will be noticed that isometric and oblique projections usually have a distorted appearance, chiefly owing to the fact that the lines do not "vanish," that is, appear to converge as they

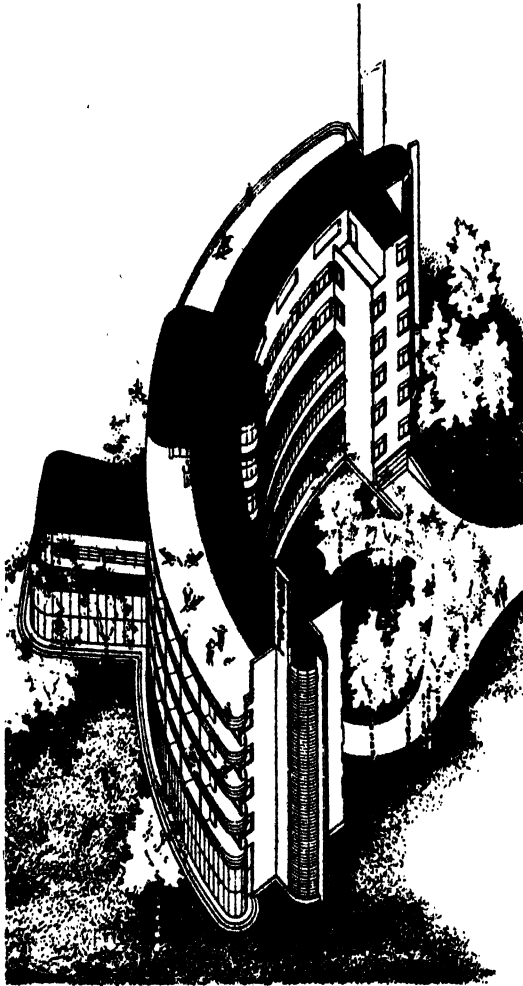


FIG. 139B. AXONOMETRIC VIEW OF AN HOTEL

recede from the eye. The larger the actual object, the greater is the apparent distortion. The only method of projection giving a natural and undistorted appearance is radial projection, commonly termed *perspective*.

PERSPECTIVE

A perspective drawing is a view like a photo-

graph, that is, as seen by the eye. Suppose we require a perspective of a small building, as shown in Fig. 140. The spectator is situated at any required point, called the *point of sight*, to get the view desired, and a sheet of glass, called the *picture plane*, is interposed between the building and the spectator. If, now, the corners of the building are connected to the eye of the spectator by thin threads, or rays of light, these threads will penetrate the picture plane in a number of points. Join these penetration points in the correct order, and a miniature representation, or *perspective*, of the building is obtained. In taking a photograph, the photographic plate or film, which corresponds to the picture plane, is placed on the other side of the point of sight, or lens, and the photograph in the camera is therefore upside down.

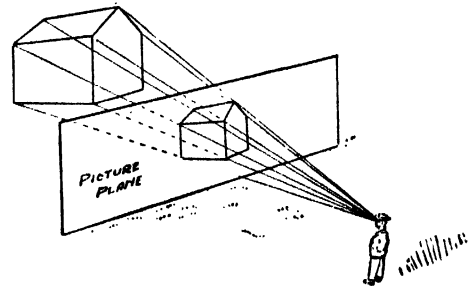


FIG. 140. EXPLAINING PRINCIPLE OF PERSPECTIVE, OR RADIAL, PROJECTION

Plan and Elevation Method. It is obviously possible to obtain the perspective view by ordinary geometry, as shown in Fig. 141. Proceed as follows. Draw a plan of the object, picture plane, point of sight, and rays of light. These rays cut the picture plane in plan at points a, b, c , etc. Now draw a side elevation, and the heights of the points a', b', c' , etc., are obtained.

Draw a *ground line* to represent the intersection of the picture plane with the ground, and set out the plan distances by projecting the points a, b, c , etc. Set up the height of each point as given in the side elevation; thus AD will equal $a'd'$, CE equal $c'e'$, and so on. When all the perspective points are located in this manner, they can be joined together, thus completing the perspective view.

Angle of Vision. There is a practical limit to the position of the point of sight. If it be placed too near the building a distorted view results, because if we stand too near a building we cannot see it all clearly at once. It is therefore usual

to select the point of sight so that the building is enclosed within an angle of rays 60° horizontally and 45° vertically. A useful rule is to take the point of sight at a distance from the building equal to three times the height of the building. The height of the point of sight is usually taken about the height of a man, say 6 ft., but in a bird's-eye view it is taken at any desired height.

Vanishing Points. All perspectives could be

will be at b_2 . Let the point B be moved farther and farther along AD produced, and as this movement continues, the projector, or visual ray, will become more and more nearly parallel to AD , until when the point B is at an infinite distance away, the projector will be parallel to AD and will cut the picture plane in a point V . This point is said to be the *vanishing point* of the line AD ; it is also the vanishing point of all lines parallel to AD .

Now consider the side elevation. As the point B recedes farther behind the picture plane, the ray becomes more nearly level, and the point of penetration rises; until, when the point B is at an infinite distance behind the picture plane the ray becomes level, and cuts the picture plane in the vanishing point V' . If we look at any level line, as a railway line, running away into the far distance, it vanishes from view at the horizon line and therefore the vanishing point, as V , locates the height of the

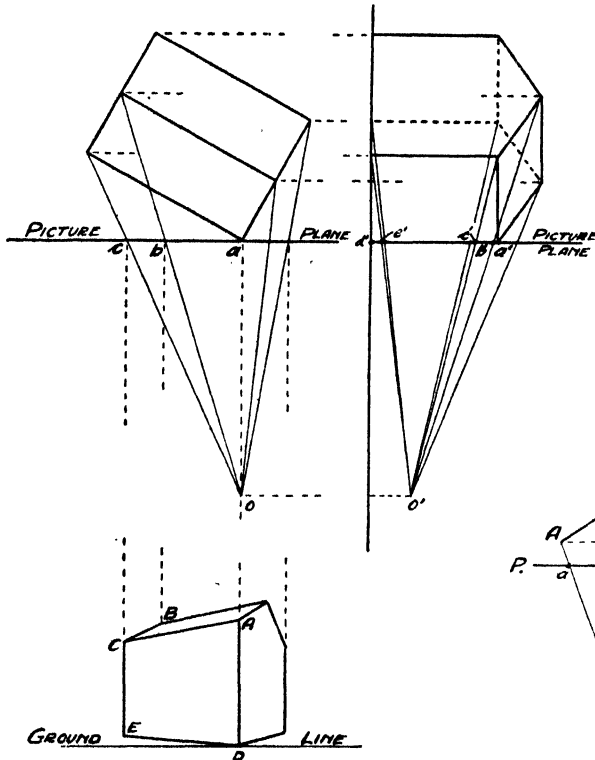


FIG. 141. PERSPECTIVE OBTAINED BY PLAN AND ELEVATION

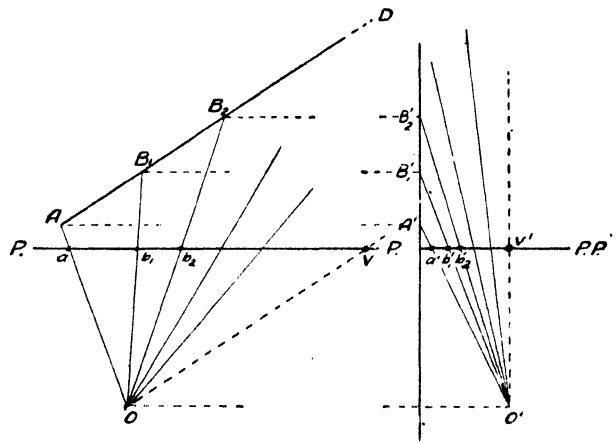


FIG. 142. EXPLAINING THEORY OF VANISHING POINTS

drawn as already described, but the method is rather laborious, and the method of vanishing points is usually adopted. The theory of vanishing points is illustrated in Fig. 142. Here is shown the plan and side elevation of the point of sight o , picture plane PP , and a line AD lying on the ground. Consider the radial, or perspective, projection of point A ; this will be a in plan and a' in elevation. Now imagine a point B on the line to move along AD from A ; when the point is at B_1 , the perspective projection in plan will be b' ; when at B_2 the projection

horizon line, which is always equal to the height of the point of sight.

Fig. 143 shows the method of vanishing points applied to the small building already considered. Draw the plan of the building, picture plane, point of sight, and rays as before. Also, draw the ground line, and the horizon line parallel to it and at a distance equal to the height of the eye from it. Find the vanishing point of ab (and all lines parallel thereto) by drawing from O parallel to ab , cutting the picture plane in V , and then projecting this point

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vertically downwards on to HL to give VP . Similarly obtain the vanishing point V_1P_1 of ac and all lines parallel thereto.

As the picture plane touches the building, the height $a'd'$ in elevation can be set up at AD . Join A and D to their respective vanishing points on HL , and project down from the points of penetration b_1 and c_1 , on PP , thus locating the

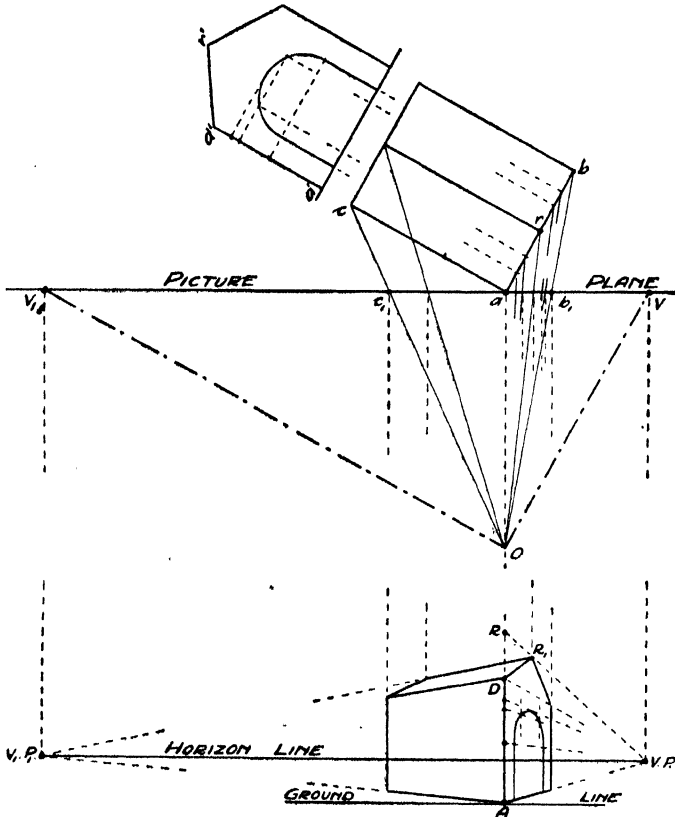


FIG. 143. PERSPECTIVE DRAWING, USING VANISHING POINTS

rectangular faces of the building. For the near ridge point, make AR equal to the height of the ridge r' , and then join R to VP . The last line (R to VP) is the perspective of a horizontal line at the height of the ridge running from the picture plane to the horizon. The intersection R of this line with the plan projector from r gives the perspective of the near ridge point. The gable can now be drawn in, and the ridge drawn to the left-hand vanishing point. The line AR is known as a height line, or *measuring line*, and on it can be set up the heights of any required points on the arch curve. Lines are

then drawn to VP to intersect the perpendiculars from PP .

When the main outlines of the building have been correctly projected, the details, such as doors, windows, and chimneys, etc., can easily be filled in.

The foregoing short explanation of perspective is only introductory; for fuller treatment the student is referred to the section on "Architectural Drawing."

Use of Pictorial Views. Isometric projection and oblique projection are very useful for making dimensioned sketches of constructional details. These views can be drawn accurately so that dimensions can be scaled off, but it is more usual to make the drawings only roughly to scale, and mark on any required dimensions. Formerly; isometric drawing was the method nearly always adopted, but of late years oblique projection has come more into use, as oblique views are easier to draw, the most difficult face of the object being first drawn, and then the side lines are added at a suitable angle to give the solid effect. Oblique projection is also very useful for illustrating mouldings, as the true section is given in the pictorial view.

Perspectives are chiefly used by architects, as clients often have a difficulty in imagining the actual appearance of a building from plans and elevations. The perspective gives a clear idea of how the building will appear when finished.

Axonometric drawing is often confused with isometric drawing, but though it gives a somewhat similar appearance, it is based on different principles. An isometric drawing is really an orthographic projection, that is, a right-angled projection; whereas an axonometric drawing is an oblique projection and belongs to a different class of drawing. There are in solid geometry three classes of projection: orthographic, where the projectors are at right angles to the plane of projection; oblique, where the projectors are inclined but parallel; and perspective, which is a radial projection.

Chapter IX—DEVELOPMENTS

A DEVELOPMENT of a surface means an unfolding of the surface so that its true shape is shown. Thus, sheet-metal workers can develop the surface of any object they may be making, so that the development can be cut out in the flat sheet and then folded into shape to give the object required.

There are three chief types of surfaces: *plane* surfaces, surfaces of *single curvature*, and surfaces of *double curvature*.

A **Plane Surface** is a flat surface; that is, a straight line can lie evenly on the surface in any direction. Hipped roofs and pyramids give examples of plane surface. A plane surface

one side of a rectangle, when the opposite side of the rectangle is taken as axis. This kind of surface can be developed evenly and in one flat piece.

A **Double-curvature Surface**, as a sphere, is generated by a curved line moving in a curved path. Thus, the surface of the sphere in Fig. 146 is swept out by revolving the semicircle about its diameter as axis. This type of surface is said to be undevelopable, but that really only means that it cannot be developed in one piece, or, in other words, it cannot be covered by one flat sheet of any outline whatever. Try, for example, to cover a ball with a sheet of paper,

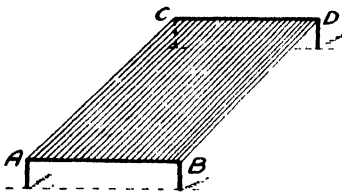


FIG. 144
PLANE SURFACE

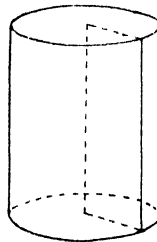
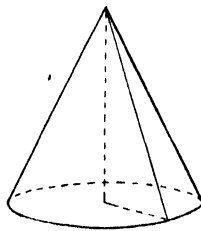


FIG. 145. SURFACES OF SINGLE CURVATURE

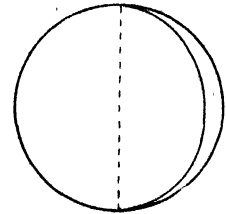


FIG. 146. SPHERE—A DOUBLE-CURVATURE SURFACE

may be assumed to be generated as shown in Fig. 144. The two lines *AB* and *CD* are level, and the surface is swept out by another line moving on these lines. The plane surface shown is horizontal, but a plane surface may be inclined to one or both planes of projection. If one of the lines *AB* or *CD* were inclined, the resulting surface would be warped, or *twisted*. A straight line cannot be made to lie in every direction on a twisted surface, as this surface is always curved in some directions; this type of surface can only be developed approximately.

A **Surface of Single Curvature** is generated by moving a straight line in a curved path, as shown in the cone and cylinder in Fig. 145. For a cone, imagine a right-angled triangle revolved about its perpendicular side as axis; then the sloping side, or hypotenuse, of the triangle sweeps out the curved surface of the cone. A cylindrical surface as shown is swept out by

and you will find that the paper will wrinkle and not lie flat on the ball. All bodies of double curvature (when they have to be covered by flat sheets and not cast, beaten, or spun) are, therefore, developed by dividing the surface into narrow strips and developing them.

PLANE SURFACES

Developing a Plane Surface. If a plane surface or figure is parallel to a plane of projection, its true shape is given by its projection on that plane; but if the surface is inclined, its true shape is not given in either plan or elevation and the surface must be developed, that is, turned parallel to a plane of projection so as to exhibit its true shape.

The plan of the roof, Fig. 147, does not give the true shape of the sloping roof surfaces. The plan shapes are narrower than the actual shapes; and if we want to determine the actual shape from the given plan and elevation, we consider

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a line as hinge, say the eaves ad , and revolve the surface until it is parallel to the ground, as shown in Fig. 148. The true shape $adCB$, Fig. 147, is thus obtained. Note that during the rotation all points in the rotating surface

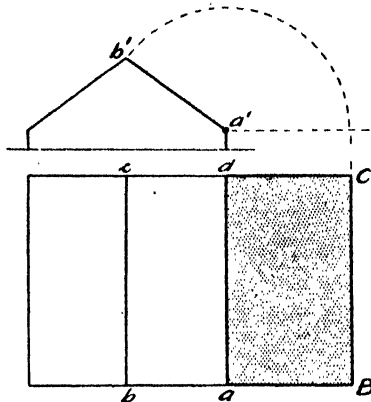


FIG. 147. TRUE SHAPE OF ROOF SURFACE

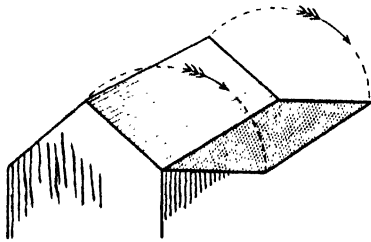


FIG. 148. METHOD OF DEVELOPING ROOF

describe arcs in elevation, and in plan describe *straight lines at right angles to the hinge line*.

Various problems on the development of plane surfaces have already been described; for instance, roof bevels, but a number of other practical examples of developments will now be given.

Square Pyramid (Fig. 149). This might be in the form of a small pyramidal roof, of which it is required to find the true shape of the sloping surfaces. To do this, hinge the face about its base line until it falls level. The method of drawing should be obvious from the figure, and the tinted portion shows the true shape.

Hexagonal Pyramid. The complete development of all the sloping faces is shown in Fig. 150, and is obtained by setting out the triangular faces side by side. Each triangular face is an

isosceles triangle having a base equal to the base edge of the pyramid, and sides equal to the sloping edges. The true length of the sloping edges is shown at $o'r'$ in elevation. The method of drawing out the development should be obvious from the illustration.

Now imagine the pyramid to be cut by an inclined plane; this would then represent a roof through which projects a hexagonal turret. The development of the portion above the sloping plane (and also that below) is obtained by finding the lengths of the edges of the pyramid above the plane. The sloping edge $o'z'$ is cut by the plane in elevation in point a' , and the true length of $o'a'$ is found by drawing a horizontal line from a' to cut the edge $o'r'$ in a'' .

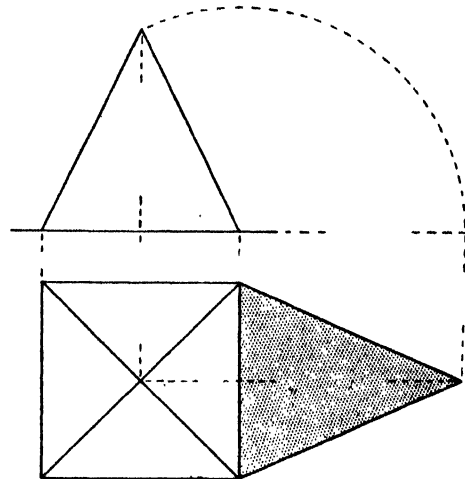


FIG. 149. TRUE SHAPE OF SIDE OF PYRAMID

Using o' as centre, turn $o'a''$ on to $o'z_1$ in the development, thus giving $o'z_1$, and deal in a similar manner with the other edges. The points thus obtained on the development can then be joined up by lines as shown.

A further problem is to find the true shape of the hole where the pyramid penetrates through the roof surface. First, find the plan of the hole, by projecting down from a' , etc., on to the edges in plan. Then revolve this figure about the horizontal trace of the inclined plane as hinge into the horizontal plane.

Splayed Hopper. Fig. 151 shows a splayed bottomless box, or hopper. The two sections should be drawn first, so that, if required, all the sides can be made of equal thickness. The plan is then projected from the two sections. Note that the edges in plan are not of equal

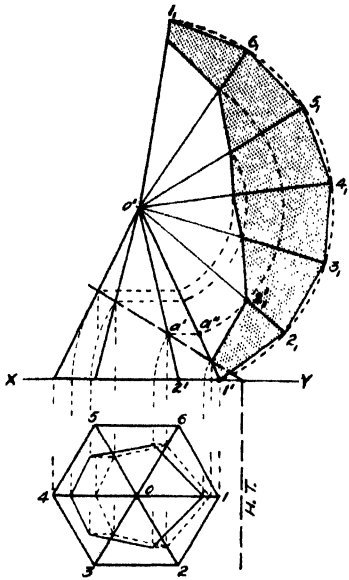


FIG. 150. DEVELOPMENTS OF HEXAGONAL PYRAMID

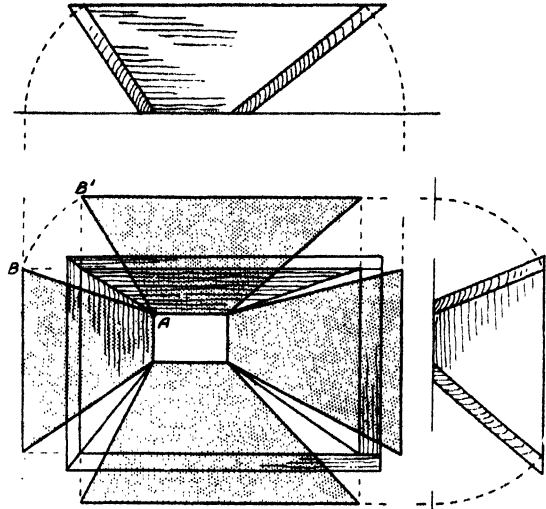


FIG. 151. DEVELOPMENT OF IRREGULAR SPLAYED HOPPER

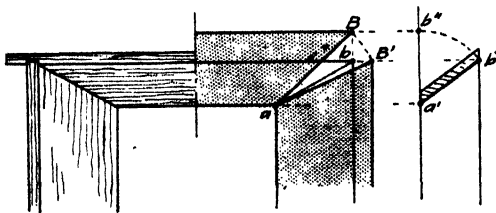


FIG. 152. BEVELS FOR LININGS

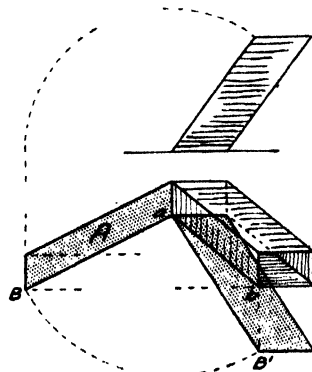


FIG. 153. OBLIQUE TUBE

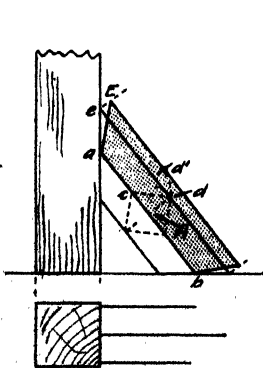


FIG. 154. SQUARE STRUT

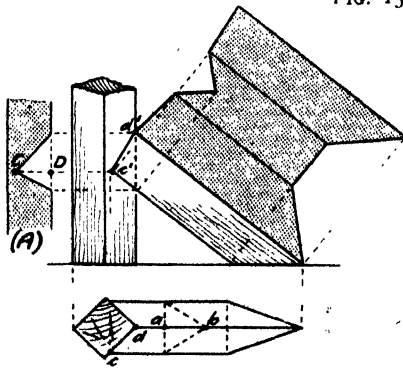


FIG. 155. TRIANGULAR STRUT

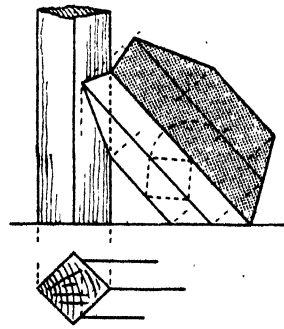


FIG. 156. FORKED SQUARE STRUT

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width, because the sides slope at different pitches.

In order to find the true shapes of the sides, they are developed by hinging them at the bottom edges. Either the inner surfaces, as shown, or the outsides can be developed in this way.

At the right-hand side lapped joints are shown and mitred joints at the left.

Note that the adjacent edges, as AB and AB' , are equal in the developments.

Splayed Linings. Fig. 152 shows the elevation

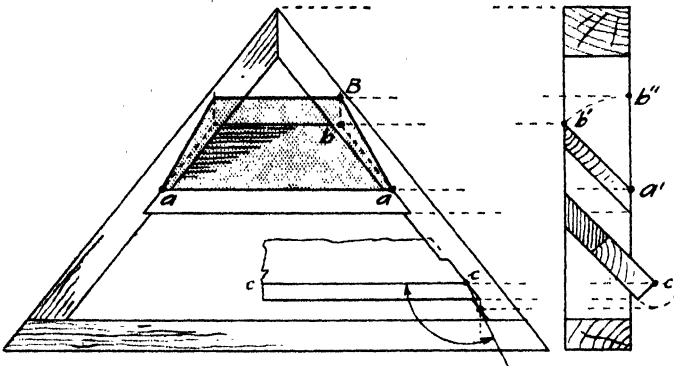


FIG. 157. TRIANGULAR LOUVRE FRAME

and vertical section of the splayed linings to a door or window opening. The bevels for the top, or soffit, lining (for cutting the trenches to receive the jamb linings) is obtained by revolving the surface about its lower edge until the true shape is seen in elevation. To draw out this operation, draw arc $b'b''$ with a' as centre, and project horizontally from b'' to meet a vertical projector from b . This locates point B , which is then joined to a .

In the example given the jamb linings have not the same splay as the soffit lining, and therefore a different bevel is required for the top of the jamb linings. With a as centre and aB as radius, describe an arc to cut a horizontal projector from b in B' .

Oblique Prism, or Tube. Fig. 153 shows the elevation and plan of a chute, or tube, in the form of an oblique rectangular prism, such as might be used, say, for a ventilating duct passing through a room between ceiling and floor.

The true shapes of the surfaces are obtained by revolving the sides into the horizontal plane. Note that after finding the true shape of A , point B' is obtained by striking off radius aB from a to cut the projector from b .

Square Strut. An inclined wooden strut butting against a square post is shown in plan and elevation in Fig. 154. The true section is shown dotted at A . To cut the inclined strut, the bevels for the ends must be obtained, and this can be done by developing one face. Take line ab as hinge, and revolve one of the upper surfaces of the strut forwards until parallel to the vertical plane. It will then show its true width in elevation. Therefore, with centre c and radius cd , make the arc dd' , and draw parallel to ab through d' . Note that eE is at right angles to the hinge, and the same with the other projector at the foot of the strut. Only the two bevels shown are required to cut the strut.

Triangular Strut. A triangular strut is shown forked to the corner of a square post in Fig. 155. It should be noticed that the width of the strut in elevation is equal to the distance ab in the dotted section. The point c' in elevation is obtained by projecting upwards from c in plan, which is drawn first. The complete development of the sides of this strut is shown. Imagine the strut to be covered with paper jointed at the upper edge of the strut, and that the paper is then unwrapped from the strut.

The true widths of the sides of the strut will thus be seen on the development, these true widths being obtained from the dotted section. The dotted projectors are drawn at right angles to the edges of the strut in elevation.

If it were desired to notch the post so that the strut could be cut along the line $c'd'$ and fit into the notch, the bevels of the notch, or slot, could be obtained by developing a face of the post, as shown at (A) . Note that in this development the width CD is made equal to cd in plan.

Forked Square Strut. This example, Fig. 156, should now present no difficulty. A symmetrical half of the strut is shown developed, and gives all the bevels required.

Triangular Louvre Frame. Fig. 157 shows the front elevation and the sectional elevation of a triangular louvre frame, as sometimes used for ventilating purposes. The louvres are boards about 1 in. thick, placed sloping so that the rain and snow cannot drive in and yet a current of air is allowed to enter. Only two louvres are shown, but as many as required are fixed about 3 in.

apart, by housing the ends about $\frac{1}{2}$ in. into the sloping sides of the frame.

Consider the front bottom edge aa as hinge and turn, or develop, the upper surface of the louvre until it is vertical, when its true shape will be seen in elevation. This is shown in the drawing by describing arc $b'b''$ with a' as centre, and projecting horizontally from b'' to meet a vertical projector from b . Join point B thus obtained to a , and angle aaB is the correct bevel for the ends of the louvre. This bevel is the same for all the louvres.

If the edges of the louvres are flush with the front (or the back) of the frame, the bevel for the edges is given in elevation. But if the front edges are square, the bevel for the edges could be obtained as shown for the lower louvre board (shown exaggerated in thickness). The procedure is similar to that already described for the top surface, cc being the elevation of the hinge line and c' the side view. But it is hardly worth while in practice to obtain this edge bevel by geometry.

Drawings of a circular louvre frame are given in the section on "Joinery."

SURFACES OF SINGLE CURVATURE

Cylinder. Imagine the curved surface of the cylinder, Fig. 158, to be covered with paper, the paper being in one piece and jointed along the line AB . If the paper is now unwrapped from the surface, by holding down one edge of the paper and rolling the cylinder on a board, it will be found that the development of the curved surface is a rectangle. One side of this rectangle will clearly be equal to the length of the cylinder, and the other side will be equal to the circumference of the circular end.

Suppose, now, it is required to develop geometrically the surface of the cylinder shown in plan and elevation in Fig. 159. Divide the circle in elevation into a number of equal parts, and step out these parts with the divider along a line, as AA . Of course, in stepping out these divisions the length of the arc between each pair of points should be taken in the dividers, but if the divisions are small the difference in length between arc b and chord c is very small. To be on the safe side, in practical work, a slight allowance can be made by setting the dividers slightly bigger than the chord. Another method would be to calculate the length of AA ; thus if the cylinder is 2 in. diameter, the length of AA will be $2 \times 3.142 = 6.284$ in.

It will be seen that in this method of developing, the cylinder is really considered to be divided up into narrow strips as shown by the thin lines.

Junction of Pipes. Fig. 160 shows the plan and elevation of two pipes joining at an obtuse angle. If both pipes are of the same size, as shown, one development will suffice for both pipes.

Half of the plan of the upright pipe is shown dotted, as only this portion of the plan is necessary for drawing the development. Divide this half plan into a number of parts, say six. Step off these plan distances along a line AA ; erect perpendiculars, and make them equal in length to the corresponding lines on the surface of the upright pipe. Points on the curved joint line are thus obtained, and the line is then drawn freehand.

Intersection of Pipes. Fig. 161 shows the elevation (A) of a small pipe intersecting a larger pipe, and it is required to find the patterns such as would be required by a sheet-metal worker or a plumber for making the pipes out of flat sheets.

It is first necessary to draw the plan (B) of the pipes, showing the line of intersection in plan. Draw a half section of the small pipe, as shown dotted in elevation. Divide this semicircle into a number of equal parts, as at points 1, 2, and 3. From these points draw horizontal lines in the elevation lying on the surface of the small pipe. Also draw these lines on the plan of the small pipe. Projectors from the intersection in elevation will then meet the plan lines on the pipe in the required intersection in plan.

The half of the large pipe containing the hole is shown developed at (C). To obtain this pattern, stretch out a_3 in elevation to give A_3 in the development. Draw the vertical lines (ordinates), and project on to these ordinates horizontally from the points on the plan curve of the intersection.

The pattern (D) for the small pipe is obtained by stretching out half the circumference of the small pipe at 33, and then projecting down from the points on the plan of the intersection. Only half of the development is shown, the other half being symmetrical.

Cylindrical Strut. The intersection of the strut and post in elevation is first obtained (see Fig. 162). To do this, lines are first drawn on the surface of the strut in plan and elevation. First consider the line ab . The elevation $a'b'$ is in the centre of the elevation, and the point

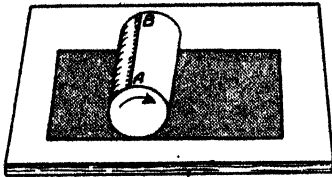


FIG. 158. METHOD OF DEVELOPING CYLINDER

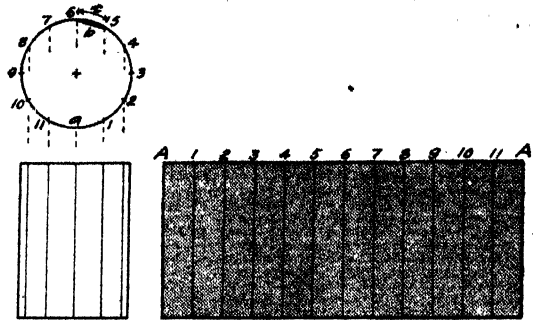


FIG. 159. DEVELOPMENT OF CYLINDER

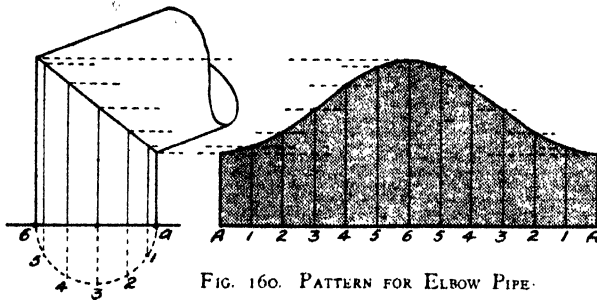


FIG. 160. PATTERN FOR ELBOW PIPE.

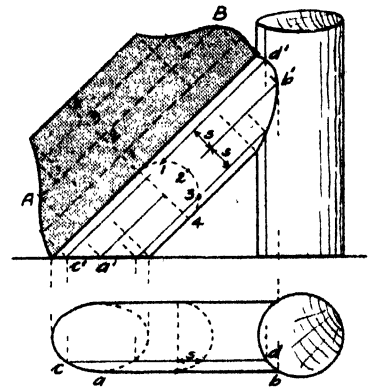


FIG. 162. CYLINDRICAL STRUT

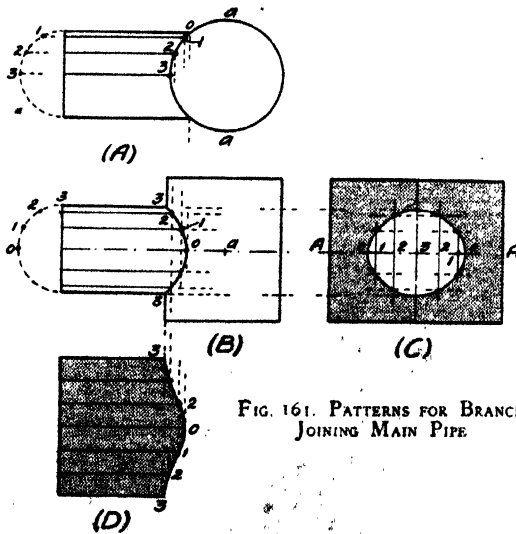


FIG. 161. PATTERNS FOR BRANCH JOINING MAIN PIPE

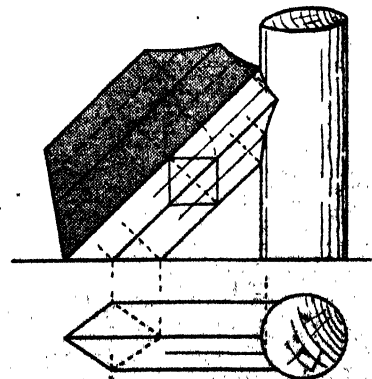


FIG. 163. SQUARE STRUT

b' must be vertically above plan b . Note that for other lines, as cd , the distances s are equal. The intersection of the strut with the ground is an ellipse, and is drawn as indicated.

A symmetrical half of the development is shown. The width of this pattern is equal to half the circumference of the strut, as shown stretched out at 1, 2, 3, and 4. The lengths of the lines shown dotted are equal to the lines on the surface of the strut; thus, AB is equal to $a'b'$.

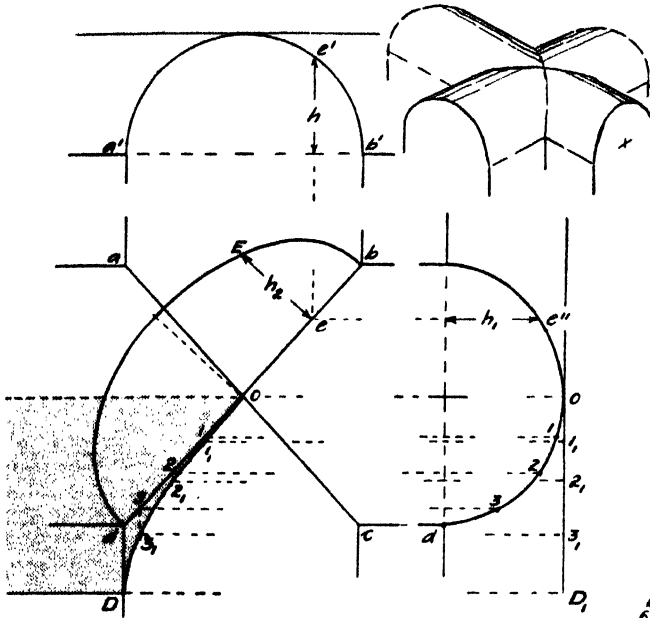


FIG. 164. INTERSECTING VAULTS

Square Strut. This example is very similar to the last. The intersection in elevation of the strut with the post must first be obtained, and also the intersection in plan of the strut with the ground. The half development is then unfolded as before

Intersecting Vaults. A semicircular vault, Fig. 164, of span ab is intersected at right angles by another vault of larger span bc . If the two vaults are the same height and the intersections, or *groins*, in plan are straight lines, then the larger vault will be elliptical in section. This section is obtained by selecting points as e in plan, obtaining the elevation e' , and then obtaining e'' by making h_1 equal to h .

The true shape of the intersection is obtained by hinging it along its plan line; thus h_2 is made equal to h .

The development of the soffit (or the true

shape of the boarding for the centering) can be obtained by taking points as 1, 2, 3, and 4 on the intersection line, stretching out this line as at o to D_1 , and completing as shown. The development of only half of the larger vault is shown.

Ogee Turret. An ogee turret rectangular in plan is shown in plan and elevation in Fig. 165. The sides can be easily developed by dividing into horizontal strips. The widths of these strips are shown at a' to 6, and these distances are set

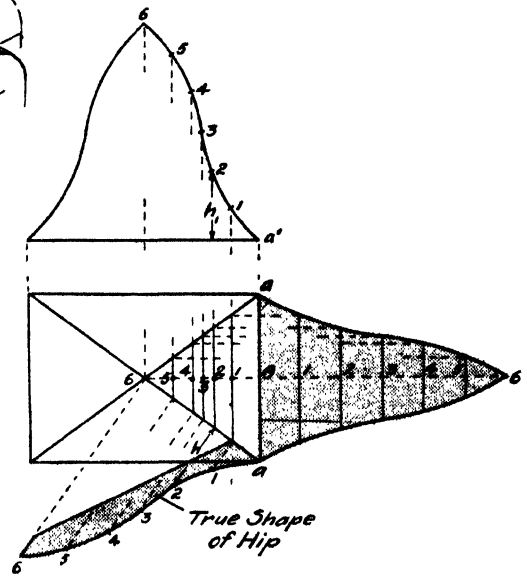


FIG. 165. DEVELOPMENT OF OGEE TURRET

out on the stretch-out $A6$ of the centre line. The lengths of the strips are given in plan, and are set out so that they lie symmetrically on each side of $A6$; this can either be done with the dividers or by projecting horizontally from the plan.

The *true shape* of the hip is obtained by drawing verticals to the plan from selected points, and setting along these verticals the heights of the respective points as given in elevation; thus h is made equal to h_1 . A fair curve through the points thus obtained gives the profile of the hip. The shaded portion indicates how the hip would be cut out of wood.

The shapes of the common rafters can be taken direct from the elevation.

Splayed Jambs and Curved Head. The elevation and plan of the inside jambs or linings of a window or door opening are shown in Fig. 166. The jambs are splayed as shown in plan, and

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the soffit of the pointed arch is composed of two cylindrical surfaces struck from points a' and b' .

SIDE ELEVATION. Choose several points as d and e on the jamb in plan, and consider these points to be the plans of vertical lines lying on the splayed jamb. These lines intersect the soffit of the arch at $d'e'$. Project to the side

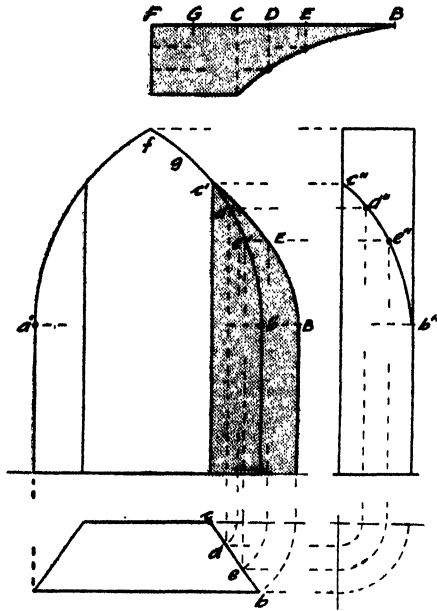


FIG. 166. SPLOYED JAMBS AND CURVED HEAD

elevation, and also project the points and the wall thickness from the plan. Points d'' and e'' on the intersection of the jamb with the soffit, and also b'' and c'' , are thus obtained.

DEVELOPMENT OF JAMB. The true shape of the lining may be obtained by revolving it about a vertical edge until the plane of the lining is parallel to the vertical plane. Note that the path lines, as $e'E$, in elevation are horizontal. The developed curve $c'B$ is thus obtained.

DEVELOPMENT OF SOFFIT. Obtain a stretch-out FB of the elevation curve fb' . The widths of the soffit at the respective points are obtained from the plan.

Right Cone. Fig. 167 shows a cone of which the development is required. Imagine the conical surface to be made up of triangular strips as shown in the small sketch. These strips are isosceles triangles, with sides equal to the generator of the cone and bases equal to a portion of the circular base of the cone.

With the apex a' as centre and radius $a'c'$,

describe an arc, and from c' step off the divisions into which the base of the cone is divided. Join the last point C on the arc to a' , and the development is given.

Truncated Cones. A cone is said to be truncated when the top is cut off. The lower part is said to be the *frustum* of a cone. When an ordinary cone is truncated by cutting parallel to the base, the frustum is easily developed, being simply a continuation of the method given in the previous problem. Thus, in Fig. 167, the cone is truncated by the line de , and after the development of the complete cone is drawn, the development of the frustum is completed by drawing the arc eE .

The development of a frustum of a cone is required in many practical building problems, such as conical window linings, shop signs round a street corner, curved pewboards, etc.

If the cone is cut obliquely, the elevations of the generators must be obtained. Thus $g'a'$ in elevation intersects the cutting plane de at f . The true length of $a'f$ is obtained by drawing a horizontal line to cut $a'c'$, when $a'F$ is the true length. These true lengths are then swung round with a' as centre until they cut the generators in the development.

Conical Linings. The plan and elevation of the wood lining to the head of a window or door, set in an opening with splayed jambs, is shown in Fig. 168. These linings may be built up of several thin layers, each of these layers when flat being the development of the frustum of a cone. Another method of building the lining is to have a thin layer for the under surface; this thin layer is bent to shape on a drum or centre, and is then covered on the back with narrow strips or staves glued together. The development is exactly on the lines of the previous problem, the positions of the plan and elevation being simply reversed.

Conical Sign Board. The portion of the sign board shown in Fig. 169 is the frustum of a cone; $a'b'c'd'$ is the elevation and $abcd$ the plan (looking up). The method of development should be obvious from the drawing.

Conical Pew Board. If a sloping shelf is fixed round a curved framing, as shown in Fig. 170, a conical surface is given. In the illustration the shelf turns through less than a right angle, but the method of development is on the lines previously indicated.

Oblique Cone. An oblique cone has its axis inclined to its base, but horizontal sections are circles as in an ordinary cone. An example of

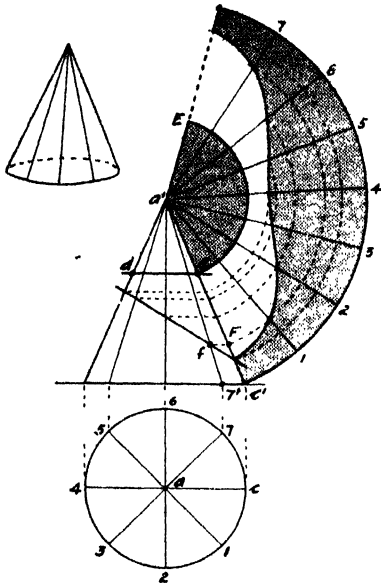


FIG. 167. TRUNCATED CONE

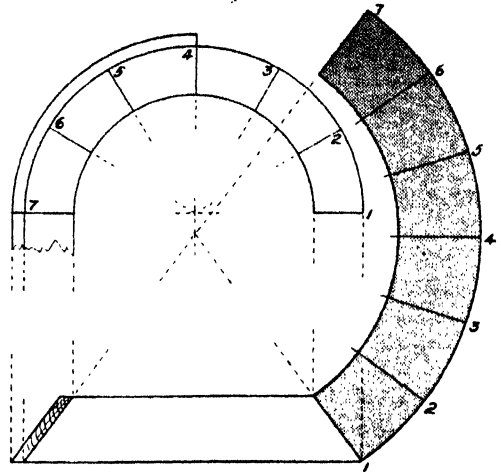


FIG. 168. CONICAL LINING

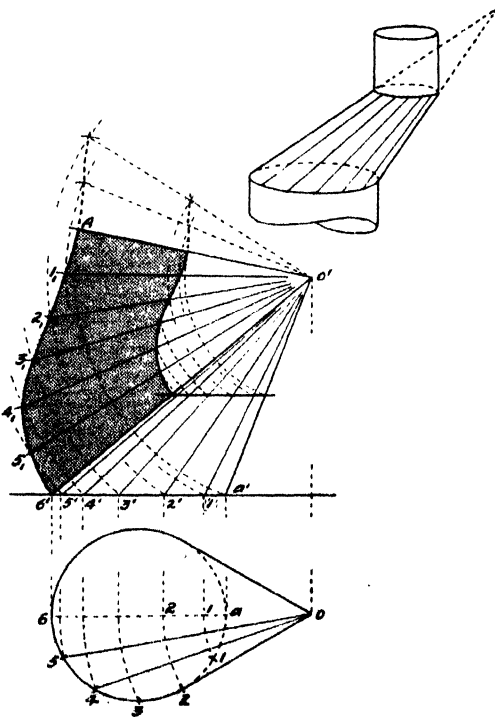


FIG. 171. TRUNCATED OBLIQUE CONE

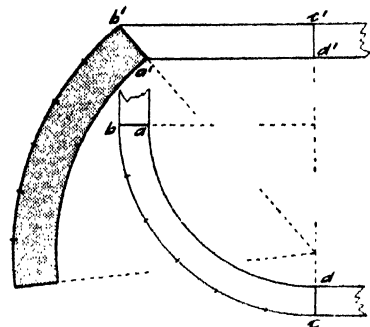


FIG. 169. CONICAL SIGN BOARD

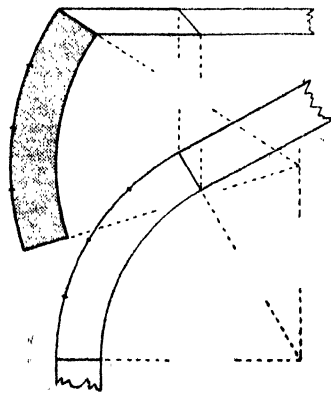


FIG. 170. CONICAL PEW BOARD

MODERN BUILDING CONSTRUCTION

its application is shown in the small sketch in Fig. 171, where a connecting piece is required between two pipes of unequal diameters, the axes of the two pipes not being in the same straight line.

Fig. 171 gives the elevation and the plan of an oblique cone. Divide the plan of the base

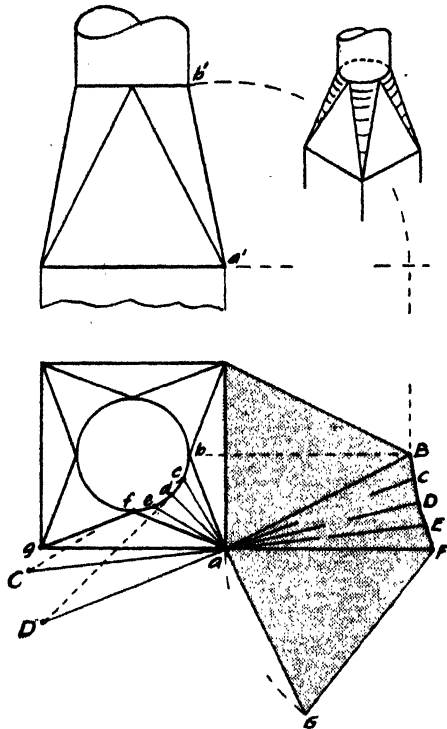


FIG. 172. CONNECTING PIPE

into a number of parts, say 12. Only half of the base really need be thus divided, as shown. If these points are joined to the apex o of the cone, as $o4$ and $o5$, the surface of the cone is divided into narrow triangles, each triangle having two generators of unequal length for the long sides and a small curved arc as base. To find the true lengths of the generating lines, put the compass point at o and swing the plans round on to the centre line, thus giving points 1, 2, etc. Project upward from the latter points to XY , giving points $1'$, $2'$, etc. With o' as centre and $o'1'$, etc., as radius, draw arcs as shown. Take a small arc of the base, as 56 in the compasses, and strike off from $6'$, thus giving 5_1 . One narrow triangle is thus developed, and the others are developed in a similar manner by stepping off the small arcs, obtained from

the plan, on to the arcs struck from o' as centre. A curve through the points $6'$, 5_1 , etc., gives the development of the base of the cone. A half of the development is shown shaded; the other half is symmetrical. If the top of the cone is cut off parallel to the base, as shown, the development of the truncated portion is obtained in a similar manner as for the complete cone.

Connecting Pipe. The small sketch in Fig. 172 shows a view of a connecting piece between a square pipe and a round pipe. The elevation and the plan are also shown.

The true shape of a triangular face can be obtained by swinging it over as shown. Each of the four curved corners is part of a circular cone, and each of these corners can be developed by dividing it into a number of narrow triangular strips. Taking the first strip nearest the triangular flat side, the length aB is already obtained. The length bc can be struck out with B as centre, but the length of the third side must be obtained; draw cC at right angles to the plan ac and equal to the height of the connecting piece, then aC gives the true length. With a as centre, strike out this true length on the development, thus giving point C . For the next strip CD is made equal to cd in plan, and aD equal to the obtained length aD . The third strip is equal to the second strip reversed, and the fourth strip is reverse of the first strip. Join Fa , thus giving a quarter of pattern, from which complete pattern can be duplicated. The development of side af is shown at aFG .

SURFACES OF DOUBLE CURVATURE

Development of Sphere. A spherical surface most often occurs in building work as a hemispherical dome. There are three ways of covering the dome. The first method, shown in Fig. 173, is by taking strips like the slices of an orange; these tapered strips are known as *gores*. When the strips have been developed, they are bent to shape and laid side by side, thus covering the whole surface of the dome.

The second method, Fig. 174, is to develop horizontal strips, or *zones* (a geographical term), each of these strips being really a truncated cone. The third method is to cover the dome with narrow boards which fit diagonally round the dome, as shown in Fig. 175. Ordinary thin parallel boards are used and are fitted a little where required, no geometrical development being required.

Development by Gores. Divide the plan, Fig 176, into as many sectors as required; the

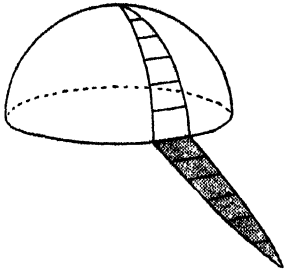


FIG. 173. VIEW OF GORE

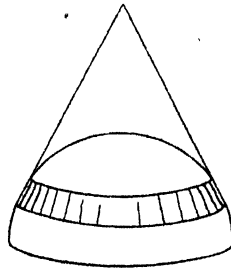


FIG. 174. SHOWING THAT ZONE IS THE FRUSTUM OF A CONE

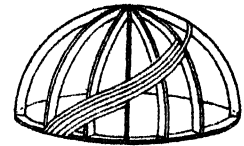


FIG. 175. COVERING DOME WITH NARROW BOARDS

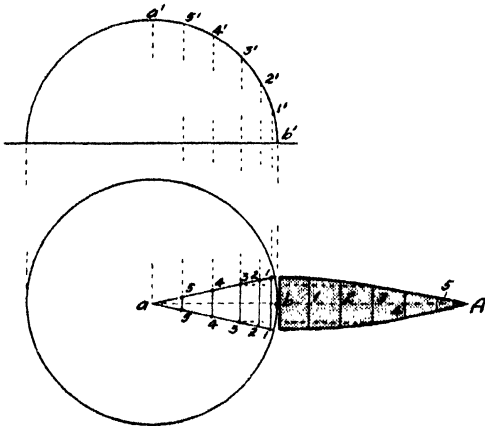


FIG. 176. DEVELOPMENT OF GORE

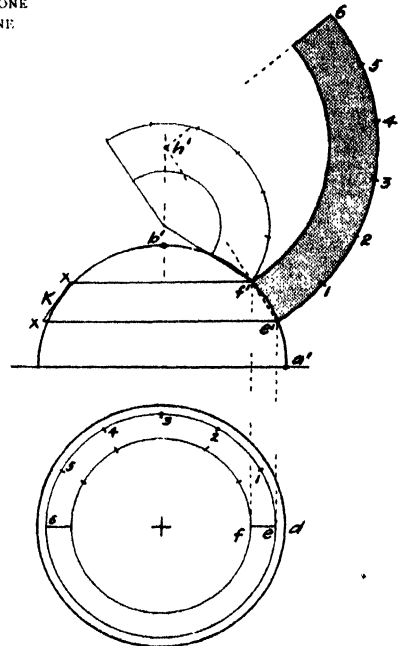


FIG. 177. DEVELOPMENTS OF ZONES

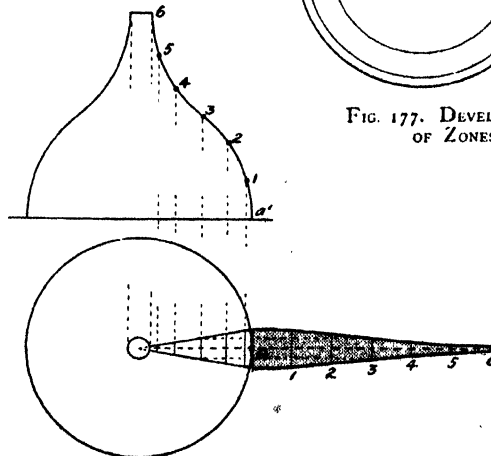
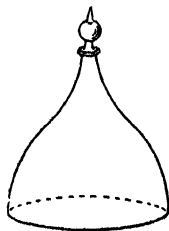


FIG. 178. DEVELOPMENT OF OGEE TURNET

DEVELOPMENTS OF SURFACES OF DOUBLE CURVATURE

MODERN BUILDING CONSTRUCTION

more gores the better will be the job. The plan of the centre line of one gore is shown at ab , and the elevation of this centre line is shown at $a'b'$. Divide $a'b'$ into a number of parts as $b'1'$, $1'2'$, $2'3'$, etc., and set off these parts along a line bA , which is then the stretch-out of the centre of the gore. The widths of the gore at points $1'$, $2'$, etc., are given at points 11 , 22 , etc., in plan. Set out these widths so that they lie symmetrically on each side of bA , and join the points thus obtained.

It will be obvious that this method is only approximate, the narrower the gores the more accurate the result. In taking the length of the gore in elevation and the width in plan, the small chords taken are, of course, slightly less than the arcs that should really be taken, so in practice it is better to allow the distances to be rather "full."

Development by Zones.

Fig. 177 shows the plan and elevation of a hemispherical dome to be covered by horizontal strips. The quadrant $a'b'$ is divided into a number of parts, such as practical considerations require. Join two of the points, as $e'f'$, and produce to cut the centre line at h' . With h' as centre and $h'f'$ and $h'e'$ as radii, describe two arcs as shown. Make these two arcs the same length as the arcs in plan by dividing the plan circles into portions, and setting off these lengths along the development arcs. By joining point 6 to h' the development of half the zone is completed. Of course, the line $f'e'$ being straight is less than the curve of which it is the chord, and therefore the developed zone is a trifle narrower than would be really required when covering the dome with, say, sheet copper; a little allowance could be made for this, either in setting out the patterns or in cutting the sheets.

If the dome has to be covered with boards in the form of gores, and greater accuracy is required, it is better to draw the lines $f'e'$, etc., tangential to the surface as shown at K , the corners xx being afterwards planed to an even curve. The upper portion of the dome is usually formed by a boss, or flat disc, which is trimmed

slightly convex on its upper surface. For wooden domes boarded on the gore method, this boss is often rebated on its upper circular edge to receive the narrow ends of the gores.

Ogee Cupola. The best method of developing an ogee cupola, as shown in Fig. 178, is by means of gores, as already described for a sphere. The plan is divided into a number of radial parts; the stretch-out of the centre line is obtained by dividing the elevation curve into a number of parts, and the widths of the gore at the various points are obtained from the plan.

Elbow Pipe. An elbow pipe, Fig. 179, is usually made of sheet metal, by dividing it into a number of radial sections as shown at (A),

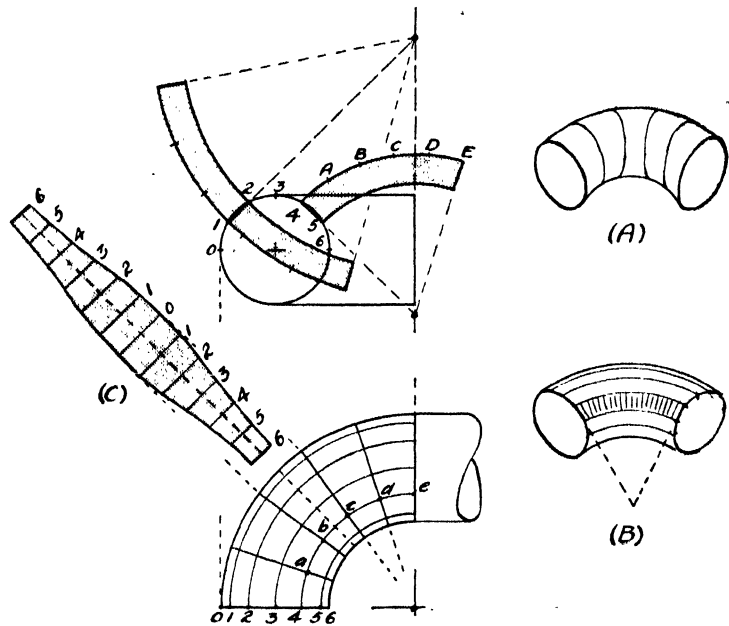


FIG. 179. ELBOW PIPE

the number of sections depending on the size and nature of the work. The quadrant is shown divided into five of these sections in plan, and the development of one of these sections is shown at (C). The length of this pattern is taken from the section of the pipe shown in elevation, and the widths are taken from the plan.

Another method of forming the pipe is shown at (B), where the elbow is shown divided into strips parallel to its centre line. Each of these strips is really quarter of a truncated cone. The centres for describing these strips are obtained as shown in the elevation, and the length of the strips are obtained from the plan.

Chapter X—CIRCLE-ON-CIRCLE WORK

IMAGINE a wall, circular in plan, as in Fig. 180 (C), pierced by a circular opening, say a semi-circular-headed door or window; the building of the brick or stone arch over this opening and the making of the timber door or window head are examples of circle-on-circle work. The templets, or patterns, used for constructing this work involve a knowledge of the development of the cylinder, cone, and conoid.

Circle-on-Circle Head with Parallel Jambs. The timber head to a window or door frame is shown at the right-hand side of Fig. 180, (A) being the plan and (B) the elevation. This frame is semicircular in elevation and segmental in plan; it is really a vertical curved slice of a horizontal half cylinder as shown in (C).

Considering the head to be in two parts, each half is cut from a plank by the aid of two *face moulds*. The thickness of the plank is obtained by enclosing the half plan between two parallel lines *ab* and *cd*, as shown. In this example the two face moulds are alike and are the vertical sections of the horizontal cylinder enclosing the head; the curves are, therefore, elliptical.

To draw the face mould, choose a number of points, as *e*, on *cd*. Project up to the elevation from the selected points, thus giving points as *e'* and *f'*, and set out the heights above *XY* of *e'* and *f'*, etc., along perpendiculars to *cd*; thus *eE* is made equal to the height of *e'* and *eF* equal to the height of *f'* above *XY*. A free-hand curve through the points thus obtained gives the outline of the face mould.

When the plank has been cut to the shape of the face moulds, a *falling mould* is often used to wrap on the soffit (underside of head) or on the parallel extrados surface, so that the outside and inside cylindrical surfaces can be cut. This falling mould is the development of a portion of a cylinder, and the method of drawing it is shown at the extreme left of the plan. The method of developing a surface of this kind has already been explained, but it may be noted that the width, as at *KL*, is projected from the plan, and that the length of the falling mould is obtained by stretching out the elevation curve; thus *GF* is made equal to *g'f'*.

If the surrounding arch is of brick or stone,

the outside vertical surface of the wall can be developed to show the true shapes of the faces of the arch stones, or *voussoirs*. Choose a number of points, as 1'2' and 3'4', on the elevation of the arch, and project these points on to the plan curve, giving points 1, 2, 3, 4. Make a stretch-out of the plan curve with these points on it. Project upwards from the points 1, 2, 3, 4, on the stretch-out to meet horizontal lines from the corresponding points elevation. Lines drawn through the points 1', 2', 3', 4' thus located give the development of the face of the arch and the true shapes of the *voussoirs*. The approximate development of only one radial joint, *MN*, is shown.

Conoid with Plane Semicular Directrix. The simplest kind of conoid, or cuneoid, is shown in Fig. 181, (A) being the plan and (B) the elevation. It is a surface swept out by a horizontal line which moves so that it always touches a vertical line *AB* and a semicircle *CDE*. The vertical line and the semicircle are each known as a *directrix*, because they direct the moving horizontal line that generates the conoidal surface. The curved directrix is, however, not necessarily a plane semicircle; it may be an ellipse or any other suitable curve. (See also section on "Joinery.")

An example of a conoid occurs in the soffit of the head of a circle-on-circle frame having radiating jambs and a level soffit at the apex, and the method of obtaining the development of the surface is shown in Fig. 181. Assume the surface to be divided into horizontal strips by the generating lines shown in plan and elevation. If the bottom strip is hinged, or developed, about its lower edge, *bF* will fall at right angles to *bE*, and will be equal to *a'f'* in elevation. Point *G* on the development can now be located by two radii, the first struck from *F* and equal to *bg*, and the second with centre *E* and radius *e'g'*. The other strips can be built up one on the top of the other in a similar manner, taking note that the true lengths of the horizontal generators are always given in plan and the true lengths of the small curved arcs are shown in elevation.

Head with Radiating Jambs and Level Soffit. The circle-on-circle head shown in Fig. 182 is

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based on the conoid already explained, and is for a wooden door or window frame. The intrados (soffit) and extrados surfaces lie on the surfaces of two conoids having a common vertical directrix. First, consider the outer soffit curve, of which the springing is at a . As the distance aa is less than bb , and as bb is a semicircle in elevation, the soffit edge will *not* be a true semicircle in elevation. In fact, no

along the generators; thus, bf is equal to $b'f'$ and HG is equal to hg .

Head Circular in Plan and Elevation. In the head shown in Fig. 183, the most prominent edge ($a'b'a'$) is a *semicircle*. The extrados curve may also be a semicircle, but this would mean that the *actual* width of the head at the springing would be greater than at the crown; and if the plan curve were "quick," this difference would

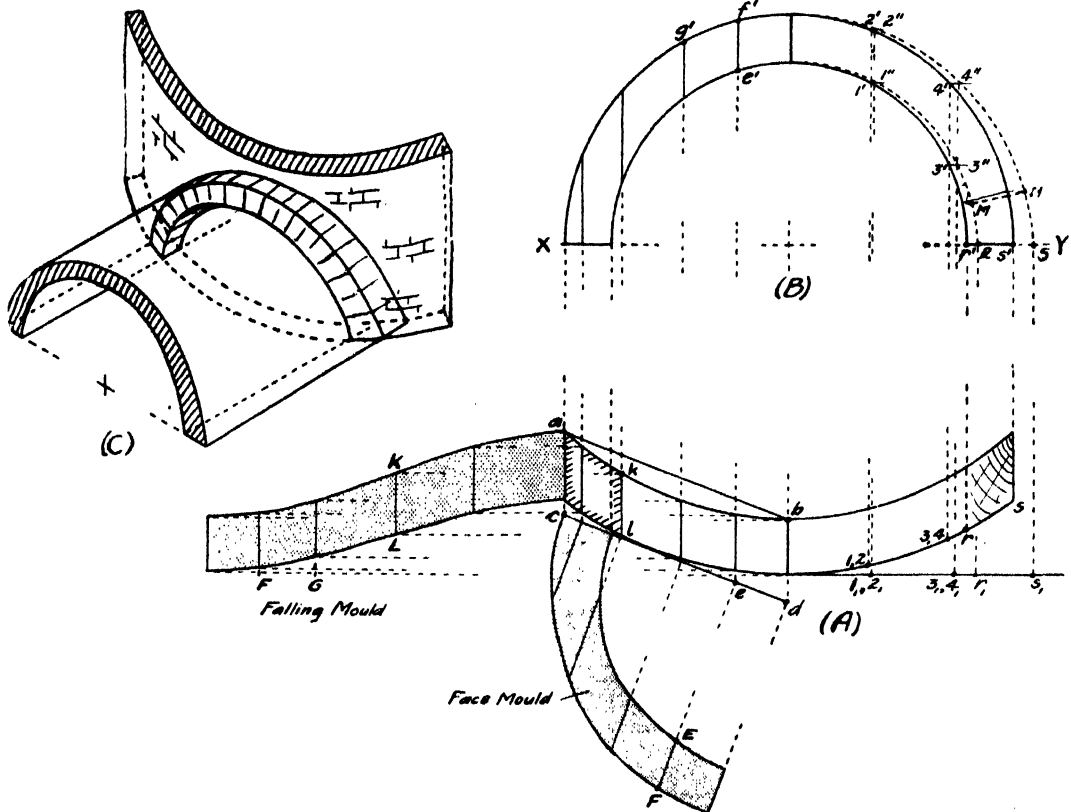


FIG. 180. CIRCLE-ON-CIRCLE HEAD WITH PARALLEL JAMBS

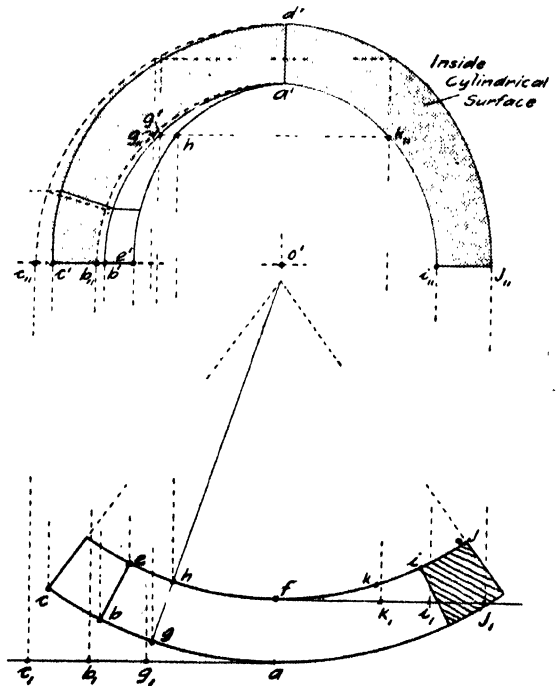
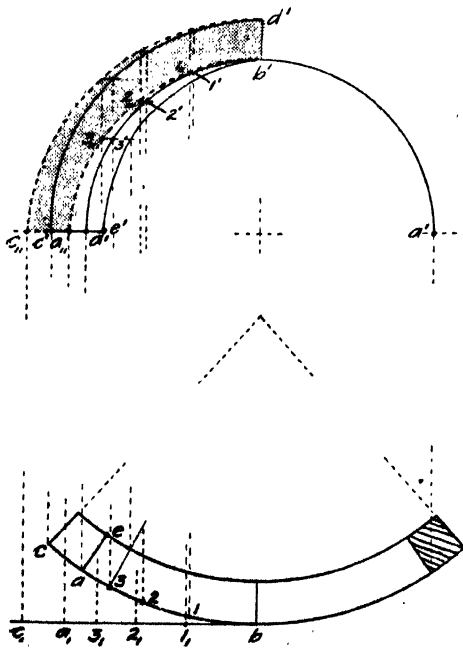
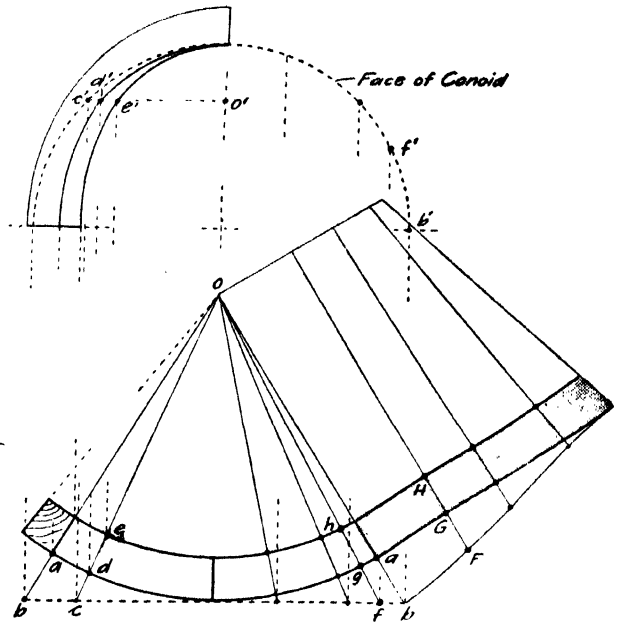
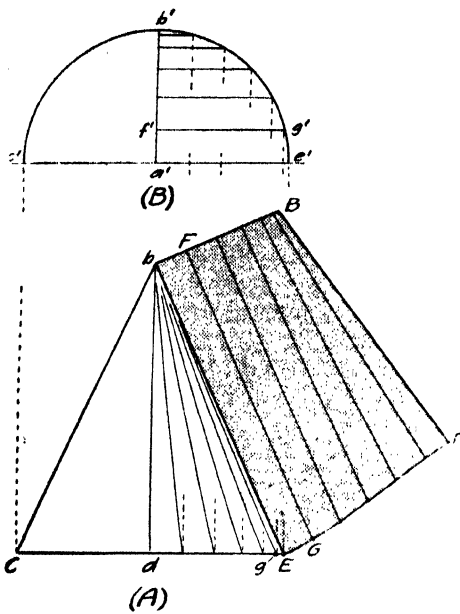
edge in elevation is a semicircle. However, this so-called circle-on-circle head is the commonest type used in practice.

To obtain the elevation of the soffit edge, draw a number of generators, as $oc, o'c'$, in plan and elevation. The plan oc of the generator cuts the front of the head at d ; then d' is a point on the elevation of the edge required. Similarly, e' gives a point on the inside soffit curve. Note that $d'e'$ is level.

The soffit can be developed by first proceeding as in Fig. 181, to obtain the development of the conoid, and then setting out the plan distances

be very marked. Make the widths at ac (plan) and $b'd'$ (elevation) equal to the required parallel width (in development) of the head. By projecting upwards from c , the width $a'c'$ in elevation at the springing is obtained. As the extrados curve is frequently not very important, it could in most cases be drawn between c' and d' by using the compasses or freehand. Such a curve is not, however, really circular, and the true method of drawing an extrados curve that is parallel in development to the curve $a'b'$ will now be given.

Obtain the development of $a'b'$ by considering



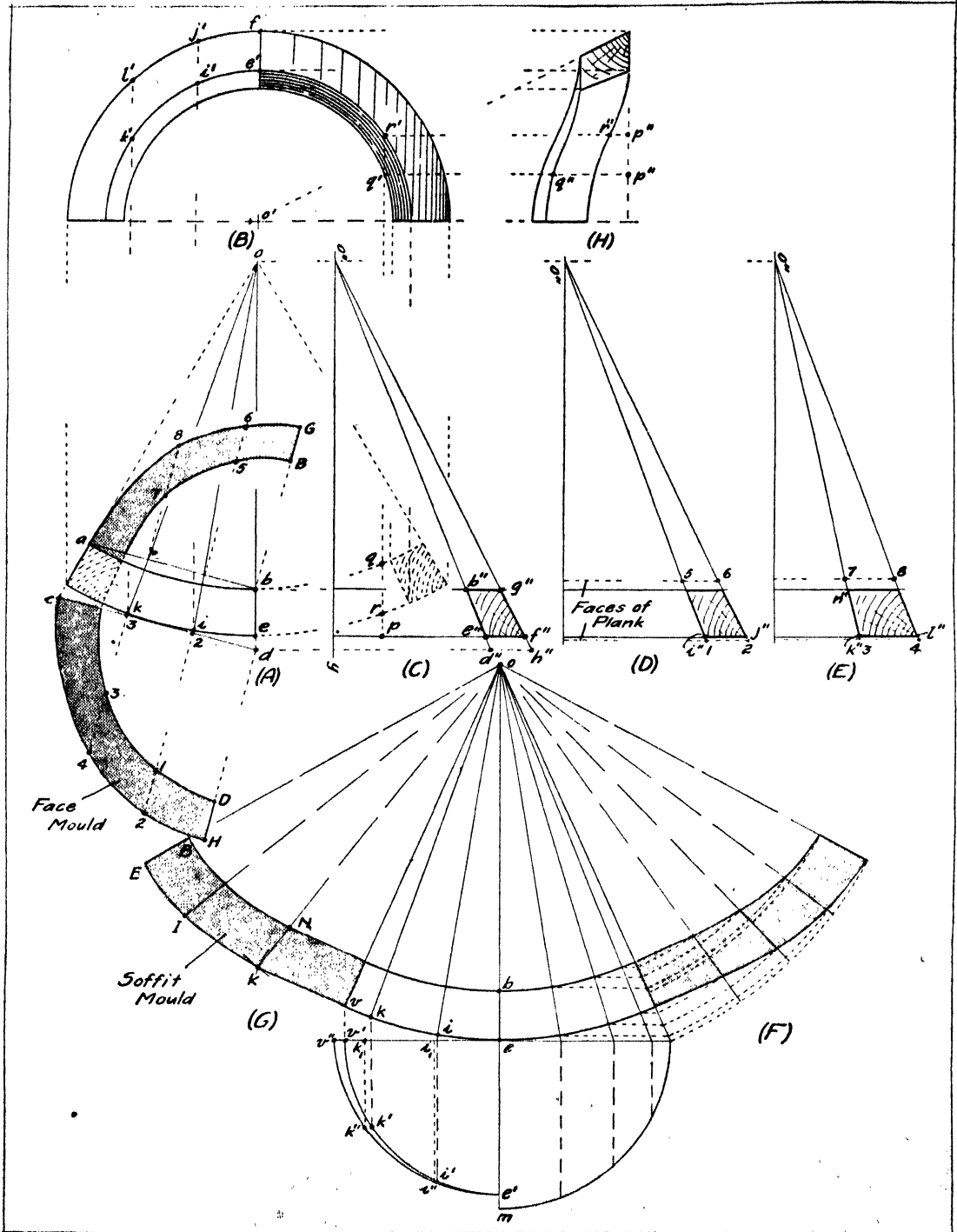


FIG. 185. TRUE CIRCLE-ON-CIRCLE HEAD WITH RADIATING JAMBS AND SOFFIT.

the vertical cylindrical surface on which it lies to be developed into the vertical plane. To do this, a number of points as 1, 2, and 3 are selected on ab , and the stretch-out ba , of this line is thus obtained. By projecting upwards from the points a , 1, 2, and 3, on the stretch-out, and horizontally from the points a' , 1', 2', 3', in elevation, points on the developed curve $b'a''$ are obtained. This developed curve is shown dotted. A curve $d'c''$, parallel to $b'a''$ is now drawn to represent the extrados line in development; and the latter line is then folded back on to the vertical cylindrical surface. The geometrical construction for this reverse operation should be obvious from the figure.

The curve $b'e'$ is obtained as in Fig. 182, and the soffit can be developed as already explained.

Arch with Face Semicircular in Development.

With stone arches it is usually advisable to have both elevation curves *circular in development*. Thus, in Fig. 184, the plan of a stone arch is given, and the elevation has to be drawn. The curved lines ab and ac are first stretched out along ac' . With o' as centre, and ab , and ac' as centres, describe the curves $c''d'$ and $b''a'$. These are the developments of the intrados and extrados curves of the face of the arch. Fold these curves back on to the cylindrical surface of the wall to give the elevation of the arch. The curve $e'a'$ can easily be drawn by making lines, as $g'h'$, level and projecting up from the plan.

The inside curves, as shown at $fkij$ in plan, are developed by first obtaining the stretch-out of the curved plan line. The developed inside cylindrical surface gives the shape of the stones on the inside face of the wall.

Head with Radiating Jambs and Soffit. A circle-on-circle head for a door or window frame is required as shown in plan (A) and elevation (B), Fig. 185. The elevation of the face of the head consists of two true semicircles, and all straight lines on the soffit and extrados radiate from the cone apex o .

Suppose it is required to find the *face moulds* as would be required for making half the head in timber. Draw a line ab and another line cd parallel to it; these two lines represent the faces of the plank from which the head will be cut, and the perpendicular distance between the lines gives the thickness of the plank.

Now draw a vertical section, as at (C), through the centre joint. To do this, take $o''y$ as ground line, project from e , and set up the heights of e' and f' given in elevation; points e''

and f'' are thus obtained. Draw radial lines from o'' to e'' and f'' . Project from the corner b to get $b''g''$, thus giving the section of the head at the joint. Similarly, by projecting from plan d , points $d''h''$ are obtained. Points $b''g''$ are on the inner face mould, and $d''h''$ are on the outer face mould.

Obtain a number of radial sections of the head, as on the lines $o2$ and $o3$, to locate other points on the face moulds. These sections are shown at (D) and (E), the heights of points $i''j''$ and $k''l''$ being obtained from the elevation. By drawing the radial lines to these points, the height points where these lines intersect the faces of the plank are obtained. The heights thus found from the sections are set up at right angles to ab and cd , and curves are drawn through the points thus located. The face moulds now being drawn, they can be applied to the faces of the plank, and the soffit and extrados of the head can be cut. (See also "Joinery," Chapter VIII.)

Two methods of obtaining the *soffit mould* are shown at (F) and (G), the plan of the soffit being reproduced for clearness. The method at (F) assumes that the soffit is part of a right circular cone, em being the radius of the base. This assumption is not correct, but the method is simple, and should be obvious from the illustration and the instructions already given on developing truncated cones.

The method depicted at (G) is not based on any incorrect assumption, and is geometrically correct. The arc ev is the plan of the outside soffit edge, and is a quarter circle in elevation, as shown at $e'v'$. The arc ev is shown stretched out at ev'' , and the development of the quadrant is shown at $e'v''$. This curve, or quadrant, before development lies on a vertical cylindrical surface, but when developed it lies on a flat plane and shows the true distances between the points $e-i$, $i-k$, and $k-v$ on the soffit edge. Note that the locus lines, as $k'k''$, are horizontal.

With v as centre and $v''k''$ as radius, describe an arc to cut another arc described from o as centre and radius $o''k''$, the latter distance being obtained from section E . Point K is thus obtained. Make KN equal to $k''n''$. The other two portions of the soffit mould are built up in a similar manner. Note that EB is equal to $e''b''$.

A side elevation of half of the head is shown at (H). This is projected by taking a number of points as r and q on the plan curves, projecting upwards to obtain the elevations r' and q' , and then projecting horizontally. Note that the distance $p''r''$ equals pr , and $p''q''$ equals pq .

Building Science

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Chapter I—CHEMISTRY OF BUILDING MATERIALS

Introduction. A detailed examination of the substances available for use as building materials, and of their resistance to various forms of corrosion, involves a knowledge of their chemical and of their physical properties. It will be convenient if we deal with the chemical aspects

chemical differences. These can be revealed to a certain extent by the use of the microscope.

In Fig. 1 we have a photomicrograph of a cross section of granite from Rubislaw, Aberdeen, in which three distinct crystalline substances can be observed. Geologically, we find that



FIG. 1. PHOTOMICROGRAPH OF RUBISLAW GRANITE
(ABERDEEN)
Showing crystal structure



FIG. 2. PHOTOMICROGRAPH OF BATH STONE
Showing rounded (oolitic) grains of calcium carbonate

first, including in our study any microscopical evidence available to us.

A simple experiment will demonstrate the essential difference between limestone (or marble) and the much harder building stone—granite. If we pour a comparatively strong acid, such as hydrochloric acid (spirits of salt), on to a small portion of each of these substances we find that the acid has little or no effect on the granite, but rapidly attacks the other stones, destroying the fabric and causing the evolution of a gas which we term carbon dioxide (carbonic acid gas). Apart, therefore, from any physical differences which exist in the stones, there are definite

there are three principal crystalline minerals usually to be found in granites, which are termed *felspar*, *quartz* and *mica*. Felspar and mica are found to be complex chemical substances produced by the fusion of sand (silica) with other materials found in the earth's crust, and they are known as silicates; quartz, on the other hand, is just crystalline silica (SiO_2), one of the most resistant and refractory materials known to us. The sand of the seashore is composed almost entirely of this material. The dense compact nature of granite has been produced by the slow cooling of fused masses of rock below the earth's surface, resulting in the formation of very hard crystalline masses.

Neither felspar, mica, nor quartz, is appreciably attacked by hydrochloric acid.

If we examine a photomicrograph of Bath limestone (Fig. 2) we find a totally different structure. We have here a partly crystalline mass in which the main bulk of the stone consists of rounded grains, resembling the eggs in the roe of a fish. It is this shape of the particle which has led us to call the Portland and Bath stones *oolitic limestones*.

Chemically they consist mainly of a material—calcium carbonate (CaCO_3)—very widely distributed over the earth's surface. The cliffs of Beachy Head; the "middle-chalk" quarried at Beer in Devon; the white marble of Carrara;

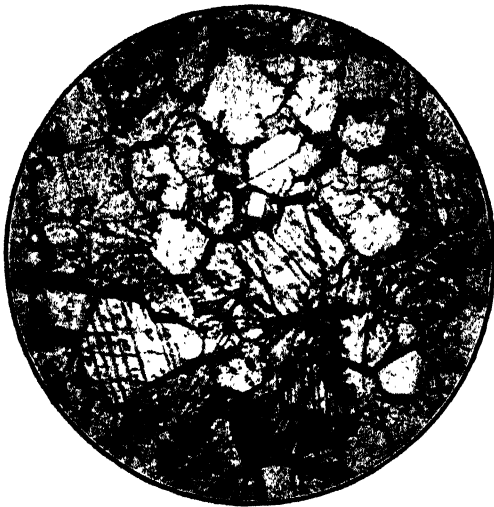


FIG. 3. PHOTOMICROGRAPH OF CARRARA MARBLE Showing crystalline calcium carbonate

the dark marbles and hard limestones of the Devon quarries; the coral and shell formations slowly forming on the bed of the ocean; and the stalactites and stalagmites of a limestone cave are all examples of the part played by calcium carbonate in the formation of the earth's crust.

In Fig. 3 we have a photomicrograph of the white crystalline calcium carbonate found at Carrara in Italy, consisting almost entirely of calcium carbonate. In this photograph we find no evidence of the oolitic structure which is the characteristic of Bath and Portland stone. Instead, we have a close-grained crystalline structure, differing from that of granite in containing only one type of material instead of three.

Both this and Bath stone—in fact, all materials containing CaCO_3 —are readily attacked by

acids, with the consequent deterioration and corrosion of the stone.

Elements and Compounds. From these considerations alone it will be obvious that we must pay some attention to the chemical nature of matter before proceeding to any intimate study of building materials.

Certain substances, such as iron, carbon, sulphur, calcium, oxygen, nitrogen, zinc, and lead, are defined as *elements*. They resist all attempts to separate them into new and simpler substances. If these elements were merely mixed together in building materials, their separation would be simple. They are frequently, however, more intimately connected one with another, and such combinations of elements are termed *compounds*.

Thus, white lead is a compound of lead, carbon and oxygen; quicklime is a compound of calcium and oxygen; marble consists mainly of calcium carbonate, which is a compound of calcium, oxygen and carbon.

Symbols. To facilitate our studies of the chemistry of Nature we devise symbols to designate the elements, and in this kind of chemical shorthand we are able to express not only the simpler statements of chemical combination, but also any numerical considerations involved. This is rendered possible by our conception of *atoms* and *atomic weights*. We find by very careful analysis that the atom of the element carbon is approximately twelve times

TABLE I
CHIEF ELEMENTS CONNECTED WITH
BUILDING MATERIALS

Name	Symbol	Approximate Atomic Weight
Aluminium	Al	27
Barium	Ba	137
Calcium	Ca	40
Carbon	C	12
Chlorine	Cl	35.5
Copper	Cu	63
Hydrogen	H	1
Iron	Fe	56
Lead	Pb	207
Magnesium	Mg	24
Nitrogen	N	14
Oxygen	O	16
Potassium	K	39
Silicon	Si	28
Silver	Ag	107
Sodium	Na	23
Sulphur	S	32
Tin	Sn	119
Zinc	Zn	65

MODERN BUILDING CONSTRUCTION

as heavy as the atom of the element hydrogen, while the atom of the element calcium is practically forty times as heavy. We can write, therefore (in our chemical shorthand), Carbon as C, Hydrogen as H, Calcium as Ca, Oxygen as O, and so on.

Moreover, we agree to indicate by the symbol C one atom of Carbon, whose atomic weight is 12; by Ca one atom of Calcium, whose atomic weight is 40; and by O one atom of Oxygen,

and (12 + 32) parts of carbon dioxide. This follows from the fact, expressed in the equation, that chalk consists of one atom of calcium, one atom of carbon, and three atoms of oxygen; that quicklime contains one atom of calcium and one atom of oxygen; that carbonic acid gas contains one atom of carbon and two atoms of oxygen.

So that, returning to our calculation, 100 parts of pure calcium carbonate will yield 56

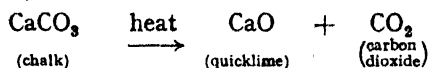
TABLE II
SOME COMMON SUBSTANCES WITH FORMULAE

Common Name	Chemical Name	Geological Name	Formula
Ammonia	Ammonium Hydroxide	—	NH ₄ OH
Sal Ammoniac	Ammonium Chloride	—	NH ₄ Cl
Alum	Potassium Aluminium Sulphate	—	K ₂ SO ₄ , Al ₂ (SO ₄) ₃ , 24H ₂ O
Carbonate of Lime	Calcium Carbonate	Chalk, Marble, Limestone	CaCO ₃
Chloride of Lime	Calcium Hypochlorite	—	CaOCl ₂
Carbonate of Magnesia	Magnesium Carbonate	Magnesite	MgCO ₃
Chrome Yellow	Lead Chromate	—	PbCrO ₄
Epsom Salts	Magnesium Sulphate	—	MgSO ₄ .7H ₂ O
Glauber's Salts	Sodium Sulphate	—	Na ₂ SO ₄ .10H ₂ O
Green Vitriol	Ferrous Sulphate	—	FeSO ₄ .7H ₂ O
Heavy Spar	Barium Sulphate	Barytes	BaSO ₄
Litharge	Lead Monoxide	—	PbO
Nitre	Potassium Nitrate	Saltpetre	KNO ₃
Quicklime	Calcium Oxide	—	CaO
Red Oxide of Iron	Ferric Oxide	Haematite	Fe ₂ O ₃
Red Lead	Red Lead	—	Pb ₂ O ₃
Salt	Sodium Chloride	Rock Salt	NaCl
Spirits of Salt	Hydrochloric Acid	—	HCl
Silica	Silicon Dioxide	Quartz, Sand	SiO ₂
Slaked Lime	Calcium Hydroxide	—	Ca(OH) ₂
Sulphate of Lime	Calcium Sulphate	Gypsum	CaSO ₄ .2H ₂ O
Vinegar	Acetic Acid	—	CH ₃ .COOH
Washing Soda	Sodium Carbonate	—	Na ₂ CO ₃ .10H ₂ O
White Lead	Basic Lead Carbonate	—	Pb(OH) ₂ . PbCO ₃
White Vitriol	Zinc Sulphate	—	ZnSO ₄ .7H ₂ O
Zinc White	Zinc Oxide	—	ZnO

whose atomic weight is 16. A short table of the chief elements found in building materials is given in Table I.

Chemical Equations. Chemical calculations are thus rendered much more simple than if a system of words was required.

For example, when chalk or limestone is heated, quicklime is produced and the gas, carbon dioxide, is driven off. This, in our system of symbols, becomes—



If we give to the elements represented here their atomic weights, we find that (40 + 12 + 48) parts of chalk yield (40 + 16) parts of quicklime,

parts of quicklime, when suitably heated. This, expressed in suitable units of weight, means that 100 grm., or oz., or tons of CaCO₃ yield 56 grm., or oz., or tons (respectively) of quicklime; or, in another form, that 56 per cent of CaCO₃ is quicklime.

In the same way the decorator's colouring material, "rouge," which is iron oxide, Fe₂O₃, contains two atoms of iron combined with three atoms of oxygen. Calculating as before, 2 × 56 parts of iron are combined with 3 × 16 parts of oxygen; or 112 parts of iron are united with 48 parts of oxygen; or 160 parts of iron oxide contain 112 parts of iron; or the percentage of iron in iron oxide (Fe₂O₃) is 70 per cent.

Enough will now have been said to indicate

the nature of, and method of using chemical formulae, and it may be interesting to draw up a list (Table II) of common substances, with their names and formulae, for reference purposes.

THE ATMOSPHERE

Constituents of the Atmosphere. A knowledge of the composition of the atmosphere is essential to an accurate understanding of the basic principles underlying the problems associated with the corrosion of building materials.

If clean iron wire is allowed to rust in a volume of air enclosed in a glass inverted over water, it will be found that after a long period the water will have risen in the vessel by about one-fifth the volume of the vessel. An examination of the residual gas reveals the fact that it is no longer capable of supporting the combustion of a taper or match, and that in general it is inert. From this and other experiments we conclude that air consists of a mixture of two different gases in the proportion of one part of active gas (*oxygen*) to four parts of inactive gas (*nitrogen*), approximately.

There are, however, a number of other constituents of the atmosphere which are of direct interest to us. Thus we find—

- (a) Water vapour.
- (b) Carbon dioxide.
- (c) Suspended dust and soot.
- (d) Ammonia.
- (e) Acid fumes, in cities.

WATER VAPOUR. The air is capable of holding in suspension comparatively large quantities of water vapour. For example, one cubic metre of air will contain, when saturated with water vapour at 0° C., 4.87 grms.; at 10° C., 9.36 grms.; at 20° C., 17.16 grms.; and at 30° C., 30.09 grms. One cubic mile of air, saturated with water vapour at 35° C. would, if cooled to 0° C., deposit approximately 140,000 tons of rain, because at the lower temperature it could not contain the quantity which would remain suspended at higher temperatures. The deposit of moisture on the inside of shop windows in winter; the "sweating" of cisterns, walls and ceilings when warm winds follow a period of frosty weather; and the deposit of dew on grass after sunset, caused by the rapid cooling of the ground by radiation, are all examples of the deposit of excess moisture from the air on any surface capable of cooling the air below its saturation limit.

CARBON DIOXIDE. This gas occurs naturally

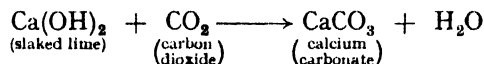
in the atmosphere to the extent of about 3 parts per 10,000, although in crowded rooms the quantity may reach ten times that amount.

It is the result of combustion, respiration and putrefaction, in each of which processes the carbon of substances becomes oxidized to CO₂. Thus, in the burning of coal and coke, the direct combination of carbon and oxygen results in a liberation of heat energy and the setting free of carbon dioxide. In the process of respiration, compounds containing carbon are similarly oxidized, and exhaled air contains on an average about 4 per cent of CO₂. These points are of importance in ventilation problems.

The gas does not appear to be an active poison, but rather a comparatively inert substance which affects the human being by depriving the lungs of the active gas, oxygen.

In contrast to this, the other gaseous oxide of carbon, carbon monoxide (CO), is an actively poisonous substance. This gas does not occur naturally in the atmosphere, but is found in the gas supply of many towns, and frequently in the exhaust gases of internal combustion engines, in which it occurs due to incomplete combustion. It forms with the haemoglobin of the blood a very stable compound which we term *carboxy-haemoglobin*, and which, when once formed, interferes with the normal action of the haemoglobin as an oxygen carrier.

The presence of the carbon dioxide in the air makes possible the use of a mixture of slaked lime and sand as a binding material between masonry courses. Ordinary mortar depends upon the CO₂ in the air for the conversion of the slaked lime into hard calcium carbonate. The chemical equation representing this reaction is—



It is obvious, therefore, that the old-fashioned mortar could not be used as a binding material for underwater work, as its setting depended upon the presence of carbon dioxide, and would, therefore, not set under water.

To meet this difficulty, hydraulic cements have been introduced which set in the presence of water and are independent of the carbon dioxide of the air (see later).

SUSPENDED DUST AND SOOT. The city "fog" consists mainly of mist (fine particles of water vapour) condensed on floating nuclei of dust. The nature of this suspended solid matter may be judged from a chemical analysis of the sooty

MODERN BUILDING CONSTRUCTION

deposit left after fog, which reveals the presence of carbon (soot), oily matter, sulphuric acid, iron and iron oxides, and silica (sand).

Researches carried out in London by Dr. J. S. Owens in connection with the question of atmospheric pollution reveal the extent to which the domestic fire adds to the impurities of the atmosphere. It is calculated that over an area round London and up to a height of 400 ft., a 4-hr. fog contains approximately 190 tons of soot. Every year about 17,000,000 tons of coal are brought to London, of which 7,000,000 tons are for domestic use.

If we take the average quantity of soot produced from home fires as 2 per cent of the quantity of coal consumed, and that produced from factory fires as less than $\frac{1}{4}$ per cent, we calculate at once that over 165,000 tons of soot fall over London in a year. Given ordinary winter temperatures, the London November fog is dependent mainly on the absence of air movement. The mean daily movement of the air past Greenwich is 280 miles—hardly more than a perceptible draught. If this movement drops to about 11 ft. per sec., or 200 miles a day, given winter conditions, a fog is certain.

The presence of sulphuric acid in the fog deposit is accounted for by the fact that all coal contains sulphur compounds, which on combustion produce sulphur dioxide, a gas having a suffocating odour and readily soluble in water. In the presence of water and the oxygen in the air this gas becomes converted into sulphuric acid, the chief corrosive agent responsible for the decay and deterioration of building stones.

AMMONIA. The presence of ammonia is noticeable where organic matter is allowed to stagnate (e.g. in ill-kept public lavatories). The quantity in the atmosphere at any particular time is usually very small, figures of three manufacturing towns being given below—

London	0.005	per cent	by weight	of air
Glasgow	0.006	"	"	"
Manchester	0.010	"	"	"

ACID FUMES. Reference has already been made to the presence of sulphuric acid in the fog deposits of large cities. Coal contains on an average some 67 lb. of sulphur per ton, mainly as pyrites (sulphides of iron and copper). The amount of sulphuric acid produced in this way is very considerable, and it has been estimated that some 400,000 tons of sulphuric acid are produced annually over London, a great portion of which descends in rain and fog upon the

buildings of the metropolis. All carbonate materials (Portland stone, Bath stone, etc.), Portland cement, most metals, and many other substances are attacked by this corrosive acid.

In addition a further problem occurs in towns (such as Widnes, for example) where chemical manufactures are centred. In chemical areas, the air may be still further polluted by active gases such as chlorine, hydrochloric acid, and similar products; and though each single factory may be conforming to the official requirements regarding the pollution of the air, the cumulative effect is to produce an atmosphere containing considerable quantities of matter of a corrosive nature.

Recent figures available for London air indicate the extent to which climatic conditions influence the amount of acid impurity in the air.

SULPHUR DIOXIDE (SO₂). On a fine November day—one volume of sulphur dioxide in two and a half million volumes of air.

On a foggy November day—one volume of sulphur dioxide in one million volumes of air.

SULPHUR TRIOXIDE (SO₃). The amounts of sulphur trioxide present in the air on an average day in different towns are shown in Table V—

TABLE III

London	25.7 to 62.2	pts. SO ₂	per million	pts. air
Glasgow	20.9 to 28.9	"	"	"
Hull	45.9	pts.	"	"
Liverpool	44.1	"	"	"
Newcastle	36.0	"	"	"
St. Helens	32.8	"	"	"
Southport	14.7	"	"	"
Malvern	10.0	"	"	"

This will ultimately descend in the rain as sulphuric acid, causing damage to marble and limestone surfaces.

WATER

Pure natural water should be clear and transparent, free from taste and smell. A classification of drinking waters (Table IV) based on their degree of purity is a fairly satisfactory one.

Spring Water. This water is frequently calcareous (hard) and often chalybeate, due to dissolved iron. The brown incrustation frequently found around the spot from which the water is issuing consists largely of oxide and hydroxide of iron (Fe₂O₃ and Fe(OH)₃).

Deep Well Water. This is a very satisfactory source of supply, particularly in sandstone areas. The water may be hard, due to the presence of dissolved salts, but its passage through the

strata of rock effectively filters it from undesirable substances. Water from wells more than 100 ft. deep is considered safe for drinking purposes (due to the filtering effect of the rock strata), provided the well is efficiently lined and contamination by surface water prevented. Artesian wells, named after the village of Artois, France, at which the first well of this kind was constructed, tap an underground reservoir under pressure, and as water tends to "find its own level," the steady flow from a well of this nature often assumes large proportions.

TABLE IV
CLASSIFICATION OF DRINKING WATERS

Degree of purity	Origin of water	Nature of water
1. Wholesome	(a) Spring water (b) Deep well water (c) Upland surface water	Very palatable
	(d) Stored rain water	
2. Suspicious	(e) Surface water from cultivated land	Moderately palatable
3. Dangerous	(f) River water (g) Shallow well water	Palatable

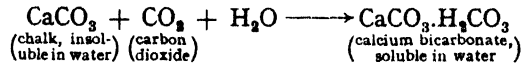
The deep well must not be confused with the shallow well, frequently only 20 ft. in depth, which merely collects subsoil water, often of very doubtful purity.

Upland Surface Water. To-day it is not uncommon for the authorities in a large city to trap, by means of a masonry dam, large quantities of clean mountain and upland water, and to convey such water across country by means of cement conduits, for the use of the city.

For example, the Dartmoor reservoir at Burrator provides Plymouth with upland water, and the Birmingham Corporation, by trapping water in the Elan Valley in Mid-Wales, supply Birmingham with some 75,000,000 gals. of good water per day.

Such water is frequently comparatively soft, due to the absence of dissolved calcium compounds. The standard "degree of hardness" in water is the solution of one grain of calcium carbonate per gallon of water, and it has been agreed that water containing six grains or less per gallon (6° hardness) shall be considered *soft* water, while more than six grains per gallon constitutes *hard* water.

The solution of calcium carbonate (CaCO₃) in water is rendered possible by the presence of carbon dioxide (CO₂). Thus—

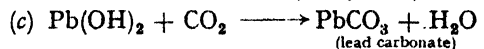
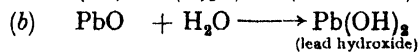
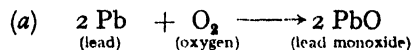


The substance calcium bicarbonate is colourless and soluble in water. It is usually spoken of as *temporary hardness*, because on boiling the water it decomposes, carbon dioxide escapes, and white insoluble calcium carbonate is precipitated. This is the origin of boiler incrustation, and of the "fur" in the kettle. *Permanent hardness* is due to dissolved calcium and magnesium sulphates, which are not removed in the same way on boiling the water.

Several methods of softening water are employed to-day. *Clark's method* consists of adding to the water 1 oz. of quicklime per 700 gals. of water for every degree of hardness present in the water. The quicklime combines with the loosely combined CO₂ in the calcium bicarbonate, and is precipitated as CaCO₃; in doing so this action decomposes the bicarbonate, so that the calcium in that is precipitated as insoluble CaCO₃ also

Other ways are: (a) by the addition of sodium carbonate (Na₂CO₃) to the water. This, however, causes frothing and pitting of the boiler plates when employed in boilers, and therefore (b) barium carbonate (BaCO₃) is sometimes employed for a similar purpose; (c) by the modern *Permutit* process, in which complex silicates precipitate the temporary and the permanent hardness together.

It should be noted that one important difference between hard and soft waters is their effect on lead. Hard waters coat lead pipes with a kind of protective skin of lead sulphate, whereas soft water dissolves lead progressively and continuously. The reactions are probably complex, but it is suggested that dissolved oxygen and carbon dioxide in the water may account for the action. The chemical equations may possibly be of this nature—



The lead carbonate so produced is not an adherent skin on the surface of the pipe, but is loose and may be carried along by the water.

Chapter II—BUILDING MATERIALS

THE study of building materials naturally divides itself into the following subdivisions—

1. Natural building stones.
2. Cements and plasters.
3. Concrete in general.
4. Bricks.
5. Constructional metals.
6. Miscellaneous materials.

For the purpose of classification we shall adopt this scheme, and deal in this and following articles with the various sections.

in this respect they differ from the crystals of quartz, which form the main bulk of a sandstone. We shall see later that on the nature of the cementing material, which serves to unite the sandstone grains, depends the life and utility of the stone. In granite no such point arises. The stone is very hard, very compact, and has a porosity in the region of 0·8 per cent.

Granites are worked in the neighbourhood of Aberdeen and Peterhead in Scotland, in the West of England, Worcestershire and Leicestershire, and in the Channel Islands.



FIG. 4. GRANITE (MOUNT SORREL, LEICESTERSHIRE)

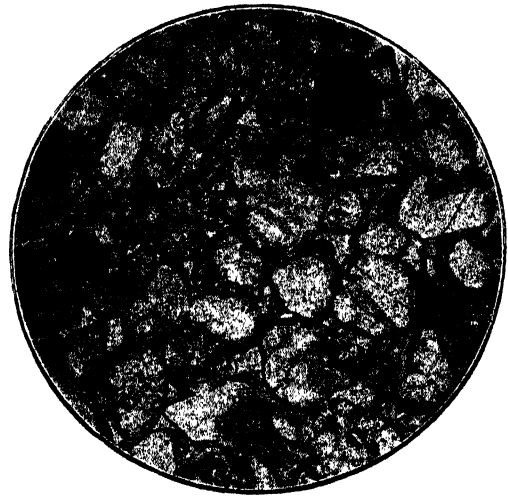


FIG. 5. RECRYSTALLIZED SANDSTONE (OLD QUARRY, PENRITH)

NATURAL BUILDING STONES

These include the granites, sandstones, and limestones (including marble).

Granites. Granite is one of the *igneous* rocks, having been formed by the fusion of rocky matter deep within the earth's crust. Subsequent slow cooling has caused the fused mass to solidify in large crystals, consisting mainly, as has already been stated, of three minerals—quartz, mica, and felspar. A photomicrograph of granite from Mount Sorrel, Leicestershire (Fig. 4), indicates the manner in which these crystals are (as it were) welded together. In

Aberdeen granite is usually of a compact, bluish-grey colour; it has been used in Trafalgar Square, London, and in London Bridge. Rubislaw granite is of a dark, greyish-blue (see Fig. 1), and was employed for the balustrade of the old Waterloo Bridge.

Peterhead granite is usually a dark, flesh colour, and it is interesting to note that the colour of a granite is almost entirely due to iron and other compounds occurring in the felspar. The quartz portion is nearly always semi-transparent and smoky in colour; the mica occurs in flakes either black or white; the felspar

may be white, but is frequently coloured and imparts this colour, in the mass, to the stone.

In the West of England the granite now worked is grey, and the Penryn Mass, in Cornwall, is responsible for the Embankment Wall, London, and was used in Vauxhall Bridge and in the New County Hall, Westminster.

Kirkcudbright granite is usually pale grey. The Mount Sorrel deposits in Leicestershire are practically unused as constructional material, but owing to their hardness are largely employed as "road metal."

Shap Fell, in Westmorland, consists of a mass of brownish-red rock, coarse in structure, of which the columns in St. Pancras Station, London, were constructed.

An average *mineral* analysis of granite shows the following figures—

	Red Granite	Grey Granite
Felspar	50% to 70%	50% Average
Quartz	23% to 35.5%	37.5% "
Mica	47% to 11.3%	12.4% "

CORROSION OF GRANITE. The disintegration of granite in town atmospheres is largely physical, there being little chemical action between the stone and atmospheric impurities. The effect of heat on granite is well illustrated by the condition of the plinth of the Nelson Column in Trafalgar Square. The surface has been destroyed in places by successive flaking under the action of heat, due to the celebration bonfires of Armistice Night, 1918. The coefficient of cubical expansion of quartz is 0.000036, and that of felspar is only 0.00017. Hence the effect of excessive heat is to cause internal stresses in the mass due to uneven expansion of the crystals, with the result that the free surface flakes. In granites suitable for use as building material, the constituents should be as nearly as possible equi-dimensional. The "weathering" of granite under natural conditions is a partial decomposition of the complex aluminium silicates called felspars, which are attacked by exposure, the soda or potash portion dissolving and leaving behind a complex hydrated silicate of alumina known as *china clay*. The mica and quartz remain practically unaltered.

Sandstones. These are what are called "sedimentary" rocks. They are the result of pressure and other influences on the products of denudation of other rock masses. For example, a

microscopic examination of the deposits of sand now in process of formation at the Mersey mouth, has shown them to consist of the fragments of rock from Whernside, Penyghent, Ingleborough, and other parts of the Pennine Range.

As a result of the process of denudation, the separate sand grains ultimately settle elsewhere, and the obvious essential for conversion of the loose sandy deposit, into what we know as a sandstone, is a suitable cementing material between the grains.

Such cementing material may be—

- (a) Chalky (calcareous).
- (b) Clayey (argillaceous).
- (c) Siliceous (of the nature of sand itself).

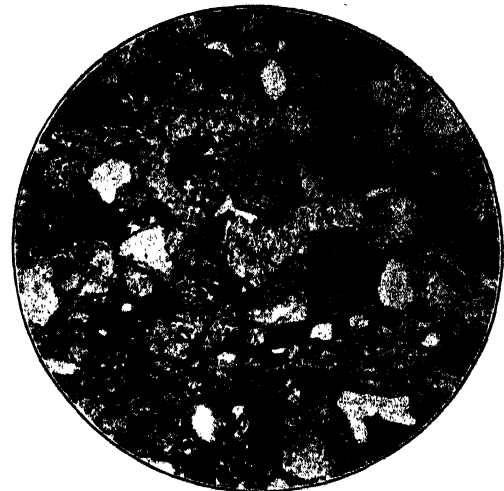


FIG. 6. PHOTOMICROGRAPH OF A CALCIFEROUS SANDSTONE (EDINBURGH)

Only the latter type is of permanent value as a building material.

Fig. 5 is a photomicrograph of a recrystallised sandstone from the old quarry, Penrith. It shows clearly the individual grains of silica (SiO₂), separate one from another, but united by the cementing material between the particles.

Fig. 6 is a specimen of sandstone, having a calciferous binding material between the grains, found at the Holyrood end of Salisbury Crags, Edinburgh. Such stones are not as durable as those in which the binding material contains no calcite, since in the presence of acid atmospheres, the calcium compounds are destroyed and the sand grains loosened.

Probably the most durable sandstone known

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is that formerly quarried at Craigleith, near Edinburgh. This is a stone in which, probably under the influence of intense pressure and partial fusion, the sand grains have become almost welded together, as in the structure of

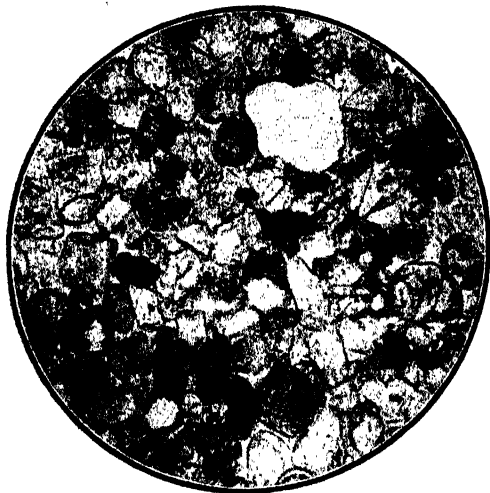


FIG. 7. QUARTZITE (CRAIGLEITH, EDINBURGH)

granite. It is, however, a sandstone as regards its mineral constituents. The photomicrograph (Fig. 7) illustrates this condition, and may be compared with Fig. 5, in which the grains are separate.

The sandstones and millstone grits of Yorkshire belong to the carboniferous system (the coal measures), and are considerably younger geologically than the granites, though much older than the limestones. Fig. 8 shows the structure of Stancliffe stone from Darley Dale.

CORROSION OF SANDSTONE. Given a satisfactory (i.e. siliceous) binding material, the main causes of corrosion in sandstones are physical; for example, the freezing of water in the pores of the stone results in a loosening of the surface grains, due to the expansive forces introduced when water freezes. In this connection it is interesting to note that a stone soaked in water has less power of resistance to a crushing stress than has a dry stone.

Limestones. Limestones, consisting largely of calcium carbonate (CaCO_3) are, by reason of their comparative softness, in great demand as building stones. Geologically they are the youngest of the natural building stones.

Under this heading are included the common

limestones, frequently fossiliferous and often distinctly crystalline in structure; the hard crystalline limestones, such as are found in the Devonshire formations, very suitable for building stone; the oolitic limestones of the Portland and Bath beds, shown in Fig. 9; and the marbles (capable of high polish), which may contain magnesium carbonate in addition to the CaCO_3 . An example of the latter is the Irish Connemara marble, shown in Fig. 10.

Portland Whitbed stone has been selected for Government buildings in the London area by the Office of Works. The arrangement of the beds at Portland is as follows—

Purbeck beds.

True roach—containing many fossil holes.

Whitbed—fine oolitic limestone.

Curf and flints.

Basebed roach.

Basebed—fine oolitic limestone.

It is peculiar that the Whitbed stone weathers better in London than does the Basebed.

CORROSION OF LIMESTONE. The presence of sulphuric acid in the atmosphere of cities is very deleterious to all limestones, since it rapidly



FIG. 8. STANCLIFFE STONE (DARLEY DALE)
A millstone grit (sandstone)

converts the calcium carbonate of the stone into calcium sulphate, thereby destroying the coherence of the stone as a constructional material.

Analysis of a specimen of Portland stone, from Hampton Court Palace, showed a large excess of calcium sulphate in the outer incrustation as compared with the centre of the stone;

and a sample of Bath stone, from the Hotel Metropole, London, showed 1·8 per cent calcium sulphate in the centre of the stone, and 38 per cent in the incrustations on the surface. Similarly, Sir Arthur Church found 73·8 per cent hydrated calcium sulphate in the black deposit formed

more resistant to corrosive influences and making it more impervious to water penetration.

A similar result is obtained by treating the stone with the substance known as "Silican Ester," which, on drying in the pores of the material, deposits hard silica (SiO₂), which acts



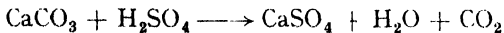
FIG. 9. PORTLAND STONE
(An oolitic limestone)



FIG. 10. MARBLE (CONNEMARA, IRELAND)

under the cornices in St. Paul's Cathedral, due to the action of the acid rain upon the limestone, of which the cathedral is constructed.

Chemically the reaction follows the equation—



Dolomitic limestones are limestones which contain magnesium carbonate (MgCO₃) in addition to the CaCO₃. Such a stone was used in the construction of the Houses of Parliament, and does not seem capable of resisting the acids of the London atmosphere.

Two important methods of treating constructional stonework, to prevent corrosion, have been developed during recent years.

One method is to wash the surface with a solution of one part of sodium silicate to four parts of water, allow to dry for twenty-four hours, and repeat the process three or four times. For this purpose, a so-called "neutral" sodium silicate is now marketed, containing a greater proportion of silica than ordinary "waterglass." The solution penetrates the stone to a depth of about half an inch, and produces in the pores hard calcium silicate, thus rendering the material

in a similar manner to the calcium silicate produced by treatment with waterglass.

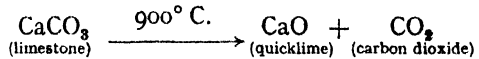
CEMENTS AND PLASTERS

Cements and plasters can be classified under the following scheme, shown in Table V.

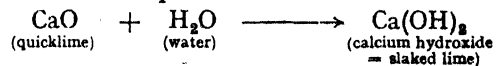
LIMES

Non-hydraulic Limes are carbonate materials which, as a result of heating, have lost their carbon dioxide and are able to recombine slowly with the CO₂ of the air, forming a hard binding material between the masonry courses.

The reaction which proceeds in the lime kiln is represented by the chemical equation—



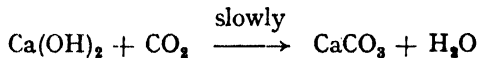
The resulting quicklime is supplied to the builder, who "slakes" it by the addition of water. The equation is—



This combination takes place with the evolution of much heat, and the resulting slaked lime,

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mixed with sand, constitutes the old fashioned "mortar." It depends for its binding properties on its power of absorption of carbon dioxide from the air with the resulting slow reformation of calcium carbonate; thus—



A **FAT LIME** is one which contains more than 85 per cent of active lime calculated as CaO (quicklime). For example, a Buxton lime shows on analysis figures similar to these—

CaO	98.7 per cent
Total SiO ₂	0.71 "
Alumina and Ferric Oxide	0.11 "
Magnesia (MgO)	0.46 "

A **LEAN LIME** contains a large percentage of silica (sand), iron, and other impurities, and is the result of heating a less pure limestone. Typical figures in comparison with those of fat limes are—

CaO	71.1 per cent
Total SiO ₂	23.54 "
Alumina and Ferric Oxide	1.64 "
Magnesia (MgO)	1.04 "

DOLOMITIC LIMES are formed by the heat decomposition of magnesian limestones or dolomites, stones which contain large percentages of magnesium carbonate (MgCO₃). Commercially they are known as magnesian limes, and show much higher percentages of magnesia (MgO) than other limes—

CaO	46.72 per cent
Total SiO ₂	2.94 "
Alumina and Ferric Oxide	1.90 "
Magnesia (MgO)	32.60 "

A fat lime slakes quickly, evolves much heat on slaking, expands considerably on slaking, and sets slowly. A magnesian lime slakes slowly, evolves little heat on slaking, expands less on slaking, and sets more rapidly. These limes cannot set under water, since they are dependent for hardening on the CO₂ in the atmosphere.

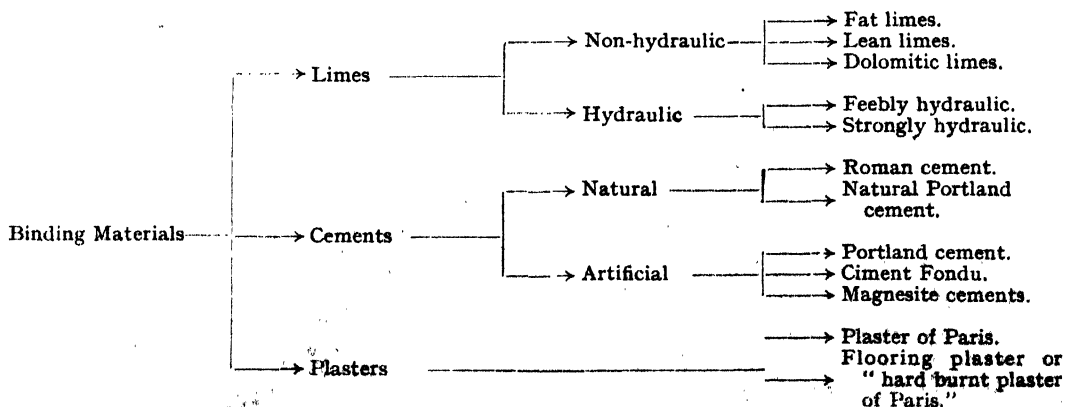
Hydraulic limes can set under water. The "Blue Lias" limestones of this country produce hydraulic limes, and Arden lime from Scotland is hydraulic. They are valuable for "pointing" the mortar courses of buildings, since they do not draw away from the stone as Portland cement frequently does.

Hydraulic limes include all cementing materials whose clinker shall, after burning, contain sufficient calcium silicate to cause it to set in the presence of water, and also sufficient free quicklime (CaO) to slake and pulverise the mass on the addition of water. A lime containing little calcium silicate is said to be *feebly hydraulic* as compared with the *eminently hydraulic* (high calcium silicate) limes. On treatment with water eminently hydraulic limes slake slowly, evolve little heat, and expand only slightly on slaking, set after a few days, and then slowly harden to a stony consistency. Feebly hydraulic limes slake more readily, evolve more heat, and show a greater increase in volume on slaking, set in from two to three weeks, and never become stone hard.

CEMENTS

Natural Cements are the result of burning clayey limestones found naturally. On roasting

TABLE V
CLASSIFICATION OF LIMES, CEMENTS, AND PLASTERS



they produce a material which, when water is added is capable of setting hard. Thus, nodules of an approximate composition—

Limestone	60-70 per cent
Clay	30-45 ..

found in the London clay, off Sheppey, produce when burnt the material known as *Roman cement*. In the same way natural mixtures are known which on burning produce what is practically Portland cement. *Medina cement*, found in the Isle of Wight, is a similar substance.

Artificial Cements. The most important manufactured cement is *Portland cement*, produced by grinding together into a cream, or *slurry*, about 75 per cent limestone and 25 per cent clay, and feeding this cream into the top end of a long tubular rotating furnace. Heat from suitable firing arrangements keeps the temperature at about 1,500° C., and the slurry as it works down is first dried, then fused, and finally leaves the lower end as a clinker.

This is then ground until not less than 90 per cent passes through a sieve of 170 meshes per linear inch, and not less than 99 per cent passes a sieve of 72 meshes per linear inch.

The cement should be of at least a certain strength, and tests are made on small blocks, or *briquettes*. These have a shank 1 in. square. They are placed in a tensile testing machine and pulled until they break. Usually the briquettes are made of a mixture of 1 part of cement to 3 of sand, and at three days after making they should have a tensile strength of 300 lb. per sq. in., and after seven days a breaking strength of 375 lb. per sq. in.

The cement should also conform to certain tests for speed of setting. Thus, the cement should have an *initial* set of not less than 30 minutes; this allows the concrete to be conveniently placed in position. The cement should also have a *final* set, when the surface cannot be easily indented by the thumb nail, of not more than 10 hours.

Chemically, the percentage of magnesia (MgO) must not be greater than 4 per cent. Magnesia combines with silica and alumina to form silicates and aluminates, which hydrate more slowly than the calcium compounds, and may therefore cause disruption after the rest of the cement has set if present in any quantity.

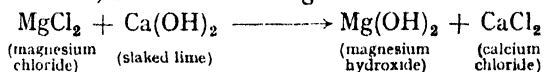
The percentage of SO₃ must not be greater than 2.75 per cent. In a chemical analysis SO₃ appears as the acidic portion of calcium sulphate (CaOSO₃ = CaSO₄), and of magnesium sulphate

(MgOSO₃ = MgSO₄). Small amounts of added calcium sulphate retard the setting of the cement and are beneficial; but larger quantities create a condition of weakness, due to the relative softness of the calcium sulphate, as compared with the harder cement.

CORROSION OF PORTLAND CEMENT. The setting of Portland cement is accompanied by the setting free of lime in the cement. *Acids* attack the lime and dissolve it, thereby destroying the coherence of the concrete. Carbonic acid gas is not harmful unless the concrete is exposed to large volumes of it, as may happen in the fermentation industries.

Acid salts, such as sodium bisulphate, and acid mineral waters slowly attack cement.

Alkalies, such as potash and soda, seem to have little effect on the cement. *Alkaline carbonates* accelerate the setting of cement, as do small quantities of calcium chloride and sodium chloride. Cement is attacked by magnesium chloride, the reaction being—



The calcium chloride so produced is soluble in water, hence the destructive effect of sea water (which contains magnesium chloride) on Portland cement.

Organic fertilizers attack lean concrete (i.e. concrete containing little cement), but good concrete, at least one month old, is unaffected.

Oils and fats attack freshly laid concrete and prevent the efficient setting of the cement.

Concrete one month old is unattacked by oils.

A cement depending for its setting power not on calcium silicate (as does Portland cement) but on aluminium silicate, is now being produced under the name of *Ciment Fondu*. It is produced by burning in nearly equal proportions lime and the clayey mineral bauxite. The product when ground develops great strength in a very short time, and is claimed to be completely immune from attack by sea water, sulphurous water, water saturated with gypsum, water containing 12 per cent of magnesium sulphate, mineral and vegetable oils, and tar.

Magnesite Cements. The so-called *Sorel cement* is of this type. It has been discovered that a paste of magnesia (MgO) and a concentrated solution of magnesium chloride (MgCl₂) of specific gravity about 1.14 will set hard, with the formation of a hydrated oxychloride, whose formula appears to be MgCl₂.5MgO.xH₂O.

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The value of x is uncertain, but appears to be about 17.

It is one of the strongest cements known; and a similar material, using zinc compounds in place of magnesium compounds, is used as a dental cement.

One part of Sorel cement, with four parts of sea sand, give a material whose crushing strength is in the region of 8,000 lb. per sq. in.

It is used as the binding material in many modern jointless and composition floorings.¹ In these compositions the binding material is the magnesite cement; the aggregate is sawdust, short-fibre asbestos, wood fibre, or a similar light and porous mass; and the colour is usually reddish-brown, due to the addition of a small percentage of ferric oxide (Fe_2O_3).

PLASTERS

These are the result of partly dehydrating the mineral gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). This mineral when heated in "kettles" to about 200° C. loses $1\frac{1}{2}$ molecules of water, and the resulting product ($\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$) is known as *plaster of Paris*. On mixing with water it has the property of recombining with the water, to produce a hardened mass of the same formula as the original gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.

This forms the basis of a number of plasters of the type of *Keene's cement*. This is practically plaster of Paris with alum. The alum accelerates the setting of the plaster of Paris and makes the result harder and more durable. It has, however, a tendency to powder after a long time. *Mack's cement*, *Martin's cement*, and *Parian cement* are similar modifications.

When gypsum is heated to from 700° C. to 900° C. it loses all its water of crystallisation. In this condition, when finely powdered, it will only recombine with water very slowly, resulting in a very hard mass used largely on the Continent as a flooring plaster.

CONCRETE IN GENERAL

CONTENT. The mixture of cement, sand and coarse aggregate which constitutes ordinary concrete is an attempt to obtain the greatest material strength with the minimum of actual cement. In general, the strongest and most impermeable concrete is that which has the greatest density; and to achieve this mixture the proportions of sand and coarse aggregate (which may consist of gravel, clinker, crushed

rock, etc.), must be carefully adjusted so that when incorporated with the cement and the necessary water the maximum degree of close packing is obtained.

PROPORTIONS. Experience has shown that certain proportions of each constituent do give a "workable mix," the proportions depending on the class of work.

For the roughest type of mass concrete, such as footings, suitable proportions are: Cement, 1 bucket; sand (damp) 4 buckets; coarse aggregate, 6 buckets; water, $\frac{3}{4}$ bucket. The maximum size of particles of coarse aggregate should be $2\frac{1}{2}$ in.

Walls below ground, and bases for machinery require a better mixture, and suitable proportions are: Cement, 1 bucket; sand, $3\frac{1}{2}$ buckets; coarse aggregate, 5 buckets; water, just over $\frac{3}{4}$ bucket. In this case the maximum allowable size of aggregate particles is 2 in.

A good mixture for general reinforced concrete work is the 1 : 2 : 4 concrete used for road slabs, walls above ground, etc. One bucket of cement, $2\frac{1}{2}$ of sand, and 4 of aggregate, with about $\frac{3}{8}$ bucket of water will usually prove satisfactory, but for reinforced work a little extra water may be added (if absolutely necessary) to assist in ensuring close contact between the concrete and the reinforcement.

In general, the amount of water specified in these various mixes should not be exceeded.

Where extra strength is required in reinforced concrete, and in the construction of pavements, steps, paths, and watertight floors and walls, a 1 : 2 : 3 mixture may be used. In this case, cement 1, sand 2, and aggregate 3 will require just under $\frac{3}{8}$ bucket of water; and the maximum size of aggregate allowable is $\frac{3}{4}$ in. in diameter.

Small precast work, and fence posts, etc., require a still richer mixture. Cement, 1 bucket; sand, $1\frac{1}{4}$ buckets, and aggregate 2 buckets, with $\frac{1}{2}$ bucket of water, is a convenient mix; the allowable size of aggregate particles being $\frac{1}{2}$ in. or less.

In calculating quantities of various materials which will be required for known mixes, it is convenient to remember that loose Portland cement weighs 90 lb. per cub. ft. Sand is almost always damp, and the quantities given above for the various mixtures allow for this water. Damp sand weighs approximately 84 lb. per cub. ft.

Similar figures for aggregates depend on the nature of the aggregate. Broken stone weighs

¹ For detailed classification see Author, *Journ. Soc. Chem. Ind.*, 12th October, 1923, page 980.

90 lb. per cub. ft., whereas shingle weighs 109 lb. per cub. ft.

Total quantities of materials necessary for particular jobs can best be calculated from the tables prepared by the Cement and Concrete Association. For small jobs the figures given above will probably be sufficient. For example, for a concrete path one would use a 1:2:3 mixture. One bag (112 lb.) of Portland cement, with $2\frac{1}{2}$ cub. ft. of sand and $3\frac{1}{2}$ cub. ft. of shingle or broken stone will make sufficient concrete to lay a path 2 ft. in width, 2 in. thick, and 15 ft. in length.

HANDLING. Though the preparation of satisfactory concrete for general purposes is now almost "fool-proof," certain precautions must be taken if maximum strength is to be obtained. Clean sand, clean aggregate, and clean water must be used. The materials should be thoroughly mixed before adding the water, and again afterwards. Tamp and spade the mixture into position within 30 minutes of mixing; and keep it moistened for 10 days.

The best results are obtained with a "quaking" or "mushy" mixture. A quaking mixture is one in which, though stiff, water can be forced to the surface by slight tamping. A mushy mixture is not watery but can be readily spaded into shaped moulds. The quantities of water recommended above for the various mixes are in general sufficient to ensure the correct quality of wet mix.

BRICKS

Bricks are manufactured from (a) *clays*, produced by the "weathering" of felspars, etc., in granites; (b) *marls*—mixtures of chalk and clay; (c) *shales*—hardened clays which have lost their original texture; and (d) *loams*—mixtures of clay and sand.

In general, a brick earth should contain half its weight of true "clayey" matter, and its ultimate chemical analysis should, therefore, show not less than 20 per cent Al_2O_3 (alumina) and not more than 75 per cent silica. Clays containing more than 4 per cent of iron (calculated as iron oxide Fe_2O_3) usually burn red, but attempts made to improve the colour of bricks, by addition of ferric oxide, have seldom been successful.

Stages of Manufacture. The usual stages in the manufacture of bricks are (a) cleaning of clay, where necessary; (b) *drying*, if necessary; (c) *tempering* (addition of water); (d) *moulding*; (e) *drying*; (f) *burning*.

CLEANING. Dealing with the chemical and physical aspects of each section, we find that the cleaning of the clay involves the removal not only of flints, but also of fragments of limestone. When a clay has to be cleaned either a screen or a wash-mill is usually employed. The most dangerous impurity in a clay is *limestone*, and particles of $\frac{1}{16}$ in. diameter can do much harm. The burning process converts this into quicklime, and this usually shows up as white spots in the brick. Moisture causes the quicklime to slake, and in the consequent expansion of the slaked lime the brick may become damaged by cracking.

DRYING is only necessary, as a rule, where a wash-mill has had to be employed to clean the clay.

TEMPERING consists in adding to the material sufficient water to render it plastic. Here it should be noted that a suitable brick-earth should contain sufficient sandy (non-plastic) material to reduce the shrinkage, which always takes place in drying and burning, to reasonable limits (usually about 1 in. per linear foot). If sand has to be added, the limit is governed by the plasticity of the material. Rich or "fat" clays shrink and twist too much in drying, and require additional sand.

MOULDING. Bricks are frequently moulded by machinery in these days, and the amount of moisture required is controlled by the method to be adopted in moulding. Fletton bricks are pressed into shape almost dry, while the wire-cut process requires a definite plastic nature in the material.

DRYING AND BURNING. In the process of drying a brick the physical considerations are of greater importance than the chemical. In general, the interior of the brick should dry at approximately the same rate as the exterior, or cracks will develop. This is purely a physical phenomenon, and there are apparently two critical periods—

(a) During the removal of the first portions of the water, when the outer particles tend to shrink more rapidly than the inner.

(b) When the bricks have a hardness about equal to that of leather. At this stage they are very sensitive to sudden temperature changes.

From an ordinary moulded brick, ready for drying, about 1 lb. of water must be removed.

A finished (baked) stock brick will absorb from one-eighth to one-tenth its weight of water on simple immersion. Such a brick is only baked to a point at which all plasticity is destroyed, and the non-plastic particles are firmly united.

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An engineering or vitrified brick, on the other hand, is very fully burned, and is usually defined as one which will not absorb more than 1 lb. of water on immersion in water for twenty-four hours.

London stock bricks have a resistance to crushing load of about 150 tons per square foot,



FIG. 11. PURE IRON ($\times 333$). CRYSTALS OF FERRITE (PURE IRON) ONLY. NO CARBON

while Staffordshire blue (engineering) bricks will stand between 380 and 440 tons per square foot.

Sand lime bricks are made by mixing lime with about nine times its weight of sand, adding a little water and compressing at a pressure of about 200 tons, afterwards heating the brick with superheated steam for some hours. A partial combination occurs between the lime and the sand, with the formation of calcium silicate, which binds the particles of the brick together. They find more favour on the Continent than in the United Kingdom.

Efflorescence on Brickwork. The unsightly white incrustation on brickwork is found on analysis to consist of sodium carbonate, with sometimes a trace of sodium sulphate, and (rarely) calcium sulphate. There is no adequate remedy for the trouble known at present. It is suggested that the sulphur content of the soil may be one of the contributory factors. It is a peculiar fact that the efflorescence is never found on a loose stack of bricks, but only on finished walls in which cement has been employed. It has been suggested that a connection may exist between the salts used to

accelerate or retard the rate of setting of cement, and the presence (and nature) of the incrustation.

CONSTRUCTIONAL METALS

Iron and Steel. Iron occurs in combination as red haematite (Fe_2O_3), brown haematite ($\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$), and the carbonate (FeCO_3). The extraction of the metal from its ores is one of reduction, in which coke is made to combine with the oxygen in the ore, setting free the metal.

The two processes employed in the manufacture of steel are shown diagrammatically in Table VI. The ore, mixed with coke and limestone, is roasted in a blast furnace, the resultant impure iron being known as pig or cast iron.

TABLE VI
MANUFACTURE OF IRON AND STEEL

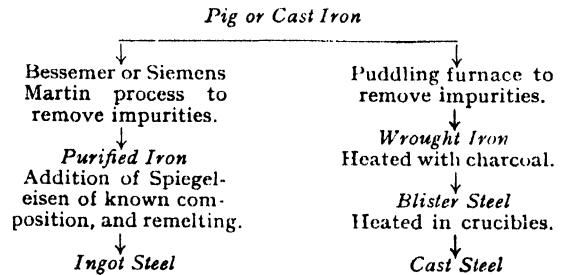


Fig. 11 shows the cross-section of a piece of

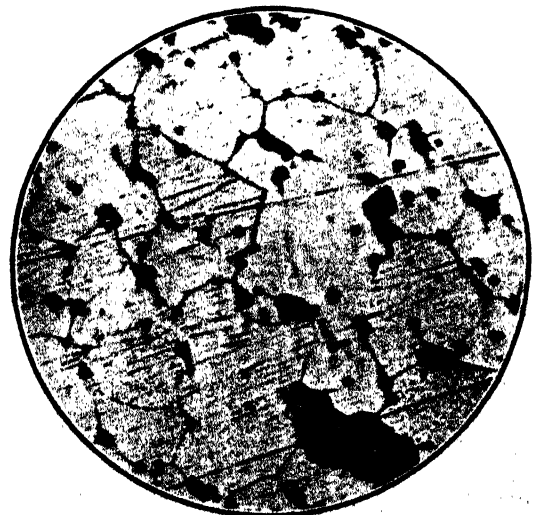


FIG. 12. WROUGHT IRON ($\times 333$), SHOWING CRYSTALS OF FERRITE (PURE IRON) AND SLAG SPOTS. NO CARBON

pure iron. The crystals are those of ferrite (pure iron), and there is no evidence of any carbon content.

In Fig. 12 we have wrought iron, showing again the ferrite crystals and slag inclusions, but no spots due to carbon.

The photo-micrograph of mild steel (Fig. 13) shows the crystals of ferrite, and also dark spots

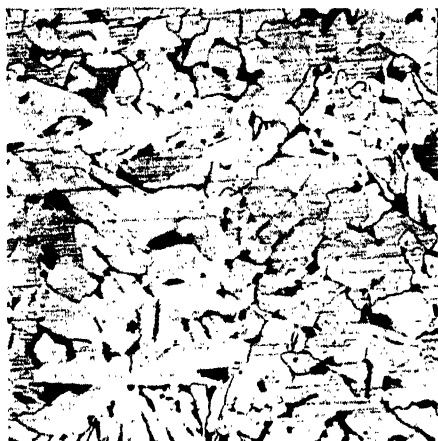


FIG. 13. MILD STEEL, CONTAINING 0.22 PER CENT CARBON

Crystals of ferrite (pure iron) and dark spots of pearlite (containing the carbon)

of pearlite, which is a mixture of ferrite and iron carbide, Fe_3C (cementite), and which contains the carbon.

Typical percentage analyses of the three chief grades of iron are shown in Table VII.

TABLE VII
COMPOSITION OF IRON AND STEEL

	Per cent Cast iron	Per cent Wrought iron	Per cent Steel
Carbon	3.81	0.10	0.65
Silicon	1.68	0.05	0.07
Phosphorus	0.70	0.15	0.03
Sulphur	0.60	0.05	0.02
Manganese	0.41	0.07	0.40
Iron	92.80	99.58	98.83
	100.00	100.00	100.00

In general, the hardness of a steel is closely related to the percentage of carbon contained therein. Table VII illustrates this relation.

In structural steel the sulphur content should be below 0.06 per cent, otherwise the metal is liable to be brittle under shock. For the same reason, the percentage of phosphorus is limited to 0.04, while manganese may have any value up to 0.5 per cent.

During the rusting of iron, the oxygen of the air is absorbed with the formation of a skin of

TABLE VIII
RELATION OF AMOUNT OF CARBON TO HARDNESS OF STEEL

Use	Per cent Carbon
Mild Steel	0.20
Structural Steel	0.30
Rails	0.45
Springs	0.70
Chisels	1.00
Lathe Tools	1.20
Surgical Instruments	1.30

hydrated oxide of iron on the surface of the metal. It is interesting to note that the carbon dioxide in the atmosphere appears to be necessary to the rusting of iron; and that iron will not rust in dry air or in air-free water, while in moist air or aerated water rusting is rapid. Stainless or rustless steel, containing about 14 per cent chromium, is interesting as possessing considerable resistance to corrosive influences; while the non-corrodible steel, known as "Staybrite," containing 18 per cent of chromium and 8 per cent of nickel, is remarkably resistant, being practically immune from attack by boiling sea water, sea salt and dry steam at 300° C., and a current of sea salt and wet steam at 200° C.

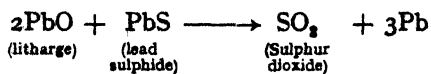
The disadvantage of these alloy steels at present is their cost.

Meanwhile, ferro-concrete is valuable as being a practical solution of the rusting problem. Although the iron reinforcement rods are, in practice, frequently allowed to rust deliberately before being surrounded by the concrete casing, the latter, when the cement sets, coats the iron with a skin containing slaked lime (see article on the setting of Portland cement), which prevents further corrosive effects as long as it adheres closely to the surface of the iron.

Lead. The extraction of the metal from its chief ore, galena (lead sulphide, PbS), is achieved by roasting the ore, whereby part is oxidised to litharge PbO , in a reverberatory furnace. Further heating of a mixture of PbO and PbS

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causes the elimination of sulphur dioxide, leaving metallic lead behind—



Lead, as obtained commercially, is almost pure, the silver which usually accompanies it in galena having been carefully removed.

Physically, the most important point to notice relative to lead, is its high coefficient of expansion, 0.00029 per degree C. This must be allowed for when working with lead sheeting.

Chemically, lead is found to be distinctly soluble in soft water (see article on "Water").

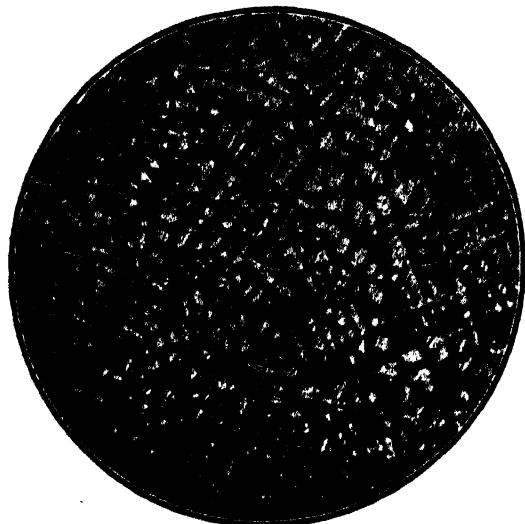


FIG. 14. CAST BRASS: 70 CU.: 30 ZN.

In order that water may dissolve lead, it would appear that both dissolved oxygen and dissolved carbon dioxide are essential. Erosion of lead pipes may be due to the production of a loose powder of lead carbonate PbCO_3 , swept along by the flow of water, or to actual solution of the metal. Peaty waters contain small quantities of acid substances, which assist in the solution of the lead. It is found that water containing as little as one-twentieth of a grain of lead per gallon, may be dangerous if consumed continuously, since lead is a cumulative poison. Hard water forms a protective skin of lead sulphate on the lead, thereby preventing further attack.

Copper. This metal, like lead, occurs largely in the form of the sulphide pyrites, which is calcined in a reverberatory furnace in order partially to oxidise the ore. The cuprous oxide

Cu_2O so produced, mixed with more sulphide, is strongly heated, when a reaction occurs, according to the equation $2\text{Cu}_2\text{O} + \text{CuS} \longrightarrow 5\text{Cu} + \text{SO}_2$.

This crude copper, from which the gaseous sulphur dioxide has escaped in bubbles, is known as *blister copper*. It is remelted, stirred with poles of green wood, and anthracite is thrown on to the surface of the metal. The resulting copper is sufficiently pure to be cast.

Copper sheeting, when exposed to the action of moist air and large quantities of carbon dioxide (as in large industrial centres), becomes coated with a green basic carbonate of copper, having the approximate formula $\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$. It has poisonous properties, and is frequently erroneously called "verdigris."

The quality of copper is much affected by small traces of other impurities; of these the most objectionable is bismuth, 0.05 per cent of which is sufficient to affect the malleability.

Copper has the property of dissolving its own oxide, and during welding operations care has to be taken to prevent this.

This tendency is overcome in two ways: (a) by the use of a suitable flux, which shall fuse just before the metal itself melts; and (b) by the use of a filling rod of copper, containing less than 0.1 per cent of phosphorus.

The function of the phosphorus in the filling rod is to combine with any oxygen which may enter the weld, converting it into phosphorus pentoxide, and removing it in that form into the atmosphere.

Zinc. Metallic zinc is obtained chiefly from the sulphide ores (*blende*), which are converted into the oxide, ZnO , by heating in a reverberatory furnace.

The oxide is then mixed with powdered coal in fireclay retorts and heated. The reaction proceeds according to the equation $\text{ZnO} + \text{C} \longrightarrow \text{Zn} + \text{CO}$, and the metallic zinc, which boils at 920°C ., distils over and is collected in suitable receivers.

It is a fusible metal and is brittle at ordinary temperatures. It becomes malleable when heated to between 100°C . and 150°C ., and brittle again at 210°C .

The most objectionable impurity is lead, 1.5 per cent of which is sufficient to prevent the metal being rolled into sheets.

The destruction of zinc sheeting may take place in three ways—

(a) Electrolytic action between the zinc and impurities, which may be present in the metal.

(b) Direct solution of the metal in the acid rain of cities.

(c) Corrosion by lime. Cements destroy zinc owing to the lime which they contain (see notes on Portland cement). This has the property of combining with the metal to form a calcium zincate, thereby destroying the continuity of the metal sheet.

Galvanizing is the dipping of sheet iron articles into a bath of molten zinc, whereby the metal becomes coated with a thin protective skin; it has no connection with the "galvanic battery."

Brass. Common brass is an alloy of 70 per cent copper and 30 per cent zinc. It can be cast and rolled into sheets.

From 1 to 2 per cent of lead is frequently added to brass to make it easier to work.

The strength of brass is increased by the addition of small quantities of aluminium.

A photo-micrograph of cast brass is shown in Fig. 14.

MISCELLANEOUS MATERIALS

Amongst the miscellaneous materials so far unclassified must be included timber, paints, and such substances as asphalt and rubber.

Timber. The varieties and treatment of timber employed for constructional purposes are dealt with elsewhere (see section on "Joinery"), but a few notes of a scientific nature may be of value.

Moist timber is liable to attack by fungi, the three principal ones being *Poria Vaporarius*, *Merulius Lachrymans*, and *Coniophora puteana*.

The most usual colour of the fruiting body or sporophore of *Coniophora puteana* (Greek, *Konis* = dust; *phoreo* = to carry) is brown, the surface being spotted or embossed with pimple-like lumps and having a white margin. This fungus demands a large supply of moisture, and therefore careful drying of wood is a great preventive of attack by it. It should be remembered, however, that *Merulius Lachrymans*, when once established, manufactures water (Latin, *Lachrymans* = weeping), and exudes drops of water in the process of growth. Hence the driest wood is not only moistened by this fungus, but rendered liable to be attacked by *Coniophora puteana*.

The fruiting body of *Merulius Lachrymans* is rusty in colour and gelatinous in appearance, with irregular furrows and ridges covering it. It frequently sends out cord-like strands over the surface of wood, and travels over mortar and brickwork to distant wood. Absence of

sunlight, and the presence of free alkali such as ammonia, favour the growth of this fungus. When present the only safe remedy is to cut out the portion of wood attacked, in its entirety, and then to kill spores in the walls by flame treatment, followed by washing with a solution of formalin or corrosive sublimate (mercuric chloride, $HgCl_2$).

The most satisfactory methods at present known for safeguarding wood against attack, are—

(a) Treatment with creosote. This is usually considered to be the most effective.

(b) Treatment with magnesium fluosilicate. This is probably the most satisfactory inorganic chemical available for the purpose.

Other treatments are—

(c) Soaking in boric acid.

(d) Treatment with the sodium salt of 2 : 4 dinitrophenol.

(e) Use of the sodium salts of dinitroresol.

Poria Vaporarius is a forest fungus which produces "red stripe" in wood. Drying will kill the spores, but insufficiently dried wood may contain live spores. The fruiting body of *Poria* is white, with regular and definite pores, these being toothed and angular.

Paints. The production and properties of paints and varnishes are dealt with elsewhere (see section on "Painting and Decorating").

Certain chemical aspects of the tarnishing of paints are interesting.

All lead paints have a tendency to blacken in an atmosphere containing sulphides, such as one finds in chemical laboratories and railway stations. In our present state of knowledge we know of no means of preventing this. Reaction between hydrogen sulphide and lead compounds results in the production of black lead sulphide (PbS), and the best varnishes known to us, though impervious to rain, are comparatively transparent to the gases of the atmosphere, and consequently do not prevent this blackening.

The colour of white lead, which has been so affected, can be restored in some measure by the use of hydrogen peroxide (H_2O_2), a compound which readily yields up some of its oxygen, and in so doing is capable of oxidising the black lead sulphide to white lead sulphate, thereby to some extent restoring the original colour.

Lithopone—a mixture of barium sulphate (*barytes*) and zinc sulphide—is not susceptible to attack by sulphides in this way, but has an unfortunate peculiarity in darkening on

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exposure to brilliant sunlight. The colour returns in the dark. Ultimately the pigment regains and keeps its white colour.

A white pigment, with marked covering power and resistance to sulphide attack, is titanium dioxide (TiO_2). Care should be exercised when using this as paint, that the medium (usually linseed oil) does not contain lead "driers," for in this case the advantage gained in the body will be lost, by the blackening of the lead in the medium.

Driers. These are substances added to linseed oil to increase the rate at which it dries. The drying of a material, such as linseed oil, is not an evaporation, but an actual combination between the oil and the oxygen of the air, by which a tough, almost impervious skin of hardened oil is formed—a valuable medium for holding the body colour. Substances such as litharge, sugar of lead, lead acetate, manganese borate, manganese oleate, and cobalt resinate are valuable driers, but should only be used in very small quantities. Excess of driers in a paint produces a hardened upper surface almost impervious to the passage of the oxygen of the air, and acting as a barrier to the access of this gas to the inner portion of the paint film, which therefore remains soft (unoxidised).

It should be noted that *rouge* (ferric oxide, Fe_2O_3) has no value as a drying agent, and that the value of *zinc sulphate* ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) is very doubtful.

Asphalt. This is a condensed form of bitumen, the latter being found naturally at such places as the island of Trinidad and Val de Travers in Switzerland.

The Trinidad lake asphalt contains some 35 per cent clay and silica. The Val de Travers deposit contains from 80 to 90 per cent of limestone.

The material can be adapted to a number of uses. Thus, the *Japan Blacks* are solutions of bitumen in volatile oils, such as benzene. The latter is capable of dissolving the bitumen, and of evaporating when the material is used as a surface coating.

Roofing felts are fibrous materials of the nature of felt, soaked in an asphalt mixture. The damp-proof course in houses frequently consists of this material.

As road-making materials, the bituminous matter should have a definite viscosity. This is determined by the rate at which an instrument—the *Hutchinson Tar Tester*—(shown in Fig. 15) sinks in the liquid under examination (when this is contained in a vessel of given

dimensions and is at a given temperature), from the ring *A* on the stem to the ring *B*.

With counterpoise No. 2, in position at *D*, the consistencies of the tars, officially specified by the Road Department, Ministry of Transport, are—

Tar No. 1 for Surface Treatment 3 to 20 seconds
Tar No. 2 for Tar Macadam 20 to 100 seconds

This substance is thus of considerable interest as a possible binding material for jointless floorings.

Rubber. The basic substance from which jointless rubber flooring is made is a white juice—*Latex*—which oozes from cuts made in the bark of certain tropical trees, such as *Hevea Brasiliensis*.

This milk-like juice is collected, and made to coagulate by means of a suitable reagent (such as acetic acid). This coagulated "Latex," squeezed between steel rollers and perhaps bleached, is now on the market as shoe-soles, under the name of "Crêpe."

The conversion of this substance into rubber is performed by the incorporation of sulphur with it, while in a plastic condition between steam-heated rollers. This process is known as "curing." The resulting material is, or can be, mixed with other substances—*fillers*—such as carbon, barytes, chalk, chromium oxide, and so on, by which means a rubber flooring composition, either uniformly coloured or mottled, can be produced. Ordinary rubber composition frequently contains only 40 per cent of pure rubber, the remaining 60 per cent being "fillers."

It may be noted that complete "curing" of the rubber results in loss of elastic properties by the finished product, and the substance so produced, having high insulating properties, and capable of taking a high polish, is known as *vulcanite* or *ebonite*.

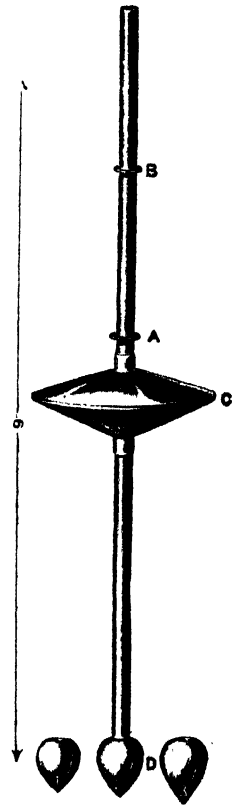


FIG. 15. STANDARD (HUTCHINSON) TAR TESTER

MODERN SYNTHETIC MATERIALS

A number of modern synthetic materials have now become available in the building industry as the result of attempts to solve problems of sound insulation, heat insulation, and light-weight construction. Among these are (a) Plastics; (b) Foamed Slag; (c) Asbestos Cement; (d) Woodwool Concrete; and (e) Sawdust Concrete.

Plastics are synthetic resins, and there are scores of different varieties. Bakelite, perhaps, being the best known in this country. Transparent plastics provide glass substitutes for our fighting planes, and plywood, treated with synthetic resins, is sufficiently strong to find a use in the wings and fuselages of Mosquito aircraft. Plywood is also being developed as external wallboards.

There is now no mechanical difficulty in moulding from a vinyl resin moulding powder, and moulded fittings such as cisterns, draining boards, skirting and ceiling mouldings, and electrical fittings, are being produced.

Laminated plastics, either as large rigid sheets or as facings to fibre board, are being used internally in many public buildings, though they have not the sound-absorbing or the heat-insulating properties of fibre board, and are not used for these purposes.

For use out-of-doors, care is necessary in the selection of weather-resisting materials, but a promising line of development lies in resin-bonded plywood, which is in use in the United States in house construction. It is being manufactured in large sheets and is proving most adaptable where pre-fabrication methods of house construction are employed.

One feature of the situation which must not be overlooked is the comparative expense of laminated plastics as wall-surfacing materials. Research is, however, proceeding so rapidly in the plastics industry that the successful application of plastic products to the building industry will be one of the features of future building development.

Foamed Slag is one of the possible modern light-weight aggregates for the production of heat-insulating concrete. It is a cellular, inert material, obtained from blast furnace slag. The molten slag is treated with applications of water in such a way that it becomes "blown out" to from 7 to 10 times its original volume.

As so produced, the foamed slag contains sealed pores. After cooling and crushing it is found still to contain a considerable proportion

of these sealed pores. The nearest similar natural product is pumice; but pumice does not in general contain the same type of sealed pore.

Wall blocks made of foamed slag concrete are used extensively in Germany, where they are pre-cast. The amount of cement used is small, the proportions of cement to foamed slag being of the order 1:12, by volume. Tests made in this country indicate that it is important to have the correct proportion of cement to slag.

COMMERCIAL PROPERTIES. It seems to be established that, when used in reinforced concrete constructional work, such slag-concrete is not more likely to cause corrosion of embedded steel than would a similar pumice-concrete. The material has moisture expansion and shrinkage coefficients which comply with British Standard Specification No. 492. Its qualities as a thermal insulator are good, and in this connection it compares favourably with even hollow pumice concrete blocks and solid pumice concrete.

It is generally believed that the sound-insulating properties of such cellular materials are high, but this is not so. In simple homogeneous structures (e.g. a partition) it is the mass per unit of area of the structure which determines the degree of sound insulation, and foamed slag concrete is no exception to the general rule.

Asbestos Cement is steadily expanding its field of usefulness. It is extensively used where large cheap roofs (e.g. those of factories and cinemas) are required. Asbestos itself is a silicate of magnesia. Italian asbestos containing nearly 80 per cent of this substance, and its fibrous structure and fireproof nature make it one of the more important building materials. Corrugated sheeting, roof pantiles, asbestos cement shelving and racking, flue-pipes, hollow construction building slabs, glazed panels, and water, gas and sewage pressure pipes are among the modern applications of asbestos cement.

One striking development of the process produced just before the outbreak of war in 1939 was a hollow load-bearing roof decking. Another important aspect of the use of asbestos products was found in the Fire Protection Panels for Air Raid Precaution schemes. A laminated material has been devised, having two light gauge steel facings keyed to a compressed asbestos-composition core. A pressure of over two tons is used in its manufacture, and the sheets are capable of withstanding temperatures up to 1,000°C., without disintegration.

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The heat transmission coefficient is only 0.69 B.Th.U.s per sq. ft. per hour for each 1° F. difference in temperature between the two faces.

Woodwool Concrete. Woodwool slabs for constructional purposes have been manufactured on the Continent for a number of years, the reason being, no doubt, that supplies of soft woods from which the woodwool is made are obtainable cheaply and in quantity in Europe. In this country we are largely dependent on Scandinavian sources for our softwoods and woodwool is imported from them. Home-grown supplies of this material, if obtained from unseasoned timber, must be dried to remove the sap before incorporation in woodwool slabs.

The detail process of manufacture is a trade secret, but in outline it is as follows: A calcium chloride solution containing about 7 per cent of CaCl_2 is mixed with Portland cement until the density of the mixture is about 1.6 (water being taken as 1). The woodwool is then added to the mix, and when thoroughly soaked is taken out, and the excess of slurry removed. It is then pressed into slabs, and left in the moulds under pressure for about 24 hours. On removal from the moulds the slabs are left to mature for 28 days, when they are ready for use.

Sawdust Cement is a variation of woodwool concrete. As a light-weight concrete possessing marked thermal insulation value it has received for several years considerable attention at the Building Research Station. In properties it may be considered as lying between ordinary timber and a light-weight concrete.

All sawdust contains substances which affect the setting and the hardening of cement. Spruce and poplar sawdusts can, in general, be used without any pre-treatment; but sawdusts from larch, beech, oak, ash and red cedar must be pre-treated before use. Numerous patents dealing with methods of pre-treatment have been taken out. Unfortunately, ordinary supplies of sawdust are so mixed that in practice the manufacturer of sawdust concrete pre-treats all sawdust to avoid trouble.

MANUFACTURE. In outline, the process of manufacture is: Sawdust from soft woods is thoroughly stirred into a solution of sodium silicate made by mixing 1 part by volume of commercial water-glass with 5 parts of water, and left to soak for 24 hours. At the end of this time the sawdust can be considered ready for further use.

It can then be removed from the silicate solution, excess of silicate separated off, and the

sawdust well mixed with cement (water can be added if necessary) until the mix is of a mushy consistency. It can then be tamped into moulds, and after two days of setting, the slabs can be removed from the moulds and left for 28 days to mature. They should then be ready for use.

The Building Research Station has devised an alternative method of pre-treatment of the sawdust which appears to be equally effective with all sawdusts.

The ratio of cement to sawdust which is used depends on the purpose for which the slabs are designed. The practical range varies from 1 cement : 1 sawdust to 1 cement : 5 sawdust, by volume.

A 1 : 1 mixture will weigh about 100 lb. per cub. ft. A 1 : 5 mixture will weigh about 40 lb. per cub. ft.

A mixture of 1 cement : 2½ sawdust will produce a product which is nailable, has a crushing strength in the region of 1,200 lb. per sq. in., and a transverse strength of about 600 lb. per sq. in., at 28 days.

COMMERCIAL PROPERTIES. One of the major disadvantages of this type of light-weight concrete is its high shrinkage on drying and its high expansion on wetting. It is true that all Portland cement products shrink on drying and expand on wetting, but in ordinary concretes these movements are caused by the cement alone. In sawdust-cement mixes, both the sawdust and the cement contribute to the expansion and contraction caused by moisture. An attempt to control the degree to which these changes occur involves the addition of a proportion of sand to the cement-sawdust mixture.

It is obvious that considerable research has still to be carried out on these light-weight concretes, nevertheless the following summary of some of the uses to which sawdust cement has been applied gives an indication of the potential usefulness of the product.

Pre-cast wall bricks, which can be nailed, are in use. Pre-cast slabs for panels have also been used but must have stiffening ribs to avoid warping. Large slabs in particular show a tendency to warp. Flat slabs can be used for roofing, if covered with felt.

Flooring can be carried out either with pre-cast blocks or in the form of a jointless surface. If the latter is desired, the sawdust-cement mix should be laid immediately on fresh concrete. If laid on concrete which has already set and hardened there is a tendency for the two layers to separate.

Chapter III—HEAT AND TEMPERATURE

Temperature. The *temperature* of a body is its degree of "hotness" referred to some agreed scale. It is not the same thing as "quantity of heat." For example, a spoonful of boiling water and a bucketful of boiling water are at the same *temperature*, but the former contains a much smaller quantity of heat than the latter; this is easily proved if they are thrown upon heaps of ice—the spoonful is able to melt far less ice than the bucketful.

We cannot rely on our bodily sensations for determining temperatures. The effects of handling a piece of hot iron and a piece which has been exposed to the open air during a winter in the Arctic are very similar—much pain and the probable loss of some skin being the result in each case. To give a more familiar example: iron railings "feel" colder than a wooden fence on a cold winter day—yet they are at the same temperature. But if we place pieces of iron and wood in a hot oven for some time, the iron will "feel" warmer than the wood when they are removed, yet, again, they are actually at the same temperature.

DETERMINATION OF TEMPERATURE. Temperatures are determined by means of *thermometers*, which depend for their action on some one or other of the effects of heat on bodies; the effect most commonly used is the expansion produced in a liquid, such as mercury (quick-silver) or alcohol when heated. One essential point is that the liquid selected shall neither boil nor freeze whilst in use. Consequently, mercury is used in most thermometers, whilst alcohol, having a lower freezing point, would be suitable for recording temperatures in very cold countries.

Such a thermometer consists of a spherical or cylindrical bulb, blown or fused at the end of a length of glass tubing, having a very narrow bore (see Fig. 16). The upper end of the tube is closed. The mercury or alcohol occupies the bulb and a portion of the stem at ordinary temperatures; when the thermometer is heated, the expansion of the liquid causes it to rise in the tube. Graduations are marked on the outside of the tube (or, sometimes, on a scale placed behind the tube), and the level of the liquid surface denotes the temperature.

Thermometer Scales. So that temperatures

recorded on different thermometers may be easily compared, they are graduated according to certain agreed scales. The temperature at which water freezes (or ice melts), and that at which water boils under normal atmospheric pressure, have been selected and are known as

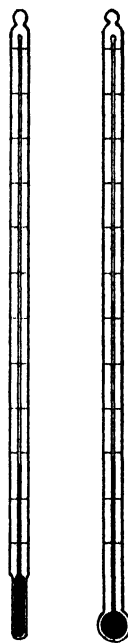


FIG. 16
THERMOMETERS

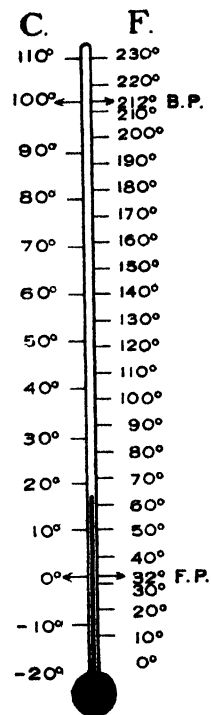


FIG. 17
THE CENTIGRADE AND
FAHRENHEIT SCALES OF
TEMPERATURE

the *fixed points*. The heights at which the mercury stands in the thermometer, when exposed to these temperatures, are marked, and the distance between them is divided into equal divisions or degrees. Similar divisions are continued above or below the fixed points.

On the *Centigrade* scale, which is in general use on the Continent of Europe (except in Scandinavia) and for most scientific work in this country, the freezing point is called 0° (read as 0 degrees) and the boiling point is 100°. On

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the *Fahrenheit* scale, which is commonly used in this country, the freezing point is 32° and the boiling point 212°. Temperatures on the Centigrade scale are written thus: 20° C., 85° C.; and on the Fahrenheit scale: 45° F., 197° F. Temperatures below the zero on either scale are written with a minus sign prefixed; thus, -14° C. is 14 degrees below zero on the Centigrade scale.

CONVERSION OF TEMPERATURE. The reader may find it necessary to convert temperatures from one scale to the other.

If *F* and *C* stand for corresponding temperatures on the Fahrenheit and Centigrade scales, respectively, then

$$\frac{F - 32}{9} = \frac{C}{5}$$

EXAMPLE. What temperature on the Centigrade scale is equivalent to 140° F.?

SOLUTION. Here *F* = 140, and we have to find the value of *C* in the above equation; substituting, we get

$$\frac{140 - 32}{9} = \frac{C}{5}$$

Whence *C* = 60° *Ans.*

The relation between the two scales of temperature is clearly set out in Fig. 17, which

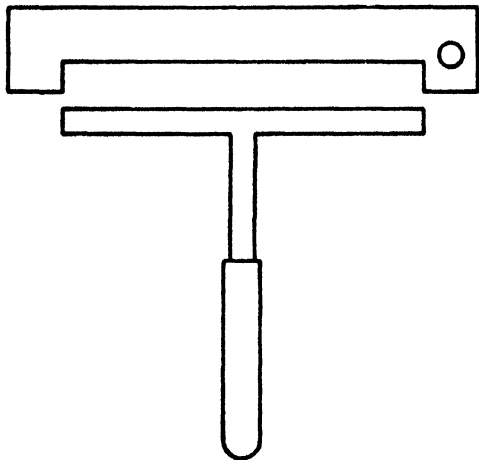


FIG. 18. THE BAR AND GAUGE

represents a thermometer with a double set of graduations.

EXPANSION AND CONTRACTION

Solids. Solid bodies generally expand when heated. If a metal bar be made so that its length just fits into a given gauge, and its section will just pass into a hole in the gauge at ordinary

temperatures, we find that the bar will no longer fit the gauge immediately after it has been heated. See Fig. 18.

COEFFICIENT OF LINEAR EXPANSION. In the case of solid bodies, we are usually concerned with the increase in length (i.e. *linear expansion*). The *coefficient of linear expansion* of a body is that fraction of its length which the body expands for a rise of one degree. (Obviously, this may be 1° C. or 1° F.) To be exact, we should reckon the expansion from the length of the body as measured *at the freezing point*, but the above definition is sufficiently accurate for all ordinary purposes. Thus a cast-iron bar 1 ft. long will expand 0.000107 ft. (or about $\frac{1}{9000}$ of an inch) for a rise of temperature of 1° C., since the coefficient of linear expansion of cast-iron is 0.000107 per degree Centigrade.

The *linear expansion of a solid* is equal to (length) × (coefficient of linear expansion) × (rise in temperature).

TABLE IX

COEFFICIENTS OF LINEAR EXPANSION OF SOLIDS COMMONLY USED IN BUILDING

Material	Coefficient of Linear Expansion	
	Per Degree Centigrade	Per Degree Fahrenheit
Brass	0.000188	0.000104
Copper	0.000168	0.000093
Iron, Cast	0.000107	0.000059
Iron, Wrought	0.000119	0.000066
Lead	0.000293	0.000163
Zinc	0.000292	0.000162
Brick	0.000054	0.000030
Cement and Concrete	0.00010 to 0.00014	0.00006 to 0.00008
Slate	0.00006 to 0.00010	0.00003 to 0.00005
Yellow Deal—		
Along the Grain	0.00005	0.00003
Across the Grain	0.00034	0.00019

Allowance must be made for expansion and contraction. Although no solid expands very much when heated (e.g. a cast-iron bar 1 ft. long only expands one-eighth of an inch when heated from 0° C. to 100° C.), yet if it is gripped tightly at its ends and held so as to prevent this expansion, the forces acting on the grips are very great. Actually, these forces are equal to those which would be needed if the bar were first allowed to expand, and were then to be squeezed back to its original length; and we

all know how difficult it is to compress any ordinary solid. In the same way, if a rod be heated, then gripped at its ends and allowed to cool, it will exert similar forces tending to draw together the appliances gripping its ends.

We should expect that these forces would be proportional to the cross-section of the bar, and such is found to be the case. That these forces are very great is easily demonstrated by means of a piece of apparatus known as the "bar breaker" (see Fig. 19). As usually constructed,

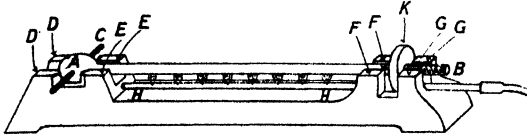


FIG. 19. THE "BAR-BREAKER"

it consists of a stout wrought-iron rod *AB*, about $\frac{1}{2}$ in. diameter and 15 in. long. The end *A* is flattened and a hole drilled through it to take a short cast-iron bar *C*, about $\frac{1}{4}$ in. diameter; at the end *B* a strong screw thread is cut, on which a large nut *K* works.

The rod is placed on a massive iron stand, so that the cast-iron bar *C* is between V-shaped stops *DD* and *EE*, and the nut is between stops *FF* and *GG*. A tube *HH*, with a large number of small slits, can be used as a gas burner. The bar *C* is placed against the stops *DD*, and the nut is turned back as far as it will go so as to press against *GG*. The gas is lighted and after a minute or so the force exerted by the expanding rod is sufficient to break the cast-iron bar *C*. On the other hand, the rod *AB* may be first heated, then a cast-iron rod *C* inserted and the nut screwed up until *C* rests against *EE* and the nut against *FF*. If now the rod is allowed to cool, the force exerted as it contracts is sufficient, in a few minutes, to break the small cast-iron bar.

Table X shows the force exerted by a rod 1 sq. in. in section if prevented from expanding (or contracting) when the temperature rises (or falls) 100° C.

TABLE X

FORCES EXERTED BY METAL RODS WHEN HEATED OR COOLED 100° C.

Material	Force in Tons
Brass	8
Copper	13
Cast-iron	9
Wrought-iron	15

PRACTICAL EXAMPLES. (a) Long lengths of piping in hot-water systems are provided with some form of expansion joint, Fig. 20. or, alternatively, a large radius bend, Fig. 21, may be introduced, which bends more or less to allow for variations in length.

(b) Leadwork on roofs, being exposed to the sun, must not be secured on all its edges. A

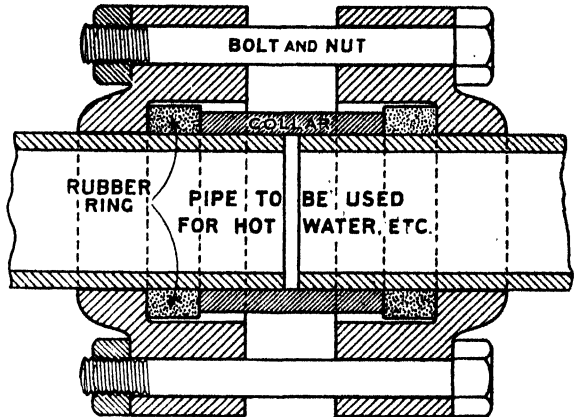


FIG. 20. EXPANSION JOINT

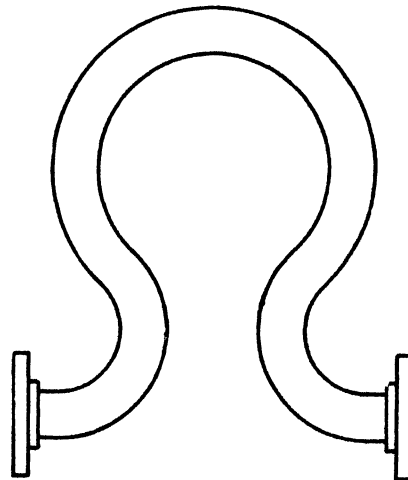


FIG. 21. EXPANSION BEND (AS INSERTED IN A STEAM PIPE)

rectangular piece must be left free on two adjacent edges to allow for expansion or contraction. The "creeping" of lead on a sloping roof is due to alternate heating and cooling combined with the weight and ductility of the metal.

(c) Long girders or large span iron roof trusses are sometimes provided with a roller bearing at

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one end, to allow the necessary movement due to expansion and contraction; at other times they are fixed at the ends by bolts which pass through slotted holes.

(d) The cracking of the glazed surface of the tiles in fire-places is due to the coefficients of expansion of the glaze and of the body of the tiles being unequal.

(e) An arrangement similar in principle to the "bar breaker" has been used for drawing together the bulging walls of buildings. Stout iron bars, screwed at the ends, are passed through such a building from wall to wall; nuts, screwed on the bars outside the walls, bear on strong iron plates. The bars are heated, the nuts screwed up till the iron plates bear on the walls, and then the sources of heat (e.g. braziers) are removed.

The contraction of the bars on cooling draws the walls together.

(f) In making riveted joints on iron plates, girders, etc., the holes are drilled about $\frac{1}{8}$ in. larger than the rivets to allow for the expansion of the rivets. The latter are inserted in the holes when red hot and hammered as quickly as possible. When they cool, they contract and hold the plates together with great force.

(g) The breaking of glass or china, when suddenly heated or cooled, is due to stresses set up owing to unequal expansion or contraction when different portions are at different temperatures. During the last few years, fused silica ware (sold under the trade name of "Vitreosil") has come into use for such purposes as globes for incandescent gas lighting. Having a very small coefficient of expansion (about one-fourteenth of that of glass) it is unaffected by sudden and great temperature changes. It may be plunged, with safety, into cold water even when bright red hot.

Liquids. It will be obvious that, with liquids, it is the increase in volume, or *cubical expansion*, which must be considered. Also, since a liquid must of necessity be contained in some vessel, the expansion which we observe (or the *apparent expansion*) is less than the *real expansion* of the liquid by an amount equal to the increase in capacity of the container.

As a rule, liquids expand considerably more than solids for the same rise in temperature; and it has been shown on a previous page that the apparent expansion of a liquid in a glass tube furnishes us with a means of measuring temperatures.

Practical points connected with the expansion

of liquids are dealt with in Chapter V, where hot-water systems will be considered.

Gases. In this case, again, we are only concerned with cubical expansion; but whilst the volume of a liquid is practically unaffected by the pressure exerted on it, the volume of a gas depends to a great extent on the pressure. For all gases which are not near their liquefying point, the following laws hold good—

BOYLE'S LAW. *The volume of a gas varies inversely as the pressure, so long as the temperature remains constant.* That is, if the pressure be doubled, the volume is halved; if the pressure becomes five times the original pressure, the volume is reduced to one-fifth of the original volume.

CHARLES'S LAW. *If the pressure be kept constant, the volume of a gas increases by $\frac{1}{273}$ of its volume at 0° C. for each degree rise in temperature on the Centigrade scale.*

We shall be concerned with the connection between the pressure and the volume of a gas when we consider the action of pumps in a subsequent chapter. The effect of heat on the volume of a gas will be seen in Chapter V to be the means by which natural ventilation is brought about.

SPECIFIC HEAT

The following experiment explains what is meant by the term *specific heat*. Equal weights (160 grams) of water, iron turnings, copper turnings, and lead shot were placed in test tubes and heated to 100° C., by standing the test tubes in a large can of water which was then heated until it boiled, and kept boiling for five minutes. Four similar copper cans were taken, each containing 160 grams of water, at a temperature of 15° C.; the hot substances were then poured in turn into one of these vessels of cold water, and the temperatures of the mixtures taken. The addition of the hot water caused the temperature to rise to 56.2° C.; the iron to 23.4° C.; the copper to 22° C.; and the lead to 17.4° C. That is, water in cooling gave out far more heat than an equal weight of the above metals, although the water cooled through a much smaller range of temperature. We commonly account for this by saying that water has a much greater *specific heat* than these other substances.

The *specific heat* of a substance is the amount of heat required to heat a given weight of that substance from any one temperature to another, compared with the amount of heat required to

heat the same weight of water through the same range of temperature. We could also compare the amounts of heat given out by the given substance and water in cooling.

Units of Heat. Since we are to measure "amounts of heat," we need some unit of quantity. Various units are used for different purposes—

(a) *The Calorie*—the amount of heat required to raise 1 gram of water through 1° C. This is a universal unit for all work in pure science; and the "Grand Calorie," which is 1,000 calories, is used on the Continent for engineering purposes.

(b) *The British Thermal Unit* (or B.Th.U.)—the amount of heat required to heat 1 lb. of water through 1° F. This unit is generally used in this country for all engineering work.

(c) *The Therm*—which is equal to 100,000 B.Th.U.'s. This is the unit used by gas companies in selling coal gas; for since the old "flat-flame" gas jet is obsolete and has been replaced by the incandescent mantle, whose efficiency depends on the temperature to which it is heated, and since coal gas is much used for gas engines, gas fires, and cookers, it is the "heat value" of the gas which is important to the consumer.

Determination of the Specific Heat of a Solid. The following worked examples will serve to illustrate the method used—

EXAMPLE I. A piece of copper, weighing 185 grams, was heated to 100° C. in a steam heater. It was transferred as quickly as possible to a copper vessel weighing 40 grams, and containing 200 grams of cold water. The temperature of the water rose from 12° C. to 19° C. Find the specific heat of copper.

SOLUTION. Let *S* be the specific heat of copper.
No. of calories given out by 185 grams of copper in cooling from 100° C. to 19° C.

$$= S \times 185 \times (100 - 19).$$

No. of calories used in warming 200 grams of water from 12° C. to 19° C.

$$= 200 \times (19 - 12).$$

No. of calories used in warming copper vessel weighing 40 grams from 12° C. to 19° C.

$$= S \times 40 \times (19 - 12).$$

Equating the heat given out to that used up, we get—

$$S \times 185 \times (100 - 19) = 200 \times (19 - 12) + S \times 40 \times (19 - 12)$$

$$\text{Whence } S = \cdot 095$$

i.e. specific heat of copper = 0.095. *Ans.*

Table XI gives the specific heats of a few common solids and liquids.

TABLE XI
SPECIFIC HEATS

Water	1.000	Lead	0.031
Cast-iron	0.115	Mercury	0.033
Wrought-iron	0.109	Turpentine	0.410
Brass	0.092	Glycerine	0.580
Copper	0.095		

Specific Heat of Water. Water has the greatest specific heat of any liquid, with the exception of a mixture of alcohol and water in certain proportions—the specific heat in this case being slightly greater than 1. Hence, water is a most suitable liquid for heating systems, as a given weight of water will require more heat to raise its temperature through a given range than the same weight of another liquid, and in cooling it is able to give out this great amount of heat. The low cost of water is, of course, another great point in its favour.

CHANGE OF STATE

Melting. It is a matter of everyday experience, that most solid bodies melt (i.e. change into the liquid state) if heated sufficiently; the exceptions are those solids like sugar, coal or limestone, which undergo some chemical change when heated. The changing from the solid state into the liquid requires a considerable amount of heat. Thus, if 500 grams of water at 0° C. be mixed with 500 grams of water at 90° C., the temperature of the mixture will be 45° C., neglecting the small amount of heat lost to the containing vessel and the air around; but if 500 grams of ice at 0° C. be mixed with 500 grams of water at 90° C., the temperature of the mix-

TABLE XII
MELTING POINTS AND LATENT HEATS OF FUSION

Material	Melting Point		Latent Heat of Fusion	
	Degrees Centi-grade	Degrees Fahrenheit	Calories per Gram	B.Th.U.'s per Lb.
Ice	0	32	80	144
Copper	1083	1980	43	77
Iron, cast	1050-1190	1922-2174	} 23-33	41-59
Iron, wrought	1600	2912		
Lead	327	621	5.9	10.6
Zinc	419	786	28	50
Solders—				
1 tin, 2 lead	227	441	—	—
1 tin, 1 lead	188	370	—	—
2 tin, 1 lead	171	340	—	—

ture will be 5° C. The heat used in changing the state of a substance without changing its temperature is known as *latent heat* (*latent* means *hidden*). Thus we say that the latent heat of fusion of ice is 80 calories per gram, or 144 B.Th.U.'s per lb., since to change 1 gram of ice

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at 0° C. into water at 0° C. requires 80 calories ; and to change 1 lb. of ice into water without alteration of temperature requires 144 B.Th.U.'s. See Table XII.

The change from the solid to the liquid state, or vice versa, is often accompanied by a *sudden* change in volume. Thus, 12 cub. ft. of ice melt to form 11 cub. ft. of water ; and the converse is equally true. This causes the well-known bursting of water pipes in frosty weather ; the damage sometimes passes unobserved until the subsequent thaw allows the water to escape, but the burst was due to the frost, not to the thaw. In passing, it might be pointed out that moving water is much more difficult to freeze than still water—hence, a running tap may prevent a burst water pipe. This expansion accompanying the freezing of water, may cause plaster to break away from walls, where a little water has got behind the plaster through cracks.

Cast-iron and type-metal are examples of other substances which expand when they solidify, but in these cases the property is of use to us, as it ensures "sharp" castings.

Lead and paraffin wax, however, expand when they melt, and contract when they solidify ; for this reason, these substances will not give good castings.

Boiling. Practically all liquids boil (i.e. change into vapours) if sufficiently heated. To bring about this change, even after the liquid has been heated to the boiling point, a great deal of heat is required. The conversion of one gram of water at the normal boiling point (100° C. or 212° F.) into steam at the same temperature requires about 537 calories ; of one pound of water into steam, under the same conditions, about 967 B.Th.U.'s. Conversely, when steam condenses to water at this temperature, it is able to give out this large amount of heat ; for this reason steam is more efficacious for warming a room than the same weight of boiling water. The numerical statement given above is usually summed up in the words, "The *latent heat of vaporisation of water* (or the *latent heat of steam*) is 537 calories per gram, or 967 B.Th.U.'s per lb. at the normal boiling point."

Effect of Pressure on Boiling Point. When water is converted into steam, it increases in volume about 1,600 times. (Hence the rough

rule, "1 cub. in. of water gives 1 cub. ft. of steam.") This increase in volume is resisted by the pressure exerted by the atmosphere, or any other gas or vapour which may be pressing on the surface of the water. Hence, an increase of pressure makes boiling more difficult as it makes it harder to bring about this expansion ; therefore the boiling point is raised. The boiling point of water is 100° C., or 212° F., only when the atmospheric pressure (or the pressure exerted on the surface of the water) is such as to support a column of mercury 76 cm. (or 29.92 in.) high in a barometer ; this corresponds to a pressure of 14.7 lb. per sq. in.

Table XIII gives the boiling point of water at different pressures ; conversely, it may be used to determine the pressure exerted on the walls of a vessel containing water which is heated to different temperatures, if the water vapour is unable to escape. Since the temperature inside such a vessel could easily be raised to 300° C.

TABLE XIII
BOILING POINT OF WATER AT VARIOUS PRESSURES

Pressure		Temperature	
Centimetres of Mercury	Pounds per sq. in.	Degrees Centigrade	Degrees Fahrenheit
76.0	14.7	100.0	212.0
77.6	15.0	100.6	213.0
103.4	20.0	108.9	228.0
129.3	25.0	115.6	240.1
155.1	30.0	121.3	250.3
206.8	40.0	130.7	267.2
310.3	60.0	144.8	292.5
413.7	80.0	155.5	311.9
517.1	100.0	164.3	327.6
775.6	150.0	181.3	358.3
1034.2	200.0	194.4	381.8
1292.7	250.0	205.0	401.0
1551.3	300.0	214.1	417.4
1809.8	350.0	222.5	432.5
2068.4	400.0	229.9	445.8

or 400° C., it will be seen that the pressures produced are such as to necessitate some form of safety valve in all closed vessels or systems where water is heated.

Chapter IV—TRANSMISSION OF HEAT

HEAT can be transmitted in three different ways: (a) by *conduction*, (b) by *convection*, and (c) by *radiation*.

CONDUCTION

Conduction is the term used when the heat is "handed on," so to speak, from a hot particle to a colder one which is touching it. Heat passes through solid bodies mainly by conduction. The metals are good conductors of heat; other solids, such as wood, ebonite, wool, felt, "slag wool" (a product obtained from blast furnaces), and asbestos (a fibrous mineral) are bad conductors. Their low conductivity accounts for the use of wood for the handles of copper soldering bits and aluminium or silver teapots, asbestos as a "lagging" for steam pipes, and slag wool as an "insulation" for cold storage chambers; in all these cases we wish to prevent, as far as possible, the transmission of heat. The "scale" which forms on the inside of boilers in certain districts where the water is hard is a poor conductor; its presence may easily cause twice the normal amount of fuel to be used in obtaining the same amount of hot water.

Liquids, except mercury, are very poor conductors of heat; in fact, as we shall see later, heat travels through liquids almost entirely by convection. Gases, such as the air, are even worse conductors of heat—the hand can be held quite close to the *side* of the flame of a blow-lamp without feeling any sensation of warmth. The bad conductivity of slag wool and of a blanket is partly due to the air imprisoned between the fibres; in the case of slag wool the volume of this air is eleven times that of the fibres.

It has been found that for sedentary work, a room temperature of about 65° F. is most suitable; sitting-rooms or dining-rooms should be at this temperature for comfort. In winter, the atmospheric temperature is, of course, much lower, hence any heating system must be able to do two things—

1. To raise the temperature of the room to 65° F.; and
2. To maintain it at this temperature; that is, to supply heat to make up for that lost by conduction through the walls, etc.

This loss depends on the nature of the materials used for the walls, on their thickness, and on the difference in temperature between the room and the external atmosphere. Obviously, the lower the conductivity of the materials used and the thicker the walls, the less will be the amount of heat lost for a given difference between the temperature inside the room and that of the open air. Because of the low conductivity of air, cavity walls allow far less heat to escape than the same amount of material made into a solid wall; double windows, consisting of two panes of glass separated by an air space, would be much better in this respect than single ones.

CONVECTION

Convection is the term used when heat is transmitted by the movement of the heated portions away from the source of heat; their places being taken by cooler parts, which are heated in their turn. It is the principal method by which heat is transmitted in liquids, and is also of importance in the case of gases.

The presence of convection currents in a liquid which is being heated at the bottom is easily shown.

Take a round bottomed flask, Fig. 22, about two-thirds filled with cold water. Drop in a few crystals of permanganate of potash; these will fall to the bottom of the flask and, being purple in colour, will be seen clearly. They will slowly dissolve. Now place a Bunsen burner underneath the flask, with a small flame, so that the point just touches the centre of the base of the flask; a narrow stream of coloured water will be seen to rise up the middle of the flask, to spread out when it reaches the surface of the water, and to descend at the sides.

[N.B. To perform this experiment successfully, use a very small flame.]

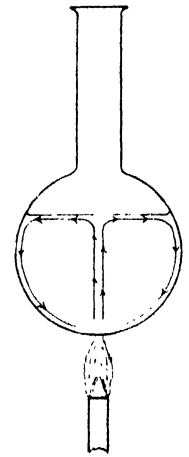


FIG. 22
CONVECTION
CURRENTS IN A
LIQUID
Arrows show direction
of currents

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The explanation of this experiment is very simple. The water expanded on being heated, and so became lighter, bulk for bulk, than that around it. This lighter water was then forced upwards by the pressure of the other denser water, in exactly the same way as a piece of cork, thrust to the bottom of a bucket of water, is forced upwards as soon as it is released.

That convection, and not conduction, is responsible for almost the whole of the heat transmitted through water, is easily shown by two simple experiments. A test tube, Fig. 23,

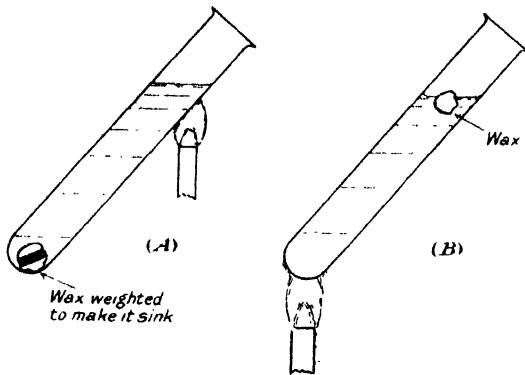


FIG. 23. TO SHOW THAT WATER IS NOT GENERALLY HEATED BY CONDUCTION

is three parts filled with water, and a small lump of paraffin wax, weighted with wire so as to sink, is dropped in. The water in the tube is heated at the top, as shown in Fig. 23 (A), the tube being held at the bottom. The water in the upper part of the tube soon boils, but the wax at the bottom does not melt, although its melting point is about 50°C . to 53°C . But, if a piece of the same wax is allowed to float on the surface of water in a similar tube, and this water is heated at the bottom, as in Fig. 23 (B), this wax will very soon melt, owing to convection currents heating all the water equally.

Hot-water Supply and Heating Systems. Convection currents are made use of in hot-water supply and heating systems. Fig. 24 shows the former in its essentials. The boiler is situated on the ground floor or in the basement. When heating is begun, hot water rises from the top of the boiler and passes into the upper part of the hot-water cistern, cold water from the latter taking its place. This circulation continues until all the water in the cistern is heated. Hot water for use in the bathroom, scullery, etc., is

drawn off from a pipe, which proceeds from the top of the hot-water cistern. Cold water, to make up for the water used, flows in from a tank in the roof; this tank has a ball-controlled cock, so as to regulate the supply as necessary. The expansion pipe allows for the increase in volume which takes place when the water is heated, and also provides a means by which air can escape

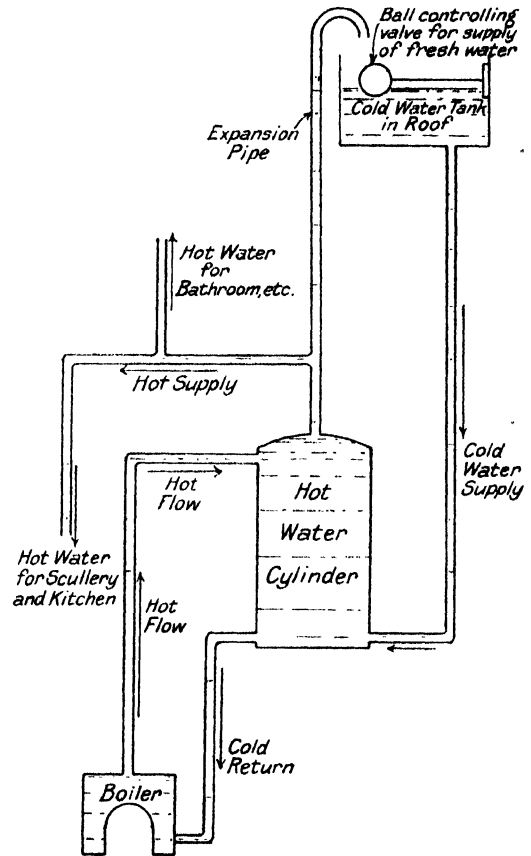


FIG. 24. HOT-WATER SUPPLY SYSTEM

from the system; the presence of this air is due to the fact that air is far less soluble in hot water than in cold.

Fig. 25 shows a simple hot-water heating system in diagrammatic form. The boiler *A* is filled with water, and is situated in the basement of the building. The hot water rises through the flow main *B* and enters the various "radiators" through small branches. These radiators expose a large surface to the air in the room; hence the air is warmed and the water is cooled. This water then passes back

through similar branches to the "return main" C, from which it again reaches the boiler. Such a system is known as a "gravity" one, since the circulation is caused by the difference between the weights of equal volumes of hot and cold water—and weight is due merely to the earth's gravitational attraction. In a large building the circulation is often assisted by a motor-driven

be replaced by air entering the room through the lower part of the window, underneath doors, through the spaces between floor boards, or, preferably, through specially designed fittings, which allow air to enter in such a manner that unpleasant draughts shall be avoided. The presence of this incoming air may be demonstrated by holding a lighted candle at the

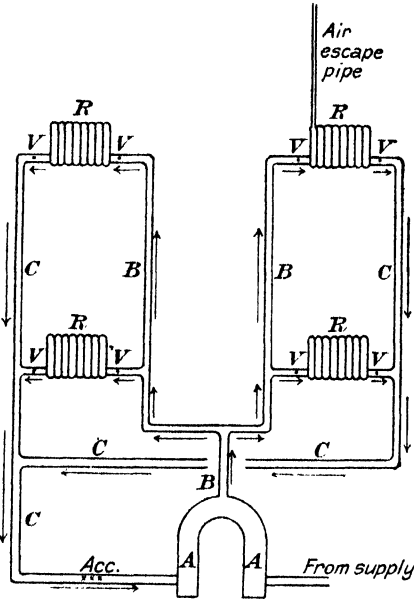


FIG. 25. HOT-WATER HEATING SYSTEM

- A = Boiler
- B, B = Flow main
- C, C = Return main
- R = Radiator
- V, V = Valves for isolating any radiator
- Acc. = Position for accelerator if fitted

"accelerator," placed in the return main at some point near the boiler; this helps to overcome the resistance to the passage of the water through the pipes.

Ventilation. The air in a room is heated mainly by convection currents; the heated air is forced to rise because it has expanded and become less dense, and the heavier colder air takes its place, to be heated in its turn. Convection currents also produce all *natural* ventilation, as well as winds; they also give rise to "draughts," which may make a room very unpleasant.

Let us consider a room in which people are working. The expired air from their lungs is warmer than the remainder of the air, and so tends to rise. It escapes, if possible, from the room through the chimney, or the upper part of the window, if this be open. This air must

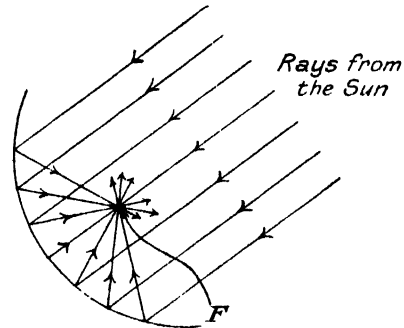


FIG. 26. RADIANT HEAT FROM THE SUN BROUGHT TO A FOCUS AT F BY A CONCAVE MIRROR

bottom of an ill-fitting door—the flame will be blown away from the door.

A fire, burning in an ordinary grate, increases the rate at which this movement of air takes place, owing to the high temperature attained by the air passing through the burning fuel; the fire is therefore an aid to ventilation, but may cause cold draughts near the floor. Modern methods, using *natural* ventilation, place the fresh air inlets above the floor level to avoid these draughts; but in many large buildings mechanical ventilation is employed—the foul air is drawn out by exhaust fans, which suck the air from the upper part of the rooms whilst fresh air, freed from dust and often warmed in winter, or cooled in summer, is forced into the room through large openings. The size of these openings is such that a slow stream of air can easily supply the necessary amount. In such a building, doors and windows are usually kept closed as far as possible, as opening them hinders the working of the ventilation scheme.

RADIATION

Radiation is the term used to describe the transmission of heat from one place to another, without the intervening medium being raised in temperature. *Radiant heat* is very similar to light in its behaviour. Like light, it can travel through a vacuum (i.e. an empty space, such as exists between the earth and the sun) with the

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enormous velocity of 186,000 miles per second. Like light, too, it travels in straight lines through any one material, and can be reflected from a smooth surface. It can be focused by a concave mirror, Fig. 26; in fact, it has been proposed to focus the sun's heat in this way in tropical countries, in order to raise steam for working small steam engines!

As we shall see in Chapter VI, a ray of light usually changes its direction suddenly as it passes from one transparent *medium* (or material) to another; this is made use of in the case of lenses. Similarly, a beam of radiant heat is usually changed in direction when it passes from one medium into another, and a glass lens, which

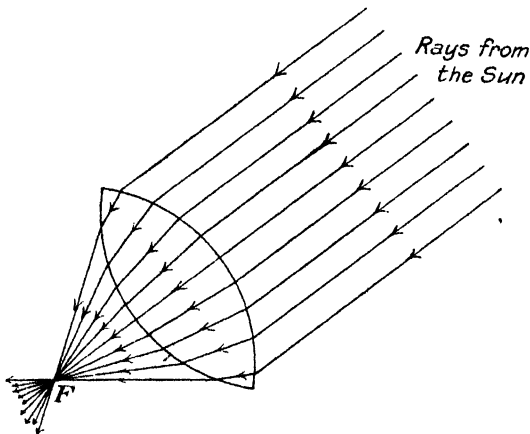


FIG. 27. THE BURNING GLASS

The sun's radiant heat is brought to a focus at the point F

will focus light, will also focus radiant heat—the common "burning glass," Fig. 27, for example.

Then, again, certain materials are said to be transparent, that is, to allow light to pass through them; others, on the contrary, do not, and are said to be opaque. Those substances which allow radiant heat to pass through them are said to be *diathermanous*; those which do not transmit radiant heat, but absorb it, are called *athermanous*; this absorption is always accompanied by a rise in temperature of the material concerned.

Dry air is almost perfectly diathermanous—hence is not heated by radiant heat passing through it. This accounts for the fact that in winter the temperature of the air may be below freezing point, although when in the sun one "feels" warm—the body being warmed by the radiant heat which falls on it and is absorbed. But those substances which readily transmit

light do not necessarily transmit heat; also opaque bodies are not necessarily athermanous. For example, water is transparent, but does not transmit radiant heat at all well; a "water cell" is used with some very powerful projection lanterns between the condenser and the slide, so as to allow the light to be concentrated on the latter without the heat, which would otherwise crack it. On the other hand, if iodine is dissolved in carbon disulphide (a liquid with a rather unpleasant smell), the solution formed is dark purple in colour, is practically opaque, but is able to transmit radiant heat well.

The behaviour of glass is very peculiar; it is a case of *selective absorption*; that is, it

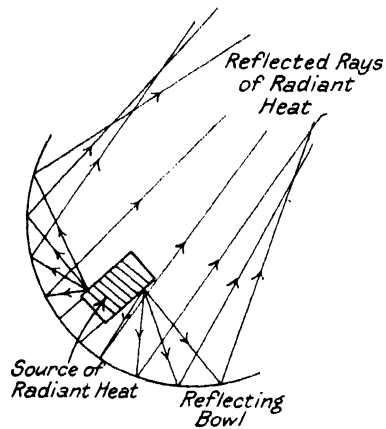


FIG. 28. REFLECTION OF RADIANT HEAT IN A BOWL FIRE

transmits radiant heat from a high temperature source, but does not transmit heat from a low temperature one. Consider what happens when direct sunlight falls on a building with a glass roof; the radiant heat from the sun (a source at a temperature somewhat above 5,000° C.) passes through the glass, falls on the objects inside, is absorbed by them, and raises their temperature. They, in turn, give out heat, partly by conduction, partly by convection in the air, and partly by radiation. But this radiant heat, proceeding from these objects, which are at a relatively low temperature, is unable to pass out through the glass, and is used in warming the building and its contents. Consequently this glass roof acts as a kind of valve; it allows radiant heat to pass into the building, but does not allow it to pass out readily; this accounts for the fact that such a building is hot in summer.

A dull black surface is the best absorber of

radiant heat; light coloured ones are not so good, whilst bright shiny surfaces reflect most of the radiant heat which falls on them. Thus we see that the polished copper of an electric "bowl fire" is useful as well as ornamental, Fig. 28.

The differences between the absorbing powers of these surfaces can be demonstrated very easily, as shown in Fig. 29. Take two similar

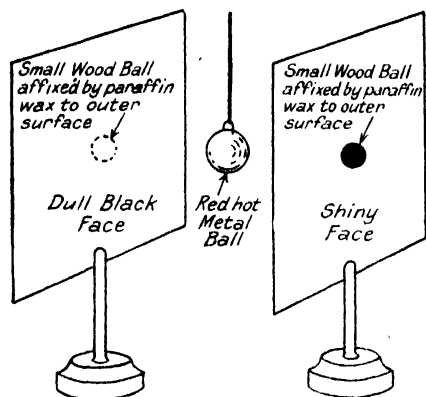


FIG. 29. TO SHOW THAT A DULL SURFACE IS A BETTER ABSORBER OF RADIANT HEAT THAN A SHINY ONE

sheets of tinned iron, about 9 in. square (the sides of a biscuit tin will do), and blacken the face of one over a smoky candle or oil-lamp flame. Fix them up facing one another, with the smoky face of the one turned towards the other, and about 6 in. from it. Fasten a small wood ball to the outer surface of each by a little candle grease. When this latter has had time to cool, hang a red hot iron ball exactly midway between the sheets; it will be found that the wood ball will fall from the sheet with the blackened face very quickly; the ball on the other will probably not fall off at all. This clearly shows that the black surface has a greater absorptive power than the polished one.

Radiating Surfaces. The rate at which heat is radiated from a given body depends on three things: (a) its temperature; (b) the temperature and nature of the surrounding medium; and (c) the area and nature of its surface. The higher the temperature of the body, and the lower the temperature of its surroundings, the greater the rate at which it radiates. Obviously, too, the rate is proportional to the area of the radiating surface. As regards the character of the surface, dull black is the best radiator, and

a bright polished surface the worst. The difference between the radiating power of two such surfaces can be readily shown by means of a differential thermometer and a Leslie's cube. The former, *ABCD* in Fig. 30, is a bent glass tube with a bulb at each end. The lower part of the limbs and the horizontal portion contain a thread of some coloured liquid, which stands at the same level at the two sides, so long as the two bulbs are at the same temperature. If, now, one bulb is heated more than the other, the liquid moves away from the hot bulb, owing to the expansion of the contained air. The Leslie's cube consists of a cubical vessel, made of sheet tin, one of whose vertical faces is painted dull black, whilst others may be left bright or painted with different colours. The cube is filled with boiling water, and supported midway between the bulbs of the differential thermometer, with the black surface facing one bulb and the shiny one facing the other. The movement of the coloured liquid shows that the bulb near the black surface is hotter than the one near the bright surface; that is, that the black surface is the better radiator. Similar experiments may be made to compare the radiating powers of other surfaces.

From this it would appear that hot-water pipes—radiators as they are usually called—should always be painted a dull, non-glossy black. But, at the temperature at which they work, most of the heat is transmitted through the metal by conduction and given off by

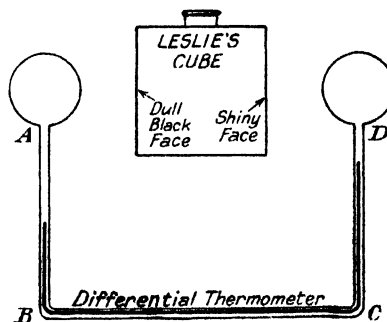


FIG. 30. TO SHOW THAT A DULL BLACK SURFACE IS A BETTER RADIATOR THAN A BRIGHT, SHINY ONE

convection, not by true radiation. In fact, in careful experiments made by the writer, it was found that a surface coated with aluminium paint gave off quite 95 per cent of the amount of heat that a dead black one did when the vessel was filled with water at the boiling point.

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A polished surface, however, was found to give off heat much more slowly.

The *thermos flask* is an example of most efficient heat insulation. As Fig. 31 shows, it consists of a double-walled glass vessel, the space between the walls being as perfect a vacuum as can be obtained commercially. The outer surface of the inner wall and the inner surface of the outer wall are silvered, and the flask is fitted inside a leather, or sometimes a paper-lined metal case, for protection. If a hot liquid is placed in the flask, it can lose little heat by

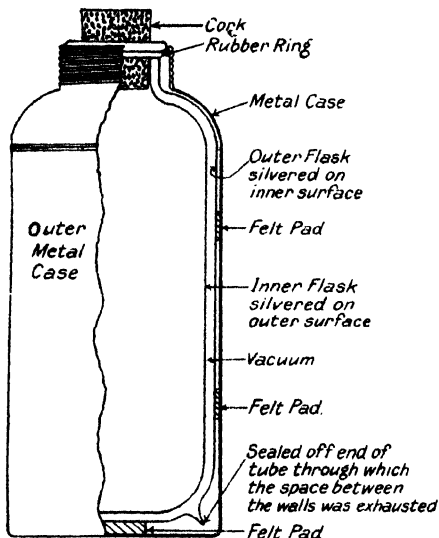


FIG. 31. A THERMOS FLASK
With portion of outer case cut away

conduction or convection, as these cannot take place through a vacuum, and the only loss possible is by conduction through the cork, which is a bad conductor. The silvered surface of the inner flask gives off very little radiant heat, and the greater part of what is given off is reflected back across the vacuum by the silvering on the outer flask. Thus the rate at which heat is lost is very slow. Similarly, very little heat from the outside atmosphere can reach the contents of the flask if these should be very cold; consequently, iced drinks can be kept cold for many hours by the use of the flask. In fact, the ordinary thermos flask is a commercial form of the "Dewar flask," invented by Sir James Dewar, for holding liquid air at a temperature of about -190°C . He found that the heat traversing such a flask was less than one-thirtieth

of that passing through the walls of an ordinary flask of the same size.

HEATING OF ROOMS

There are two totally different methods of artificial heating; we may either warm the *air* in our rooms, or we may depend for comfort upon the absorption by our bodies of radiant heat given out by suitable sources.

Air warming is produced by convection currents, and may be obtained in various ways. For instance, air may be warmed by a central plant serving the whole of a building, this air being discharged into the various rooms through suitable apertures; or so-called hot-water, or steam, "radiators" may be fitted in the various rooms; or, on the other hand, *enclosed* coal, coke, or gas fires or even a number of gas burners, whose flames do not strike any solid material, may be used.

Radiation heating is obtained from all heaters where some red-hot or white-hot substance is exposed. Open coal, coke, or gas fires and the high-temperature electric heaters, whose "elements" are open to the air, are examples of such sources.

As a matter of fact, sources used mainly for convection heating give out a small amount of heat by radiation, whilst sources of radiation heating produce a little air-warming directly. In the case of coal or coke fires, the air warmed by contact with the hot fuel passes up the chimney; but the radiation falling on the walls and contents of the room raises their temperature, and they give rise to convection currents in the air.

In any well-ventilated room, these convection currents of air not only provide a circulation of warmth, but can be made to ensure a supply of clean, fresh air. Heating and ventilation of rooms are closely associated.

Warmed air, including exhaled "bad" air from peoples' lungs, being slightly less dense than the rest of the air, tends to rise to the upper parts of a room, and may escape from adjustable ventilators placed high up in the walls or through the open top of a window. As the bad air escapes fresh cooler air enters by any opening lower down, such as the space between the door and the floor.

This may create an unpleasant draught. One way to prevent this would be to admit the necessary fresh air by special intake openings half way between floor and ceiling.

Chapter V—LIGHT

TWENTY years ago the average scientist would have been quite ready to say what light is—he would have told us that light consists of waves spreading through the ether; and that this ether was a medium which filled all space, and even existed between the “molecules” or minute particles which build up all bodies. But, to-day, we are not quite so confident—we are by no means certain that the ether even exists! Still, although we are not sure as to what light *is*, we do know a great deal about what it *does*; and that, after all, will enable us to employ light.

RECTILINEAL PROPAGATION OF LIGHT

That light travels in straight lines (so long as its path remains in any one substance) is a fact which we unconsciously assume in everyday life. We “sight” along the edge of a plank to see if it is straight; we use “sights” in levelling; and yet few people trouble to think of the principle underlying these actions. The truth of our assumption may be demonstrated in many ways—

(a) We cannot see round corners.

(b) The edge of the beam of light from a searchlight (clearly visible in foggy weather), or of the beam from a cinema lantern (easily seen when smoke is present in the air), is quite straight.

(c) The sizes and shapes of shadows cast by opaque objects are such as would result if light travelled only in straight lines.

Shadows. The subject is so important that a few cases must be considered. If we place an opaque sphere *A*, Fig. 32, between a *very* small source of light *S* and a screen, we shall see that a very dark, sharply defined circular shadow is cast; the remainder of the screen will be illuminated. It is easily seen that light from *S* cannot reach any part of this circular shadow.

But suppose we take a source of light *S* that cannot be considered as very small; in such a case we see, as in Fig. 33, that the central completely dark shadow *BC* is surrounded by an intermediate region of partial shadow, which shades from dense shadow at *B* and *C* to no shadow at *D* and *E*. It is easily seen that the

area between *B* and *C* receives no light from any point on the source; whereas places between *B* and *D* or *C* and *E* receive light from

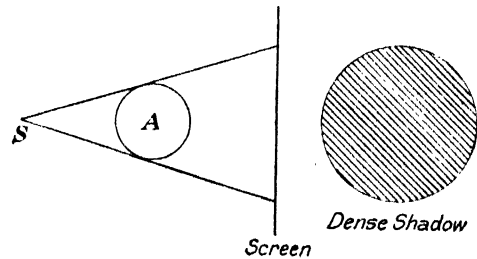


FIG. 32. SHADOW CAST BY A SMALL SOURCE OF LIGHT

a portion only of the source; points on the screen outside *D* and *E* receive light from all

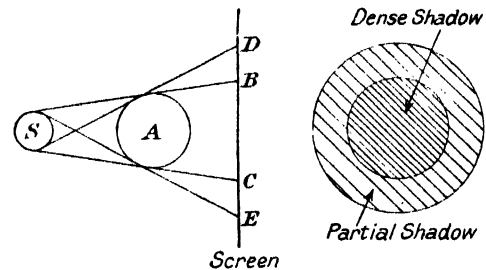


FIG. 33. SHADOW CAST BY A LARGER SOURCE OF LIGHT

parts of the source, and are therefore brightly illuminated.

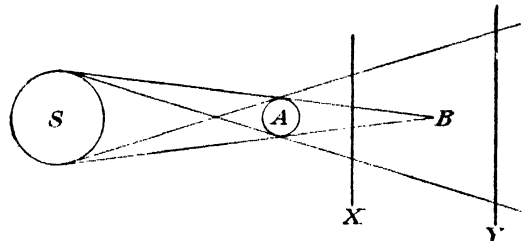


FIG. 34. SHADOW CAST BY A SOURCE LARGER THAN THE OPAQUE OBJECT

If, as sometimes happens (see Fig. 34), the source of light is larger than the opaque body, the only region of complete shadow is a cone having its apex at *B*. If the screen is placed

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at X , there will be a small circle of dense shadow, surrounded by a large circle of partial shadow. Should the screen be placed at Y , there will be no complete shadow, since a straight line can be drawn from *any* point on Y to some portion of S without touching A .

An electric arc lamp without its diffusing opal globe is an example of a source, as in Fig. 32. The lamp with an opal globe behaves

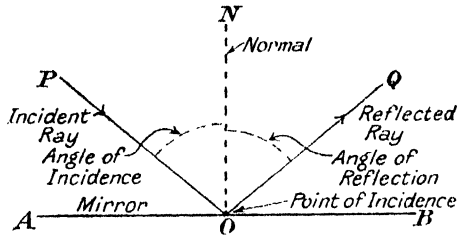


FIG. 35. REFLECTION FROM A PLANE MIRROR

as a large source of light, and gives much "softer" shadows. A similar advantage arises from the use of "opal type" lamps in place of the ordinary "gas-filled" electric lamps in dwelling houses.

Transparent, Opaque, and Translucent Substances. Light striking a surface, separating one substance from another, may be reflected back into the first substance, or pass into the second, or be absorbed. Sometimes portions are affected in all three of these ways.

A *transparent* substance is one through which light can pass without loss; an *opaque* one is one through which it cannot pass. No substance is perfectly transparent—even a piece of glass will cast an appreciable shadow—but the air, water, and glass are almost perfectly transparent. Similarly, many substances usually considered to be quite opaque are not so when their thickness is small; thus gold leaf transmits a small amount of light which is found to be green in colour; sections of rock or stone can be ground so thin that they can be examined under a microscope by passing light through them—the photographs of the stones, shown in the chapter on "Building Materials," were obtained in this way.

Translucent substances transmit some of the light which falls on their surfaces, but bodies cannot be seen clearly through them; this is probably because the roughness of the surface (as in the case of "ground" glass), or slight variations in composition (air spaces between

the fibres in paper, or floating fat globules in a mixture of milk and water) causes irregular bending of the rays of light passing through it. But ground glass may be rendered transparent by filling up the surface roughness by smearing with vaseline, and white paper by application of oil or crystal varnish, which fills up the air spaces as well as soaking into the fibres themselves.

REFLECTION OF LIGHT

In Fig. 35, AB is a plane mirror, PO is a ray of light striking the mirror (usually called the *incident ray*), and OQ is the reflected ray. ON is a line perpendicular to the surface AB , and is called the *normal* to the mirror at the point of incidence O .

As a result of experiments, we find that the angles PON and QON are always equal, and that a plane (i.e. flat) surface will always pass through the lines OP , OQ , and ON .

Laws of Reflection. Stated in general terms, these are—

1. The incident ray, the reflected ray, and the normal to the reflecting surface at the point of incidence lie in one plane.

2. The incident and reflected rays are on opposite sides of the normal, and make equal angles with it.

In the case of curved mirrors, the same laws hold good. These mirrors are usually portions

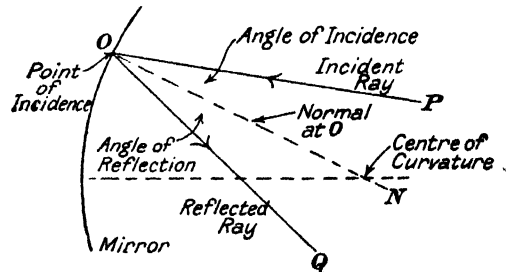


FIG. 36. REFLECTION FROM A SPHERICAL MIRROR

of the surfaces of spheres, and it can be proved by geometry that any line drawn from the centre of a sphere to the surface (i.e. any *radius*) is perpendicular or normal to that portion of the surface which it meets.

Regular and Irregular Reflection. A highly polished plane surface gives *regular* reflection; the reflected beam is similar to the incident beam (e.g. a parallel beam is reflected as a parallel beam), and if a normal be drawn to the reflecting

surface; the angles of incidence and reflection are equal. Examples of such surfaces are: that of still water or other liquids, polished glass, glass "mirrors," and polished metal surfaces.

Some other surfaces spread the reflected beam somewhat. The greater portion is reflected as in regular reflection, but a small amount is scattered slightly. This may be termed *spread*

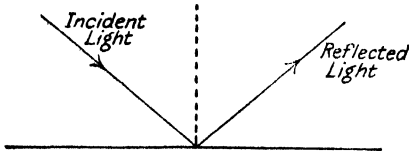


FIG. 37. REGULAR REFLECTION

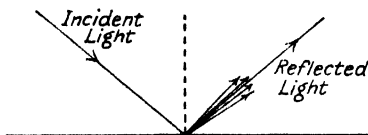


FIG. 38. SPREAD REFLECTION

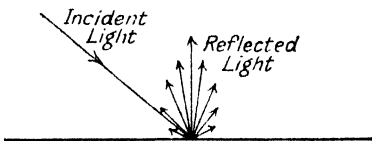


FIG. 39. DIFFUSE REFLECTION

reflection, and is due to very slight irregularities on the surface. Examples of such surfaces are glazed paper and "satin finished" opal glass reflectors.

Matt surfaces (e.g. white blotting-paper) produce *diffuse* reflection. A beam of light falling on such a surface is broken up and light is reflected in all directions, which bear no relation to the angle of incidence. The maximum reflection is in a direction perpendicular to the surface. Examples of such surfaces are opal glass, painted "reflectors," and the ceiling and walls of a room.

If the substance on whose surface the light falls is translucent, a portion of the incident light, instead of being reflected, will be transmitted either as a "spread" or "diffused" beam.

Practical points arising from the above will be dealt with later.

REFRACTION OF LIGHT

As a general rule, a ray of light is refracted, or bent suddenly, as it passes from one trans-

parent medium into another. That this bending does take place can be demonstrated quite easily.

Obtain a metal dish, as in Fig. 40, and fix a rule to the bottom by means of sealing wax, or even candle grease. Stand some distance from the dish, which should be on a table below the eye level, and notice the graduation *P* on the

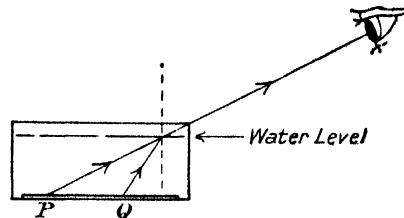


FIG. 40. THE REFRACTION OF LIGHT

rule, which can be seen just over the top edge of the dish. Keeping the head fixed, get someone to pour water into the dish. Immediately this is done it is found that graduations, which were previously hidden by the edge of the dish, become visible, and *Q* appears to be in line with the edge. This experiment may be repeated, using other transparent liquids in the place of water.

Laws of Refraction. 1. The incident ray, the refracted ray, and the normal to the refracting surface at the point of incidence lie in one plane.

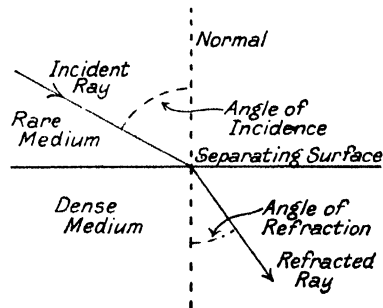


FIG. 41. THE REFRACTION OF LIGHT

2. The incident and refracted rays are on opposite sides of the normal to the refracting surface.

3. For any given pair of media, and for light of any particular colour, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant. This ratio is known as the *index of refraction* from the first medium to the second. If, as is often the case, the first

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medium is air, then this ratio is often spoken of as the *refractive index of the second medium*; for example, the *refractive index of water* really means the index of refraction from air to water.

That medium in which the ray makes the smaller angle with the normal is said to be

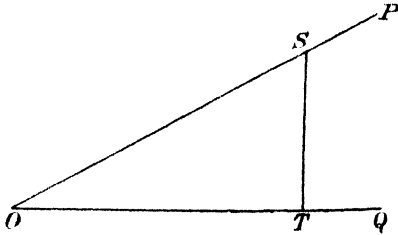


FIG. 42. THE SINE OF AN ANGLE

optically denser than the other, which is called the *rarer* one. Thus water is seen above to be optically denser than air.

For the sake of those whose mathematical knowledge is limited, it may be well to explain here the meaning of the term *the sine of an angle*, though readers will find a full explanation of trigonometrical ratios in the section on "Building Calculations."

Consider the angle POQ in Fig. 42. From any point S in OP , draw ST perpendicular to OQ . Then the ratio of ST to OS is the sine of the angle POQ ; that is—

$$\frac{ST}{OS} = \text{Sine of } POQ$$

(usually written *Sin. POQ*).

The refractive index of ordinary glass for yellow light is about 1.52; of water for yellow

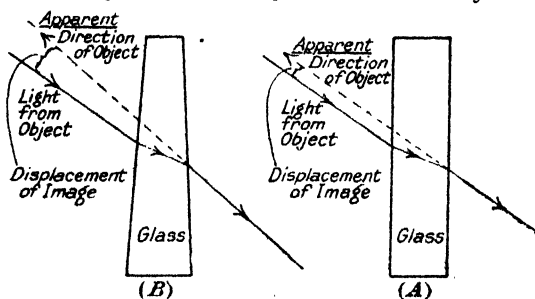


FIG. 43. VISION THROUGH WINDOW GLASS

Note that the displacement of the image is much greater in the case of the faulty glass than with the glass having parallel faces

light about 1.33. The refractive index is generally denoted by the Greek letter μ (pronounced "mew").

OBJECTS SEEN THROUGH WINDOWS. Every one must have noticed that straight lines (e.g. edges of roofs or corners of buildings) seen through windows appear anything but straight. It can be proved both mathematically and by experiment, that when a ray of light passes through

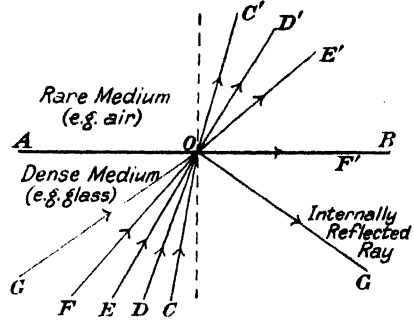


FIG. 44. REFRACTION AND TOTAL INTERNAL REFLECTION

a slab of transparent material having parallel faces, the incident and emergent rays are parallel. If the faces are not parallel, then these rays are not so. Thus, if window glass were so made that its faces were truly parallel, all points on a horizontal straight line, seen through it, would appear to be displaced by the same amount from their true position, and so the line

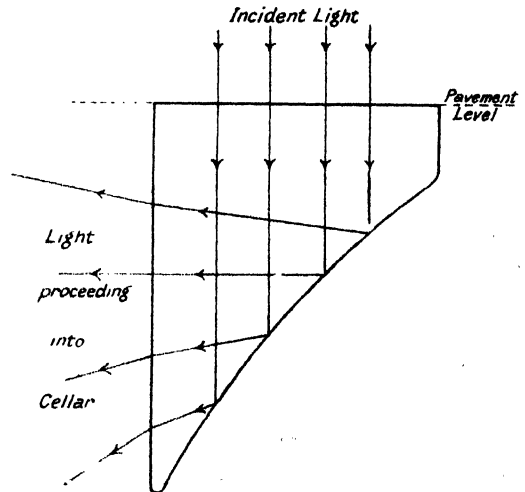


FIG. 45 REFLECTING PRISM IN PAVEMENT LIGHT FOR CELLAR

would still appear straight (see Fig. 43 (A)). But if the faces are not parallel, then the apparent displacement is different (see Fig.

43 (B)). Hence, in the case of ordinary window glass, where the thickness varies considerably (especially in the cheaper varieties), we get varying displacements in neighbouring parts, with the consequent distortion of objects seen through them. It may be observed that this distortion becomes more serious when we look obliquely through the glass than when we look nearly perpendicularly to the surface.

Total Internal Reflection. In Fig. 44, *AB* represents the surface separating a dense medium (glass) from a rarer one (e.g. air). *COC'*, *DOD'*, etc., represent the paths of rays of light, which travel through the glass and strike the separating surface. So long as the angle of incidence in the

Such globes should not be used for mere "prettiness"; they should be scientifically designed to gather up light proceeding in unwanted directions, and to redirect it towards those places where it is wanted. Fig. 46, copied by permission from section 20 of the catalogue of Messrs. Holophane, Ltd., shows some forms of glass prism embodied in globes made by that firm, together with their action on the direction of beams of light. Those most commonly used are the second, fourth, and sixth; they are known as refracting, reflecting, and diffusing prisms, respectively. The reflecting prisms are employed in the glass "reflectors," whilst the other two are used in the glass "globes" which

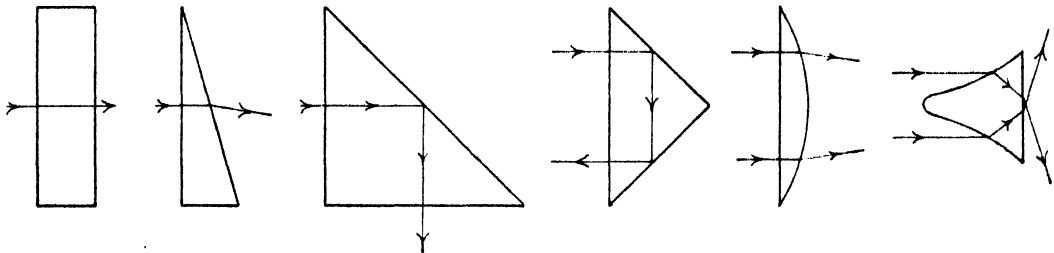


FIG. 46. PATHS OF RAYS OF LIGHT THROUGH GLASS "PRISMS" OF VARIOUS SHAPES

glass is below a certain value, the ray emerges into air; in the case of the ray *FO*, the emergent ray *OF'* is seen to pass along the surface *OB*. If, now, a ray *GO* in the glass makes a bigger angle with the normal than *FO* does, the ray is no longer refracted out into the air, but is internally reflected and proceeds along the path *OG'*. Since *all* the light is then reflected at *O*, this is known as *total* internal reflection. The value of the angle of incidence when the emergent ray passes along the separating surface (as in the case *FOF'*), is called the *critical angle*; for any greater angle of incidence in the dense medium, total internal reflection takes place. The value of the critical angle for glass of refractive index 1.52 is approximately 41° ; for water, the value is about $48\frac{1}{2}^\circ$.

Its value for any other substance of refractive index μ is given by the equation—

$$\sin(\text{critical angle}) = \frac{1}{\mu}$$

Totally reflecting glass prisms, set in pavements, are sometimes used for directing light into cellars (see Fig. 45), but the chief importance of refraction and total internal reflection to the building student is concerned with their use in the globes for lamps—especially electric lamps.

completely enclose the lamp. As a rule, these globes have a set of diffusing prisms on their inner surface and a series of refracting prisms on the outer surface. By varying the curvature of the surfaces of the prisms, and the general profile of the reflector or globe, the light from the lamp may be spread widely or more or less focused; this enables the user to select the fittings which shall give the distribution of light most suitable for his purpose.

In glass reflecting prisms, ordinary dust or dirt on the outer surfaces does not decrease their efficiency, as the reflection takes place at the surface separating the glass and air; and ordinary dust particles apparently adhering to such a surface are really surrounded by air and are not in optical contact with the glass at all. *Oily* dirt, however, does make actual contact with glass, and thus spoils the internal reflection of such prisms.

Diffusing and refracting prisms are, of course, affected by the presence of dust as the light must pass through them.

Actual experiment has proved that dirt on the bulb of an electric lamp has an even greater effect than dirt on the reflecting shade; the two together may often cause a loss of 40 per cent of the light.

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LIGHTING OF BUILDINGS

General Principles. The importance of suitably illuminating our homes and all other buildings, whether by daylight or by artificial light, can hardly be overestimated. To consider the subject fully would require a lengthy description of the eye and its parts, together with their functions; but in order to save time, we can discuss the chief points after accepting the truth of the following statements, all of which are capable of proof.

1. Luminous bodies are seen by the light which they emit; non-luminous bodies by the light which they reflect to our eyes. Therefore, for non-luminous bodies we must be sure that sufficient light falls on them, since only a *portion* of this light will be reflected to our eyes. As dull, dark surfaces reflect a much smaller proportion of incident light than bright or shiny ones, the former surfaces should receive more light than is necessary for the latter.

2. The intensity of illumination should depend on the work to be done in the room. For example, a drawing office requires more illumination than a coal cellar.

3. The illumination must not be *too* intense, otherwise eye strain will result.

4. Exceedingly bright lights should not be in such positions that the eye is likely to look straight at them.

5. Flickering lights, or great variations in the intensity of the illumination in adjacent parts of a room, should be avoided, as they produce eye strain.

6. Lamps should not be placed so that light from them can reach the eye by *regular* reflection from the surfaces of polished desks, etc. A slight raising of the lamps will often prevent this.

With regard to the natural lighting of rooms, the utmost that the builder can do is to fit large windows so as to admit as much light as possible. These windows will require blinds if in such positions that the sun can shine through them. Windows should not be so placed that any person using the room needs to look directly at a window for long periods. For example, in a schoolroom, windows should be at the sides (mainly on the left of the scholars), and not at the front or back of the room—otherwise children, or teacher, will be looking at a window.

When, on the other hand, we consider artificial lighting, the positions, numbers, and powers of the sources of illumination are all capable of adjustment to give the best possible results. We must, at the start, draw a distinction

between "illuminating power" and "intensity of illumination."

The *illuminating power* of a source is the amount of light it gives out; it is usually expressed in "candle-power"; for example, a 32 c.p. electric lamp gives as much light as 32 "standard candles."

The *intensity of illumination* produced on a given surface is measured by the amount of light falling on it, divided by its area. The unit generally used in this country, for intensity of illumination, is the *foot-candle*, that is, the illumination received by a surface held normal to the direction of the light at a distance of 1 ft. from a source of 1 c.p. Another similar unit—the *metre-candle*—is occasionally used; the distance in this case being 1 metre (= 39 $\frac{1}{8}$ in. approximately).

The Standard Candle was defined by Act of Parliament (the Metropolitan Gas Act of 1860) as a candle of spermaceti wax, six of which weigh 1 lb., and burning at the rate of 120 grains of wax per hour.

The amount of light produced by such a candle was found to be affected to a considerable extent by the purity and pressure of the air, and since 1909 the "Vernon Harcourt Pentane Lamp" has been taken as the standard in this country, France, and U.S.A. *Pentane* is an oil obtained from paraffin, and when the flame from this lamp—which burns a mixture of air and pentane vapour—is adjusted in accordance with standard specification (see Notification of the Metropolitan Gas Referees for 1916, published by H.M. Stationery Office), and burnt under standard conditions of atmospheric temperature, pressure, and humidity, the illuminating power is equivalent to ten candles. In actual practice, sources of light are compared with special electric lamps, which have themselves been compared with this "10 candle pentane lamp."

INVERSE SQUARE AND COSINE LAWS

Inverse Square Law. For light falling at a fixed angle on a surface, the intensity of illumination varies inversely as the square of the distance of the surface from the source of light. That is, if we double the distance, the intensity of illumination is only one-quarter of its former

value $\left[\text{since } \frac{1}{4} = \frac{1}{(2)^2} \right]$; and if the distance is made six times what it was, the intensity of illumination is reduced to $\frac{1}{36} \left[\text{since } \frac{1}{36} = \frac{1}{(6)^2} \right]$.

Cosine Law. For surfaces inclined at different angles to the direction of the incident light, but at the same distance from the source, the intensity of

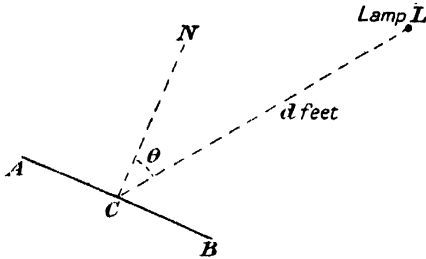


FIG. 47. ILLUMINATION

the illumination varies as the cosine of the angle of incidence.

To take an example showing the application of these laws, let the lamp *L* in Fig. 47 have a candle-power *P*. Suppose we wish to find the intensity of the illumination (*I*) it will produce

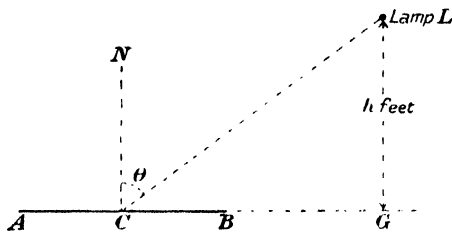


FIG. 48. ILLUMINATION ON A HORIZONTAL PLANE

at the point *C* on the given surface *AB*. If *CN* is the normal to *AB* at the point *C*, the angle *LCN* is the angle of incidence; denote this angle by the Greek letter θ (called "theta"). Then, if $LC = d$ feet,

$$I \text{ (in foot-candles)} = \frac{P}{d^2} \times \cos \theta$$

Now in the great majority of cases, the illumination is required to be on a horizontal plane, such as a table, or work-bench; in such a case, it can be proved that the formula becomes

$$I = \frac{P}{h^2} \times \cos^3 \theta$$

where *h* is the height in feet of the lamp above the horizontal illuminated plane (see Fig. 48).

Since raising the lamp will increase *h*—tending to decrease *I*—but at the same time making θ smaller, and thus making $\cos \theta$ (and consequently *I*) larger, it is evident that there is one certain value of *h* which will produce maximum intensity of illumination at a fixed point *C*. It

can be proved mathematically that *h* should be about seven-tenths of the distance *CG*, if we assume that *L* emits light equally in all

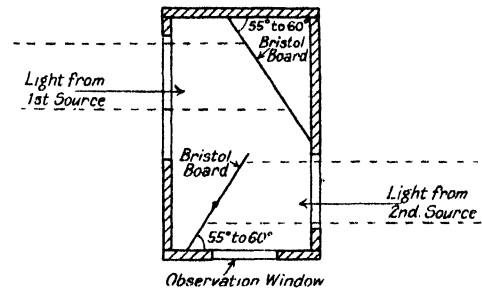


FIG. 49. THE CONROY PHOTOMETER

directions. This is far from being the case in practice, and the use of lamp shades further complicates matters. Consequently, firms such as Messrs. Holophane, Ltd., and the Benjamin Electric, Ltd., who make scientifically designed shades for industrial and domestic lighting, give a "spacing rule" for each type of shade; that is, they give the ratio which should be observed between distance apart of lamps and the height of lamps above the work-bench, or table.

PHOTOMETRY

Photometry is that branch of applied optics which deals with the comparison of light sources and with the measurement of the intensity of illumination at any point. Instruments for the former purpose are generally termed *photometers* (light measurers); those for the latter are called *illumination photometers*. One of each type will now be described.

The Conroy Photometer. This is one of the most simple of the photometers to use, is easily made, and gives results whose accuracy is exceeded only by those obtained from very elaborate instruments. As shown in Fig. 49, it consists of a wood box having three windows; light from the sources to be compared enters through two of these, and the observer looks through the other. Inside are two screens made of Bristol board (a white cardboard), from which the glaze has been removed by wiping with a damp cloth; these screens are fixed in position at an angle of 55° to 60° to the sides of the box, the inclinations being the same for the two screens. The sources to be compared are situated in the directions shown. Obviously, the observer will see each screen illuminated by one source only. He moves the sources to and fro until the two screens are equally illuminated

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—in other words, until they appear as one when viewed through the window. If P_1 and

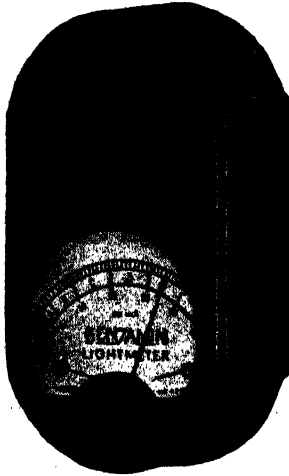
$$\frac{P_1}{(d_1)^2} = \frac{P_2}{(d_2)^2}$$

since the angle of incidence is the same in each case. From this equation the candle-power of one source can be calculated if the other is a standard.

The Benjamin Lightmeter. This is a simple and easily portable illumination photometer. It consists of a small light-proof box, containing a small electric lamp of known candle-power designed to operate from a 2-volt secondary battery, or 3 volts (two dry cells), which illuminates a translucent glass screen on the top of the box. The screen is protected by very thin glass, and in use it is important that this should be kept free from dirt or dust.

In general, such Bunsen screens have a "grease-spot" as the essential feature. When the light falling on the screen from above is greater than that reaching it from the lamp below, the "grease-spot" appears darker than its surroundings; when the light from above is less than that from below, the "grease-spot" appears brighter than the screen around it.

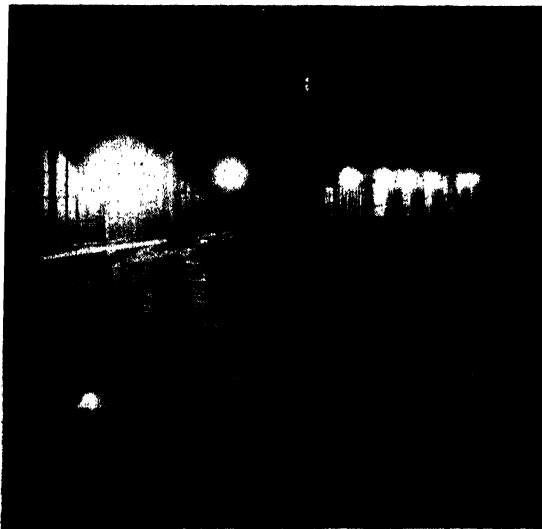
To adjust the current through the standard lamp, the instrument is held in a horizontal position, and the moving pointer in the ammeter is made to point exactly to the calibra-



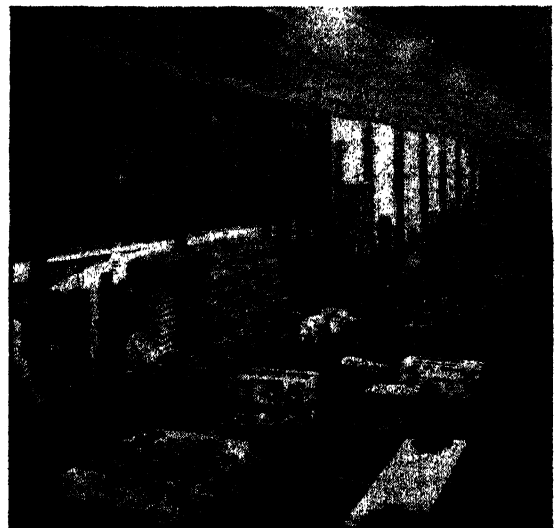
(Benjamin Electric Limited, London)

FIG. 50. THE BENJAMIN LIGHTMETER

P_2 are the candle-powers of the sources, and d_1 and d_2 their distances from the photometer, when the screens are equally illuminated, then



This picture shows exactly how the factory was partially lighted—brilliant lights contrasting with deep shadows; this made accurate work almost impossible



The same factory after the bad lighting had been corrected by using "Benjamin" fittings properly arranged. The illumination is even all around and under the work—as it should be

FIG. 51. GOOD AND BAD LIGHTING
(Benjamin Electric Limited, Tottenham, London, N.17)

tion mark on the dial (shown in the centre of Fig. 50) by moving a projecting arm of a sliding rheostat. The instrument is arranged that direct readings can be obtained by adjusting the pointer to the 1·0 mark, while for one-tenth of direct reading, pointer should be on the 0·1 mark and, for one-hundredth of direct reading, on the 0·01 mark.

To measure degrees of illumination, the instrument is placed in the desired position, or laid on a surface the illumination of which it is desired to obtain, and the sliding scale bar (shown on left of Fig. 50) is moved in or out until a balance is obtained on the circular Bunsen screen. If the light to be tested is of a similar spectral colour, the centre of the screen should nearly disappear when correct balance has been obtained, and when viewed from an angle at which no image of the light source is seen reflected.

When the ammeter reading has been accurately adjusted by means of the adjustable rheostat, and the photometric balance carefully made on the circular Bunsen screen, the reading on the scale bar will be within the limits of accuracy defined in Clause 10 of the British Standards Institution Specifications Nos. 230, 1925, and 667, 1934, relating to Portable Photometers.

INTENSITY OF ILLUMINATION

The figures in Table XIV, the majority of which are taken by permission of Messrs. Hologhane, Ltd., from their *Illuminating Engineering Data*, give the intensity advocated in a few cases.

In order to obtain the necessary illumination, and at the same time avoid unnecessary expenditure on lighting, care must be taken to place the light sources to the best advantage. The colour and nature of the surface of the walls of a room are also of great importance; some surfaces absorb almost all the light which falls on them, whilst others reflect the greater part, and so add to the general illumination of the room.

Study of Table XV would almost lead one to suppose that the originator of the fashion for dark wall papers for dining-rooms, etc., must have been a shareholder in some electricity or gas undertaking; at any rate, such a wall surface entails the use of quite 50 per cent more light than a lighter coloured wall surface would require in order to produce the same illumination.

As an example of what constitutes good and bad illumination under industrial conditions, the two pictures in Fig. 51 will show more clearly than pages of explanation. In that on the left,

TABLE XIV
INTENSITY OF ILLUMINATION

Location	Illumination (Foot-candles)
Art Gallery (Walls)	4 to 5
Church	2 " 3
Drawing Office	6 " 10
Factory—	
General Illumination	1 " 2
Bench Illumination	3 " 5
Bench Illumination (for Fine Work)	8 " 10
Market	2 " 3
Residence—	
Hall	5 " 1·5
Drawing-room	2 " 3
Dining-room (General)	5 " 1·5
Dining-room (Local, on Table)	4 " 6
Kitchen	2 " 3
Bedrooms	1 " 2
Schoolrooms	4 " 6
Shop Interiors—	
For Light Goods	4 " 6
For Dark Goods	6 " 8

TABLE XV
THE COEFFICIENT OF REFLECTION OF VARIOUS SURFACES

Surface	Coefficient of Reflection (Per Cent)
Aluminium Paint	72
Black Paint (Matt)	6
Buff (Matt)	36
Caen Stone	72
Concrete (Unpainted)	45
Cream (Matt)	62
Galvanized Iron (Unpainted)	16
Grey, French (Matt)	28
Green, Light (Matt)	41
Green, Dark (Matt)	27
Ivory (Glossy)	69
Ivory (Matt)	64
Plaster (Keene's Cement Finish)	75
Red (Matt)	9
Tiles, White (Glossy)	80
White Paint (Glossy)	78
White Paint (Matt)	77

patches of brilliant light are seen to be surrounded by areas of deep shadow. This has been corrected in that on the right, where the illumination over, around, and under the work is practically uniform.

Chapter VI—SOUND

Production of Sound. Sound is always due to the movement of some material substance. Let us consider a few everyday examples of sound production to see that this is true: a hammer strikes a nail, a drum is sounded, the strings of

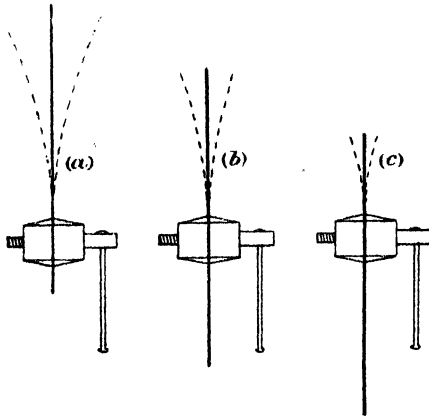


FIG. 52. THE VIBRATING CLOCK SPRING

a banjo are plucked, steam is allowed to pass through a factory "hooter," a bee produces a buzzing with its wings; in each case, the sound, whether musical or otherwise, was caused by the motion of some substance or other. In all these examples it is possible to show that the sound is actually due to *vibrations*; that is, to something moving rapidly to and fro in the same way as a pendulum can vibrate from side to side.

The question next arises as to what conditions must be fulfilled if a vibrating body is to produce a sound. A great deal can be learnt from a piece of clock-spring, 6 in. or 7 in. long, and a vice. Clamp one end of the spring in the vice, see Fig. 52 (a), and pluck the free upper end. When released, the spring will vibrate slowly from side to side, but no sound will be heard. If, now, the vibrating portion of the spring be gradually shortened, see Fig. 52 (b) and (c), it will be seen that the vibrations follow each other more rapidly and at last a sound is produced. If the spring be made still shorter, the *frequency* (i.e. the number of vibrations per second) increases, and the note rises in pitch. In pass-

ing, it should be noted that a *complete vibration* is a whole "to and fro" movement; that is, if *p*, *q*, and *r* in Fig. 53 represent the mean and the two extreme positions, respectively, of the end of the vibrating spring, a complete vibration is performed when the end moves from *r* to *q* and back again to *r*; or, if we like, when it moves from *p* to *q*, *q* to *r*, and from *r* back again to *p*.



FIG. 53
A COMPLETE
VIBRATION

PROPAGATION OF SOUND

Sound travels much more slowly than light. The flash of a distant gun is seen some appreciable time before the report is heard; if the gun is a mile from the observer, the interval between the flash and the report is about 5 seconds, yet both actually occurred at the same instant. The speed of light in air is, roughly, 186,000 *miles* per second; the speed of sound in air is about 1,100 *feet* per second at ordinary temperatures. Knowing these figures, we can see that the distance of a gun from an observer can be approximately found if he notes the interval which elapses between seeing the flash and hearing the report.

Sound needs a material medium for its propagation. Practically all the sounds we hear in everyday life reach our ears through the air. So, we see that sounds can pass through a gas. But we can show that sounds can also be transmitted through liquids and solids. Thus, during the last war, submarines were detected, when running submerged, by the noise made by their motors; and this noise is transmitted through the water. We can demonstrate the passage of sound through iron, or wood, very easily. Rest one ear against the end of a long length of pipe, or scaffold pole; let someone strike the far end; the sound will be heard very distinctly. If a sufficient length is used, *two* separate sounds will be heard by the observer—the first reaching him through the solid, and the second through the air.

So far, we have proved that sounds can be transmitted by solids, liquids, and gases; we must next show that they cannot pass through

a vacuum. This can be demonstrated by means of the apparatus shown in Fig. 54. An electric bell is hung inside a glass receiver *A* standing on the plate *B* of an air pump. By connecting to a suitable battery the bell is made to ring. The pump is now worked and air is slowly drawn from the receiver; it will be noticed that the ringing of the bell becomes fainter and fainter, until at last it can be heard only with

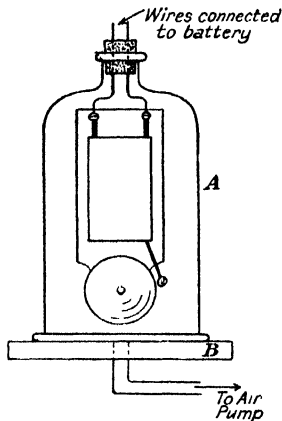


FIG. 54. APPARATUS TO SHOW THAT SOUND CANNOT PASS THROUGH A VACUUM

difficulty. When air is allowed to re-enter the receiver, the bell sounds as loudly as it did in the beginning. The very faint sound heard when the air had been withdrawn was transmitted through the wires used to suspend the bell. Hence, since a vacuum does not transmit sounds, a room constructed on the principle of a huge thermos flask would be sound-proof; but the production and maintenance of the necessary vacuum between the inner and outer walls would be too expensive.

Sound transmitted by Wave Motion. It is very evident that the transmission of sound through any medium is not brought about by a movement of that medium *as a whole* from the source of sound to the observer. We may be quite certain of this since, in the air, sounds travel *against* the wind as well as with it; in a river, they travel *against* the current as well as in the direction of flow; and when sound travels through a solid, it is clear that the whole mass does not travel along.

Sound is transmitted through bodies by *longitudinal vibrations*—that is, the particles of the body vibrate to and fro over a small distance in the same line as the sound wave is travelling.

Longitudinal vibrations may be illustrated by hanging a large spiral spring from the ceiling. Fig. 55, a weight sufficiently heavy being hung at the lower end to keep the coils apart. If, now, the weight be raised an inch or so, the coils at the bottom end are brought close together for an instant. Owing to the elasticity of the spring, these coils try to separate, and this causes the second coil from the bottom to approach the third. This is continued, with the result that a pulse (or disturbance) travels up the length of the spring, although each coil only moves through a short distance. Such a pulse is known as a "pulse of compression." On the other hand, if a pulse were started by suddenly pulling the weight *downwards*, this pulse would be a "pulse of expansion," since each little section of spring would be stretched in its turn.

Sound is actually transmitted by these pulses of compression and expansion, which follow one another very rapidly. We can imitate such a state of affairs on the spring by first raising the weight, immediately bringing it back to its original position, and holding it there. A pulse of compression will travel up the spring, to be followed by a pulse of expansion—each particle of the spring will execute a small up and down movement along the line in which the pulses travel. A succession of such waves of alternate compression and expansion can be obtained if the weight at the end of the spring is raised, and then lowered at equal intervals of time. In the case of a sounding body, the to and fro movement of the source of sound causes a series of waves to travel outwards through any suitable medium.

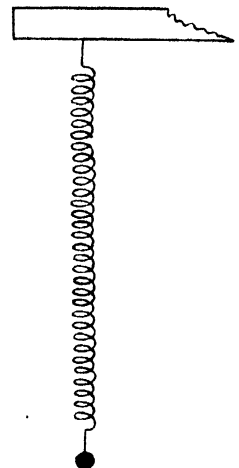


FIG. 55. THE OSCILLATING SPRING

Now, the property of the spring which enables it to transmit vibrations from one point on its length to another, is its *elasticity*; and the same property accounts for the transmission of sound waves. The terms, elastic and elasticity, are used rather carelessly in ordinary life. We shall consider an elastic body as being one which offers a resistance to any force which tends to

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change its shape (or size), and which recovers its original shape (or size) when the deforming force is removed. Thus, if a wire, or spiral spring, be stretched, it returns to its original shape as soon as the stretching force ceases to act. If a lath be bent or twisted, it tends to regain its original shape as soon as it is free. If the outlet of a cycle pump be closed, and the handle pressed inwards, the contained air is compressed; but as soon as the pressure is removed, the air returns to its former volume. It can also be shown that liquids are *slightly* compressible, and that they regain their original volumes so soon as the compressing force ceases to act. From our definition of elasticity, it is easily seen that steel is more elastic than rubber; whilst sawdust, feathers, or cloth are almost devoid of elasticity. Hence, rubber transmits sound less readily than steel does, whilst double-walled rooms, having the space between the inner and outer walls filled with sawdust, or similar substances, are almost sound-proof.

TABLE XVI
VELOCITY OF SOUND

In Air at 0° C.	1,090 ft. per second
„ Coal gas at 0° C.	1,600 ft. „ „
„ Water	4,700 ft. „ „
„ Iron (approx.)	16,000 ft. „ „

We can now account for the fact, which we have previously mentioned, that sound cannot pass through a vacuum. In a perfect vacuum, nothing remains to be compressed, consequently sound waves, which consist of alternate compressions and expansions, cannot occur in it. Hence it follows that no sound produced on the moon could ever be heard on the earth, since a vacuum intervenes between the moon and the earth.

Reflection of Sound. The reflection of sound is similar to the reflection of light, the only difference of practical importance being that, for sound, the reflecting surface need not be nearly so smooth as for light. Thus we find quite rough walls and archways reflecting sound and producing *echoes*. Hard surfaces reflect sounds much more powerfully than soft ones do; these latter absorb much of the sound which falls on them.

The repeated reflection of sound in a hall used for concerts, or lectures, is very objectionable at times; the sound is reflected from the walls, ceiling, and floor, decreasing in strength at each reflection, until at last it becomes so

faint as to be inaudible. This is known as *reverberation*, and in extreme cases causes a speech to be heard, by an audience, as a confused mass of sound from which the individual words can be distinguished only with great difficulty. For a hall to be good from a *sound* standpoint, the duration of the reverberation of a syllable should be slightly less than a second. If much less than this, speech in such a hall would sound "dead"; but this defect is very rarely met with. If, on the other hand, the period of reverberation exceeds a second, it should be reduced. This can be done by substituting badly reflecting surfaces for those which are reflecting the sound too well; thus, suitable draperies can be hung on the walls, floors may be covered with carpets or linoleum, and in very bad cases a great improvement has been effected by coating the walls with felt. It has been found by experiment that brick walls, lath and plaster walls, and glass absorb about 3 per cent of the sound which strikes them; pine boards absorb about 6 per cent; linoleum and carpets from 12 to 25 per cent, according to their thickness; whilst hair felt, 1 in. thick, absorbs from 50 to 75 per cent of the sound which falls on it. These figures may aid the reader in his endeavours to improve the faulty "acoustics" (or behaviour with respect to sound) of halls, etc. The ideal, of course, is for all such rooms to be so designed that subsequent remedial measures shall not be necessary. But it may be of interest to point out that halls having an original period of reverberation of 9 seconds or more have been successfully treated, and the reverberation reduced to the limit we have previously mentioned as being desirable, viz. about a second. In conclusion, it may be noted that stretching wires across the roof of a faulty hall is of very little practical use.

The Problem of Noise. The introduction of radio sets into almost every home has greatly accentuated the problem of noise, in both dwelling houses and flats.

When the stem of a vibrating tuning fork is held against the wooden top of a table, the loudness of the sound produced is greatly increased. On a large scale this phenomenon may be reproduced in a house. Not only is the velocity of sound waves in pine wood (3,320 metres per second along the fibre) about ten times its velocity in air, but a radio-gramophone in operation may set up forced vibrations in the floor itself, which may act as a huge sounding board.

Chapter VII—MECHANICS

FORCES

Definition of Force. Force is that which changes, or tends to change, a body's state of rest or of uniform motion in a straight line.

Everyday experience teaches us that a stationary body will remain at rest unless, and until, some force sets it in motion. A book resting on a table can be moved if a sufficient force is applied. If, however, we push against it *gently* it does not move—this force *tends*, or *tries*, to move it, but is unable to do so as it is opposed by the friction between the book and the table top. On the other hand, a moving body will continue to move at the same rate and in the same direction until it is acted on by some force. It is true that in practice moving bodies come to rest sooner or later, but we shall find that where the retarding force is not easily apparent, friction in some way or other has acted in opposition to the body's motion. Suitable forces can alter the velocity of a body, or may alter the direction in which it moves.

To describe a force completely, we require to know four different items concerning it—

- The point at which it acts. (For example, O in Fig. 56.)
- The *direction* of the line along which it acts. (Say, $A'OA$, making an angle of 10° with the horizontal.)
- The *sense* in which it acts; that is, whether the force acts towards A' or A .
- The *magnitude* of the force.

A force may be represented by a straight line. (a) In Fig. 56 the point O can be taken to represent where the force acts.

(b) $A'OA$ represents the direction of the line in which it acts.

(c) An arrow-head can represent the *sense* in which it acts.

(d) And, lastly, the length OA can represent the magnitude of the force on some convenient scale.

Resultant and Equilibrant. The single force which can produce the same effect as a number of other forces acting together, is called the *resultant* of those forces; and the forces are called the *components* of their resultant.

The single force which will balance a number of other forces acting together, is called the *equilibrant* of those forces. Obviously, it has the same magnitude as their resultant, and acts along the same line but in the opposite sense.

The process of finding the resultant of a number of forces is referred to as the *composition of forces*, and the converse process of replacing

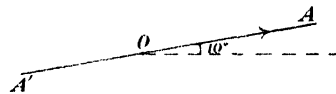


FIG. 56. REPRESENTATION OF A FORCE BY A STRAIGHT LINE

a force by two (or more) components is known as the *resolution of that force*.

The resultant of a number of forces all acting along the same straight line is obviously equal to the *algebraical* sum of the forces; that is, their sum after giving them signs according to their sense. The usual convention is to regard horizontal forces acting to the right as positive (+); those acting to the left as negative (-); vertical forces acting upward are considered positive; those acting downward, negative. For forces in other directions there is no convention—the student can call whichever sense he wishes positive.

EXAMPLE 1. Find the resultant of horizontal forces of 6 lb. and 8 lb., both acting to the right along the same line.

SOLUTION. $R = +6 + 8 = +14$ lb.
That is, a force of 14 lb. acting to the right.

EXAMPLE 2. Find the resultant of a force of 10 lb. acting vertically upwards, and one of 14 lb. acting downwards along the same line.

SOLUTION. $R = +10 - 14 = -4$ lb.
That is, a force of 4 lb. acting vertically downwards.

Parallelogram of Forces. This is a method of finding the resultant of two inclined forces.

If two forces acting at a point be represented in magnitude, direction, and sense by two straight lines drawn from that point; and if the parallelogram be constructed having these two lines for

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adjacent sides; then the diagonal of the parallelogram drawn through this point will represent their resultant in magnitude, direction, and sense.

In Fig. 57, OA and OB drawn from the point O represent, to some convenient scale, two forces acting at that point, in magnitude and in direction and sense. $OBCA$ is the completed

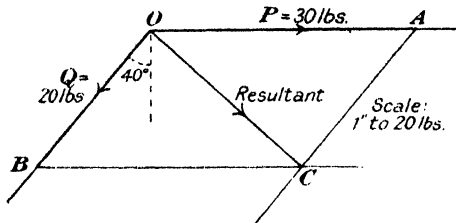


FIG. 57. THE PARALLELOGRAM OF FORCES

parallelogram. Then the diagonal OC represents the resultant of the two forces to the same scale.

For example, in Fig. 57, OA and OB represent two forces, the one horizontal to the right, and the other at an angle of 40° to the left of the vertical; the magnitudes of these forces are 30 lb. and 20 lb., respectively. The scale chosen is 1 in. to 20 lb. The length of OC is 1.15 in., indicating that the resultant force acts in the direction OC , and has a magnitude of $1.15 \times 20 = 23$ lb.

It is clear that a force of 23 lb., acting in the direction CO , would be the *equilibrant* of the forces represented by OA and OB .

Since the opposite sides of a parallelogram are equal to one another, it is evident that the three sides of the triangle OAC will represent the two given forces and their equilibrant in magnitude and direction. We shall make use of this in the sections which follow.

Triangle of Forces. *If three forces acting at a point can be represented in magnitude and direction by the sides of a triangle taken in order, then these forces must be in equilibrium.*

The converse of this statement is even more important. "If three forces acting at a point are in equilibrium, then they can be represented in magnitude and direction by the sides of a triangle taken in order."

Note (i). The words "taken in order" are exceedingly important. In the triangle OAC of Fig. 57, if OA represents the sense of one force, another must be represented by AC , not by CA .

Note (ii). The above theorem is only a special case of a more general one—the *polygon of forces*. This is similar to the above, but is concerned with the relation

between any number of forces acting at a point in one plane and the sides of a polygon.

Bow's Notation. It is usual to draw one diagram, generally known as the *position diagram*, showing where the various forces act; and another, known as the *force diagram*, by which the magnitude of any unknown forces may be determined. Thus Fig. 58 (i) represents a 20 lb. weight suspended by two cords—it is the "position diagram" of the three forces keeping the knot in equilibrium; these forces are the weight (20 lb.) acting vertically downwards, and the tensions in the cords. If the angles which the cords make with the vertical are known, the "position diagram" can be drawn accurately. Fig. 58 (ii) is the "force diagram" for the knot, the sides of this triangle taken in order representing the directions of the forces, and their magnitude on some convenient scale.

A useful convention—known as "Bow's Notation"—is to place capital letters between consecutive forces in the position diagram, each force being denoted by the two letters on either

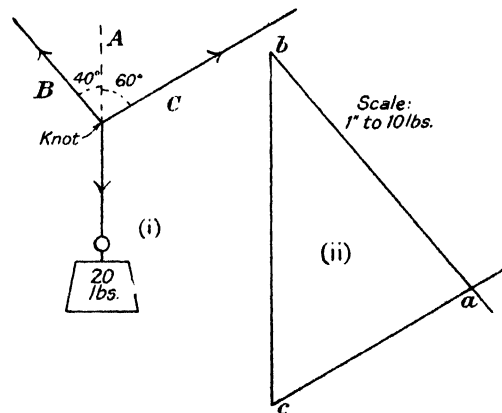


FIG. 58. TRIANGLE OF FORCES

side of it; for example, the vertical force, due to the weight, is denoted as BC . The corresponding lines in the force diagram are denoted by corresponding small letters, placed at each end of the line; thus the line bc corresponds to the force BC .

N.B. In the following examples, the student should draw the various diagrams accurately, and to as large a scale as possible.

EXAMPLE 1. In Fig. 58 (i) let the two cords make angles of 40° and 60° with the vertical. Calculate the stress in each cord.

Note. A triangle can be constructed, if we know the length of one side and the directions of all the sides.

SOLUTION. Draw a vertical line bc , 2 in. long, to represent the force BC to the scale of 1 in. to 10 lb. From b and c draw lines parallel to the cords; these lines intersect at a . Then abc is the force diagram for the knot. ab is 1.76 in. and ca 1.3 in. Hence, to the scale of 1 in. to 10 lb., they represent forces of 17.6 lb. and 13 lb. These are the stresses in the cords.

EXAMPLE 2. Fig. 59 (i) represents the horizontal and inclined members of a triangular wall bracket, a

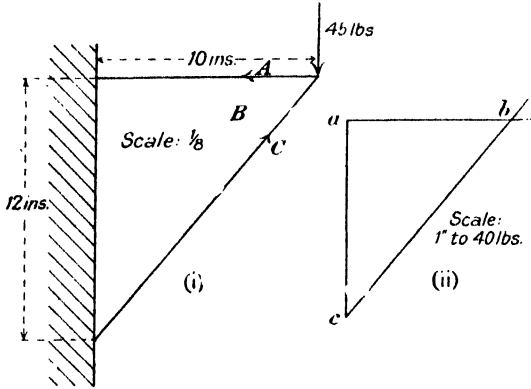


FIG. 59

number of which support a shelf. If each bracket has to sustain a load of 45 lb. at its outer point, find the forces acting in the horizontal and inclined members.

SOLUTION. Draw Fig. 59 (i) to any convenient scale; this is the position diagram. Then, the three forces acting at the outer point of the bracket, and keeping that point in equilibrium, are: AB horizontally, BC along the inclined member, and $CA = 45$ lb. vertically. In Fig. 59 (ii) draw ac vertically to represent 45 lb. to some convenient scale (e.g. 1 in. to 40 lb.). Draw cb parallel to the inclined member, and ab parallel to the horizontal member, intersecting at b . Then acb is the force diagram.

$ba = .94$ in. (i.e. represents 37.6 lb.)
 $cb = 1.46$ in. (i.e. represents 58.4 lb.)

Hence, required forces are 37.6 lb. in the horizontal member, and 58.4 lb. in the inclined one.

EXAMPLE 3. Fig. 60 (i) represents a triangular frame (e.g. a simple roof truss) drawn to scale. Find the forces in the members and the reactions at the supports P and Q , due to a load of 150 lb. hanging from the top joint.

Note. It is evident that the sum of the vertical reactions at P and Q must be 150 lb. to balance the load. Also, since the framework and the loading are symmetrical, the reactions will be equal, and hence each equal to 75 lb. We shall see that our drawing gives us this result.

SOLUTION. In Fig. 60 (ii), bc represents $BC = 150$ lb. to some convenient scale. As in the other examples, the force diagram cab , for the upper joint, can now be drawn. Measuring ca and ab , we find that the forces in the inclined members of the roof are 131 lb. each. We now draw ad from the point a parallel to AD , i.e. parallel to the "tie" of the roof. The

triangle bad is evidently the "force diagram" for the point P , since its sides are parallel to the forces acting at that point. ba represents the force acting along the inclined member (to the chosen scale); hence the other sides represent the forces acting as a reaction, due to the support at P , and the force in the tie. Measuring the lengths of db and ad , we find that these forces are 75 lb. and 107 lb. So that,

Force acting in inclined member = 131 lb.
 Force acting in the tie = 107 lb.
 Reaction of support at P (or Q) = 75 lb.

Stresses in Members. Members may be in a state of *tension*, that is, tending to draw the ends together; or in *compression*, that is, tending to keep the ends apart. In most cases of a simple nature we can see, quite readily, the kind of stress for each member; we need merely to consider what would happen if the particular member were weakened. Thus, in the last example, if either inclined member were weakened, it would be compressed; that is, the inclined members must be in compression. On the other hand, if the horizontal tie were weak, it would be stretched; that is, the tie must be in tension.

The following method, however, is applicable in *all* cases. Start with a joint where the *sense* of one force is known; for example, the top joint in Fig. 60 (i). Consider the force diagram

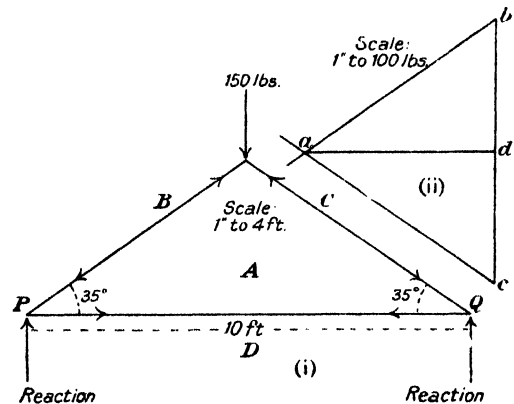


FIG. 60

of that point. The load is represented in *sense* by bc ; consequently, according to the triangle of forces theorem, the *sense* of the other forces acting at this point is given by ca and ab . These directions should be marked with arrows on the position diagram; they are seen to act towards the upper joint.

It is now evident that the inclined members must be in compression, since they are tending

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to keep the top joint up; they must, therefore, tend to keep the lower joints P and Q down. Hence ba represents the sense of one of the forces acting at P , and bad is the force diagram for that point. Therefore, ad and db represent the senses of the other forces acting at P . These directions are shown by arrows marked on

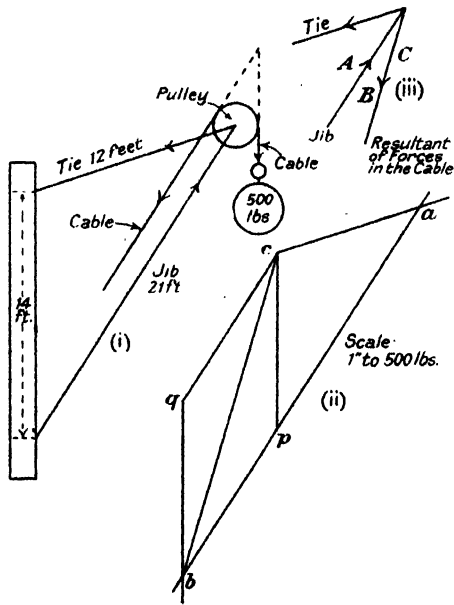


FIG. 61

the structure or position diagram. Similarly, the senses of the forces acting at Q may be determined.

EXAMPLE. Fig. 61 (i) is a diagrammatic representation of a crane. There is a pulley at the top joint, and the cable which passes over this pulley is parallel to the jib. Find the stresses in the tie and jib when a load of 500 lb. is suspended from the cable.

SOLUTION. Fig. 61 (i) is drawn to scale. The forces acting on the pulley are four in number: the load 500 lb. acting vertically downwards, an equal pull of 500 lb. along the inclined cable, the stress in the tie, and the stress in the jib. The first pair act at the circumference of the pulley; the last pair act at its centre. Hence, we cannot apply the triangle of forces directly. We can, however, find the resultant of the two forces of 500 lb. acting along the cable, by means of the parallelogram of forces. This resultant will be found to bisect the angle between the two portions of the cable, and to pass through the centre of the pulley. We may now consider the centre of the pulley to be in equilibrium under the action of this resultant and the stresses in the tie and jib, i.e. three forces acting at a point, to which the triangle of forces will apply.

In Fig. 61 (ii), aq and cp represent the forces acting in the cable in direction and in magnitude to a convenient scale. Completing this parallelogram, we

obtain their resultant represented by the diagonal cb . The three forces which keep the centre of the pulley in equilibrium, are represented by CB , BA , and AC in Fig. 61 (iii), CB being the resultant just found, and the others the stresses in the jib and tie. In Fig. 61 (ii), ba is drawn from b parallel to the jib, and ca from c parallel to the tie. ba and ac now represent the stresses in the jib and tie to the scale originally selected. By measurement we obtain—

Stress in jib = 1,250 lb.
Stress in tie = 430 lb.

No doubt the reader will have noticed that the examples relating to the theorem of the triangle of forces are of the *paper* variety. No mention is made of the weight of the various portions of the structures concerned, neither is any allowance made for any deformation or bending of any of the members; in other words, the materials are considered to be weightless and perfectly rigid. In practice, however, as the student is well aware, such is not the case; all structural materials have weight and all are subject to deformation. It often happens, in fact, that the forces produced by the weight of the structure alone are far greater than those due to any load which the structure carries; a familiar example is a *cantilever bridge* like the Forth Bridge. But, in even the most complicated cases, due allowance can be made for the weights of the various portions and for the effects of wind pressure, etc.; the triangle of forces can be applied then. For these more difficult examples the reader must turn to the sections on "Structural Engineering," but the simple examples already considered should show him the usefulness of this theorem.

MOMENTS

Definition. The moment of a force about a point is its turning effect about that point; it is measured by the product of the force, and the

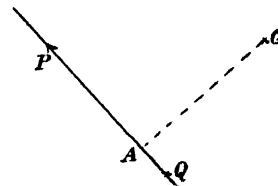


FIG. 62. THE MOMENT OF A FORCE ABOUT A POINT

length of the perpendicular drawn from that point to the line of action of the force.

Thus, in Fig. 62, the moment of the force P , about the point O , is equal to the product of

P and the length of the perpendicular OA . The student should note that it is useless to speak of "the moment of a force" without mentioning the point about which the moment is being considered.

UNITS. If the force is expressed in pounds, and the length of the perpendicular in inches, the moment is in pounds-inches. Other units often met with are pounds-feet and tons feet.

Moments of a force about a point on its line of action. If the point Q be taken on the line of action of the force P in Fig. 62, the length of the perpendicular, drawn from Q to the line of action of the force, is clearly zero. Hence the moment of the force about Q is equal to the product of P and zero; that is, the moment is zero.

Principle of Moments. If a rigid body is in equilibrium under the action of any number of forces, then the sum of the moments of those forces, tending to rotate it in a clockwise direction about any given point (or axis), must be equal to the sum of the moments of those forces which tend to rotate it in a counter-clockwise direction about the same point (or axis).

EXAMPLE 1. A beam, Fig. 63, weighing 80 lb. is supported at both ends so as to be horizontal; the supports are 20 ft. apart. A load of 400 lb. is placed 4 ft. from one end, and a load of 500 lb. acts 8 ft. from the other end. Find the reaction at the supports. [The weight of a uniform beam acts as though concentrated at its middle point.]

SOLUTION. Let the forces at the supports be P lb. and Q lb. (see Fig. 63).

If we take moments about A , the clockwise moments will be $(400 \text{ lb.} \times 4 \text{ ft.})$, $(80 \text{ lb.} \times 10 \text{ ft.})$, and $(500 \text{ lb.} \times 12 \text{ ft.})$. The counter-clockwise moment will be $(Q \text{ lb.} \times 20 \text{ ft.})$. The moment of the force P lb. about A is zero.

Hence $(Q \times 20)$

$$= (400 \times 4) + (80 \times 10) + (500 \times 12)$$

That is, $Q = 420 \text{ lb.}$

Similarly, by taking moments about B , we get

$$(P \times 20) = (500 \times 8) + (80 \times 10) + (400 \times 16)$$

That is, $P = 560 \text{ lb.}$

The student will note that $P + Q = 980 \text{ lb.}$; that

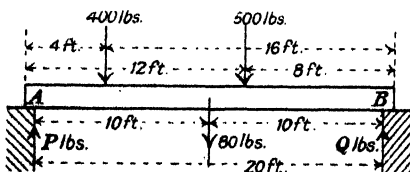


FIG. 63

is, their sum is equal to $(80 + 400 + 500) \text{ lb.}$, or to the sum of the downward forces. Clearly this must be so, otherwise the beam as a whole would move

either up or down. Also, as he now knows the magnitude of all forces acting on the beam, he should test the truth of the "principle of moments" with respect to some point other than A or B .

EXAMPLE 2. A platform BC , Fig. 64, is hinged at B to a wall and is supported by two chains, one at each

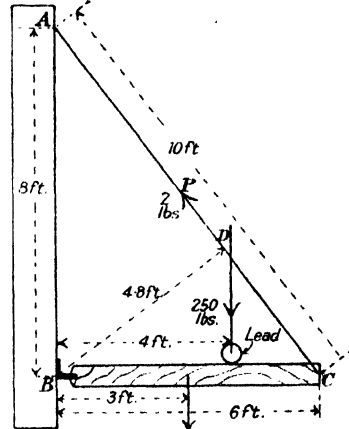


FIG. 64

end. These chains are made fast to the ends of the front edge of the platform and to points A on the wall, 8 ft. above the ends of the hinge. The platform, which is uniform, weighs 60 lb. and is 6 ft. wide. A roll of sheet lead extends the whole length of the platform and weighs 250 lb. Its distance from the wall is 4 ft. Find the stress in each chain.

SOLUTION. As we do not know, and are not concerned, with the force acting on the hinge at B , we shall take moments about the hinge.

Draw BD perpendicular to AC (see Fig. 64).

Measure (or calculate) the length of BD . $BD = 4.8 \text{ ft.}$

Let $P \text{ lb.} =$ stress in each chain.

Then, since there are two chains, the force acting along CA may be considered as $2P$.

Take moments about the hinge.

Moment in a clockwise direction

$$= (60 \text{ lb.} \times 3 \text{ ft.}) + (250 \text{ lb.} \times 4 \text{ ft.})$$

Moment in a counter-clockwise direction

$$= (2P \text{ lb.} \times BD) = (2P \text{ lb.} \times 4.8 \text{ ft.})$$

Therefore, for equilibrium

$$(2P \times 4.8) = (60 \times 3) + (250 \times 4)$$

Whence $P = 123 \text{ lb.}$ (approx.)

Therefore, stress in each chain = 123 lb. Ans.

EXAMPLE 3. A wall is 5 ft. high and 9 in. thick and is built of brickwork weighing 112 lb. per cub. ft. If it is exposed to a wind pressure of 10 lb. per sq. ft., will the wall overturn?

SOLUTION. Fig. 65 represents a cross-section of the wall, with the wind blowing in a direction at right angles to DC . Evidently the wind pressure tends to overturn the wall about B . This overturning is resisted by the weight of the wall.

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Consider 1 ft. run of wall.

The area of the exposed face is $(5 \times 1) = 5$ sq. ft. Therefore wind pressure on this face = 50 lb.

This wind pressure acts over the whole face, but may be assumed to be concentrated at E , the middle point of CD .

The volume of this 1 ft. run of wall = $(5 \times 1 \times \frac{1}{2})$ cub. ft.

Its weight = $(5 \times 1 \times \frac{1}{2} \times 112 \text{ lb.}) = 420 \text{ lb.}$

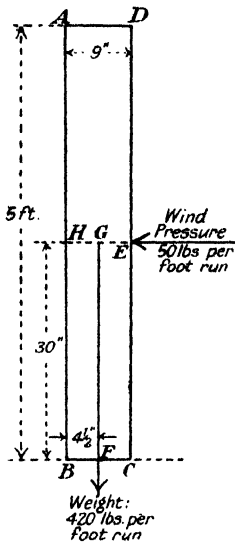


FIG. 65

This weight may be considered as concentrated at G the centre of the section $ABCD$.

Through E draw EH horizontally, cutting AB at H . Draw GF vertically, cutting BC at F .

Moment of force about B tending to overturn the wall = $(50 \text{ lb.} \times BH) = (50 \text{ lb.} \times 30 \text{ in.})$
 $= 1,500 \text{ lb.-in.}$

Moment of force about B tending to keep wall upright
 $= (420 \text{ lb.} \times BF) = (420 \text{ lb.} \times 4 \frac{1}{2} \text{ in.})$
 $= 1,890 \text{ lb.-in.}$

That is, the moment of the force tending to overturn the wall is *less* than the moment of the force tending to keep it in position. Therefore, the wall will not overturn.

N.B. The student should calculate the wind pressure per square foot, which would make the moment of the overturning force just equal to the moment of the restoring force, when the wall would be on the point of overturning. He will find this to be 12.6 lb. per sq. ft.

CENTRE OF GRAVITY

The force of gravity results in each particle of a body being attracted towards the centre of the earth. This centre is so far off that we may regard the attractive forces, acting on the

particles of a body, as being parallel. The point in, or on, a body, where one single force could replace all the parallel forces acting on the different particles, is known as the *centre of gravity*, or *centroid*, of that body. All the weight of a body may be considered to be concentrated at its centre of gravity.

The position of the centre of gravity of some common surfaces and solids should be known. In Table XVII the composition of the body is assumed to be uniform throughout.

TABLE XVII
CENTRES OF GRAVITY

Body	Position of the Centre of Gravity
LINE— Straight Wire	Middle point
SURFACES— Rectangle	Intersection of the diagonals
Parallelogram	Intersection of the diagonals
Triangle	Intersection of the "medians" (This point is one-third of the distance along the line joining the middle point of one side to the opposite angle; these lines being the medians)
Circle	Centre of the circle
SOLIDS— Cylinder	Middle point of the axis
Rectangular Solid	Middle point of the line joining the centres of gravity of opposite faces
Cone	On the axis, at a point one-quarter of the distance from the centre of the base to the vertex
Sphere	Centre of the sphere

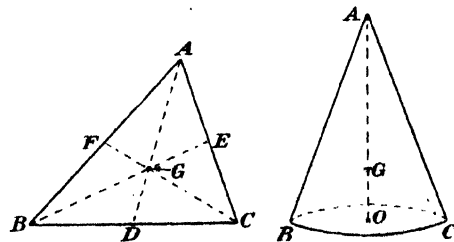


FIG. 66. CENTRES OF GRAVITY

Triangle
 D, E, F are the middle points of the sides.
 AD, BE, CF are the medians.
 G , their point of intersection, is the centre of gravity of the triangle.
 $DG = \frac{1}{3}AD, EG = \frac{1}{3}BE,$
 $FG = \frac{1}{3}CF.$

Cone
 O is the centre of the base.
 AO is the axis of the cone.
 If $OG = \frac{1}{4}AO$, then G is the centre of gravity of the cone.

A body is able to stand so long as a vertical line drawn from its centre of gravity falls within the base of support, assuming, of course, that no force other than its own weight is acting on it. Thus, if a rectangular solid $ABCD$, Fig. 67 (i), is placed on a surface PQ , which can be inclined at different angles, the solid is in equilibrium so long as the vertical line drawn through G cuts the base BC . If, however, this vertical line should cut BC produced, as in Fig. 67 (ii), the solid will overturn unless prevented from doing so by some external force.

WORK AND POWER

Work. When a force acting on a body causes that body to move, *work* is said to be done. The amount of work done depends on the magnitude of the force, and also on the distance through which it acts, being equal to the product of these quantities.

UNITS OF WORK. The unit usually employed in this country is the *foot-pound*; that is, the amount of work done when a force of 1 lb. acts through a distance of 1 ft. Another unit, the *foot-ton* (whose definition is self-evident) is sometimes used.

EXAMPLE 1. The work done in raising a block of stone, weighing 200 lb., to the top of a building 40 ft. high, is $200 \times 40 = 8,000$ ft.-lb.

EXAMPLE 2. A piston 20 sq. in. in area is forced 2 ft. into a cylinder against a *constant* resistance of 6 lb. per sq. in. Find the work done.

SOLUTION. Resistance opposing motion of piston
 $= 6 \times 20 = 120$ lb.

This is the force which must be exerted.

Therefore, work done $= 120 \times 2 = 240$ ft.-lb.

The work done in pushing a pound weight through a distance of 1 ft. across a table is *not necessarily* 1 ft.-lb. The force which is exerted has to overcome the *friction* between the weight and the table; it may be greater than, or it may be less than, the 1 lb.

WORK DONE AGAINST GRAVITY. This is equal to the product of the weight of the body moved, and the *vertical* distance through which it is raised.

WORK DONE BY A VARYING FORCE. This is equal to the product of the *average* value of the force and the distance through which it acts. In a great many practical examples, the force varies *uniformly*, that is, increases or decreases by equal increments when it moves through equal distances. In such a case the *average* value of the force is the *mean* (or half the sum) of its initial and final values. When the variation is

not uniform, the calculation may be more difficult. The magnitude of the force at small intervals must be obtained in some way, and the average value found.

EXAMPLE. A windlass is on a platform 60 ft. above the ground. The steel winding cable weighs 4 lb. per foot; the hook, etc., at the end of the cable weighs 30 lb., and the load to be lifted is 400 lb. How much work is done in raising the load 40 ft.?

SOLUTION. The load and hook (total weight 430 lb.) are raised 40 ft. Therefore, work done $= 430 \times 40 = 17,200$ ft.-lb.

The weight of the cable to be raised is originally $60 \times 4 = 240$ lb. When the load is in its final position, only 20 ft. of cable hang from the windlass. The weight of this cable is then $20 \times 4 = 80$ lb. Also, the weight of cable hanging from the windlass decreases uniformly

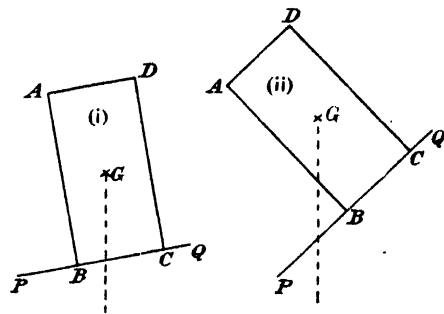


FIG. 67

Vertical line through the centre of gravity G falls within the base. Solid will not overturn

Vertical line through the centre of gravity G does not fall within the base. Solid will overturn, unless prevented by some external force.

(at the rate of 4 lb. per foot rise). Therefore, average force required to raise the cable is

$$\frac{240 + 80}{2} = 160 \text{ lb.}$$

Work done in raising cable

$$= 160 \times 40 = 6,400 \text{ lb.}$$

Total work done

$$= 17,200 + 6,400 = 23,600 \text{ ft.-lb. Ans.}$$

WORK DONE IN RAISING A NUMBER OF BODIES. This is equal to the total weight multiplied by the distance through which the centre of gravity of the whole is raised.

EXAMPLE. Find the work done in filling a tank 16 ft. \times 4 ft. \times 6 ft. deep with water from a river, the bottom of the tank being 15 ft. above the surface of the river. [1 cub. ft. of water weighs 62½ lb.]

SOLUTION. The centre of gravity of the water required to fill the tank is $6 \div 2 = 3$ ft. above the bottom.

This is $(15 + 3)$

$$= 18 \text{ ft. above the river.}$$

Weight of water

$$= 16 \times 4 \times 6 \times 62\frac{1}{2} \text{ lb.}$$

$$= 24,000 \text{ lb.}$$

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Therefore, work done
 $= 24,000 \times 18 = 432,000 \text{ ft.-lb. Ans.}$

Power. This may be defined as the *rate of doing work*.

The unit usually employed in this country is the *horse-power*, which is equal to 33,000 ft.-lb. per minute, or 550 ft.-lb. per second.

EXAMPLE. A load of 500 lb. is raised by a crane through a distance of 40 ft. in 20 seconds. At what horse-power is the crane working?

SOLUTION.

Work done $= 500 \times 40 = 20,000 \text{ ft.-lb.}$

Power $= \frac{20,000}{20} = 1,000 \text{ ft.-lb. per sec.}$

Therefore, horse-power

$$= \frac{1,000}{550} = \frac{20}{11}$$

$$= 1 \frac{9}{11} \text{ h.p. Ans.}$$

IMPACT

When one body strikes another, and suffers an appreciable change of velocity in a short period of time, *impact* is said to occur.

The commonest example occurs when a moving body strikes another and is brought to rest very quickly. In such cases, the forces acting between the moving and stationary bodies are often very great. The formula given below will enable these forces to be calculated. (This formula can be derived mathematically, but the process is not likely to be of interest to the building student.)

Let W = the weight of the moving body (in pounds).

v = the velocity (or speed) with which it strikes the stationary one (expressed in feet per second).

t = the time (in seconds) in which it is brought to rest. [This will often be a small fraction of a second.]

P = force in pounds exerted by the stationary body in bringing the other to rest. This is also the force exerted by the moving body on the stationary one.

$$\text{Then, } P = \frac{Wv}{32t}$$

P is sometimes called the *force of the blow*.

If the moving body is falling vertically, its weight W also acts on the stationary body. In such a case the total force exerted is

$$\left(\frac{Wv}{32t} + W \right) \text{ lbs.}$$

The reader will observe that P is made greater by reducing t , and that P is diminished by increasing t . This is the reason why springs are used in many cases to prevent injury when one body strikes another; for example, in spring buffers between railway coaches, the presence of the spring increases the time taken by the one body to come to rest with respect to the other.

In working examples on the "force of a blow," the reader will often need to calculate the velocity which a body acquires by falling freely through a certain distance.

If v = velocity acquired (in feet per second), and d = vertical distance (in feet) through which the body falls,

$$\text{Then, } v = 8\sqrt{d}.$$

This is true for all bodies except those, like a sheet of paper, or a feather, whose motion is appreciably affected by air resistance.

EXAMPLE. A man weighing 11 stone drops from a height of 25 ft. Find the average force between his body and the plank on which he drops if the latter yields to the shock for $\frac{1}{2}$ second.

SOLUTION. Velocity (v) with which man strikes the plank

$$= 8\sqrt{25} = 40 \text{ ft. per sec.}$$

Average force

$$= \frac{Wv}{32t} + W$$

$$= \frac{154 \times 40}{32 \times \frac{1}{2}} + 154$$

$$= 385 + 154$$

$$= 539 \text{ lb. Ans.}$$

$$W = 11 \times 14 = 154 \text{ lb.}$$

$$v = 40 \text{ ft. per sec.}$$

$$t = \frac{1}{2} \text{ sec.}$$

That is, $3\frac{1}{2}$ times the man's weight.

If the plank were so stiff that it yielded for $\frac{1}{10}$ sec. only, the force would be 4,004 lb. = $35\frac{1}{2}$ cwt.

This force would certainly produce serious injury.

Chapter VIII—MACHINES.

Definition. A *machine* is a contrivance for overcoming a force at one point by means of another force applied at some other point; thus, a screw-driver, a lever, or a pulley are machines.

The force to be overcome may be the weight of a body which has to be lifted, or it may be the resistance which a body offers to compression, stretching, bending, cutting, etc.; in all cases we shall refer to it as the *resistance* and denote it by W . The applied force will be referred to as the *effort* and denoted by P . The point on the machine at which the resistance acts is the *working point*; that at which the effort is applied is the *driving point*.

Velocity Ratio, Mechanical Advantage, and Efficiency. Let us suppose that in a given machine the effort moves through a distance a , whilst the resistance is overcome through a distance b . In the great majority of cases the ratio of a to b will be constant for a given machine throughout its working. This is the case in the wheel and axle, and its modifications such as the winch; also for pulley blocks and the screw-jack. Then, $\frac{a}{b}$ is called the *velocity ratio* of the machine.

The ratio of the resistance W to the effort P is called the *mechanical advantage*. Now, the work done by the effort is $(P \times a)$; whilst the work done against the effort in the same time is $(W \times b)$. *If the machine were perfect, these quantities would be equal to one another,*

i.e. $(P \times a)$ would equal $(W \times b)$

or $\frac{a}{b}$ would equal $\frac{W}{P}$.

But in any *actual* machine, work is always wasted in overcoming friction and in producing slight amounts of bending of the various parts. Hence, the work done by the effort (or *total work*) is always greater than that done against the resistance in the same time (or *useful work*). The difference between these two amounts is often called the *lost work*, whilst the ratio of the *useful work* to the *total work* is called the *efficiency* of the machine; this latter is always less than unity.

If E = efficiency, M = mechanical advantage, and V = velocity ratio, then as above

$$V = \frac{a}{b} \text{ and } M = \frac{W}{P}$$

Also, $E = \frac{Wb}{Pa} = \frac{W}{P} \div \frac{a}{b} = M \div V$

It should be noted that the velocity ratio of a machine depends solely on its construction and

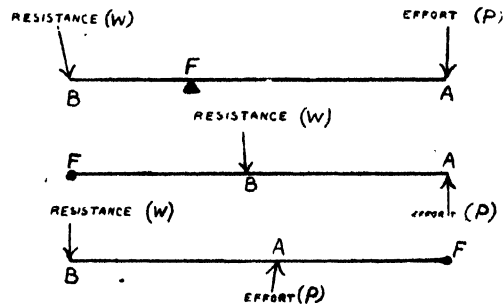


FIG. 68. THE LEVER

- A = Driving point
- B = Working point
- C = Fulcrum

dimensions. The mechanical advantage and efficiency depend also on its *condition* (that is, state of wear or of lubrication).

In many cases low efficiency in a machine is regarded as a serious defect. But it should be remembered that if the efficiency is less than one-half, and if, in addition, the frictional forces are not affected by removing the effort, then the machine will not reverse under the action of the resistance (or load) when the effort is removed; that is, it cannot run back. Now these two conditions are fulfilled in the *Weston differential pulley* and the *screw-jack*. Consequently a load can be raised by these, and will remain so raised when the effort is removed, without any need for pawls or stops to prevent its fall.

SOME SIMPLE MACHINES

The Lever. In its simplest form this consists of a rigid rod which can turn freely about a fixed point called the *fulcrum*. This point is often between the working point and the driving point, but need not be so placed. Fig. 68 shows

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the various ways in which these three points may be arranged. The reader should note that the resistance (W) and the effort (P) are not always perpendicular to the length of the lever, neither need they be parallel to one another.

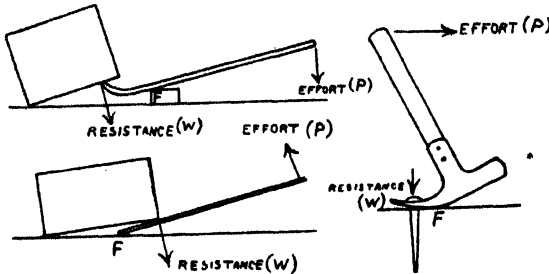
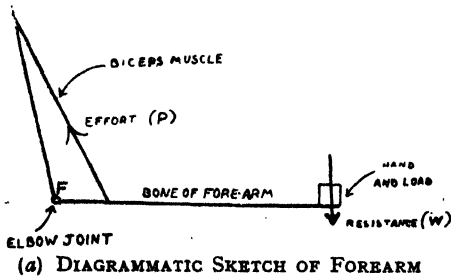


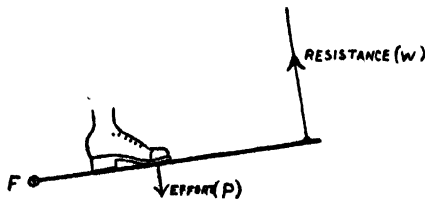
FIG. 69. EXAMPLES OF LEVERS
Velocity ratio greater than unity

But, in all cases, the relation between them can be found by taking moments about the fulcrum F . Evidently, the weight of the lever itself must be regarded in practical examples.

In most cases where a lever is used, the mechanical advantage is greater than one; that



(a) DIAGRAMMATIC SKETCH OF FOREARM



(b) A TREADLE

FIG. 70. EXAMPLES OF LEVERS
Velocity ratio less than unity

is, a small effort is used to overcome a large resistance. This is done by so arranging matters that the perpendicular drawn from the fulcrum to the line of action of the effort P is longer than the perpendicular drawn from the fulcrum to the line of action of the resistance W . Examples of this are shown in Fig. 69. The

student will see, however, that for a large mechanical advantage to be obtained, the effort must move much faster than the resistance (or load).

In the usual form of balance, or "scales," the

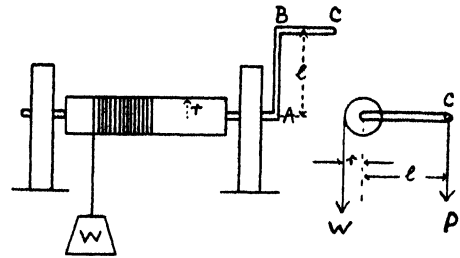


FIG. 71. THE WINDLASS

mechanical advantage is unity; here the body being weighed is the resistance and the "weights" the effort.

Occasionally the lever is used in such a way that the effort applied needs to be greater than the resistance. This is done when we wish the working point to move faster than the driving point. Fig. 70 shows examples of this: (a) the human forearm, where a small movement of the point where the biceps muscle is attached to the bone of the forearm, raises the hand through a much larger distance; and (b) a treadle.

The Windlass. As will be seen from Fig. 71, the windlass is merely a modification of the lever. Neglecting friction, and assuming that the effort is applied at right angles to the radial portion, AB , of the handle, take moments about F .

$$W \times r = P \times l$$

This gives a mechanical advantage equal to $\frac{l}{r}$.

In practice, the actual value will be only slightly less than this if the bearings are in good condition and well oiled.

The Fixed Pulley. A pulley is said to be *fixed* when it is so used that the wheel or sheave merely rotates, but the pulley as a whole does not move. Neglecting friction, we see that the effort must equal the resistance. The only use of a fixed pulley is to change the *direction* of a force.

Movable Pulleys. A pulley is said to be *movable* when so used that it moves as a whole. Thus, in Fig. 72, the load W , suspended from

the block of the single movable pulley, can be raised by a suitable effort P . It is evident that P moves twice as fast as W . Hence, the velocity ratio of a single movable pulley is 2. The mechanical advantage will be rather less than this, as work is wasted in raising the pulley itself and also in overcoming friction.

Fig. 73 represents a pair of double pulley blocks as used in builders' yards. A single rope passes around all the sheaves in turn, one end is attached to the upper or fixed block, whilst

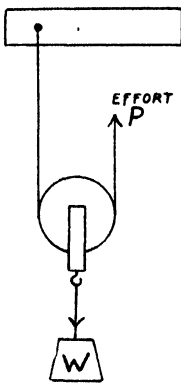


FIG. 72. SINGLE MOVABLE PULLEY

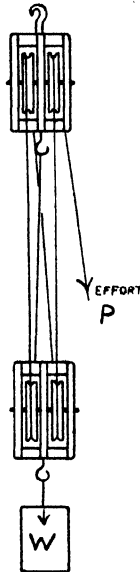


FIG. 73. PAIR OF DOUBLE PULLEY BLOCKS

the effort is applied at the other end. The velocity ratio can be calculated thus: suppose the lower block (and load) to be raised through 1 ft. The amount of rope between the blocks will be decreased by an amount equal to 1 ft. multiplied by the number of ropes proceeding to the lower block; in this case 4. Hence the effort will move through a distance of 4 ft., whilst the load rises 1 ft. Therefore the velocity ratio is 4; that is, equal to the number of cords proceeding to the movable block. The mechanical advantage will, of course, be less than this.

The efficiency is greater than a half; the reader knows by experience that this machine will "run back" if left free to do so.

The Weston Differential Pulley. This most useful form of pulley is shown in Fig. 74. The upper block contains *one* wheel, with two grooves

of slightly different diameters; the lower one, from which the load hangs, is a single movable pulley. An endless chain passes round the blocks as shown; it is unable to slip on the upper block as projections on the surface of the grooves fit into the links. The effort is applied as shown in the figure.

TABLE XVIII
RESULTS OF A TEST ON A PAIR OF DOUBLE PULLEY BLOCKS

Velocity Ratio = 4

Load	Effort	Mechanical Advantage = Load ÷ Effort	Efficiency = Mechanical Advantage ÷ Velocity Ratio
28 lb.	13.0 lb.	$\frac{28}{13} = 2.15$	$\frac{2.15}{4} = .54$
56 lb.	23.6 lb.	$\frac{56}{23.6} = 2.37$	$\frac{2.37}{4} = .59$
84 lb.	34.2 lb.	$\frac{84}{34.2} = 2.46$	$\frac{2.46}{4} = .61$
112 lb.	44.7 lb.	$\frac{112}{44.7} = 2.51$	$\frac{2.51}{4} = .63$
140 lb.	55.3 lb.	$\frac{140}{55.3} = 2.53$	$\frac{2.53}{4} = .63$

Suppose that the upper wheel is made to rotate once in the direction indicated. The effort will descend through a distance $2\pi R$, where R is the radius of the outer groove. As a consequence, the chain AE will be shortened by this amount. But the chain CF will, at the same time, be lengthened by an amount $2\pi r$, where r is the radius of the inner groove. Hence the total shortening of the loaded chain is $(2\pi R - 2\pi r)$, and the load will rise through one-half this distance, or $(\pi R - \pi r)$. Hence the velocity ratio is $2\pi R \div (\pi R - \pi r)$, or $2R/(R - r)$.

Since R and r are nearly equal, it follows that the velocity ratio is large. There is a considerable amount of friction in this machine, consequently the mechanical advantage is much less than the velocity ratio. As will be seen from Table XIX, the efficiency is less than one-half. The reader will find from experience that this machine does not "run back," and this fact more than counterbalances its low efficiency, as the mechanical advantage is still large.

The Wedge. Fig. 75 represents this appliance. It is obvious that if the effort moves the wedge forward a distance equal to AO , then the resistance is overcome through a distance BC . That is, the velocity ratio is equal to length of

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wedge ÷ thickness. The mechanical advantage is considerably less than one-half of this in the case of all wedges used in practice. Hence the efficiency is low and such a wedge will not "run

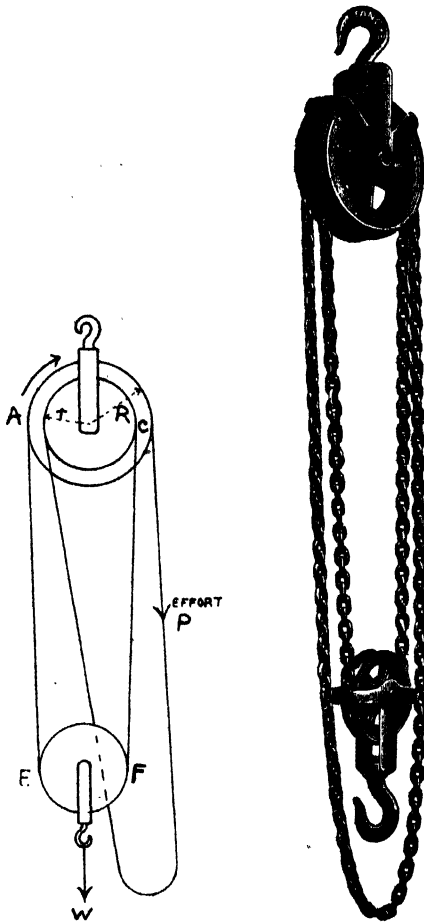


FIG. 74. THE WESTON DIFFERENTIAL PULLEY

back"; that is, it is not forced out when the effort ceases to act.

The mechanical advantage of the wedge is increased by decreasing the angle between its faces, but it must not be made too slender, otherwise it is liable to double up in use. As a rule, the wedge is used not so much on account of its great mechanical advantage, but rather because it will not "run back," and also because it enables a force to be exerted between two bodies which are very close together.

The Screw. The effort causes the screw to rotate, and in doing so it moves forward either

TABLE XIX

TESTS ON A WESTON DIFFERENTIAL PULLEY

Radius of Outer Groove = 1 7/8 in. (approx.)

Radius of Inner Groove = 1 1/8 in. (approx.)

$$\text{Velocity Ratio} = \frac{2 \times 1\frac{7}{8}}{1\frac{7}{8} - 1\frac{1}{8}} = \frac{3\frac{1}{2}}{\frac{1}{2}} = 15$$

In a test, effort descended 100 in. whilst load rose 6 1/2 in. Hence velocity ratio

$$= \frac{100 \text{ in.}}{6\frac{1}{2} \text{ in.}} = 15.4$$

This value is more reliable than that given above, being based on larger measurements.

Load	Effort	Mechanical Advantage = Load ÷ Effort	Efficiency = Mechanical Advantage ÷ Velocity Ratio
28 lb.	6.0 lb.	$\frac{28}{6} = 4.7$	$\frac{4.7}{15.4} = .30$
56 lb.	10.2 lb.	$\frac{56}{10.2} = 5.5$	$\frac{5.5}{15.4} = .36$
84 lb.	14.3 lb.	$\frac{84}{14.3} = 5.9$	$\frac{5.9}{15.4} = .38$
112 lb.	18.3 lb.	$\frac{112}{18.3} = 6.1$	$\frac{6.1}{15.4} = .40$
140 lb.	22.3 lb.	$\frac{140}{22.3} = 6.3$	$\frac{6.3}{15.4} = .41$

in its nut or through the wood, if a wood-screw is being used. The distance which the screw advances for one complete turn is known as its *pitch*. In the case of wood-screws and all other "single start" screws, this is the distance measured along the length of the screw between two adjacent threads; a "single start" screw being one where a single thread passes around the cylindrical part. (Occasionally, in special cases,

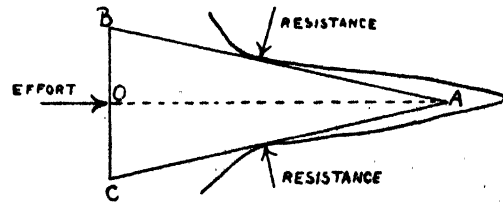


FIG. 75. THE WEDGE

where the pitch is large, one or more intermediate threads are used for very large screws moving in nuts; such are known as "double start," "treble start," etc.).

Let p in. be the pitch of the screw, and let d in. be the diameter of the handle of the screw-driver.

During one rotation the screw will advance p in.

But the effort will, at the same time, move through a distance πd in.

Therefore the velocity ratio is $\pi d/p$.

The mechanical advantage will be *much* less than this, probably only about 20 per cent, but this low efficiency is of little importance compared with the fact that the screw does not run back when the effort ceases to act.

EXAMPLE. A screw has 18 threads to the inch. The diameter of the handle of the screw-driver is 2 in., and the effort applied is equal to a force of 5 lb. weight. Calculate (a) the velocity ratio, and (b) the pull exerted by the screw, using an efficiency of 20 per cent.

$$d = 2 \text{ in.}, p = \frac{1}{18} \text{ in.}$$

$$\begin{aligned} \text{Velocity Ratio} &= \frac{\pi d}{p} \\ &= \frac{3\frac{1}{2} \times 2}{\frac{1}{18}} = 113 \end{aligned}$$

$$\text{Efficiency} = 20 \text{ per cent} = \frac{1}{5}$$

$$\therefore \text{Mechanical Advantage is } \frac{113}{5} = 22.6$$

$$\begin{aligned} \therefore \text{Pull exerted} &= \text{Effort} \times 22.6 \\ &= 5 \text{ lb.} \times 22.6 = 113 \text{ lb.} \end{aligned}$$

The Screw-jack. This appliance is shown in Fig. 76, one side being partly in section to show

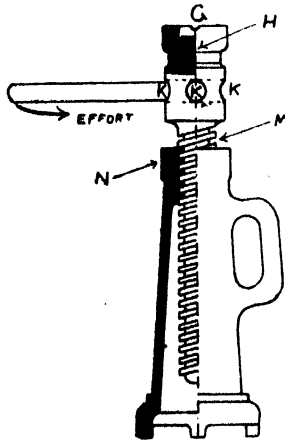


FIG. 76. THE SCREW-JACK

the construction. It is used where a heavy load has to be raised a short distance. The load rests on the collar G, which can turn freely on the

pivot H. A bar is passed through one of the holes K and the effort applied in a horizontal direction at right angles to the bar. This causes the screw M to turn in the nut N. It is clear that for one turn of the screw, the load is raised a distance equal to the pitch of the screw; the effort moves through the circumference of a circle whose radius is equal to the distance of the driving point from the axis of the screw.

$$\text{Hence, velocity ratio is equal to } \frac{2\pi \times l}{p}$$

where l = distance of driving point from axis of screw

p = pitch of screw.

To obtain the figures for the following table, G and H were removed and in their place a circular piece of stout wood was fixed. The load rested on this and a cord was wound around its circumference. This cord passed over a small fixed pulley, and small weights hung from its end were the efforts used.

TABLE XX

TESTS ON A SCREW-JACK

Distance of driving point from axis of screw = 4 in.

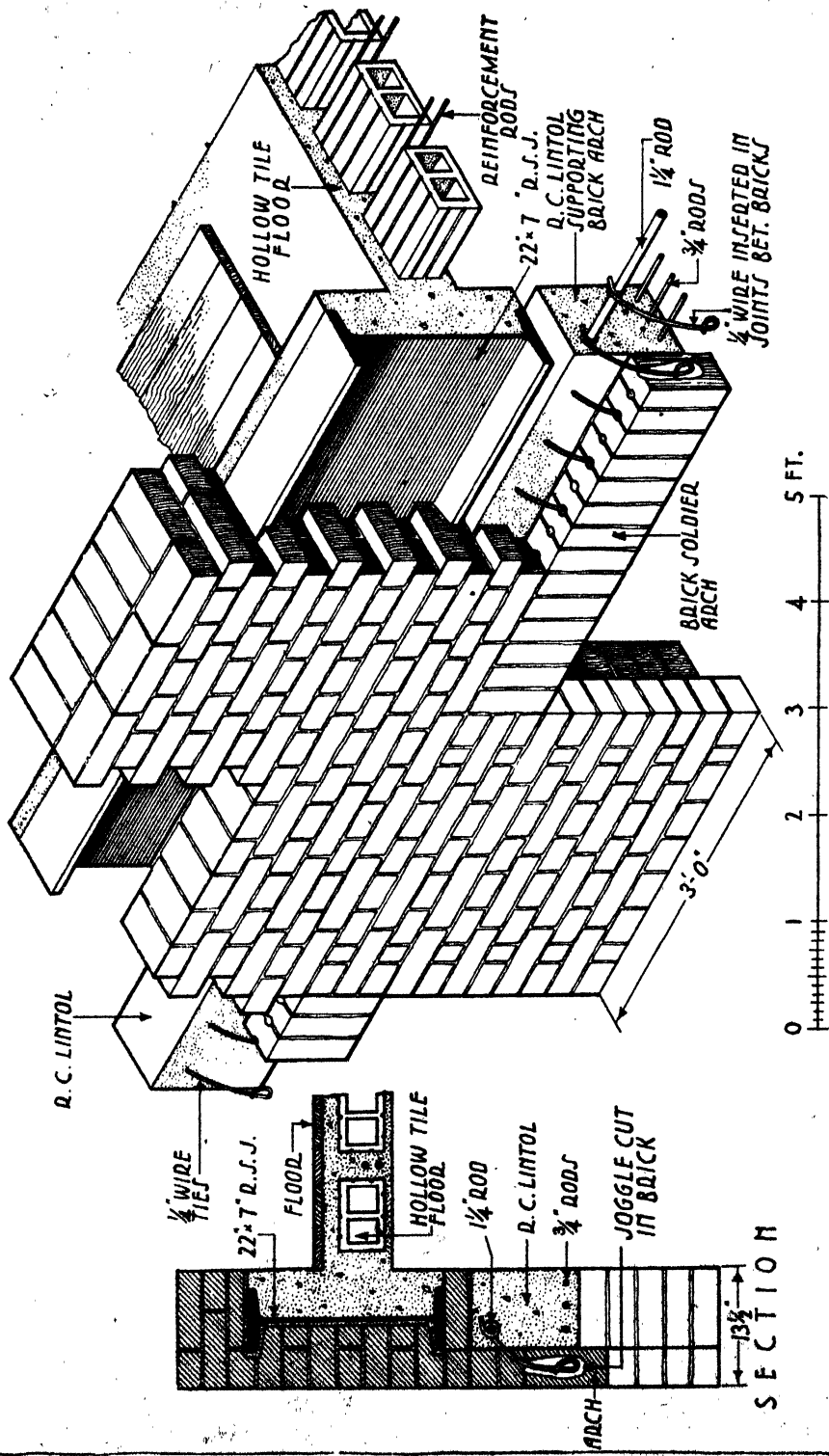
Pitch of screw = $\frac{1}{8}$ in.

$$\therefore \text{Velocity ratio} = \frac{2\pi \times 4}{\frac{1}{8}} = 50.3$$

Load	Effort	Mechanical Advantage = Load ÷ Effort	Efficiency = Mechanical Advantage ÷ Velocity Ratio
28 lb.	2.0 lb.	$\frac{28}{2} = 14$	$\frac{14}{50.3} = .28$
56 lb.	3.3 lb.	$\frac{56}{3.3} = 17$	$\frac{17}{50.3} = .34$
84 lb.	4.7 lb.	$\frac{84}{4.7} = 17.9$	$\frac{17.9}{50.3} = .36$
112 lb.	5.9 lb.	$\frac{112}{5.9} = 19$	$\frac{19}{50.3} = .38$
140 lb.	7.2 lb.	$\frac{140}{7.2} = 19.3$	$\frac{19.3}{50.3} = .38$

NOTE. (i) The efficiency of a screw-jack is always less than one-half; it never runs back.

(ii) In practice, the driving point would be considerably farther from the axis of the screw than was possible with the disc used. If it were 12 in. instead of 4 in., this would give a velocity ratio of about 151 with mechanical advantages of 42 to 58.



BRICK SOLDIER ARCH
SUITABLE FOR BIG SPANS

Brickwork

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Chapter I—BRICKS AND MORTAR

AN appreciation of the beauties of a craft is essential to the making of a good craftsman. Many fine examples of the use of brickwork as an ornamental feature are still in existence, and in these the artistry of the craftsman is made apparent by the well-balanced lines and curves of his work, as distinct from the designer's efforts.

The student, therefore, should endeavour to obtain a good knowledge of the materials of his craft, and the possibilities and limitations of their application. The latter may more readily be observed by frequent visits to some of the existing brick masterpieces. Among these are St. James's and Hampton Court Palaces, the old palace at Richmond, Esher Water-tower, and the cloisters of Windsor Castle. Deserving of particular attention is the Temple, as the entrance to the Middle Temple is executed in rubbed brickwork. Kew Palace, built 1613, is an interesting example of craftsmanship. The quaint columns and the pilasters over the front entrance are particularly worthy of notice; also the Orangery at Kensington Palace. A more recent example is London House; Guildford Street, just off Gray's Inn Road, built in 1937.

The foregoing are merely cited as examples, and the student would be well advised to visit any modern specimens of the bricklayer's art which are within his own knowledge.

The trade presents unlimited scope for the craftsman possessing expert knowledge, by reason of a general shortage of men in the trade and a serious dearth of really capable mechanics. The rates of pay and the conditions of employment have improved so much of late years as to make the trade, in the opinion of the writer, a desirable one; particularly when the possibilities for many years to come are fully considered.

APPRENTICESHIP. This period ranges from three to five years, with rates of pay varying from $\cdot 2$ of current rates during the first year to $\cdot 7$ during the last. The current rate of pay in

London is, at the time of writing, 2s. 2d. per hour, and about 1d. less in the provinces.

Possibilities open to the earnest student are various. The post of foreman bricklayer carries with it an advance of from 2d. to 4d. per hour on current rates, while the positions of general foreman and clerk of works produce from £7 to £12 per week.

Many important positions in the educational world are being filled by men who were at one time employed in the craft. There is also the prospect of becoming an employer to be considered.

BRICKS

Manufacture. Bricks are manufactured from clay or loamy earth, the suitability of which is determined by practical trials and chemical analyses. The method generally used is to manufacture, by the ordinary processes, a test brick from the selected earth. If this proves unsatisfactory, chemical analyses will generally suggest additions of an improving nature. Brick earths are seldom found ready for use without special preparations, and the constituents of various earths differ to a great extent.

Processes of manufacture vary considerably throughout the country, and even in adjacent brickyards, but the following are general: (1) Preparation of the earth; (2) moulding; (3) drying; and (4) burning.

The finished articles may be classified thus—

1. Hand-moulded bricks (clamp burned);
2. Machine-made wire-cuts (kiln burned); and
3. Machine-made pressed bricks (kiln burned).

There is another classification of process which is known as (1) plastic; (2) semi or stiff plastic; (3) semi dry.

In the first process of manufacture, clay-getting takes place in the autumn. The top spit of earth, containing vegetable matter, is removed, the clay being dug and then heaped up

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on a level piece of ground, when all stones are carefully removed by hand.

The earth is spread in layers, with intermediate layers of coke breeze and liquid chalk to a thickness of four or five feet. This pile is left during the winter, the action of frost and snow disintegrating the mass. If a superior

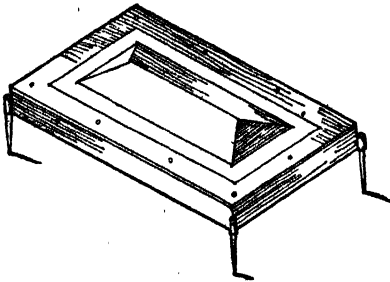


FIG. 1. STOCKBOARD

brick is required, the earth and chalk are mixed in wash-mills, passed through sieves into settling pits, and the excess water drained off. When fairly firm, the sediment is covered with a layer

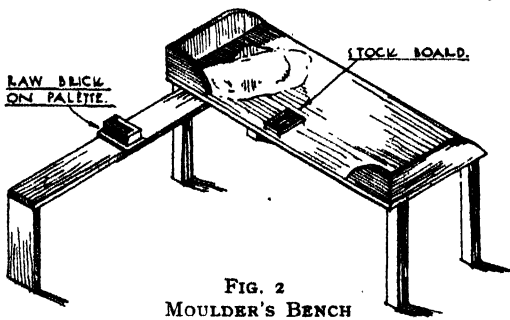


FIG. 2
MOULDER'S BENCH

of ashes, and the whole left to disintegrate as before.

In the spring, the mass is ground in a pug-mill. This machine has a stationary cylinder, with revolving knives, which cut and knead the clay into a plastic state, fit for the moulder. This is known as the plastic process.

Moulding. A piece of board, Fig. 1, called a *stockboard*, having a reverse mould of the indentation, or *frog*, of the brick, is fixed at one corner of the moulder's bench, Fig. 2. A wooden or metal box, as shown in Fig. 3, and called a *mould*, is fitted over the stockboard. This mould is minus top and bottom, and of the exact shape but larger by one-tenth in all dimensions than a brick.

The mould having been wetted or sanded to prevent the clay sticking to its sides, the clay

is dashed into it and pressed into the corners, the surplus being removed by drawing a short pine straight-edge (*strike*) over the top edges of the mould. The moulder then places a piece of $\frac{3}{8}$ in. board, called a *pallet*, on the top, lifts

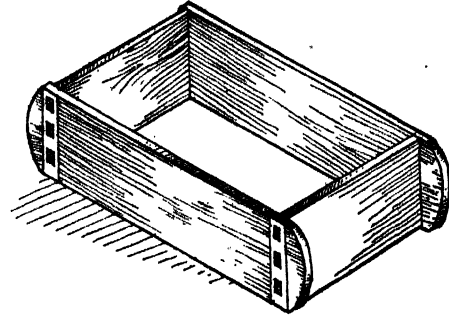
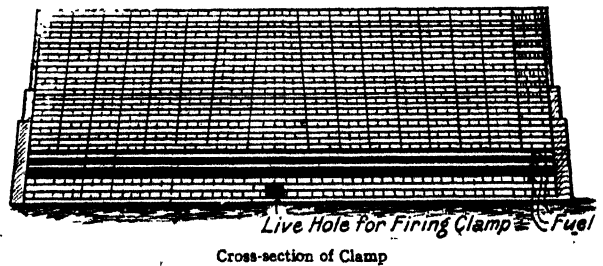


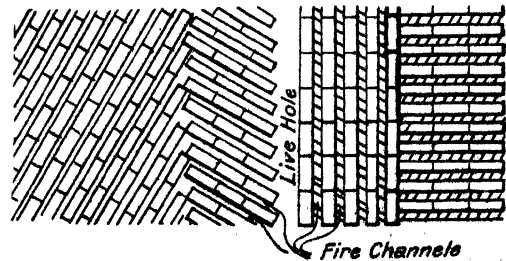
FIG. 3. MOULD

the mould and its contents off the stockboard, reverses it, and removes the mould, thus leaving the raw brick on the pallet.

The bricks are loaded on to a specially constructed wheelbarrow fitted with springs to



Cross-section of Clamp



Method of Stacking Bricks at the Base of Clamp to form Fire Channels

FIG. 4. PART-PLAN AND CROSS-SECTION OF CLAMP

prevent damage through vibration, and taken to the drying hacks. The hacks are long, level, concrete banks about 6 in. above the general ground level, where the bricks are stacked on edge about $\frac{3}{8}$ in. apart and about seven or eight courses high, with their ends exposed to the

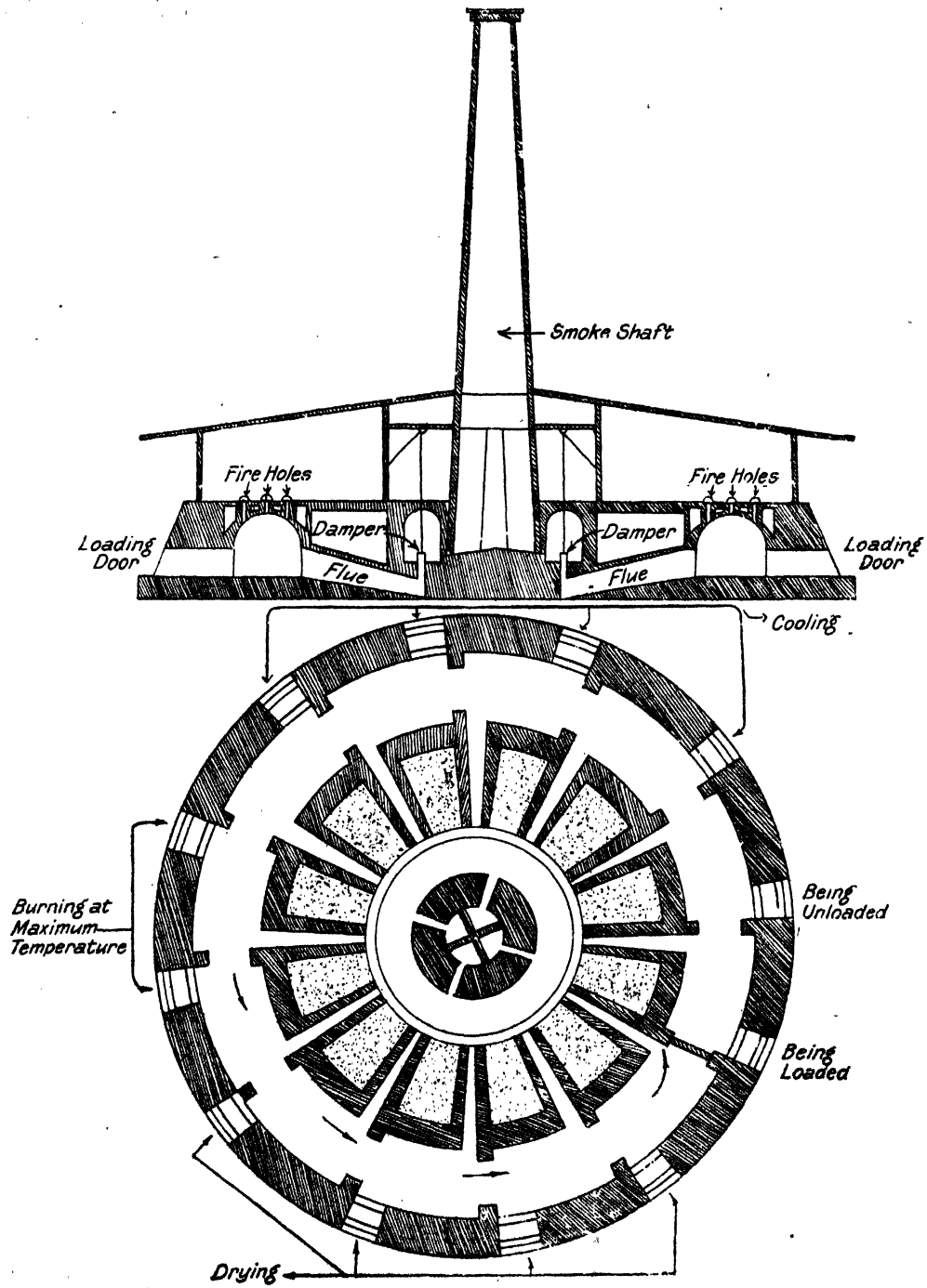


FIG. 5. SECTIONAL ELEVATION AND SECTIONAL PLAN OF HOFFMANN KILN

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weather. Here they remain for about two weeks. At the end of this time they are stacked diagonally about 2 in. apart, each course in opposite directions, so that the wind may more effectually dry them. The bricks are protected from the weather by wooden frames, matting, or tarpaulins.

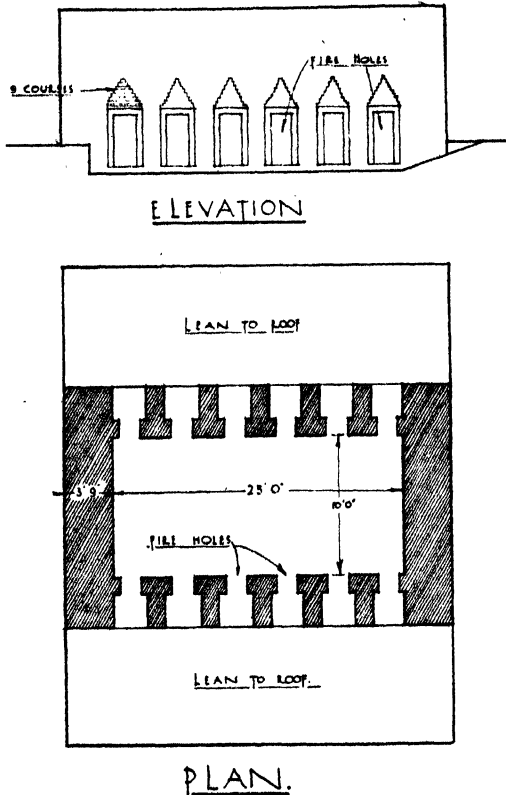


FIG. 6. RECTANGULAR KILN, WITH OPEN TOP
Scotch type

Burning. Fig. 4 shows a *clamp* as used for burning bricks. A level platform is formed, on raised ground, with underburned bricks from previous burnings, in which a series of horizontal channels, called *fire-holes*, are arranged. These holes are filled with faggots. Two layers of bricks on edge are then placed over the whole surface, spaced about 2 in. apart, and laid diagonally across the clamp. The spaces are filled with breeze; over this a layer of unburned bricks on edge is stacked close, and covered with 7 in. of breeze. These are followed by two courses of unburned bricks, with 4 in. of breeze between, and a 2 in. layer over all. The clamp is completed with a series of close-stacked, thin

walls, called *bolts*, built up to a height of about 14 ft., the outer walls battering, or sloping, inwards. The clamp is ignited through the fire-holes, the whole burning through in from three to six weeks.

When the mass is sufficiently cool to permit of handling, the work of unloading is commenced.

Stock bricks are produced by this process, and are classified according to quality. This is determined by the amount of care exercised in the preparation of the earth, and the degree of perfection to which the bricks have been burned. The latter depends upon their position in the clamp.

The bricks at the base of the clamp, being subject to a very intense heat, fuse, and run together into lumps, and are useful only for rough walls, rockeries, etc.

The centre of the clamp produces bricks of the best quality, the more uniform temperature minimizing risks of fusion and distortion.

Toward the outside of the clamp, the bricks are inclined to be underburned, while those on the extreme outside are rendered, by the action of the weather, so full of cracks and flaws, as to be useless for constructional work.

Stock Bricks. The types of stock bricks are as follows—

1. Malms. 2. Malmed. 3. Common stocks.

Malms are not now made in any quantity, as the careful washing of the earth in its preparation renders the process uneconomical, producing an article too expensive for general use.

For the second type, washed and unwashed earths are mixed in certain proportions, thus reducing cost, and also quality.

Common stocks are most generally used, and can be obtained in various qualities to meet those requirements for which their colour is suitable.

Machine-made, kiln-burned stocks are being extensively manufactured in Kent, great quantities being used in and around London. These are usually termed *Kentish stocks*.

Kiln-burned Bricks. The preparatory processes are similar to those previously described, though usually carried out by machinery. The burning, or perhaps more appropriately, the baking, is carried out in enclosed structures, through which circulates, for varying periods, air at a very high temperature.

Many types of kilns are used in different localities: the Hoffmann, Fig. 5, the improved Hoffmann, and the Scotch, Fig. 6, being most generally employed.

Scotch kilns, as shown in Fig. 6, generally take the form of rectangular chambers, roofless and furnished with fire-holes at the bases. Bricks are stacked in the kiln, and so spaced as to allow the heat to circulate freely. The top layer is protected by a covering of old bricks, which also conserve the heat during burning.

These kilns are a big improvement on the clamp, the bricks being more uniform in colour and shape, their quality depending, as in the clamp, upon their position in the kiln.

The Hoffmann kiln, Fig. 5, is undoubtedly the most successful type. In these kilns, the whole of the heat generated is utilised progressively, with the result that the process of burning is very gradual. This minimises the risk of cracking and distortion, and ensures the production of a good quality brick.

These kilns are circular or rectangular in structure and divided into a number of chambers, often twelve, interconnected by small openings at the bottom of the dividing walls. Each chamber is provided with a flue, which carries the gases of combustion and steam into a shaft. When the chambers are stacked with bricks, fuel is fed from traps in the flat top of the kiln into spaces left against the division walls.

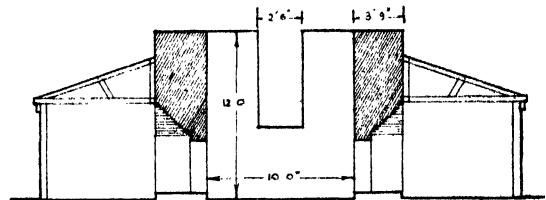
When the kiln is in action, two adjacent chambers are open, one being unloaded, the other loaded. The following four chambers are in the cooling stage, the next two burning at the maximum temperature, and the remaining four in various stages of drying. The opening between the last chamber and the chamber being loaded is covered with sheets of paper, to prevent air passing during the loading process.

When loading is complete, the opening to the next chamber, which by this time has been unloaded, is in its turn sealed with paper, and the last damper opened. Thus the cycle of drying, burning, cooling, loading, and unloading proceeds continuously.

The improved Hoffmann, or *Warren's Perfected*, is similar in most respects, except that it is rectangular in shape, with rounded ends, and usually contains about fourteen chambers. In these kilns, considerable economy in heat is effected by the use of a hot-air flue, to which each chamber is connected by ducts. When a cooling chamber is opened, its duct is also opened, creating a draught around the cooling bricks. The heated air passing through the flue, and from thence to the drying chambers, utilises the heat to the uttermost, thereby economising in both fuel and time.

Machine-made Wire-cuts. After thorough incorporation in the pug-mill, the clay is pressed through a rectangular die, from which it emerges in the form of a long slab about $9\frac{1}{2}$ in. \times 5 in. in section. A series of wires attached to a framework is pulled across the bench on which the slab rests, and cuts the slab into 3 in. blocks, which are afterwards kiln burned.

Fletton Bricks. These machine-made bricks are manufactured in the Peterborough district, from a local shale known as Oxford clay. The process, known as the semi-dry process, is different from all others, except in the burning, usually carried out in a Hoffmann kiln. The clay is dug, dried, and ground in a mill similar to a mortar-pan. The resulting powder is shot into a revolving sieve, the residue being carried back to the mill for further pulverisation. The sieved earth is moulded under great pressure in



CROSS SECTION.

FIG. 6A.

a machine which also measures the exact quantity required for the finished brick. The bricks are carried direct from the machine to the kiln. Burning continues for about three weeks.

Millions of bricks are turned out weekly by this process, which is so rapid that it is possible for only twenty minutes to elapse between digging the clay and stacking the kiln. The finished bricks are tough, compact in texture, well-shaped, with clean and sharp arrises.

Their colour varies from a dull cream to light red, not very pleasing in tone, and unsuitable for use as facings in important positions, but excellent for interior work. A special kind is made for walls that are to be plastered, a key being formed by undercut grooves on the face.

Engineering bricks of the red Southwater and the blue Staffordshire type are made under a similar process, except that extra water is added to the clay after grinding. This is the semi-plastic process. This type of brick is subject to a much higher temperature during burning.

VARIETIES AND CHARACTERISTICS

The colour of bricks depends principally on

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the chemical nature of the earth, and the effects of burning. Clays containing considerable quantities of iron oxide, but otherwise free from alkalis, burn to a clear bright red. The presence of alkalis, in conjunction with prolonged burning at a high temperature, will change the colour to a dark bluish green, as in the case of Staffordshire bricks. Clays free from iron burn white, while small quantities of chalk and iron produce a creamy tint. Clays with much iron and manganese in their composition burn black. Magnesia, with small quantities of iron, gives a yellow colour to the brick.

Varieties. The varieties of brick in general use are Stocks, Flettons, Wirecuts, Gaults, Suffolks, red Southwaters and blue Staffordshires, red facings and rubbers, Luton greys, sand-lime bricks, paviments (Dutch and adamantine clinkers), fire-bricks, insulation bricks, salt-glazed, and enamelled bricks.

GAULTS are manufactured near Rochester, at Hitchin, and in Suffolk. Gault clays frequently contain large quantities of iron oxide and sometimes large quantities of chalk. In the first instance the colour is red, and the brick of an inferior quality. The chalky clay produces a white brick. Owing to the strong nature of the clay, gaults are frequently made with perforations, to reduce the possibility of twisting and warping during burning. These are a good, hard, and durable type of brick, and the best of the kind is the white Suffolk.

RED FACINGS are made from a loamy earth containing a proportion of sand and iron oxide, and are generally sand-faced. Messrs. Lawrence & Co., Bracknell, and Messrs. Collier, of Reading, are well-known makers, and they also produce the 2 in. old English multicoloured facing-bricks and red rubbers. The latter are manufactured from specially selected earth, carefully washed and sieved to remove the smallest stones, and burned to a state little short of vitrification. These bricks contain rather more sand than the ordinary facing brick. They are largely used for decorative work, as their fine texture and the presence of the extra sand enables them to be easily carved, cut with a wire brick saw, or rubbed to a very fine arris on a stone.

SAND-LIME BRICKS are a machine-pressed brick made from pure silica sand and lime. They are not burned in a kiln in the usual way but are subjected to a steam pressure which has the effect of fusing the lime with the sand. This gives an almost pure white brick of close texture, smooth face, and with sharp even arrises. Two

well-known types in London are the Ryarsh and the Midhurst. They are used a great deal for internal fair-faced work, and for facings in positions where light and light reflection is required.

FIRE-BRICKS are made from clays of a highly refractory nature. They are capable of resisting high temperatures without fusion, and with very little change of form due to expansion or contraction. Manufacture is carried on in various parts of the country: at Stourbridge, Stamford in Lincolnshire, Poole in Dorsetshire, Wortley in the West of Scotland, and in Wales. Although the Stourbridge brick is in most general use, the Dinas brick, made by the Ynysmuden Co. near Swansea, is considered by many to have a far greater heat-resisting capacity. Fire-bricks are of a yellow colour and are close in texture.

INSULATION BRICKS. There is a variety of this type of brick on the market, the Fosalsil insulation brick being one of the best known. It is made from diatomaceous or fossilized earth. It is a wire cut brick with smooth faces and is very light in weight, so much so, that when first immersed in water it will float.

Insulation bricks are used for the insulation of furnaces and the lining of furnace and boiler flues, the main object being to keep the heat in the space designed for it and to prevent it from contacting any other part of the building where expansion and contraction would be detrimental.

SALT-GLAZED BRICKS. The faces to be glazed are exposed when these are stacked for burning. When burning has reached a certain stage, salt is thrown into the kiln; the salt when volatilized by the heat, penetrates into the pores of the exposed surfaces, covering them with a thin coating of glass, which forms part of the brick itself.

ENAMELLED BRICKS are obtainable in white, cream and other colours. Enamelling is accomplished by partially burning the raw brick, afterwards coating it with enamel by dipping its face in a vitreous slip, or thin paste; this slip is made from ground flint and china clay, with the addition of a metallic oxide. Lead oxide was at one time extensively used, but owing to objections arising on account of its being injurious to health, the oxides of sodium, potassium, zinc or tin, are now generally employed. The process is completed by subjecting the brick to a further burning. This process is called *biscuiting*. Enamelled bricks are also manufactured by enamelling the raw brick and

fixing the colour in one burning. Greater durability is thus obtained, but costs are much heavier owing to large numbers being spoiled during burning.

The following characteristics of various bricks will enable them to be more easily recognised.

HAND-MOULDED AND CLAMP-BURNED. These bricks are of irregular shape and colour, arrises not sharp, only one frog. When broken, traces of breeze may be seen. Texture is tough, and inclined to be vitreous, but not dense.

WIRE-CUTS. These have no frog, are regular in form, and dense. The cutting wires leave slightly serrated edges, and their marks may be seen on the beds of the brick. Generally of inferior quality, and difficult to cut.

MACHINE-PRESSED AND KILN-BURNED. Regular in form, clean, sharp arrises, cleanly formed frog, frequently on both beds, and maker's name or mark stamped thereon. Colour in the best types is uniform, but inferior kinds are graded in colour, and their faces have a striped appearance. Texture very dense.

Characteristics. Good bricks are regular in shape, uniform in size, compact in texture; free from particles of lime, stone, pebbles, and cracks or flaws of any description. They should not absorb more than about one-sixth of their weight of water. They should be well burned, hard, tough in texture and, when struck together, give a metallic sound. A dull thud indicates a soft brick, or the presence of limestone or pebbles in its interior. A good criterion of the quality of bricks in bulk is the condition of deliveries. If a lot of dust and a quantity of broken pieces are present, one can generally be sure that the quality leaves something to be desired.

SIZES. Sizes of bricks still vary considerably in different localities. Considerable success has, however, attended the efforts of British architects and brick manufacturers to standardise sizes. These now vary from $8\frac{1}{2}$ in. \times $4\frac{5}{8}$ in. \times $2\frac{3}{8}$ in. to 9 in. \times $4\frac{3}{8}$ in. \times $2\frac{1}{8}$ in. In parts of the Midlands and in the north much thicker bricks, from 3 in. to $3\frac{1}{2}$ in. in depth, are still being made. The average size of a Fletton brick is $8\frac{1}{2}$ in. \times $4\frac{1}{2}$ in. \times $2\frac{1}{8}$ in. The proportion of the depth to the other dimensions is of no great import, but the relation between breadth and length is very important. Twice the breadth, plus the thickness of one joint, should equal the length. The reason for this will be more clearly seen when the principles of bond are being considered.

MORTAR

The mortars used in bricklayers' work consist of an admixture of lime, or Portland cement, and sand. A knowledge of the properties of these materials is very necessary to the craftsman, if he is to obtain the best results from his labours.

Lime is manufactured by the calcination, or burning, of a carbonate of calcium, of which chalk is the commonest example. During calcination, decomposition occurs, and carbonic acid and water are driven off, an oxide of calcium (quicklime) remaining.

If water be added to lumps of quicklime, rapid combination ensues, great heat and volumes of steam being generated. The lumps disintegrate with a series of small explosions, and are eventually reduced to a very fine powder. This process is termed *slaking*; and when making mortar it is highly necessary that it should be thoroughly carried out, as any unslaked particles subsequently expand and seriously damage the work.

Limes may be divided into three distinct classes—

1. Rich limes.
2. Poor limes.
3. Hydraulic limes.

Rich limes contain not more than 6 per cent of impurities, slake very rapidly, and are entirely dependent on external agents for setting power. They are chiefly used for interior plasterers' work.

Poor limes contain from 15 per cent to 30 per cent of useless impurities, and possess the general properties of rich limes, only to a lesser degree. They are only fit for unimportant work.

Hydraulic limes contain certain proportions of impurities, which, during calcination, combine with the lime, and endow it with the valuable property of setting under water, or without external agents. The proportions of these impurities determine whether a lime is *eminently*, *moderately*, or only *feebly* hydraulic. The principal limes used in making mortar for constructional work are of the Greystone variety, obtained from Dorking, Halling, Merstham, and the district around the River Medway. These have hydraulic properties, and will take a large proportion of sand, without weakening their setting powers. The usual proportions are from two to four parts of sand to one of lime.

The *setting of lime* depends largely upon its

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absorption of carbonic acid from the atmosphere. The particles return to their original form of a carbonate, and crystallize. These crystals have a tendency to adhere to anything rough, such as sand or the surfaces of a brick.

Pure lime mortars built into thick walls never harden in the interior. The crystallisation of the exterior of the joint when set prevents access of carbon dioxide to the inside of the wall. For this reason, pure lime mortars should not be used for constructional work, only those which are not entirely dependent on external agents. For more important work, where great strength is required, Portland cement is used instead of lime.

Portland Cement is an artificial cement, manufactured by calcining chalk and clay, or river mud containing certain chemical constituents in definite proportions. The chalk and clay are ground and mixed into a slurry, which after being strained through very fine sieves, is pumped into an orifice in the top of an inclined revolving cylinder. A blast of intense flame is directed through this cylinder, which is lined with firebrick. As the slurry drops through the flame, it is burned into small clinkers, which are afterwards ground exceedingly fine in specially constructed mills, and then passed through sieves, having as many as 35,000 meshes to the square inch. The powder is aerated by being spread on wooden floors, with an occasional turning, to ensure the thorough slaking and cooling of all particles. It is then put up in sacks ready for use.

This process of aeration has now been superseded in many cement works by the addition of a small quantity of gypsum (plaster of Paris), which retards the otherwise rapid-setting tendency of a freshly-ground cement.

Sand. When used for mortar, sand should be angular in grain, free from clay or dirt, and moderately coarse. If too fine, the proportion of lime or cement will have to be considerably increased.

Mixing. This should be carried out on a close-boarded platform, or stage. In the case of *lime mortar*, sand is best measured when brought to the stage, and the heap opened out into the form of a ring. The correct proportion of lime is measured into the ring, clean water being added to start the slaking, and more as the process advances. When the generation of steam ceases, the mass should be stirred with a long-handled, hoe-shaped tool called a *larry*,

until a thick, cream-like consistency is obtained. The sand may then be gradually drawn into and thoroughly mixed with the lime by means of the same tool. The mortar should be allowed to stand for some days before use, and again well beaten up with larry and shovel.

For *cement mortar*, the sand is measured and heaped on the stage, and a bottomless box of definite capacity is placed on the top of the sand. This box is filled with cement, and then removed. The dry heap is turned over at least twice, and opened out into a ring. Clean water is added in sufficient quantity to wet the whole mass, which is then thoroughly mixed in the same manner as lime mortar.

Cement mortar should be used directly after being made, and should not be subjected to further mixing after setting has commenced. If this is done, the cement rapidly loses its strength, and further repetition would render it practically inert.

The *proportions* of sand and cement or lime, are from two to four parts of sand to one part of either, according to the class of work for which the mortar is required.

Another mortar mix which is becoming popular, and which some engineers have proved to be stronger for some classes of work such as reinforced brickwork, is 4 parts of sand to 1 part of Portland cement and $\frac{1}{4}$ th part of lime.

On large works, mixing is usually performed in a *mortar mill*, which consists of a pair of heavy millstones and a pan, or container, into which the measured ingredients are fed. The mill, by reason of its large and rapid output, has a distinct advantage over hand-mixing. It also has many disadvantages unless operated by a reliable man. Grinding may be carried on to such a stage that the sand is ground so fine as to render the original quantity of lime or cement inadequate. Cement mortars may be also ground long after the initial setting has commenced, and thus rendered useless for the required purpose.

The writer has also seen mortar mills made the receptacle for all manner of rubbish which is ground in with the mortar, a practice which cannot be too strongly condemned.

Small concrete mixers can and are used very effectively for mixing mortars. Their only drawback is that the mixing blades in the drum have to be cleaned off several times during the day owing to the mortar sticking to the blades and preventing the mixing action.

Chapter II—BOND

General Principles of Bonding. The arrangement of bricks when building is of great importance, as upon this depends the strength and appearance of the work. It should be systematic, and have definite principles which the craftsman can readily follow, and which will ensure the requisite strength with a minimum outlay.

If we consider the arrangement shown in Fig. 7, it is clear that a wall built in this manner would tend to split along the continuous vertical joints if subjected to any irregular

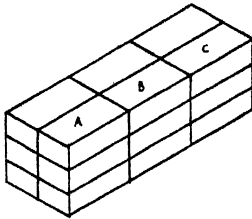


FIG. 7. WALL WITHOUT BOND

strain. The sections, A, B, C, etc., are entirely independent, and receive no support from each other.

If, however, the wall be built in the manner indicated by Fig. 8, the whole mass is in combination and mutually supported. The same quantities of materials have been used and the same labour expended in each case, but there is no comparison between the strengths of the two examples.

In Fig. 8 it will be noticed that the bricks in one course overlap those in the course below, forming an interlocking arrangement throughout the whole wall. The length of the lap is equal to one quarter the length of a brick, or $2\frac{1}{4}$ in. This arrangement is termed *bonding*.

There are several recognised types of bond, the two principal being English and Flemish.

If the principles of these two are thoroughly understood, the others, which are but variations of them, will present no difficulty.

A number of specimens of bonding will be illustrated, applicable to various examples of brickwork, which may at first present some difficulty to the young craftsman.

The writer's experience has convinced him of the futility of endeavouring to memorise diagrams illustrating many and complex forms of bonding, and he is convinced that a few definite rules and principles, thoroughly understood, will enable the young artisan readily to overcome many difficulties likely to be encountered during the ordinary course of events. The diagrams here given are for the purpose of demonstrating these fundamental principles.

Terms. Repeated reference to certain terms in general use will be necessary in explaining the

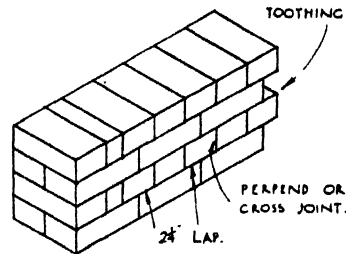


FIG. 8. BONDED WALL

principles of bond, so definitions are appended below.

Header. A brick laid with its $4\frac{1}{2}$ in. \times 3 in. end on or parallel with the face of the wall.

Stretcher. A brick laid with its 9 in. \times 3 in. side on or parallel with the face of the wall.

Bat. Any portion of a brick cut or broken across its length; for example, half bat, $4\frac{1}{2}$ in. \times 3 in., three-quarter bat, $6\frac{3}{4}$ in. \times 3 in.

Bed. The bottom surface of a brick which rests upon the mortar spread to receive it.

Frog. The indentation on one or both $4\frac{1}{2}$ \times 9 in. surfaces of the brick.

Arrises. The edges of the brick where its surfaces intersect.

Course. A complete layer of bricks laid on the same bed.

Perpends. The short vertical joints in the face of the wall that fall vertically over one another in the alternate courses. Instead of *perpends*, a practical term frequently used is *cross joints*.

MODERN BUILDING CONSTRUCTION

Rules for Bonding. To ensure good bond, the following rules should be observed—

1. The amount by which the bricks in one course overlap the bricks in the course below should be, along the length of the wall, $2\frac{1}{4}$ in., and $4\frac{1}{2}$ in. across the thickness of the wall.
2. The vertical joints in the alternate courses should fall in a plumb (vertical) line from the

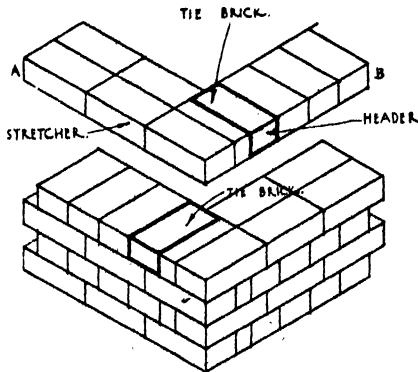


FIG. 9. ONE-BRICK WALL, IN ENGLISH BOND

top of the wall to its base, whether on the face or in the interior of the wall.

3. Bats should be used as little as possible, and where used, should be evenly distributed throughout the whole of the work.

4. The bricks should be uniform in size, and the proportion of length to breadth be such that the length equals twice the width plus one joint. Good bond is impossible otherwise, as the lap would not be uniform.

5. The bricks in the interior thickness of the wall should be laid with their length across the wall, or, as it is termed, headerwise.

English Bond. In this bond the facing bricks are laid in alternate courses of headers and stretchers.

This is undoubtedly the strongest of all bonds; the arrangement of the bricks is such that no joint or part of a joint is continuous with any joint in the course below, or, as it is often stated, there are no straight joints.

Flemish Bond. The facing bricks in this bond are laid as alternate header and stretcher in the same course. It is not so strong as English bond, on account of the numerous straight joints $2\frac{1}{4}$ in. long, which occur repeatedly throughout the wall, and the greater number of bats that are used, particularly where the wall has an odd half-brick in its thickness. If the

bond is carefully arranged, it is considered sufficiently well bonded for all general purposes. Careless workmanship in this respect has, however, been the cause in many instances of walls built in this bond splitting in two along their thickness.

Methods of Bonding. Fig. 9 is an isometric view of a portion of a one-brick wall built in

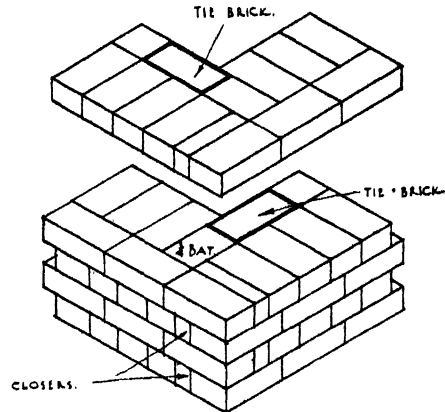


FIG. 10. ONE-AND-A-HALF BRICK WALL, IN ENGLISH BOND

English bond, at the external angle, or, as it is technically termed, *quoin* of a building. Note that the bond on the external faces changes in the same course. At *A* they are stretchers; at *B*, headers. Observe also, that the first header on the quoin is followed by a small bat, one-quarter the length of a brick. This is termed a *closer*, and its object is the commencement of the bond. It will readily be seen that the insertion of the closer moves the second header $2\frac{1}{4}$ in. along the wall, which is the necessary distance to form the lap over the stretcher below. This is consequently repeated throughout the length of the wall. Again, notice that all joints crossing the thickness of the wall pass from the exterior face to the interior in a continuous line.

We have now three definite facts to memorize—

1. Where a wall changes direction, the face bond in the same course changes.
2. That the quoin header is followed by a closer. There are exceptions to this rule, which will be explained later.
3. That all transverse joints should pass in an uninterrupted line across the wall.

Fig. 10 shows a portion of a $1\frac{1}{2}$ -brick wall at the quoin of a building. Here it is noticeable that the bonds on the exterior and interior faces of the same course are different (those shown in Fig. 9 depict headers on both faces); also that the heavily outlined bricks in the interior angles (hereafter called tie-bricks) are in different positions in each case. The tie-brick in Fig. 9 has its header face parallel with

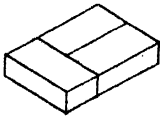


FIG. 11. UNIT OF ENGLISH BOND

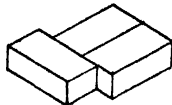


FIG. 12. WRONG ARRANGEMENT

the wall face, whilst in Fig. 10 the stretcher face is in that position. In both cases, $2\frac{1}{4}$ in. of the faces bond into the return wall, and are on the opposite face of the course, commencing with a quoin header.

From the foregoing we may deduce several more facts, which should be committed to memory.

4. That where a wall has an even number of half-bricks in its thickness, the bond on the interior and exterior faces of the same course is

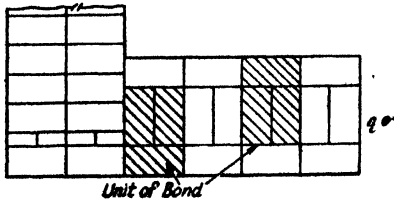


FIG. 13. TWO-BRICK WALL

the same, and that the tie brick in the interior angle has its header face parallel with the wall face.

5. That where a wall has an odd number of half-bricks in its thickness, the bond on exterior and interior faces of the same course is different, and the tie-brick has its stretcher face parallel with the wall face.

6. That in every case the tie-brick is in the same course as, and on the opposite face to, the quoin header.

Consider a part of one course of bricks arranged as in Fig. 11. Let us call this a *unit of English bond*. If work is proceeding correctly, this unit repeats itself along the entire length of the wall. Should the arrangement shown in Fig. 12 occur, it is apparent that the work is

constructionally wrong, because $4\frac{1}{2}$ in. of the side joints of the header-bricks in the next course will fall vertically over the joints in the course below, with a resultant series of straight joints in the interior thickness of the wall. The unit shown is part of a $1\frac{1}{2}$ in. brick wall. The principle will, however, apply with slight modifications to any thickness of wall.

Consider the previous rules. The unit has

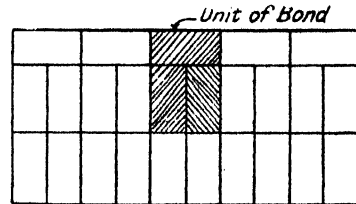


FIG. 14. ENGLISH BOND: TWO AND A HALF BRICKS IN THICKNESS

an odd half-brick in its thickness, and therefore the bond is different on each face.

Fig. 13 shows part of one course of a two-brick wall. The bond is the same on both faces; the bricks in the interior of the wall are laid headerwise, and the unit repeats itself on either face.

Fig. 14 indicates a $2\frac{1}{2}$ brick wall. The unit

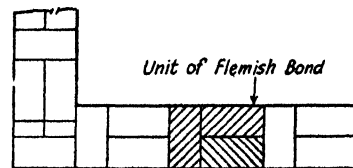


FIG. 15. FLEMISH BOND: ONE-BRICK WALL

repeats itself along one face only, its thickness being insufficient to take two units. The interior bricks are laid headerwise, and the transverse joints cross the wall in a straight line, unless stopped by a face stretcher. As the wall has an odd half-brick in its thickness, the bond on its opposite faces is different.

In Flemish bond, let us consider the unit to be a face header and stretcher. In a one-brick wall, Fig. 15, this repeats on both faces. In a $1\frac{1}{2}$ -brick wall, Fig. 16, the units move along on either face a distance equal to the width of the header on the opposite face. That is to say, the headers are laid side by side on the opposite faces of the same course.

In a two-brick wall, Fig. 17, the headers are arranged to be opposite each other in the same course. Now remember some of the previous

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rules. The bricks in the interior thickness of the wall should be laid headerwise; bats are to be used as little as possible, and distributed evenly in the interior thickness. It will be

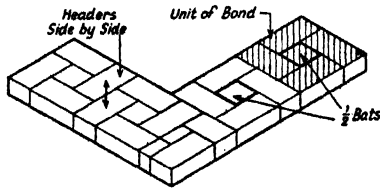


FIG. 16. ONE-AND-A-HALF BRICK WALL IN DOUBLE FLEMISH BOND

seen in the arrangements shown, that in the one and two-brick walls, no bats are required. In the $1\frac{1}{2}$ -brick wall, a certain number are unavoidable.

Now consider Figs. 18 and 19. Two methods

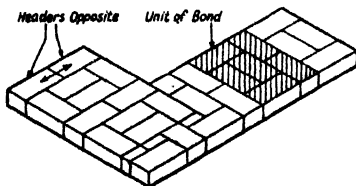


FIG. 17. TWO-BRICK WALL IN DOUBLE FLEMISH BOND

of arranging the bricks in one course of a $2\frac{1}{2}$ -brick wall are shown in plan. Where the face-headers are opposite each other, Fig. 18, a large number of bats is required. Where the face-headers pass, as in Fig. 19, the number of bats is

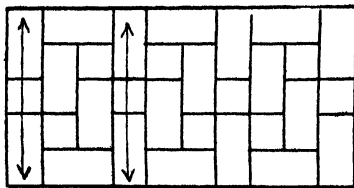


FIG. 18. INFERIOR METHOD OF BONDING
Excessive number of bats required by arranging face headers opposite each other

considerably less, and they are more uniformly distributed along the wall.

In Flemish bond, therefore, it can be assumed that where a wall has an odd half-brick in its thickness, the facing headers should be arranged to pass each other as in Figs. 16 and 18. If an even number of half-bricks in thickness, the face-headers should be arranged opposite each other, as in Figs. 15 and 17. These arrangements will usually be found to provide a more uniform

bond, involving the use of the least possible number of bats, and, in consequence, producing a much stronger wall. Note that in Flemish bond, the face-headers are always placed over

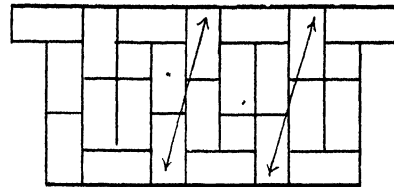
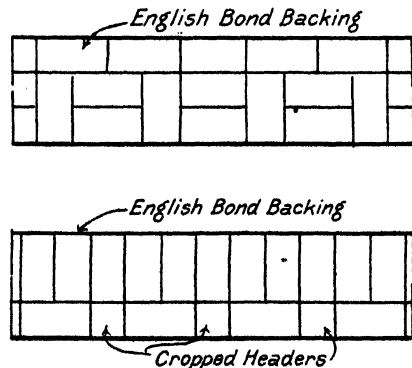


FIG. 19. GOOD METHOD OF BONDING
Number of bats reduced to the minimum by arranging the face headers to pass each other

the centre of the stretcher in the course below, and never over a perpend.

Flemish bond is frequently used as a facing bond only, the remainder of the wall being built in English bond. To put it concisely, Flemish facing with English backing, and usually termed *single Flemish bond*. The object is to obtain the greatest strength possible, where Flemish facing is desired. In this type of bonding, the facing headers in alternate courses are half-bats, or, as they are termed, *cropped headers*. An example is shown in Fig. 20.



PLANS OF ALTERNATE COURSES OF SINGLE FLEMISH BOND

FIG. 20. SINGLE FLEMISH BOND

Window and Door Openings. In forming window and door openings, Fig. 21, some modifications of the foregoing rules are necessary, and will entail the use of several different types of closer.

The vertical sides of an opening are usually termed *reveals*, or *jamb*s, the latter term being more usual when speaking of door openings. Sometimes the distinction is made that the *jamb*s are the vertical faces of the opening and

the reveals are the projecting parts of the jambs. In most cases, the reveals are recessed to receive the door or window-frame. As a general rule, where the frames are solid, such as for a door or casement frame, the recess is $2\frac{1}{4}$ in. deep. Where a cased or built-up frame is used, such as for sliding or double-hung sashes, a $4\frac{1}{2}$ in. recess is necessary. The projecting reveal on the outside face of the wall is usually termed the external reveal or jamb, and the recessed reveal on the inside face, the internal.

For fixing these frames, wooden slips, called *fixing pads*, are built into the joints of the internal reveal about every fourth course. Bricks made of breeze concrete, into which nails may be driven, are also used for this purpose. These make a better job, as there is no fear of shrinkage and loosening as in the case of the wooden slips. Galvanized hoop iron cramps as Fig. 20A make an excellent fixing, but these have to be built in with the brickwork, the window or door frame having to be fixed in position before the brickwork to the jambs is built. A number of examples are here given, showing the arrangement of brickwork in forming openings in walls of various thicknesses.

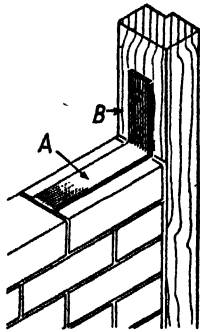


FIG. 20A. METHOD OF FIXING DOOR AND WINDOW FRAMES
A. Galvanized hoop iron turned down in cross-joint
B. Door frame

Where the recess is $2\frac{1}{4}$ in., the reveal header is mitred across its width, the outside face being $4\frac{1}{2}$ in., and the inside $2\frac{1}{4}$ in. ("mitred closer" or bat). The closer next to the reveal header is cut $2\frac{1}{4}$ in. in width on the face to $4\frac{1}{2}$ in. half-way along its length (King closer). Where the recess is $4\frac{1}{2}$ in. in depth the reveal header is a half bat, and the closer is cut across its length showing $2\frac{1}{4}$ in. on its face and $4\frac{1}{2}$ in. at the back (bevelled closer).

Whatever the thickness of the walls, it should be noticed that the arrangement on the face does not alter. Where the wall is over $1\frac{1}{2}$ bricks in thickness, the internal reveal is treated as a quoin, and starts with a closer next the header on the external reveal.

Intersecting Walls. Where two walls meet at an angle, the bond at the junction should be arranged, if possible, so that the *indent* is in the stretching course, and the *tie*, or projecting toothing of the joining wall, in the heading

course. This rule will considerably simplify matters for the young craftsman. A number of examples are given in Fig. 22 to emphasize the rule.

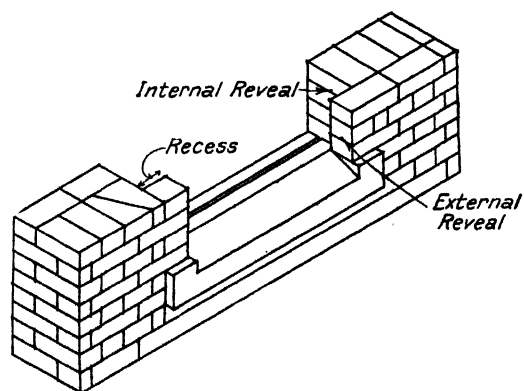
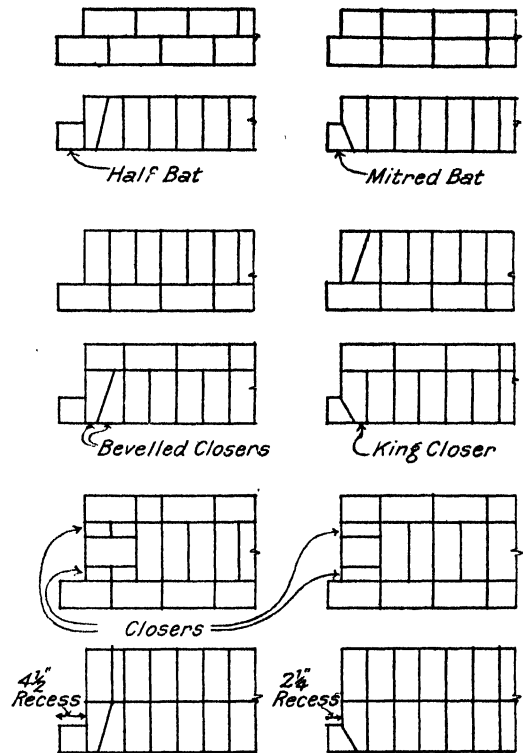


FIG. 21. WINDOW OPENINGS

Squint Quoins. Where the corner, or *quoin*, of a building is formed by two walls meeting at an angle other than a right angle, specially shaped bricks are required at the external angle

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(see Fig. 23). Bricks purposely manufactured can be obtained for angles in common use,

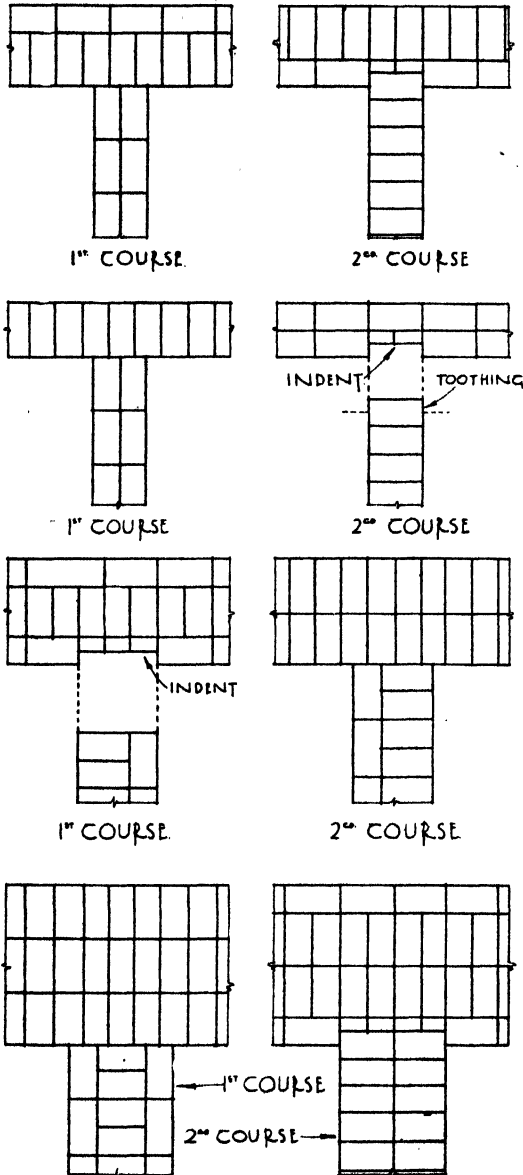


FIG. 22. INTERSECTING WALLS

otherwise they must be cut on the job. To prepare the cutting mould where the angle is greater than a right angle, or, as it is termed, *obtuse*, cut a piece of $\frac{1}{2}$ in. pine board to the shape of a brick in plan. Mark off from one corner

$2\frac{1}{4}$ in. along the stretcher face, and draw a line from this point at the required angle, say 45° . Measure $2\frac{1}{4}$ in. along this line, and square a line away from the last point. Cut away the two corners, and the result is the required mould as shown by the shaded portion in Fig. 23A.

Acute angles are treated much in the same way as a square quoin, except that the corner

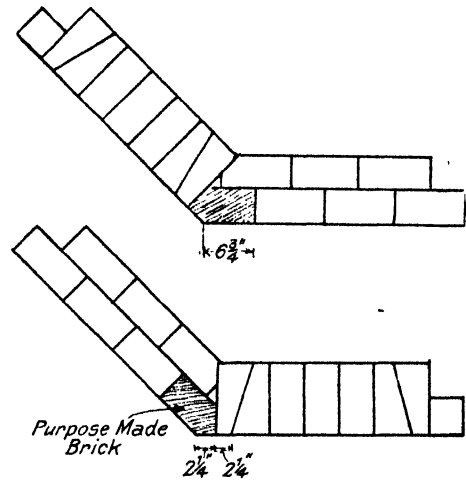


FIG. 23. SQUINT QUOIN

brick has to be cut to the desired angle. There can be no hard and fast method of arranging the bond at these angles, but the craftsman should

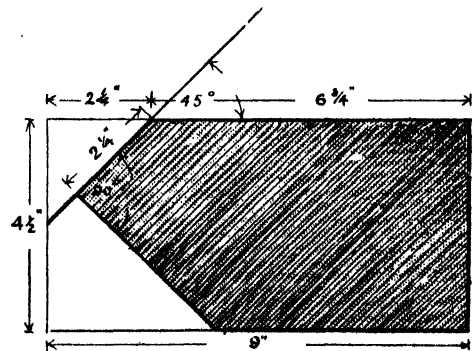


FIG. 23A. CUTTING MOULD

experience no difficulty in devising suitable arrangements of bond for any angle he may be required to set out.

VARIOUS BONDS

Stretching Bond. This bond, Fig. 24, applies to a wall half-brick thick, such as sleeper or

partition walls, and also to chimney stacks, where it is frequently termed *chimney bond*. The lap in this bond is $4\frac{1}{2}$ in.

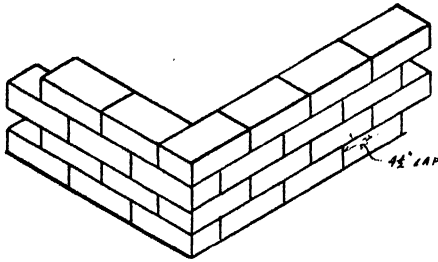


FIG. 24. STRETCHING BOND

Dutch Bond. This is practically the same as English bond proper, except that in the

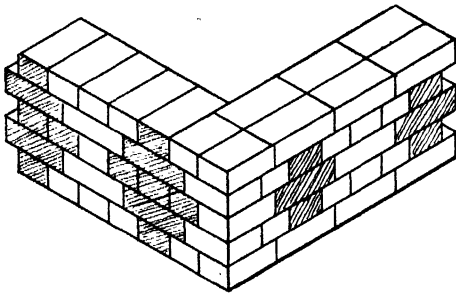


FIG. 25. DUTCH BOND

stretching course a three-quarter bat is used on the quoin and the closer omitted, Fig. 25, or a

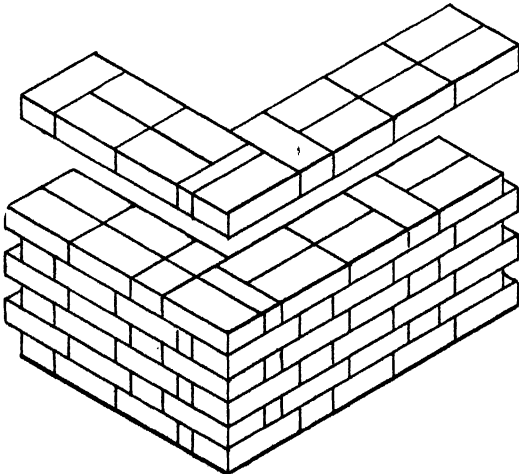


FIG. 26. FLEMISH GARDEN WALL BOND

header placed next to the quoin stretcher in every alternate stretching course. This arrange-

ment with variations can be seen in many of the older examples of brickwork, where darker facing-bricks have been used to form diamond or trellis patterns. *English Cross Bond* is similar but *with header* and closer at the quoin.

Garden Wall Bonds. Where two fair faces

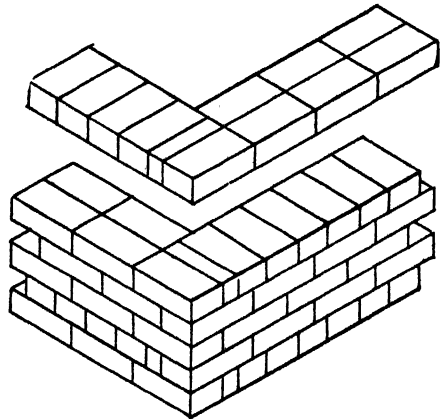


FIG. 27. ENGLISH GARDEN WALL BOND

are required in a 9 in. wall, a greater proportion of stretchers is used than in the recognised bonds. The types in general use are called English and Flemish *garden bonds*, but are sometimes given

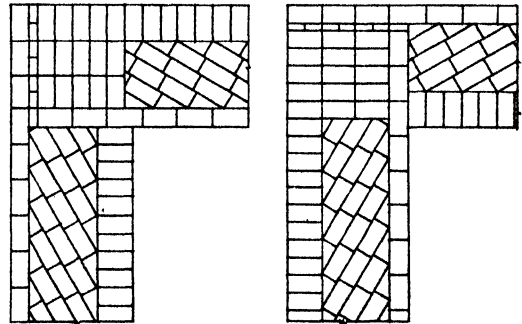


FIG. 28. RAKING BOND

local terms, such as "Scotch" or "Sussex" bond.

Flemish Garden Wall Bond. Three stretchers are laid between the headers in each course, as shown in Fig. 26. As in Flemish bond proper, the header should come over the centre of the centre stretcher in the course below.

English Garden Wall Bond. Three courses of stretchers are built to every course of headers, the stretching courses being arranged with a $4\frac{1}{2}$ in. lap as in stretching bond, Fig. 27.

Both of the above bonds are deficient in

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strength, particularly the latter, which is likely to bulge at the stretching courses, these having no tie across the thickness of the wall.

Raking Bond. This bond is used to strengthen thick walls longitudinally. The bricks in the

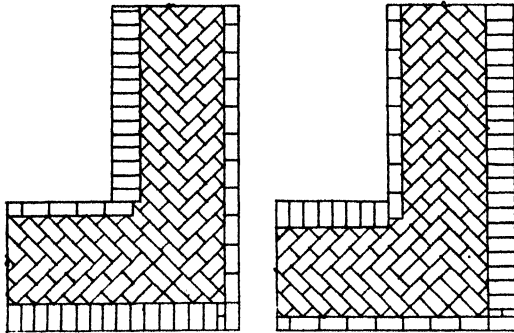


FIG. 29. HERRINGBONE COURSES

interior of the wall are laid diagonally across the wall at an angle of about 30° , Fig. 28, or laid herringbone fashion, Fig. 29, the quoins being built in the usual manner. The angle of rake should be arranged to give the greatest number of full stretchers across the wall, with the minimum amount of cutting. These raking courses

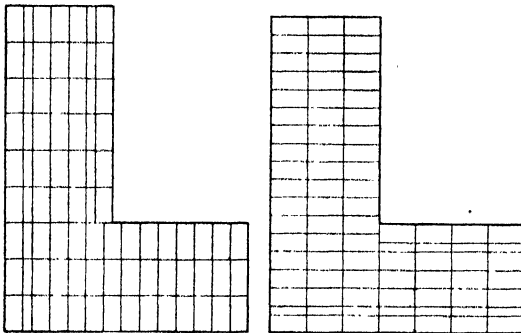


FIG. 30. LONGITUDINAL BOND

are arranged at intervals of from three to eight courses.

Herringbone courses are not generally used for walls less than four bricks in thickness.

Longitudinal Bond is used with the same

object as the raking bonds. The bricks on the interior of the wall are laid stretcherwise to the face of the wall, Fig. 30.

Hoop-iron Bond. To reinforce walls in their length pieces of hoop-iron (galvanised or tarred and sanded) are built in between the courses

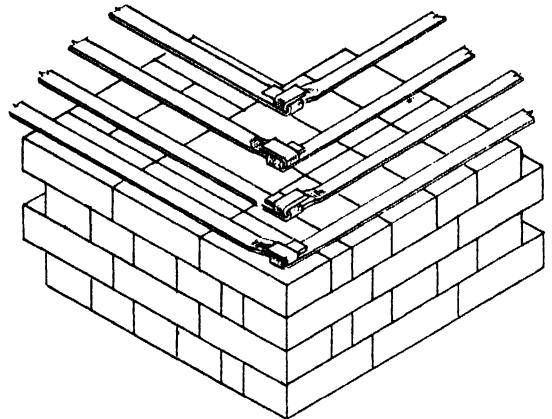


FIG. 31. HOOP-IRON BOND

at certain intervals lengthways along the wall, as shown in Fig. 31. Their ends are jointed to make them continuous. This system was introduced by Brunel, a civil engineer, about 1835. It is not much used at the present time, unless to strengthen the connection where

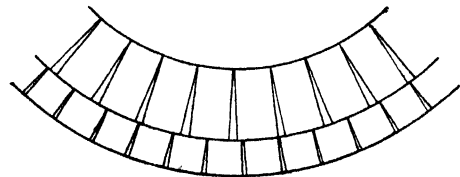


FIG. 32. HEADING BOND

a toothing has been left in a wall for future extensions.

Heading Bond. This bond, Fig. 32, is used for circular sweeps where stretchers would give the curve an irregular appearance, or, as the craftsman would say, "make the work hatch and grin."

Chapter III—BRICKLAYING

THE skill in any craft is not always apparent to the uninitiated onlooker, and particularly is this the case when the operations of a capable craftsman are being considered.

The apparent ease with which the work is executed is due to the skill of the mechanic, acquired after much practice and a great deal of careful study. Other important factors essential to success are the cultivation of clean, neat habits, and the development of the powers of observation and deduction. The acquisition of these will save the craftsman much manual effort, and will enable him to accomplish with ease that which would otherwise be strenuous.

The young beginner should cultivate the habit of thinking in advance; that is, to consider his efforts before making them. This lack of forethought in simple processes is responsible for much waste of time, energy, and material.

A few examples will more clearly explain these points. The mechanic who spreads his mortar with an eye to the thickness of the required bed, sets his brick into position with a slight pressure of the hand as he lays it. Another operative will have practically to hammer every brick into position with his trowel, frequently damaging the face of the brick in the operation. Again, when requiring a square good-faced brick for a corner, one man will pick up a dozen at random, reject them and throw them down again, one after the other, before finally selecting the one that suits him. The thoughtful worker will look round the bricks as they are stacked on the scaffold, and generally this cursory examination enables him to pick out the right brick the first time, thus saving time and himself the physical effort of stooping several times, the repetition of which counts considerably at the end of the day's work. Apart from this, there is the risk of damage to the bricks—an expensive item when good facing bricks are being used. One should always remember that the employer has to be considered, and that damage done due to thoughtlessness or carelessness is as culpable as wilful damage.

Clean habits are generally economical. Considerable wastage of mortar occurs in the ordinary course of any job; but note the quantity of mortar droppings at the base of the wall or

pier that is being built by an indifferent craftsman, or track a flue that has been built by the same man and note the amount of material drawn from the flue when it is cored, and compare it with that of the clean, neat workman.

Tools. The working tools of the bricklayer as carried in his kit are shown in Fig. 33. Their uses will be explained chiefly in connection with the work for which they are required.

There are several other tools mostly used for arch cutting, and some of which are supplied by the builder. These are shown in Fig. 36.

The *brick trowel*, being the most important, is the one to consider first. It is used for picking up and spreading the mortar, and for rough cutting where approximate sizes and shapes only are required. One edge of the blade is curved slightly for this purpose, the other being straight. It is with the latter edge that the bricklayer picks up mortar from his board, and removes surplus mortar from the joints, as the bricks are laid. Skill in the manipulation of this tool makes all the difference between clean, neat, and easy workmanship, and a slovenly, laboured effort.

Where more accurate cutting is necessary, the bricklayer uses the *club*, or *mash*, *hammer* and *boaster*. The sharp edge of the latter is usually just over 3 in. in width, to enable the brick to be cleanly cut across the face at one cut. In using this tool, the best results obtain from a sharp direct blow, and not a series of taps, which are more likely to leave a ragged edge.

Operation of Bricklaying. In building permanent structures, the bricks are bedded in lime or cement mortar, the object of which is to even up the irregular bearing surfaces of the brick, and to enable the separate layers, or courses, to be brought to straight and level lines as the building rises. Other objects are to unite the separate units into a homogeneous mass so as to prevent the penetration of moisture and the direct passage of external air in volumes sufficient to interfere with the health and comfort of the occupants, and ensure uniformity of temperature within the building.

The operation of bricklaying in ordinary work is accomplished by spreading a bed of mortar, and setting the bricks into position by a sliding

MODERN BUILDING CONSTRUCTION

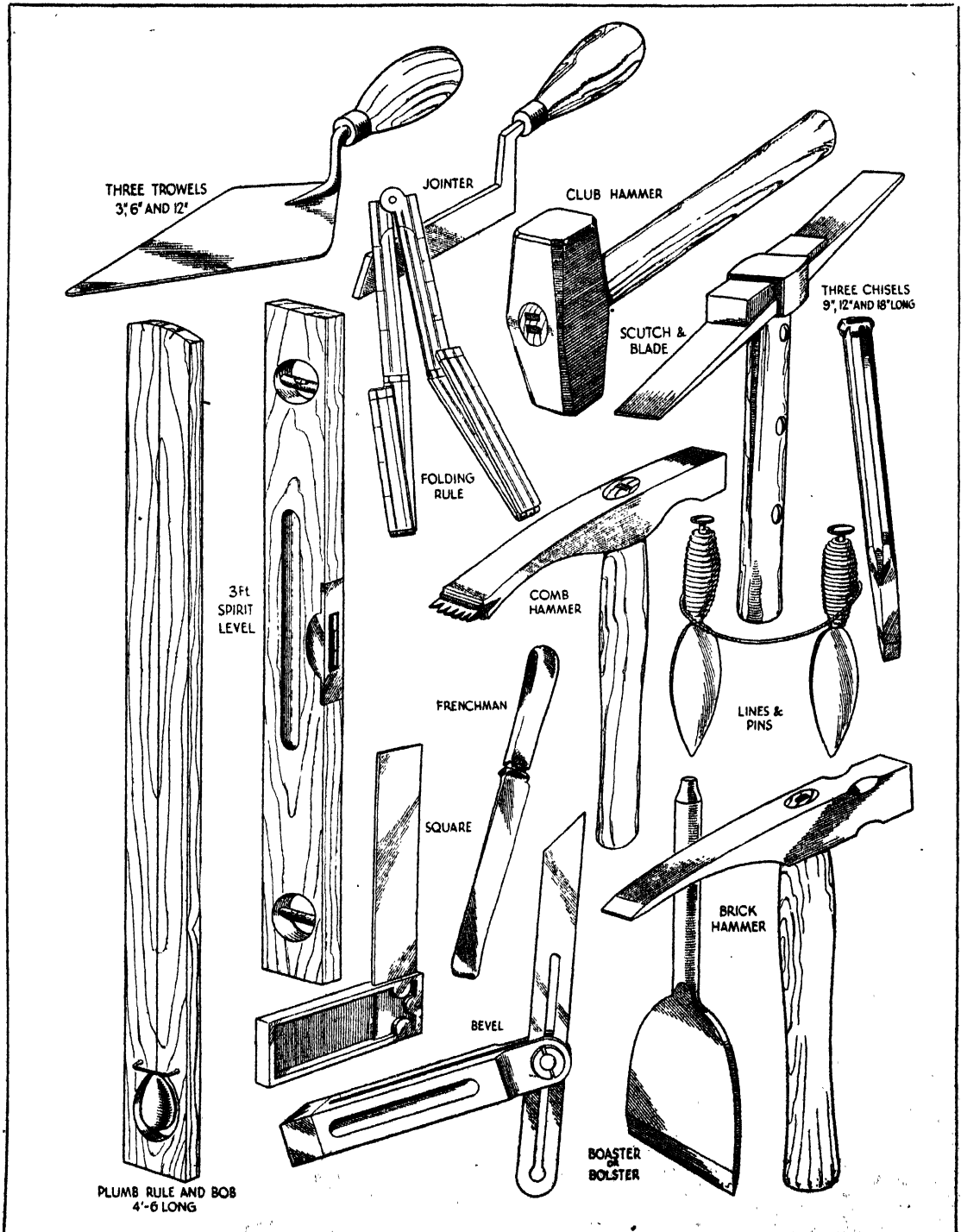


FIG. 33. BRICKLAYER'S TOOLS

movement; drawing them along the bed with a downward pressure sufficient to bring them approximately to the line, when a slight tap with the trowel will set them into the desired position. The surplus mortar squeezed out of the joint in the process is removed by drawing the straight edge of the trowel along the face of the bricks, collecting the mortar on the blade and using it for buttering the end of the brick last laid, for the vertical joint of the next brick. This is repeated along both faces of the wall, the interior filling bricks being laid in a similar manner, and the open joints filled with mortar as each course is completed. This *flushing-up*, as it is termed, is frequently omitted for several courses on some jobs, and afterwards only done in an inefficient manner, but it is essential that every course should be flushed up if good work is required.

GROUTING. Where brickwork is set with a fine joint, it is usual to fill the interior joints with a thin liquid mortar. This process is called "grouting."

LARRYING. In heavy engineering works or buildings where the walls are very thick, the facing bricks are laid in the usual manner. Mortar is then shovelled into the interior of the course, spread out with a larry, and water added at the same time to thin out the mortar. The filling bricks are then squeezed into position,

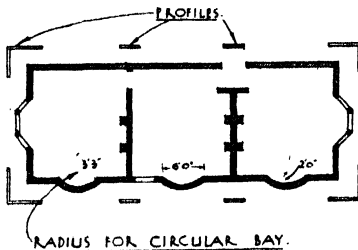


FIG. 34. SETTING OUT A SMALL BUILDING

the mortar rising and filling the vertical joints completely and forming an exceedingly strong and solid wall. This is known as "larrying."

SETTING OUT

Setting Out a Small Building. A knowledge of the general methods of setting out the foundations of a building is essential, and a simple description at this stage will enable the student more readily to understand the processes of bricklaying. (For design of foundations, see page 223.)

It is proposed to set out the small building

shown in Fig. 34. The building line is generally fixed by the architect or surveyor. The position of the building on this line is set out by wooden stakes driven into the ground, and having nails driven into their heads to define more accurately their positions. Strain a stout ranging line to coincide with these pegs, but extending beyond

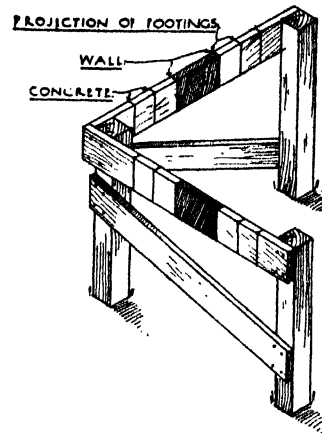


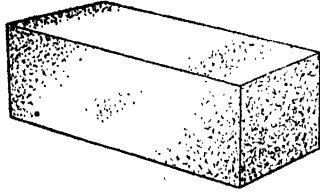
FIG. 35. DETAIL OF PROFILE OF QUOIN

the extremities of the building. Set out on a piece of stout board the thickness of the wall, projections of the footings, and the concrete on either side. Nail this to two stout pegs driven well into the ground, as shown in Fig. 35, with the face line of the wall, as indicated by the board, coincident with the ranging line. Repeat the operation at the opposite extremity of the line. These "profiles," as they are termed, fix the position of the front wall of the building, the projection of the footings, and the line of excavation for the concrete bed.

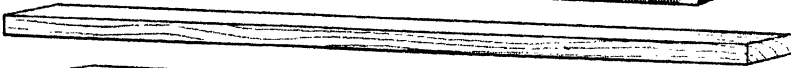
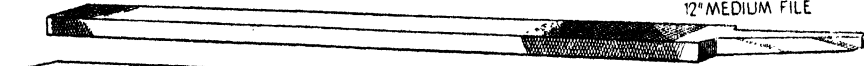
In fixing profiles, care should be taken to ensure that they are placed clear of and not too near the excavations, or in any position where interference can take place before the foundations are completed.

Fix the position of walls, making junction with the front wall by means of pegs and nails, and set up profiles as before from lines ranged at the correct angles, checked from the drawings. If the walls are at right angles, the ranging may be either performed with a *builder's square*, or by the construction of a right-angled triangle by the 3, 4, 5 method, as shown in Fig. 37. Mark off along the frontage line a distance of 4 ft. from the point fixing the position of the joining wall, and from the same point, along the line which is to be squared, mark off 3 ft. Now fix

CARBORUNDUM
STONE



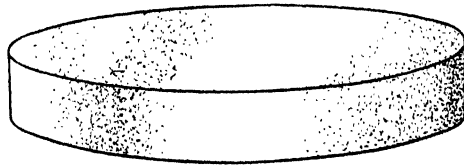
12" MEDIUM FILE



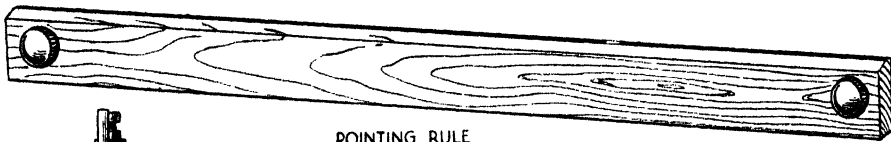
PAIR OF TRAVERSING RULES



GRUB SAW



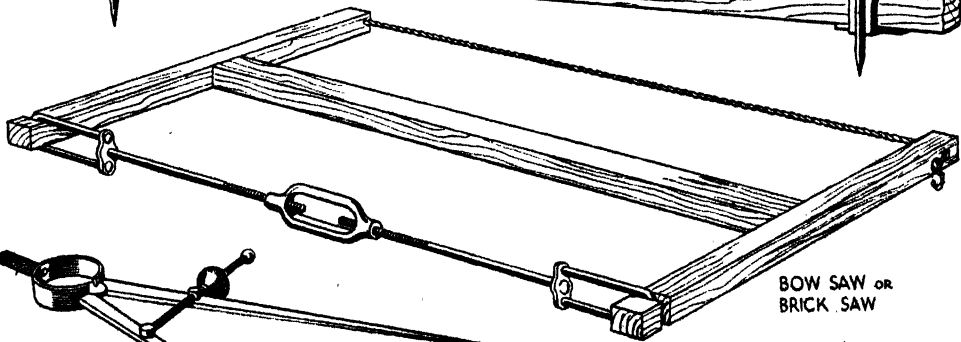
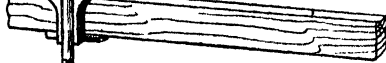
YORK RUBBING STONE



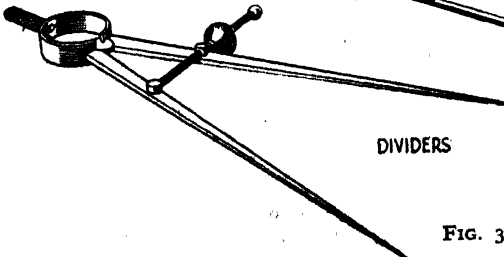
POINTING RULE



TRAMMEL PINS AND ROD



BOW SAW OR
BRICK SAW



DIVIDERS

FIG. 36

the position of this line so that the distance across the angle included by the two lines, and taken from the two measured positions, will be 5 ft. Other measurements may be used if desired, provided the ratios are constant, such as 6, 8, 10; 9, 12, 15; 12, 16, 20, and so on. Should the angle be other than square, a tie-line across it should be fixed on the drawing, the three

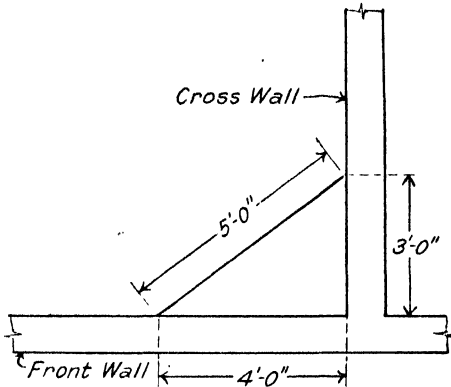


FIG. 37. SETTING OUT A RIGHT ANGLE

measurements carefully checked to scale, and reproduced in the actual setting-out.

Walls parallel with the frontage may be now set out to the correct dimensions, and profiles fixed as before.

Setting Out Circular Bay. The circular bay may be set out by two methods—

1. By taking a mould constructed of thin boards well braced together, and cut to the curve of the bay, set in position with the ranging line, and projections of footings and concrete set out from this.

2. By means of a trammel. The radius of the curve may be obtained either geometrically or by calculation. If of large radius, considerable space would be required for the graphical method, so calculation becomes necessary. A simple formula, also useful for setting out arches is here given. Terming the chord of the arc the "span," and the perpendicular distance from the centre of the span to the arc, the "rise" (as in arch construction); then $R = \frac{S^2 + V^2}{V \times 2}$, where R is required radius, $S = \frac{1}{2}$ span, and $V =$ the rise.

The "span" of the bay under consideration is 6 ft. and the rise 2 ft. From the formula, $R = \frac{9 + 4}{4} = \frac{13}{4} = 3\frac{1}{4}$ ft. Applying this method

to construction: bisect chord of the bay, and square a line away from this point. Measure 3 ft. 3 in. from one end of the chord to a point on the line, and drive a stout peg well into the ground. Bore a $\frac{1}{2}$ in. hole in the head of the peg at the exact point, and fix therein a short length of $\frac{1}{2}$ in. gas barrel or iron rod, braced in an upright position. Make a wooden trammel,

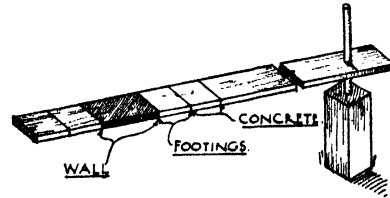


FIG. 38. TRAMMEL FOR CIRCULAR BAY

Fig. 38, greater in length than the required radius, and bored at one end to slip over, and rotate on, the gas barrel. Mark on the other end the thickness of walls, footings, and concrete. In setting out, the trammel should always be kept approximately level and can be

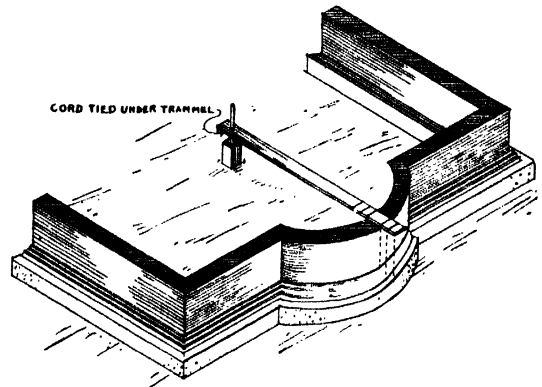


FIG. 39. BUILDING CIRCULAR BAY WITH TRAMMEL

raised with each course by tying a cord round the iron rod below the trammel as in Fig. 39.

If the work is to be carried to any height, a mould cut to the curve will have to be made for the use of the bricklayer.

Building the Quoins. It frequently happens that a young operative commencing work on a new job is called on to set up the quoins of the first wall. Without doubt, he will get considerable "kudos" from his foreman by knowing how to proceed without a lot of instruction.

Fig. 40 shows the external lines *A* and *B* of the wall in their respective positions on the profiles. The wall is a brick and a half thick;

MODERN BUILDING CONSTRUCTION

the bottom footing is twice this thickness, its projection on each side of the wall being three-quarters of a brick, or $6\frac{3}{4}$ in.

At a point near the corner on line *A*, mark the position of the line on the concrete bed by using the plumb-rule, as shown in the sketch. To

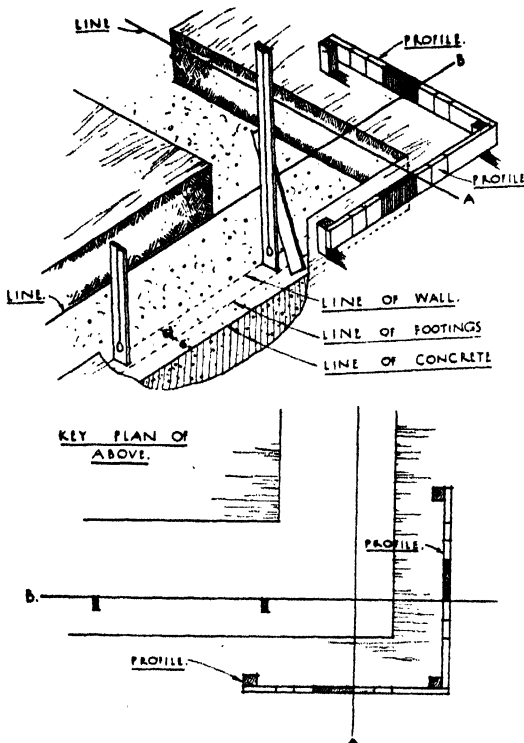


FIG. 40. SETTING OUT A QUOIN OF A BUILDING

steady the rule, hold at its back a straight-edge, in a raking position, and with one end resting on the concrete. In a similar manner mark another position farther away from the corner, and measure out $6\frac{3}{4}$ in. from these points. A line along these positions will be the line of the bottom course of footings. Repeat the operation on line *B*, and begin the first course of footings, three bricks thick, from the point of intersection of the two lines. No closers are used in footings, and bricks should be laid headerwise where possible.

In commencing the second course of footings, set back $2\frac{1}{4}$ in. from the edge of the first on both sides of the wall. This course will be two and a half bricks thick. Keep the headers on the outside faces, and lay the stretchers in the centre of the wall. Repeat the process with the

next course, which will be two bricks thick. The next will be the first course of the wall proper, or, as it is termed, the "neat work." This course should be set by plumbing down from the setting out line to make sure it is exactly in line.

The opposite corner having been built in the same manner, the remainder of the wall can be built to a line strained from corner to corner for each course.

When straining the line for each course of the wall, the line pins should be fixed in the joints at the return ends of the corners, Fig. 41, several courses below the one that is being laid, and brought over the corner of the quoin brick; otherwise, the line is apt to cut too deeply into the unset mortar, and the work set back slightly from its accurate position in consequence.

Where the distance between the two corners is great enough to cause the line to sag in its middle, a loop of string, called "a tingle," is attached to the line about its centre. A brick is then bedded near the centre of the length of the wall, and the line fixed by the tingle, on the top of which a bat is bedded to hold it in position. Care should be taken to keep the tingle in the same position vertically for every course, and this place in the wall kept plumb. The horizontal line should be sighted through for each course before the bat is bedded, to ensure the work being kept straight and level.

Levelling. It may generally be assumed that the concrete bed is only approximately level, and in raising the corners the bricklayer should level from corner to corner when the work is three or four courses high, and establish a level bench mark from which he can gauge his work as it rises, so that by the time the wall is above ground, it will be level enough to receive the superior work that will be exposed to view. In important elevations, where good class facing bricks are used, nothing offends the eye so much as a series of thick joints at one end of a wall, used to bring it to a level line.

Racking Back and Tothing. It frequently happens that some portion of a building has to be left down for some reason, and the remainder proceeded with. In this case, each successive course of brickwork on that side of the wall which is left down is stepped back, as shown in Fig. 41, or a tothing left. The latter is not good practice in main or external walls, as the joints cannot be satisfactorily filled when building into them, resulting later in unsightly cracks appearing, but in many instances it cannot be

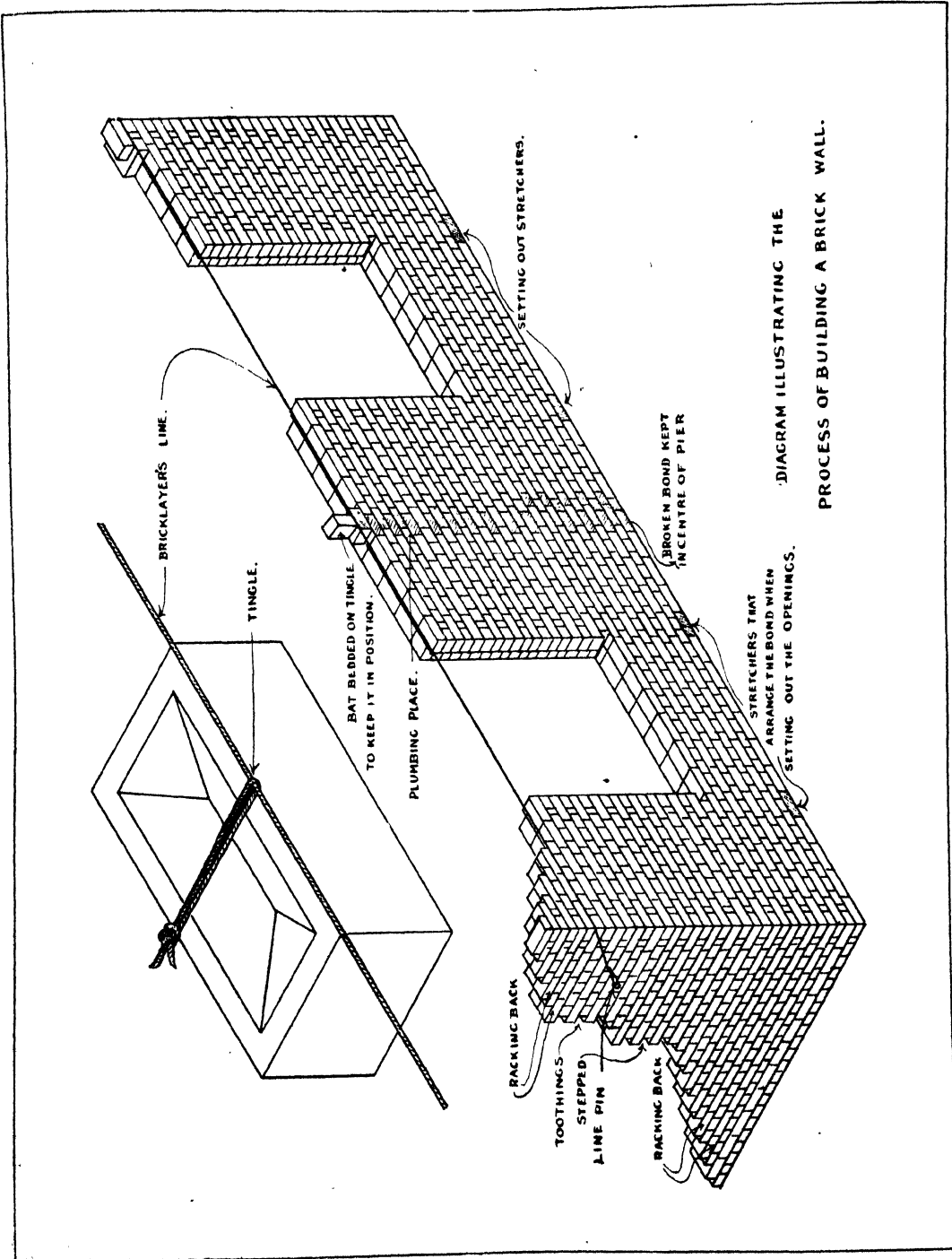


DIAGRAM ILLUSTRATING THE
PROCESS OF BUILDING A BRICK WALL.

FIG. 41

MODERN BUILDING CONSTRUCTION

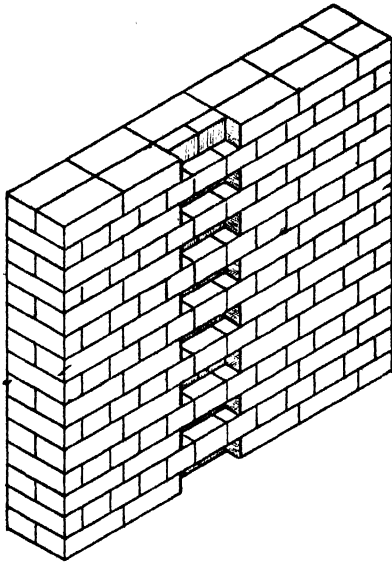


FIG. 42. INDENT TOOTHING

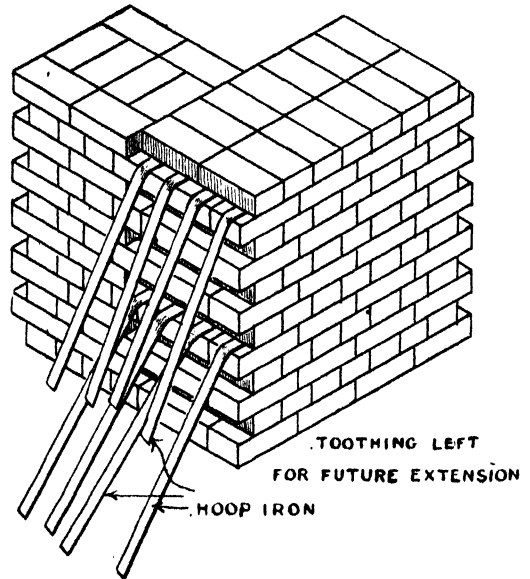


FIG. 43. HOOP-IRON BOND

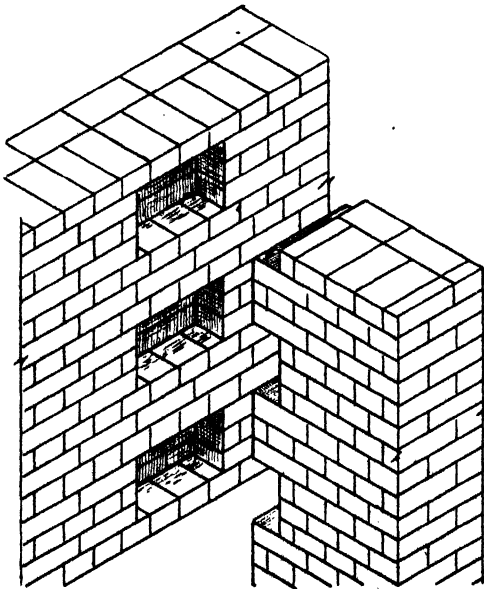


FIG. 44. BLOCK BONDING

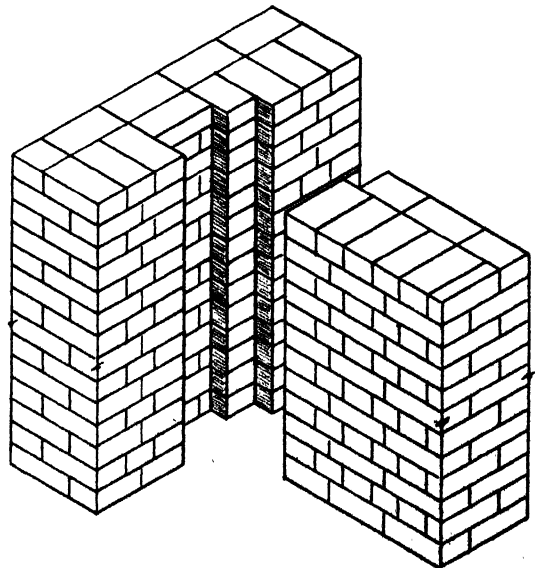


FIG. 45. CHASE BONDING

avoided. If toothing cannot be avoided, it is better to do it in short vertical lengths, racking back a course here and there so that the toothing itself is stepped (see Fig. 41).

Interior partition walls are often left down until the main walls are completed, sinkings, or *indents*, Fig. 42, being left in the alternate courses of the main walls, into which the partition walls are bonded when they are eventually built. These indents are termed *toothings*.

Toothings are generally left when it is desired to extend a building at some future date. To strengthen the junction when made, strips of galvanized hoop-iron are built in the wall that is toothed, at intervals of from three to six courses, and turned down out of the way for the time being (see Fig. 43).

In joining up new work to old, when the new and old walls are in the same straight line on an important frontage, toothings have to be cut in each *alternate* course of the old wall. If the join is in a position not exposed to view, or the new wall joins the old at an angle, it is better to make the connection with *block toothings*, as shown in Fig. 44.

Where one part of a building is carried to a much greater height than the remainder, as in the case of a tower or tall chimney, and in consequence the load on the foundations is much greater, a good method of preventing unsightly fractures due to unequal settlement, is to bond the heavier portion into a *chase*, Fig. 45, so that the heavy wall is free to take up its bearing independent of the other walls; the chase can be filled in and pointed up at completion.

Protection of Brickwork. Work built during frosty weather should be protected by covering it with straw, tarpaulins, empty sacks or boards, particularly during the night and early morning, as the water in the mortar freezes and expands. If frost is allowed to penetrate into the wall to any extent, this expansion will be sufficient to lift each course off its bed, thereby weakening the wall considerably.

Work built in Portland cement mortar is rarely affected unless the frost is very severe, as the mortar sets before freezing takes place. Lime mortar is more readily affected by frost;

but if reasonable precautions are taken, work may be continued even with the latter, if the pointing is left until more favourable weather. When the work has been well protected, only the surfaces of the joints will have been affected, and these will have to be raked out before the pointing is proceeded with. It may be generally assumed under these conditions, that by using only sufficient water to make the mortar workable, and keeping the bricks fairly dry, work can be proceeded with so long as the mortar does not freeze on the mortar boards.

Wetting Bricks. The principal reasons for this process are—

1. To ensure that sufficient water is retained in the mortar long enough for the process of setting to take place satisfactorily. This largely depends upon the combination of the water with the ingredients composing the mortar, particularly in the case of hydraulic limes and cements.

2. To remove any dust or loose particles from the bricks, so that the mortar will adhere more readily to their rough surfaces.

The wetting of bricks has, in the past, been laid down rather dogmatically in many textbooks on building, and is generally the subject of a clause under "Bricklayer" in most specifications, with no reference to weather conditions.

It is undoubtedly necessary during the hot summer months, when the bricks and mortar have both parted from their moisture by rapid evaporation.

During the winter months, particularly frosty periods, this process is liable to do more harm than good.

Dry bricks may absorb some of the water from the mortar, but it is retained in the bricks for a considerable time, long enough for the mortar to draw upon it for the setting process. Also, the atmosphere in winter time generally contains much moisture, which is absorbed by any porous type of brick.

Taking these facts into consideration, it is obvious that a little sound judgment should decide as to whether this process would be beneficial or otherwise in the production of satisfactory work.

Chapter IV—WALLS

WALLS are erected for the following purposes: To enclose a space, and for the division of a structure into a number of apartments; as supports to carry the weight of secondary structures, such as floors and their loads, partitions, and roofs.

Before walls are built many conditions affecting their stability have to be considered: the materials of construction, their thickness, height, and length; the nature of their loading and its distribution.

In considering their loads, the weight of the walls themselves, and the weight of interior parts that are transmitted to the walls, must be included; also the thrust of arches, corbels, flights of stairs, etc.

Thickness of Walls. The thickness of walls largely depends, apart from their loads, upon the relation of their height to their length, and to the spread of their bases to prevent overturning. An isolated wall, such as a boundary or parapet wall, would require a greater thickness, and consequently a wider spread of foundation, than the walls of a residence, which receive much support from intersecting, joining, and returned walls.

The length of a wall, in relation to its height, is that part of the wall between any joining wall connecting at an angle, and which receives no intermediate support from an abutting or intersecting wall.

Thickness is also dependent upon the weather-resisting properties of the materials with which the walls are built. The walls should be sufficiently thick to prevent the too rapid conduction of heat, both artificial and natural; also to prevent the passage of sound from apartment to apartment.

The thickness of external walls should not be less than one-sixteenth of the height of the story in the case of residences, and not less than one-fourteenth in the case of warehouses.

The following particulars are a good guide for the requisite thickness of walls under ordinary circumstances—

Walls of two stories not exceeding a total height of 25 ft., one brick thick.

Three stories in height: top story, one brick thick; lower stories, $1\frac{1}{2}$ bricks thick.

Forty feet to 50 ft. in height: top story, one brick thick; lowest story, two bricks thick; and the intermediate stories, $1\frac{1}{2}$ bricks thick.

Fifty feet to 60 ft. high: two bottom stories, two bricks thick, and the upper stories $1\frac{1}{2}$ bricks thick.

Pipe chases are frequently cut into existing walls, without any thought as to the weakening effect they may have upon the wall; in the case of a heavily loaded wall, the result may prove serious, and should never be allowed without the sanction of someone in authority sufficiently experienced to decide whether it would be safe to do so.

Cavity Walls. In bleak and exposed situations subject to driving rain and snow, the external walls of buildings are frequently built with a space in their thickness, usually $2\frac{1}{2}$ in. wide, to prevent penetration of dampness into the interior of the building, Fig. 46. Near the sea, the spray carried by the wind deposits salt on the face of the walls, and this permanently attracts moisture from a humid atmosphere. A cavity ensures a more uniform temperature inside the building, and protects from decay any woodwork in contact with the wall.

In constructing hollow walls, the outside portion should only be considered as a protecting skin, and not as any part of a load-supporting structure. The inside wall should be of sufficient thickness to carry the weight of floors and roof. The outer wall actually receives support from the inner, by the bond ties which are built in as the work proceeds. These may be specially made vitrified bricks, or cast-iron, wrought-iron, or wire-shaped ties as shown in Fig. 46, placed in rows about 1 ft. to 1 ft. 6 in. apart vertically, and about 3 ft. apart horizontally. Each row is set centrally between the row below, or, as often described, "chequer-wise."

The cavity must be well ventilated by inserting sufficient air-bricks just below the eaves of the roof, and at the base of the wall just above ground level. Provision must also be made for drainage of any accumulated condensed moisture, by leaving small weep-holes at the bottom of the cavity just above the damp-proof course. Gratings should be fitted to exclude vermin.

All floors should be ventilated direct from the atmosphere and not from the cavity. The usual method is to build in short lengths of pipe through the thickness of the walls, and sloping towards the outer face so as to convey no moisture to the inner wall. All window or door frames must be protected from falling moisture by building in a strip of lead in the shape of a small gutter, and extending sufficiently beyond each side of the frame so as to allow any water to drip clear of the woodwork.

The cavity must be closed at the top to prevent access of vermin, and to ensure uniformity of temperature in the building.

When building hollow walls great care is required to keep the cavity clear of falling mortar. The writer has, on more than one occasion, been called in to ascertain the cause of dampness showing on the inside of a cavity wall.

The stains were, in one case, in patches, and nowhere near a down-spout or water-pipe of any description. On cutting an opening in the outer wall near one of the patches, it was found that mortar droppings had accumulated on the wall-ties until a fair sized part of the cavity was practically solid. The accumulated mortar was saturated with condensed moisture. To prevent this occurring, when building cavity walls, lay battens bound with hay along the wall-ties as the work proceeds. These battens catch falling mortar, and are drawn up when the wall reaches the height of another row of ties, the process being repeated throughout the building of the wall.

PIERS

In forming window or door openings or recesses, a wall is divided into a number of piers, which become the subject of concentrated loads. The openings between the piers are spanned by girders, lintels, or arches, which carry the weight of the work above and transmit it to the piers; the various thrusts at the abutments of arches have also to be considered.

The sectional area of the piers, that is, their length multiplied by their breadth, must be sufficient to carry the concentrated loads, and it frequently becomes necessary to thicken the wall at these points.

Isolated piers receiving no support from abutting walls need to be of a greater sectional area than connected piers. Their height is relative to their sectional area, and varies with different materials to a point, where it gradually becomes weaker owing to its liability to buckle under its

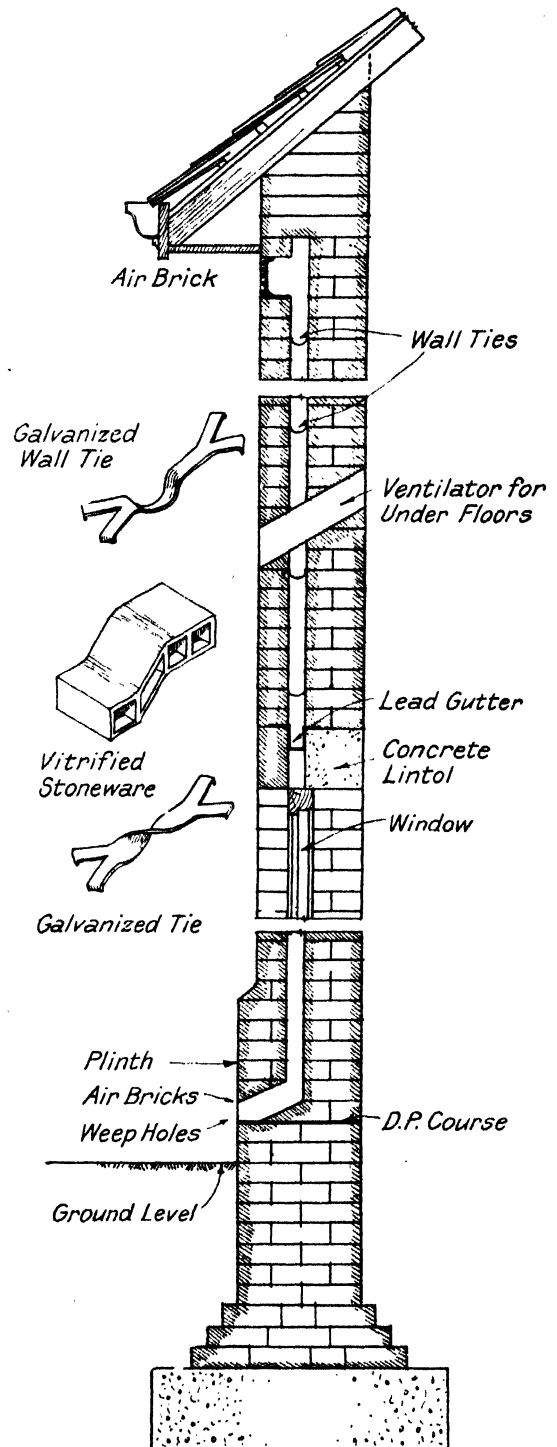


FIG. 46. CAVITY WALL

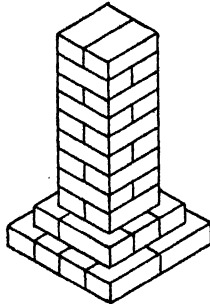
MODERN BUILDING CONSTRUCTION

own weight, apart from its load. No isolated pier should be built higher than from ten to twelve times its least diameter.

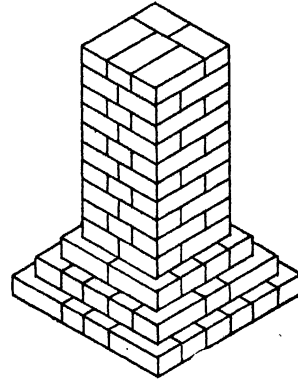
A pier 10 ft. high will only carry half the weight that it will carry when only 1 ft. in height.

eliminated by the skill and knowledge of the bricklayer in arranging his bond to produce the greatest strength, and by using a reasonably strong cement mortar.

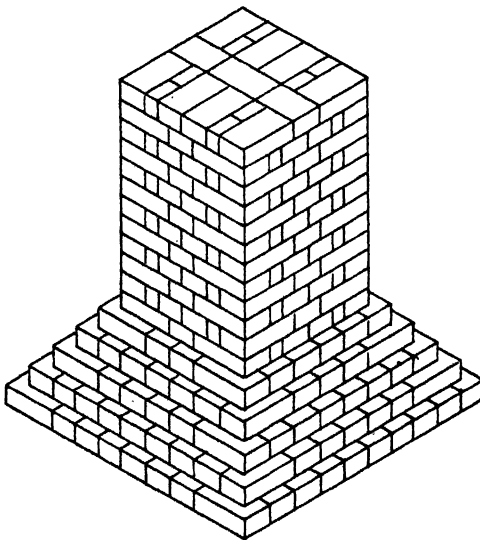
The foregoing will assist the craftsman to



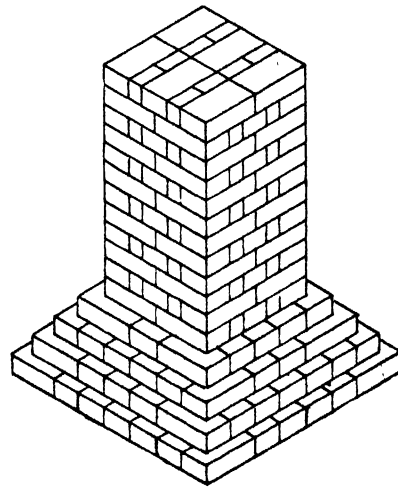
1 BRICK PIER.



1½ BRICK PIER.



2½ BRICK PIER.



2 BRICK PIER

FIG. 47. PIERS

The density and hardness of the material with which a pier is constructed affect its stability.

Stock brickwork crushes under a load of about 130 tons per sq. ft.; half this load will cause failure by cracking, which will eventually destroy the structure. A safe load would be one-fifth of that which causes fracture, and one-half of this result for a pier 10 ft. in height.

The vertical joints in brick piers are a decided source of weakness, much of which can be

realize the importance of a good knowledge of the principles underlying brickwork construction, and materially help him at any time he is employed in a supervisory capacity where the responsibility for a satisfactory job is his.

The foundations for brick piers in the ordinary way are the same as for walls, the spread of the footings being equal to twice the least thickness of the pier. This again depends upon the load it is called upon to support. Special treatment

BRICKWORK

in this respect is a matter for the architect ; in this section it is therefore only necessary to consider ordinary foundations. A number of examples are illustrated in Fig. 47.

An easy rule for calculating the number of courses of footings for any thickness of wall, is to reckon one course of footings for every half-brick in the thickness of the wall, the bottom course of which will be twice the thickness of the wall ; as an example, a one-brick wall has two half-bricks in its thickness, therefore there will be two courses of footings, and the bottom course will be two bricks wide.

Again, a two-brick wall has four half-bricks in its thickness ; there will be four courses of footings, the bottom course being four bricks wide.

Each course of footings is set back $2\frac{1}{4}$ in. from the face of the course below, forming a series of steps on each side of the wall. These steps are called *offsets*.

DAMP-PROOF COURSES

Damp and ground air not only rise through the spaces in the lower floors, but will penetrate and find entrance by rising through the pores of the bricks and mortar, unless a layer of some impervious material is inserted in the brickwork to prevent it. The movement of warmed air in a building tends to draw dampness into the interior.

In cases where there are no apartments below ground level, the rise of moisture can be obviated by inserting a horizontal layer of impervious material in all the walls at a level of not less than 6 in. above the ground, preferably 9 in. to 12 in., and necessarily below all timbers, which would otherwise be destroyed by decay from the penetrating dampness.

In cases where there are apartments below ground level, all walls that abut the face of the earth must be provided with a vertical layer, in addition to the horizontal layer. Where the level of the subsoil water rises at any time above the level of the lowest floor, it frequently becomes necessary for the whole level surface between the enclosing walls to be covered in the same manner (see Fig. 48).

Varieties. *Asphalt* is the best material for damp-proof courses, as it is impervious to moisture, practically indestructible, and not likely to fracture owing to its elastic nature. It is easily laid, particularly in the case of vertical layers, where other materials would be difficult to fix.

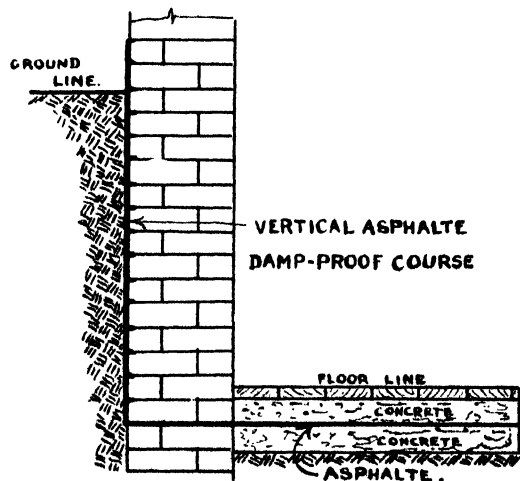
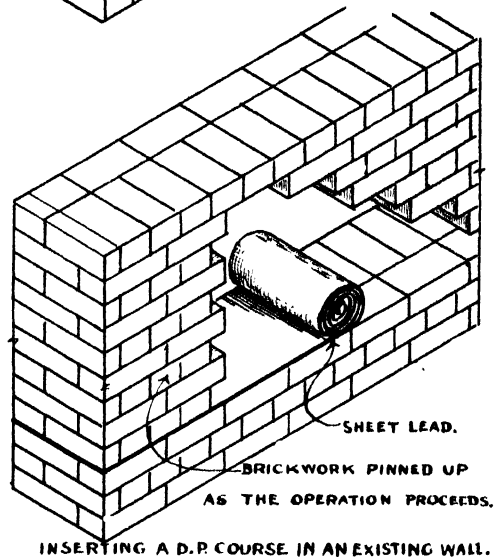
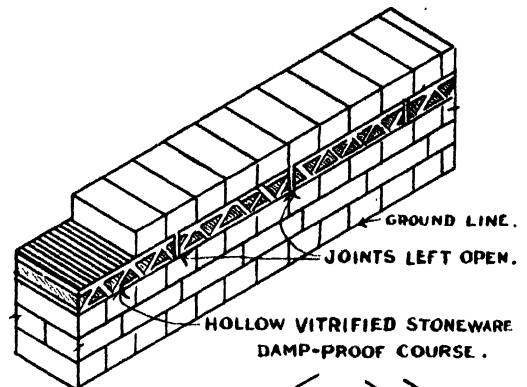


FIG. 48. DAMP-PROOF COURSES

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There are two kinds of asphalt—*natural* and *artificial*. The former is far and away the best, but is practically twice the cost of the latter, which may contain oil, coal tar, pitch, and lime. The principal objection to their use is that they soften to such an extent during hot weather, and then compression, due to the weight of the building, squeezes the material out of the joints between the bricks, until the layer becomes so thin that the bricks come into contact with each other where their bedding surfaces are irregular, and the insulation is thereby seriously impaired.

Bituminous sheets are manufactured by several firms, which are extremely satisfactory as damp-resisting courses. Messrs. Callenders make such sheets in lengths of 24 ft. by any width that may be required. The sheets are unrolled on the surface of the walls, and joined up by forming the seam with hot irons, the damp-proof layer being continuous round the walls of the whole building.

Vulcanite, Ltd., is another maker of an excellent bituminous sheeting, their "Reliance" brand being composed of two outer sheets, with an intermediate layer of lead foil. A number of bituminous felts are also on the market, which are principally used for temporary structures.

Two courses of *roofing slates* bedded in cement mortar and half bonded form an excellent damp-proof course, but any settlement that causes fracture destroys its continuity and perfect insulation.

Hollow vitrified stoneware blocks, the width of the wall and made in short lengths, form a good damp-resisting layer, and at the same time the perforations provide ample ventilation for under the floors; in fact, in the latter respect, there is the objection that the amount of air may be too great during the winter months, making the building too cold. In fixing these blocks, the bricklayer should not make the common mistake of making the vertical joints between the blocks solid with mortar. These joints should be left open, as the joints, if of porous material, form a communication between the work above and below the impervious layer. Even were the jointing material impervious, any fine crack caused by settlement or shrinkage of the material itself would attract damp by what is known as capillary attraction.

Sheet lead has been used in the past and forms an excellent damp-resisting layer, but its cost is almost prohibitive, particularly at the present time. It can be used with advantage where a

damp-proof course has to be inserted in an existing building, as it can be unrolled as the short lengths of the wall are cut away, and the underpinning proceeded with. The lengths are soldered together as the work proceeds.

POINTING

The mortar joints on the face of external walls are treated in several ways, according to the kind of finish desired by the architect. This is a matter of some importance, and it affects the durability of a building to a far greater extent than is generally realised.

The primary object must be to protect the mortar in the interior of the wall from the effects of the weather, and to prevent driving rain from penetrating the brickwork. The secondary object is appearance, the beauty of a brick building being frequently marred by badly finished mortar joints.

The joints may be finished as the building proceeds, or raked out and left until the building has been completed, and the whole of the joints finished afterwards.

In the former case the process is usually termed *jointing*, and is spoken of by the craftsman as *struck joint*; in the latter, *pointing*. Some various types of joints are shown at Fig. 49.

The *flat joint*, as at *A*, is finished with the mortar joint flush with the face of the bricks, and is ironed smooth with a trowel or jointer. Many craftsmen have a tendency to iron in the joint at the bottom edge, which is bad, as it leaves a small channel on which rain-water will lodge and become absorbed by the bricks.

The *weather joint* *C* is a good form of joint. This joint sheds the rain-water, being recessed at the top to a depth of from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. The bottom projects slightly over the edge of the brick below, and is cut off straight with the tool called a *frenchman*, shown in the illustrated list of tools. The cut is made with the edge of the tool, the turned-up point removing the surplus mortar below the cut. Straight edges, with small pieces of cork tacked on one side, to keep them clear of the wall and allow the cuttings to drop clear, are used as a guide for the frenchman.

At *D* is a form of ornamental pointing called *tuck pointing*, used generally on old walls where the edges of the bricks are weathered away, making the joints large and irregular. It is not a durable type, and the surface of the joint is rapidly destroyed by weather.

In this kind of work the old joints are raked out to a depth of $\frac{1}{2}$ in., and well brushed out with a stiff brush; the whole wall is washed

the face of the stopping with a jointer, the edges being cut true top and bottom with the frenchman.

In many cases the old bricks, and also the mortar stopping, are coloured, the whole surface being rubbed over with a piece of sacking to make it uniform, before the white joint is put on.

The colouring for stock brickwork is made with a solution of copperas (sulphate of iron), coloured with yellow ochre; for red brickwork, copperas, Venetian red, and Spanish brown. A small knob of lime put in the solution will brighten up the colours considerably, and remove the dull, drab, doll's-house effect one so often sees where old fronts have been coloured.

In raking out the joints of old work, see that the old mortar is raked out clean to the full depth of the joint, so that the edges of the bricks are clean for the pointing materials to adhere to, as shown at *E*, and not as at *F*, where the joint cannot be expected to adhere to the old friable mortar, and will undoubtedly fall out with the advent of the first serious frost.

COPINGS AND CORNICES

The tops of all walls and cornices exposed to the weather have to be protected by some form of covering, to prevent the penetration of rain-water, which would otherwise soak down through the wall into the interior of the building.

The methods with which the bricklayer is concerned in this respect are (Fig. 50): (*A*) by finishing the top of the wall with a course of bricks bedded on edge in cement mortar, with a projecting course of brick under the brick-on-edge course; or (*B*) two courses of roofing tiles laid half-bond, also in cement mortar immediately below the brick-on-edge course. The top projecting edges of this *tile creasing*, as it is termed, are finished with a splayed cement fillet to shed the rain clear of the wall.

Another method (*C*) is to form a saddle-back coping of cut bricks.

Special impervious coping and sill blocks are manufactured for this purpose, with sloping or weathered surfaces for the top, and grooved or throated on the edge of the underside, forming a drip which stops the water from running back to the face of the wall; see (*D*).

Projecting brick cornices should be finished in the same manner, unless covered with asphalt or lead.

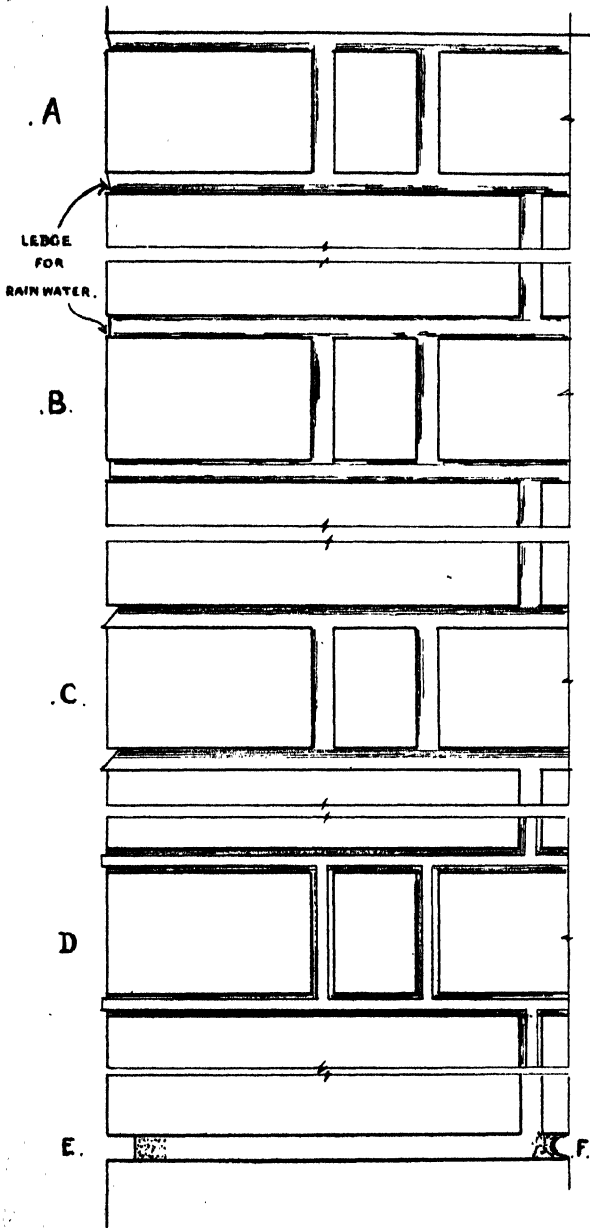


FIG. 49. TYPES OF POINTING

down and soaked with plenty of water. The joints are then filled up flush with mortar stopping; a fine white joint of mortar, made of lime and silver sand in equal parts, is then put on

MODERN BUILDING CONSTRUCTION

COPINGS.

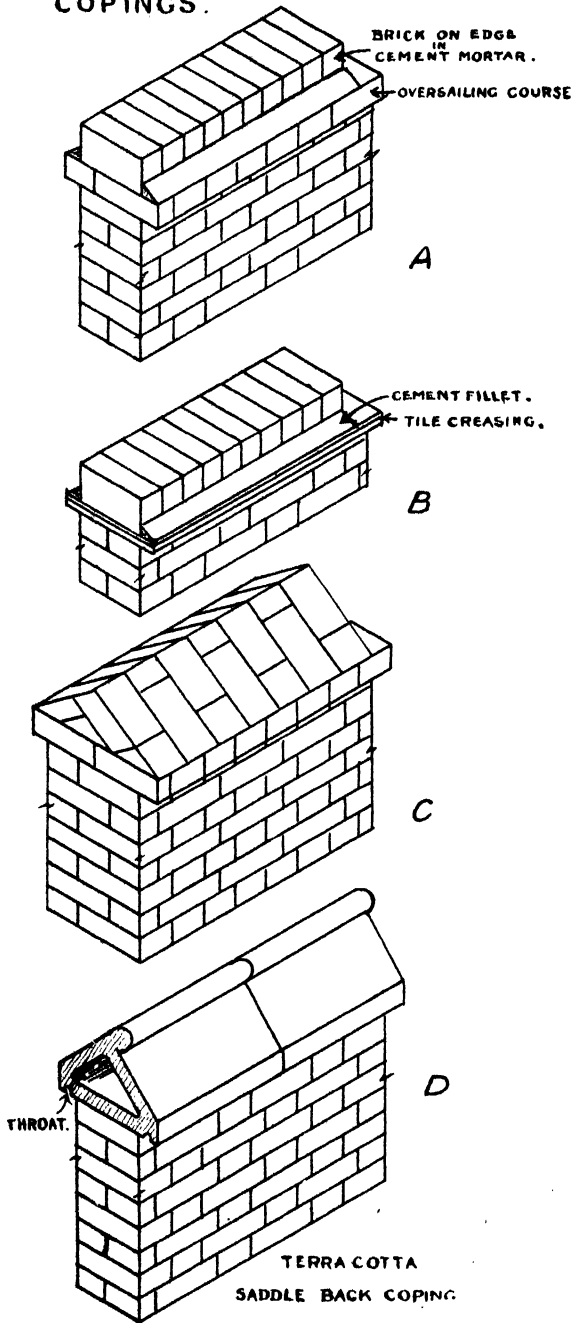


FIG. 50. COPINGS

Corbels are courses of brickwork which project from the face of the wall, for the purpose of forming a support to carry some portion of the interior structure, such as wall plates, that carry the joists of a floor or the rafters of a roof; the base of a chimney breast or a stack that projects beyond the face of a wall above ground level; or the bases of projecting ornamental features, such as columns, pilasters, and cornices on external walls.

FOUNDATIONS

It is not for the bricklayer to concern himself with the designing of foundations, which is the business of the architect. At the same time, a knowledge of the principles governing the construction of the ordinary types is necessary.

The natural foundation is the earth directly supporting the structure. The term "foundation," in the accepted sense, usually applies to that part of the building in direct contact with the soil, and may consist of an extended base of brickwork to the walls, a bed of concrete, or both.

The objects of foundations are—

(a) To distribute the weight of the superstructure over an area sufficiently large to prevent undue or irregular settlement likely to cause fractures in the building.

(b) To provide a level surface for the commencement of building operations.

If the natural foundation is rock or compact gravel of great depth (which is practically incompressible), the wall may be built direct upon it after forming a level surface and ensuring the absence of faulty places such as soft patches and loose shale. If these should be present, they should be excavated and filled in with concrete.

In good dry soil, which is compressible but reasonably firm, an artificial foundation is necessary to increase the bearing surface. The subject, however, is too wide to be dealt with here. (See "Preliminary Operations.")

SETTLEMENT

This important subject has already been referred to in the previous paragraphs on foundations, toothing, and bonding.

Some further information is, however, necessary to a clearer understanding of the various causes that produce unsightly fractures in the walls of a building.

Settlement invariably occurs when constructing any heavy building. Providing this settlement is not undue or irregular, no ill effects will

result. The object to be aimed at is uniformity of settlement without excess.

The concrete bed should be one homogeneous mass of sufficient strength to resist fracture. Close supervision is essential when preparing foundations to see that the work is continuous, and that no vertical break is made in the concrete bed, particularly with respect to main external walls.

Complete lengths of foundations, that require some days to finish, should be laid in complete layers daily, the last layer of the day being raked over and left rough; under no circumstances should the bed be laid in short sections.

The difficulty of this procedure on large jobs is thoroughly appreciated by the writer, who, from experience, feels sure that this is the most prevalent cause of fractures showing in newly completed buildings, and that every effort should be made to ensure that every concrete bed is practically monolithic.

Another point is to build the walls evenly over the whole site. This means that one part of the building should not be more than 5 ft. higher than another part during construction, so that the foundations are loaded evenly while the building gradually rises.

There are causes of settlement resulting in fracture that are not confined to the foundations.

Much care and forethought has to be exercised when the operations of extensive alterations and additions to existing buildings are carried out, and considerable judgment is necessary in making provision for any settlement that is likely to occur, due to the extra loading of some parts of the structure. Although the walls are sufficiently strong to support the added loads, some further compression of the soil beneath the foundations will probably take place. This, although slight, may create unsightly cracks where the new brickwork joins the old, unless some provision has been made for the settlement, by chase bonding, previously described, or by leaving the joints of toothings empty until the new work has taken its proper bearing, and the joints filled then. Some objection may be raised to the latter method, on account of the difficulty of filling the toothings after the wall has been built. Carefully done, it is quite a satisfactory job, even if not quite solid, whereas a solid connection in the first place would have resulted in a vertical fracture along the line of

toothings, from the top to the bottom of the wall.

Compression of the mortar joints in the new portions of the work as it proceeds, and any compressible materials built in the walls, such as timber, have to be considered.

When the ends of timbers are built into a wall, the brickwork should be so arranged that any weight above is not directly supported by the timber, as shrinkage or decay, should it occur, will cause fracture through the settlement of the brickwork above. Many cases of this occur where no relieving arch has been built over the lintel spanning a door or window opening. The decayed lintel has been crushed by the weight of the unsupported triangle of brickwork over the opening, with serious results. Cracks in brickwork are frequently the result of timbers having been built into the walls, subsequent decay causing settlement.

Where some portions of a building connect up with steel construction, it is wise to make some allowance for the compression of the mortar joints in the brickwork, particularly when the progress of building is fairly rapid. Take an example in point. The ends of a series of steel joists, forming a heavy floor, may be supported on steel construction at one end, their opposite ends being supported by a brick wall. Unless some allowance is made for settlement, due to the compression of the joints in the wall, a floor out of level will undoubtedly be the result. The brickwork in cases of this description should always be slightly higher than the steelwork; in some cases 1 in. for every 10 ft. in height has been found necessary. The allowance is dependent largely upon the composition of the mortar, and the speed with which the work is being carried out.

Arches of large span usually settle slightly when the centres are removed. If carefully done no damage may occur; careful supervision is necessary, and the supports of the temporary centering should be so arranged that it can be lowered evenly and gradually, to enable the loaded arch to take its proper bearing without damage to the brickwork above.

Where drains, ventilating ducts, or channels for heating pipes, etc., are taken through the foundation walls of a building, the brickwork should be arched over, to ensure that no weight likely to crush the pipes is carried by them, which would cause the brickwork to settle and fracture the wall.

Chapter V—FIREPLACES AND CHIMNEYS

PROVISION for open fires is usually made in most residential buildings (see Fig. 51). With the advent of central heating and patent gas fires, this provision is omitted in some cases. There is considerable divergence of opinion as to the merits and demerits of the open fire, but it is not proposed to discuss that matter here.

In making provision for open fires, an adequate supply of air for the purpose of combustion is necessary, otherwise the fire is not going to burn satisfactorily; an air inlet of some description must, therefore, be provided.

The position of the fireplace is of considerable importance. It should not be too near, or in a direct line with, a door, or the fire will smoke with the sudden opening or closing of the door. It is best built against an internal wall, as the flue temperature would be rapidly lowered by conduction if built against an external wall. In the latter case, the resultant dense column of cold air will need considerable heat to displace, with the result that some difficulty will be experienced in starting the fire, and the flue will always be sluggish.

Fireplace openings are formed by building piers, or *jamb*s, projecting from the face of a wall a distance sufficient to provide a space in their width to form a conduit to carry off the waste products of combustion. These conduits are called *flues* and are usually rectangular in shape, and not less than 9 in. by 9 in. or greater than 9 in. by 14 in. in size for any ordinary type of stove or range.

If the fireplace is a large open one, as sometimes used in Club rooms and hotel lounges, it is as well to get the necessary authority to sanction the building of the large size flue such as 9 in. by 14 in.

At the top of the fireplace opening, projecting courses of brickwork are built, forming a funnel-shaped opening and closing in the space until the correct size of the flue is reached. The flue is then continued to a suitable point above the roof for the discharge of the smoke.

The sizes of fireplace openings are dependent to a great extent upon the size of the rooms. A large room will provide sufficient air for a fairly large opening, but a large opening in a small room is likely to create down-draught.

The enclosing walls of a fireplace should not be less than 9 in. in thickness, the fireback being continued at the same thickness to a point 12 in. above the top of the opening.

Fireplace openings on the different floors are, where possible, arranged above one another, and the flues from the lower floors are formed in the jambs of the fireplaces on the floors above. All the flues converge to a central group, where they emerge from the roof. The upper part of the structure is termed the *chimney stack*; its termination should not be less than 3 ft. above the highest point where it leaves the roof, this 3 ft. being built in cement mortar.

Where any flue or flues pass through a floor or roof space, the outside of the walls should be plastered with 1 in. of cement mortar, as a preventive measure against fire.

That the brickwork should be properly bonded, and the joints filled, is of the utmost importance, particularly the division walls between the flues, otherwise communication between the flues will result in retarding the up-draught, and also result in smoke being drawn down one of the flues into a room where there is no fire burning. Under no circumstances should any two flues communicate.

All wood and metal work should be kept clear of the flues. Model by-laws say that no timber shall be nearer than 9 in. or metal fastenings 2 in. to the interior of a flue, but for safety the latter should not be nearer than $4\frac{1}{2}$ in.

Thin division walls only $4\frac{1}{2}$ in. thick between the flues are an advantage, as the flues help to warm each other and increase the draught; but the external walls of the stack could with advantage be 9 in. thick, so that they can be satisfactorily bonded, also for protection of the flues from the cold outer air.

The maximum height of a stack is six times its least width at the last point of support. If this height is exceeded, iron bands and stay rods will have to be provided, and fixed to some part of the roof for added support.

The interiors of all flues are plastered with cement mortar, so as to reduce friction, and thus not retard the up-current carrying the smoke. This process is called *pargetting*.

Where it is necessary to change the direction

.CHIMNEYS.

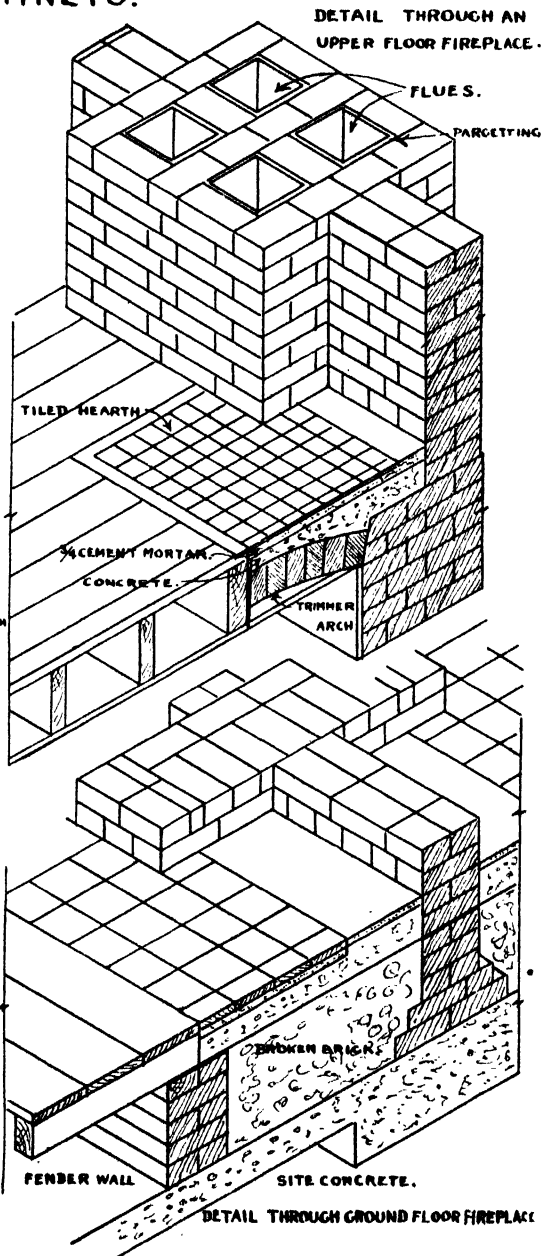
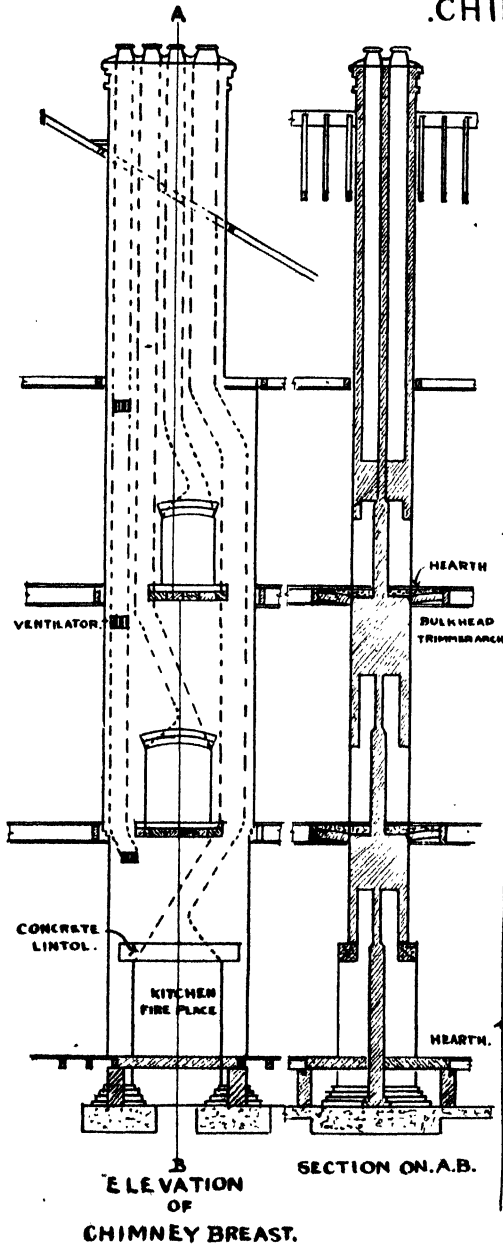


FIG. 51. CHIMNEYS

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of a flue, the angle of rake of the bend should not be less than 60° . But there are sometimes occasions when a flue has to be carried to another position, say, 10 ft. away from where it is first formed, and where there is very little height to allow the flue to rise.

It has been found that so long as the flue has a rise of, say, 6 in. in this part, and that there is a good height of vertical flue beyond this, the draught will be satisfactory. The L.C.C. By-laws state that there must be at least $8\frac{1}{2}$ in. of brickwork or concrete on the top side of a flue raking at less than 45° , and soot doors must be provided for cleaning purposes. Slight bends are beneficial in preventing down-draught, but do not, as many craftsmen believe, increase the draught. The fastest flue is undoubtedly the perfectly straight one, but it presents no obstacle to down-draught.

Short flues are generally sluggish.

Building Flues. In building flues, care should be taken to see that mortar droppings are not allowed to accumulate at the angle of bends. A good method of preventing this is to draw a bundle of hay or straw through the flue as the work proceeds. If this is not done, holes should be left in the brickwork at places where such an accumulation is likely to occur, so that the mortar droppings can be cleared out. These holes are called *coring holes*.

Terra-cotta tubes are occasionally used on good-class work for lining the inside of flues, and make a first-class job where cost is not a primary consideration. The manufacturers make a variety of bends at various angles for changing the direction of flues.

Chimney Stacks. The foundation of a chimney stack generally carries more weight than the wall against which it is built, and will need a greater spread of footings. It is usual to consider the projection of the jambs from the wall or the width of the jamb, whichever is the greatest, when deciding the number of courses of footings that will be required. It is better to consider the height of the stack and the width and the weight of the breast walling when deciding this matter.

Fireplaces do not always commence at ground floor level. When starting from an upper floor, projections for the jambs are built out from the main wall with oversailing courses of brickwork, each course projecting not more than $2\frac{1}{2}$ in.,

preferably less. Projecting stones or reinforced concrete slabs are sometimes built into the walls for this purpose. The total projection, in any case, should not exceed the thickness of the wall from which they spring, and care must be taken to see that there is sufficient weight in the structure built above them to tail them down. These projecting courses are called *corbels*.

Hearths. Level with the floor of every story a slab, or *hearth*, of non-combustible material must be fixed. This hearth slab should extend 6 in. on each side of the fireplace opening, and 18 in. beyond the face of the jambs. On the ground floor, this hearth rests on a dwarf wall $4\frac{1}{2}$ in. or 9 in. thick, built up off the site concrete. These dwarf, or *fender*, walls also carry the plates supporting the floor joists. On upper floors the hearth is supported by a small brick arch, which springs from the breast walling below, and abuts the face of a timber called a *trimmer*, running parallel with the chimney breast. The arch is formed in one half-brick ring, and is contained within the depth of the floor (see Fig. 51).

In place of these trimmer arches, reinforced concrete slabs may be fixed. These slabs have two or three of their reinforcing rods sufficiently long to extend into the wall at one side, and at the other side these rods are long enough to pass through the trimmer to be screwed up with nuts.

Another method frequently used consists of tee irons built into the wall at one end, with tiles laid on the flanges to form a permanent centering for the support of the concrete to carry the hearth.

For bonding chimney stacks, which are built with half-brick walls, stretching bond is used for longitudinal strength; closers should not be used, as they are a source of weakness in half-brick walls. The dividing walls of the flues, or *withes*, as they are termed, must be bonded into the external walls every alternate course, and it will be occasionally necessary to use three-quarter bats to obtain this bond. The bats are frequently used at the quoin of the stack, but it is better to insert them away from the corner where possible, so that the corner has the benefit of a full $4\frac{1}{2}$ in. lap. Chimney bond should always be carefully considered, to ensure the use of the least possible number of bats.

Chapter VI—ARCHES AND THE NICHE

SIMPLE ARCHES

Origin of Arch. The principles of arch construction, design, and their mathematical theory are too involved to discuss here at any great length. It is hoped, however, that a knowledge of their origin and a few elementary principles will prove of some value and interest to the student.

The actual origin of the arch is somewhat vague. As far as can be traced, it is first met with as an ornamental feature in some of the ancient buildings of Western Asia. The Palace of Sargon, Khorsbad, Babylonia, 722 B.C., furnishes one of the finest examples of the semi-circular arches of history. A later example was the great central arch at the entrance to the Palace of Ctesiphon, Assyria, A.D. 550, a semi-circular arch with the enormous span of 83 ft.

The ancient Egyptians used the principle of arch construction chiefly in the form of vaulting, some of their ancient buildings being roofed in this manner.

The *pointed arch* is assumed by some to have originated with the building of the Mosque of Ibn Tulun, Cairo, built in the ninth century. The pointed arches of this mosque, correct in construction, and with a span of 15 ft., are considered as being among the finest examples of ancient craftsmanship in arch construction. Similar arches had been constructed in the Great Mosque outside the city of Samaria, Mesopotamia, some years earlier. Ibn Tulun, it appears, was born in the latter city, so there was probably some connection relative to both of these examples.

The pointed arch was, however, known to have been used as early as 722 B.C. in the construction of drains and culverts, but was very crude in form. It is probable that those previously referred to may have originated in correct form as an ornamental feature in the building of these mosques.

Flat arches, as they are called, were probably the outcome of a desire to imitate the keyed lintels to the square openings constructed with stone in buildings of the Renaissance. Constructed in brick, they lack the dignity, strength, and stability of the massive stone lintels of that

period. Whether in stone or brick, they are a weak form of construction, and cannot correctly be defined as arches, but can only be considered as a scheme for spanning an opening.

The arch proper, as an architectural feature, came into general use with the advent of the Roman Empire, and still remains one of the chief features in architectural design, even in the present era of concrete and steel.

Lintel and Corbel. The introduction of the arch was preceded by the use of the *corbel* and *lintel*. The corbel dates back beyond the history of Greek architecture (in which the arch was not used). The method of construction was to build projecting courses in the side walls of the opening to be spanned, commencing at a suitable height, and continuing until both sides met at the apex of a triangle, or so far reduced the span that it could be safely bridged with a single stone (see Fig. 52A).

The Anglo-Saxons used inclined stone beams, meeting at the apex of a triangle.

Straight beams of stone were another ancient form of construction used for covering openings of limited span. The texture of the stone, even in the strongest specimens, was not suitable for openings of large span, on account of its comparative weakness in tension.

Stone lintels now used are generally strengthened by a supplementary structure in the form of an arch built in the mass of the wall directly over the lintel, with its abutments clear of the ends of the lintel, so that very little direct weight is actually supported by the lintel. Concrete lintels, reinforced with longitudinal steel rods, are extensively used at the present time, and are much more satisfactory.

Ancient examples of the use of the arch, in conjunction with the corbel, may lead one to assume that it was the outcome of a desire to abolish the unsightly appearance of the pyramidal crown to an opening.

If we consider the semicircular arch, we can see that the offsets of a brick corbel can be made to follow the curve of the arch up to a certain point. The offsets then become too great to follow the remainder of the curve. In this connection, examples of ancient brickwork show a short arch used to span the remainder of the

MODERN BUILDING CONSTRUCTION

opening. It would be reasonable to suppose that the semicircular arch was a further development of the same scheme (see Fig. 52A).

LOAD ON ARCH. The load carried by an arch is the triangle of brickwork contained within the lines of the offsets, or lap, of each course of brickwork above the arch, and in the case of a

seating which is at right angles to the curve, or, to be more correct, normal to the curve, meaning that the seating or abutment is on a line, which, if produced, passes through the centre from which the curve is struck. These voussoirs terminate in a block at the centre of the crown, this centre block being called the *key*.

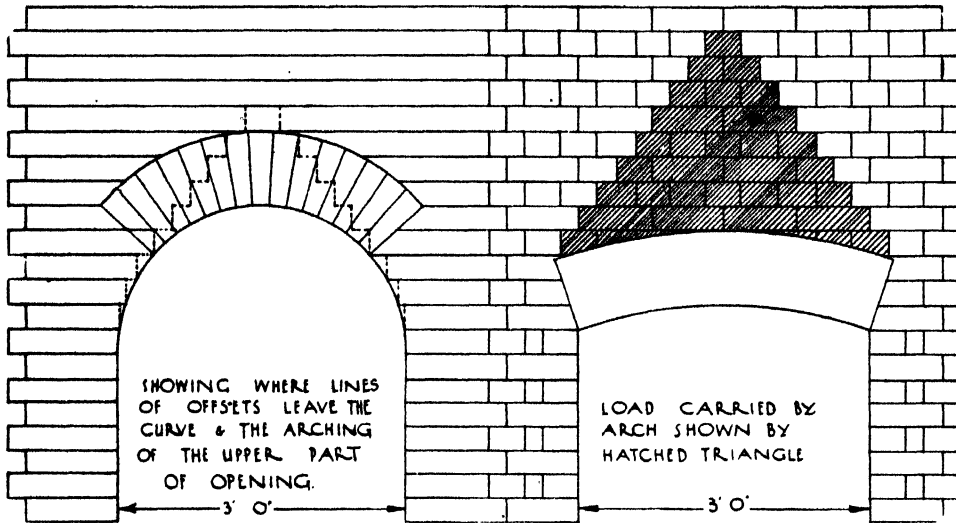


FIG. 52A. FORMATION OF ARCH

FIG. 52B. LOAD ON ARCH

semicircular arch tangential to the curve of the arch. In a segmental arch this triangle covers the entire span (see Fig. 52B).

TERMS. That portion of the semicircular arch on either side, from the abutments to the point where the sides of the triangle meet the curve, is called the *haunch*; the remaining portion between these points is called the *crown* (see Fig. 53).

The load carried by a semicircular arch rests upon the crown, and from thence is transmitted via the haunches to the abutments. This force on the haunches would throw the arch out of equilibrium and cause fracture, unless some opposite force were there to resist it. This opposing force, or *reaction*, is provided by the mass of brickwork called the *spandril*, which is built at the sides of the arch, and which abuts the outer curve, or, as it is called, the *extrados*. The inner curve of the arch is called the *intrados*. The face of the arch under this inner curve is called the *soffit*.

Arches are built up with a number of wedge-shaped blocks called *voussoirs*, starting from a

The horizontal line, or course, from which the arch commences is called the *springing line*, and if the curve is less than a semicircle, the line of abutment is termed the *skewback*. The points on the springing line, from which the abutment starts, are called the *springing points*.

TYPES

There are many different forms of the arch in use at the present time, built up in many instances by a combination of different curves. The setting out of these will not present any great difficulty, once the student is thoroughly acquainted with the methods of connecting different curves with their centres in proper relationship to each other.

Most of the ordinary types of arch are struck from one or two centres. Where a combination of curves is used, the number of centres ranges from three upwards. This number can be varied at the will of the craftsman to suit the type of curve he wishes to obtain, without the curve having the appearance of being crippled where the different curves connect.

Arches can be divided into three classes—

1. Rough arches.
2. Axed arches.
3. Gauged arches.

Arches can also be classified according to their shape, and the number of centres from which they are struck—

- | | |
|-------------------------------|-------------------------------------|
| (a) Semicircular arch. | } One centre. |
| Segmental arch. | |
| Flat, or camber, arch. | |
| (b) Pointed, or Gothic, arch. | Two centres. |
| (c) Semi-elliptical arch. | Three, five, seven,
and upwards. |
| Tudor arch. | Four centres. |

Rough Arches. Where appearance is of no importance, or when it is intended to plaster the face of the arches, they are constructed of uncut bricks, usually built up in concentric rings half a brick thick, the number of rings varying with the span of the opening. The only connection between each ring is a collar joint of mortar.

In arches of very wide span, the different rings are sometimes bonded to each other by inserting courses of stretchers in the depth of the arch at intervals. These are termed *lacing courses* and any benefit is derived from the introduction of these lacing courses is a debatable point; many experienced craftsmen say that this partial interlocking of each ring interferes with the proper settlement of the loaded arch when the centres are struck, and frequently results in a fracture across the lacing courses. The writer has experienced this on one occasion, in which case the joints of the lacing course near the top portion of the arch opened slightly, and the top three courses of stretchers fractured across in line with the collar joint. It would, therefore, appear that a certain amount of shear along the line of the collar joints takes place when the arch settles.

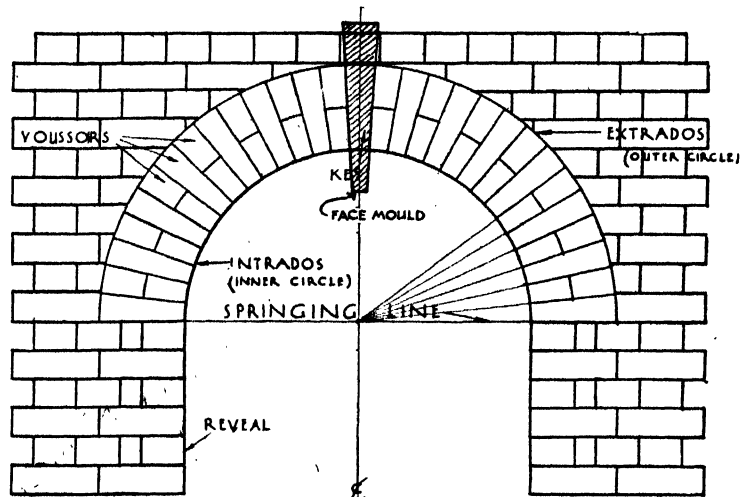
The reason for using half-brick rings in this type of arch is to reduce the size of the mortar joint at the extrados of each separate ring. It will be readily seen that when the voussoirs of an arch are not cut wedge-shape, the necessary

radiation can only be obtained by thickening the joint at the outside curve. For arches of sharp curvature, the use of 9 in. rings would result in excessively wide joints at the extrados. It is for this reason that the half-brick ring is generally used.

RELIEVING, OR DISCHARGING, ARCHES. Rough arches of small rise are used to relieve the weight above the heads of door and window frames, or over interior openings that have been spanned by timber beams.

In constructing these arches, care should be taken to see that no actual load is permanently transmitted to any place other than the abutments of the arch.

The method of construction generally used is to form a curved surface of rough brickwork



SEMI-CIRCULAR ARCH.

FIG. 53

called a *core*, cut approximately to shape by a wooden mould, which is tacked on to the face of the lintel. A layer of sand is then spread to the correct curve, and the arch is built with its soffit resting on the sand, the skewback being formed clear of the ends of the lintel (see Fig. 58). When the bedding material, with which the arch has been built, has properly set, the sand is raked out, ensuring thereby that the whole of the weight resting on the arch is being carried by the abutments, so that in the event of the lintel being destroyed, either by fire or decay, no settlement of the brickwork would take place.

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PLAIN ARCHES. Arches constructed with uncut bricks are frequently used in good class facings on elevations of some importance. In such cases they are called plain arches. They are usually arches of simple curvature, or in the

The former usually applies to arches of sharp curvature, where strength is required and appearance is of little or no consequence. Where both appearance and strength are essential, and the arch is an ornamental feature, fine-axed work is generally used. The arrises of the bricks are cut true and sharp, their beds being trimmed to a true surface and finished with a few rubs on the rubbing stone, so that the voussoirs can be bedded with a fine joint, usually about $\frac{1}{8}$ in. to $\frac{1}{4}$ in.

Gauged Arches. Where a still finer finish is required, or special mouldings are to be cut on the face of the arch, rubber bricks (previously described) are cut to shape by means of a wire saw, and the beds and arrises finished on the rubbing stone, the arch being set in lime putty with a $\frac{1}{16}$ in. joint.

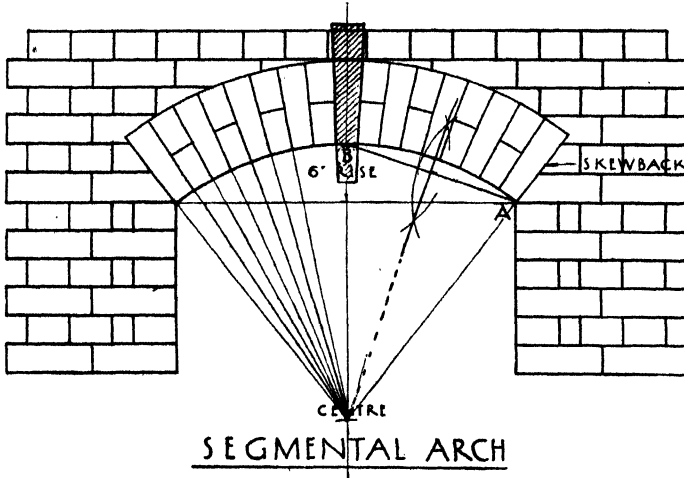


FIG. 54

form of relieving arches over a series of small openings which are spanned by stone lintels, or they may be flat, or ornamental, arches constructed in rubber or other soft kinds of bricks.

SETTING OUT

Semicircular Arch. This arch is one of the simplest kinds to set out; Fig. 53 explains this clearly. The springing line is drawn, and the span of the opening marked off on either side of a centre line.

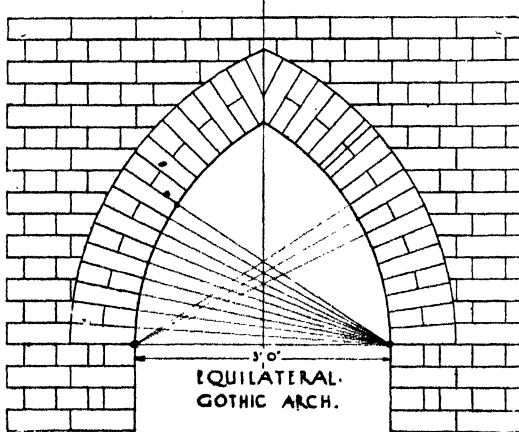


FIG. 55

Axed Arches. This term is applied where the voussoirs are cut to a wedge-shape, by means of the boaster, and trimmed to an approximately true bed with the scutch. They may be rough axed, or fine axed, according to the class of work.

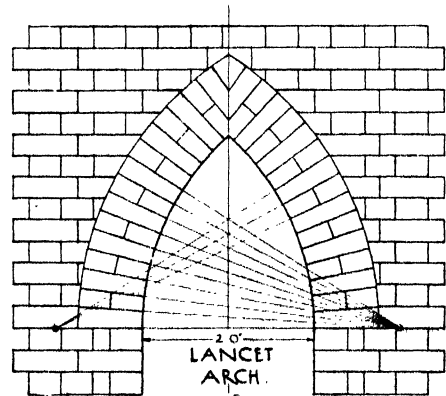


FIG. 56

The inner and outer curves of the arch are struck from the point where the springing line and centre line intersect. Measure the width of the bricks that are to be used for cutting the arch, and divide the outer curve, or

extrados, into a number of equal divisions. These divisions must not be greater than the width of the bricks, otherwise the bricks will not hold out to size in the cutting. In setting out these divisions, start from the key brick and work down to the springing line. As all the bed joints will radiate to the centre from which the arch is struck, join up these divisions with the centre. The wedge-shape between any two of these radial lines will contain the mould of the voussoirs. The key is usually taken for the purpose of making this mould, and is shown by that part which is marked by hatched lines in Fig. 53.

Segmental Arch. The procedure is similar to that of the semicircular arch, but as the curve is less than a semicircle, the centre will lie below the springing line. Mark off the rise on the centre line above the springing line, and join this point with the diagonal *AB* to the springing point; bisect the line *AB*. The bisector produced will cut the centre line at a point that will be the centre of a curve passing through the points *A*, *B*, and *C*. Proceed with the marking of the voussoirs as described for the semicircular arch. The two outside radial lines will give the skewback, and the mould is obtained in the same manner as for the semicircular arch (see Fig. 54).

Gothic, or Pointed, Arch. These arches consist of two curves meeting at the apex of a triangle, which is invariably either equilateral or isosceles.

The centres from which the curves are struck may be on or below the springing line, in between or outside the springing points. In the two examples, shown in Figs. 55 and 56, the centres are on the springing line; in the equilateral arch they are on the springing points; and in the lancet arch, outside these points. Where the rise of the arch is less than the span,

the centres will be below the springing line, a distance that can be varied to suit any required curve. The curves for each half of the arch are set out by the same process as for the segmental arch; the voussoirs, however, terminate at the

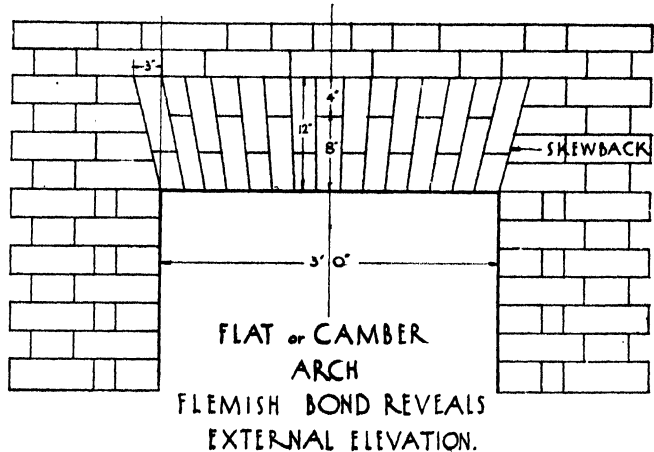


FIG. 57

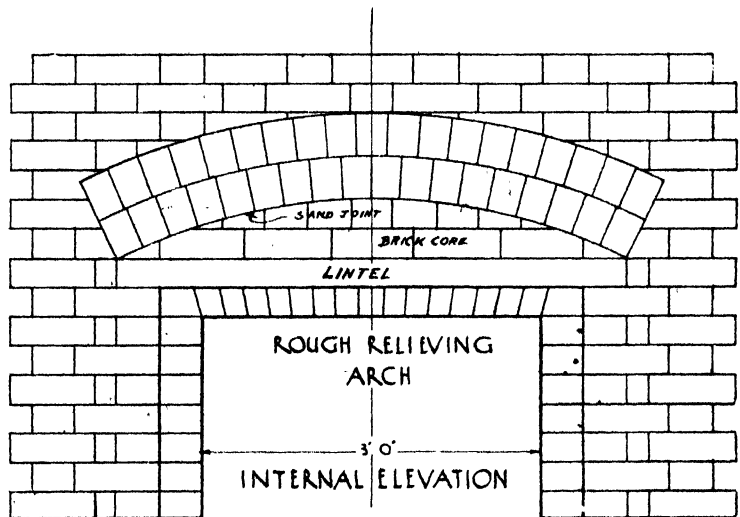


FIG. 58

apex, and on the centre line with a straight joint. It is not an uncommon thing to see these arches constructed with a key brick bird's-mouthed at the apex of the soffit, and the bed joints radiating to one centre. In this case the construction is wrong. Properly constructed, there should be no key brick.

Flat, or Camber, Arches. Fig. 57. In setting

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out these arches, the top and bottom edges are equally divided for the voussoirs, as too much room would be required to line out the radials to a centre. One of the older methods, frequently used for constructing these arches, was to build them up on an inverted equilateral triangle, the base of which represented the springing line, the sides of the triangle produced forming the skewback. The objection to this method is that very acute angles are formed on the voussoirs as they approach the skewback, creating a liability to fracture even under a small load, or through a slight settlement.

If one takes the trouble to examine many of the old buildings where these arches have been used, and where the splay of the skewback is excessive, it will be noticed that they are

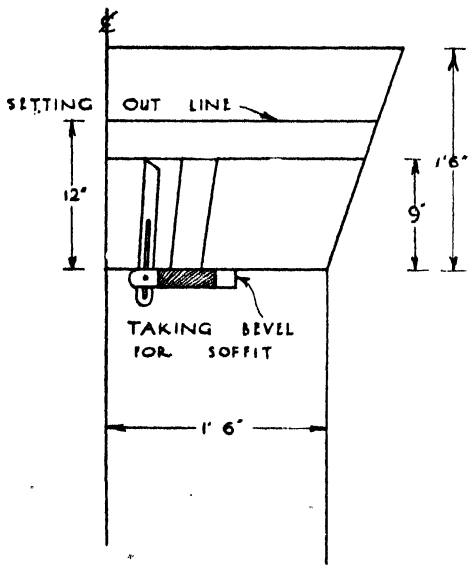


FIG. 59. SHOWING SETTING OUT FOR CAMBER ARCH

invariably fractured across the voussoirs nearest the skewback.

If we consider the complete arch as a wedge, it is obvious that the flatter the splay of the wedge, the greater will be the friction on its sides, and we know that owing to this friction it is almost impossible to drive in a wedge of this description. This wedge constructed in soft brick would, therefore, be bound to break across its weakest point before it would settle under a load, on account of the friction on its abutments.

This type of arch at its best is weak, and will not carry any great load. To overcome this liability to fracture, these arches are now constructed with a skewback, obtained by the following rule: Allow 1 in. skewback for every foot in span, the depth of the arch on the face to be 12 in.

Whatever the actual depth of the arch, the angle of skewback is constant, and the arch

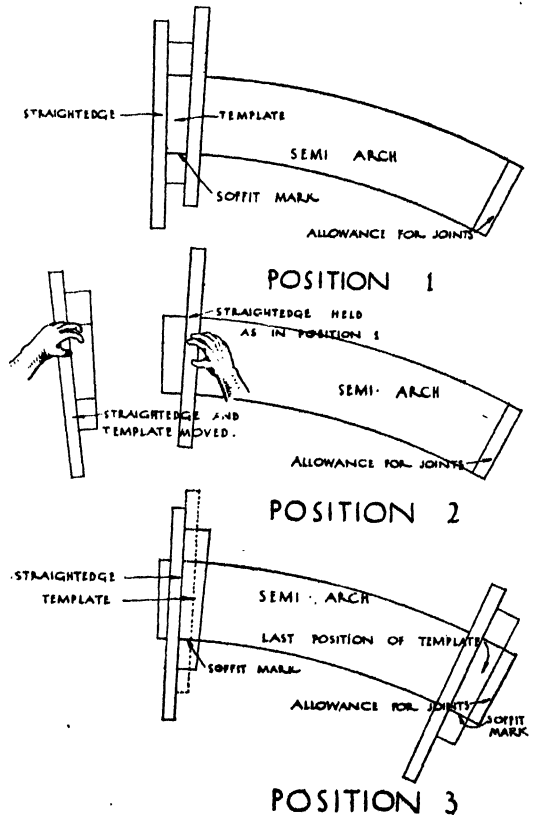


FIG. 60. TRAVERSING A MOULD

should always be set out as being 12 in. in depth. The method of setting out a camber arch, either 9 in. or 18 in. high, is shown in Fig. 59.

If these arches are set with the soffit perfectly level, they appear to sag in the centre. To overcome this illusion they are given $\frac{1}{8}$ in. rise to every foot in span.

TRAVERSING A MOULD

When the face mould of an arch has been obtained by the foregoing methods, a wooden template is cut to the mould. Great care is

necessary in cutting this template, which must be perfectly true; any slight inaccuracy is necessarily multiplied by the number of the voussoirs in the arch. To prove its accuracy the process called *traversing* is adopted, Fig. 60. In this process, allowance is also made for the bed joints, whatever their thickness is to be, the finished template, or templet, being the exact shape and size of each cut course of the arch.

It is only necessary to set out a little more than half the arch, sufficient to include the key. Count the number of bed joints from the key to the springing line, and multiply this number by the desired thickness of the joint, which will give the total allowance for the joints in one-half of the arch. Mark this distance off from the springing point along the intrados, and draw a line parallel with the abutment. Get two light parallel straight-edges perfectly true, and place one along the radial line on the outside of the key. Place the template with one edge against this straight-edge, and position it until its other edge is the thickness of one joint away from the other side of the key, as drawn on the setting-out board. Now mark on the edge of the template a point coincident with the soffit line. Place the second straight-edge against this edge of the template, hold it firmly in position, and with a sliding motion draw both the template and the first straight-edge away; now place the first straight-edge against the edge of the one you are holding, and hold that firmly in position. This is now in the same position as the edge of the template last occupied. The template is now applied in its second position with the pencil-point again on the line of soffit. This process is repeated, and if the template is accurate it should finish with its edge parallel to the line drawn, and which makes the allowance for the joints. Should it fall directly on this line, there will be no further need to repeat the operation. Should it finish short of the line, start again from the key and put the soffit mark a little higher. This slightly increases the width of the voussoirs. Then traverse the arch again. This process will have to be repeated until the edge of the template finishes in contact with the line (see Fig. 60). If, in the first traverse, the template finishes beyond the line, then the soffit point will have to be moved down; this slightly diminishes the width of the voussoirs.

To obtain the soffit bevel. Square a line across the template from the pencil-point which marks the soffit line; reverse the square, and

place its stock against the other edge of the template, and draw a line from the same point. You then have two lines across the face of the template, making an angle which has its vertex on the soffit-point. Bisect this angle, and the bisector gives the required bevel (see Fig. 61).

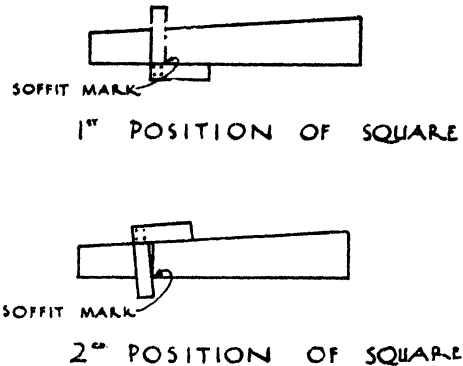


FIG. 61. SOFFIT BEVELS MARKED ON TEMPLATE

This will also be the bevel of the transverse joints of the arch, and of the extrados.

In a camber arch, the soffit bevel for every course is different, and should be transferred from the setting-out drawing to the template,



FIG. 62. OBTAINING SOFFIT BEVELS FOR CAMBER ARCHES

when the traverse has been completed (see Figs. 59 and 62).

It must not be overlooked that in this arch there are right-hand and left-hand voussoirs for each side of the arch respectively.

CUTTING THE ARCHES

Having mastered the setting out and traversing, the process of cutting the various types of arches should be fairly simple to the craftsman student.

In axed work, a rough bench is required for scribing the bricks, and a cutting block for the fixing. The craftsman will, after some practice, find out all the little labour-saving devices in connection with this process. Much time can be saved by the method he uses in scribing the bricks; this method is dependent to a great extent upon the materials he is using, and the particular type of arch he is cutting. If the

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soffit bevel is very slight, he will undoubtedly find it best to cut, or rub, this bevel on the brick first. He will then only have one side on bed of his brick to cut; but if the bevel is acute, or if he is using glazed bricks, he will be compelled to leave the soffit untouched, and cut both sides of the brick to the wedge-shaped template.

A good method in axed work is to tack a thin strip of wood across the template to the soffit line, and apply the mould with this strip abutting the end of the brick. Scribe the edges of the

ARCHES WITH MORE THAN TWO CENTRES

Semi-elliptical Arch. No part of the circumference of an ellipse can be drawn from any fixed centre, as it contains no part of a circle. Normals to the curve, therefore, do not radiate to any definite centre.

As the bed joints of a properly constructed arch should be normal to the curve of the arch, it will readily be seen that in a semi-elliptical arch each bed joint would have to be set out separately. Consequently, the voussoirs in each

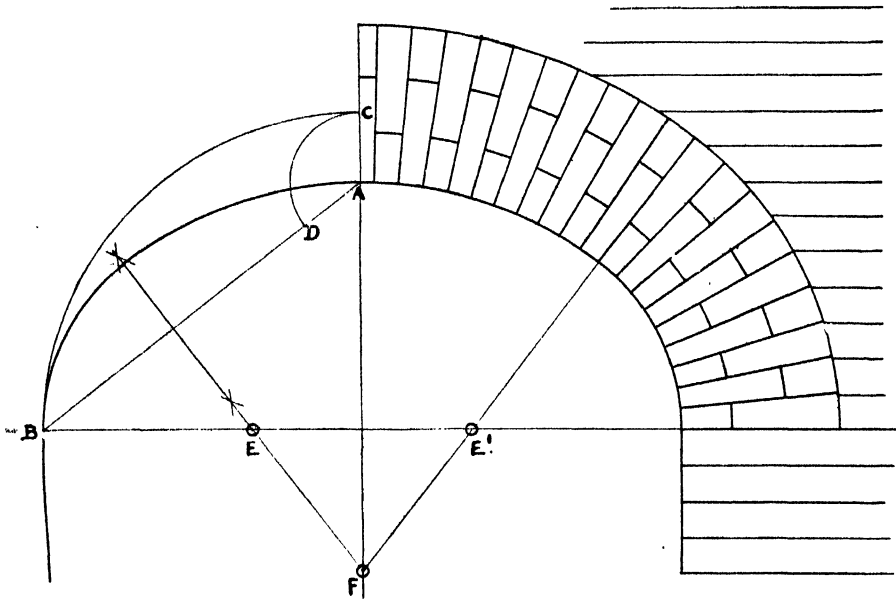


FIG. 63. THREE-CENTRED ARCH

voussoir with a tin saw, which is usually a piece of tin plate let into the edge of a wood block, and used like a mason's grub saw; the saw is worked backwards and forwards against the edge of the template, until a fine cut about $\frac{1}{4}$ in. deep is made in the face of the brick. The edges outside the cut are removed with the boaster, and the rough irregular surfaces trimmed with the scutch to form true beds. Each course of the arch is stacked as it is cut, until the whole arch has been completed. If the cutting has been accurately done, the work will stack close and the courses will not rock, or wobble, although they are unset. This is an excellent criterion of good workmanship. Work that is cut well will stack well.

half of the arch would be different in shape, and a separate template would be needed for each one. This would involve an enormous amount of labour in an arch of large span. To overcome this difficulty when constructing arches of this description in brickwork, the method usually adopted is to build up the arch in sections on the curves of circles of different sizes. The bed joints of each section radiate to the centre from which each curve is drawn. By this method all the voussoirs in each section are exactly the same shape, one template only being required for each section.

Fig. 63 shows an arch of this description which is built up on two curves, the complete arch containing three sections—the two at the

haunches, which are alike, and the one at the crown. Two templates are, therefore, needed. The complete arch is struck from three centres, and is termed a *three-centred arch*.

The method of setting out this arch is as follows: Draw the springing and centre lines; set out half the span and the rise; draw a semi-circle on the springing line, with radius equal to half the span; and draw the diagonal AB . With A as centre and radius AC , draw an arc cutting this diagonal at D . Bisect DB . The

so that the effect is likely to be somewhat unsightly.

A symmetrical curve is somewhat difficult to obtain with three centres only in many cases, and a more pleasing curve can be drawn by increasing the number of centres.

Fig. 64 shows a method of increasing the number of centres to five, seven, nine, and so on. In the example five are used, but the principles are similar for any number.

Set out half the span and the rise as before.

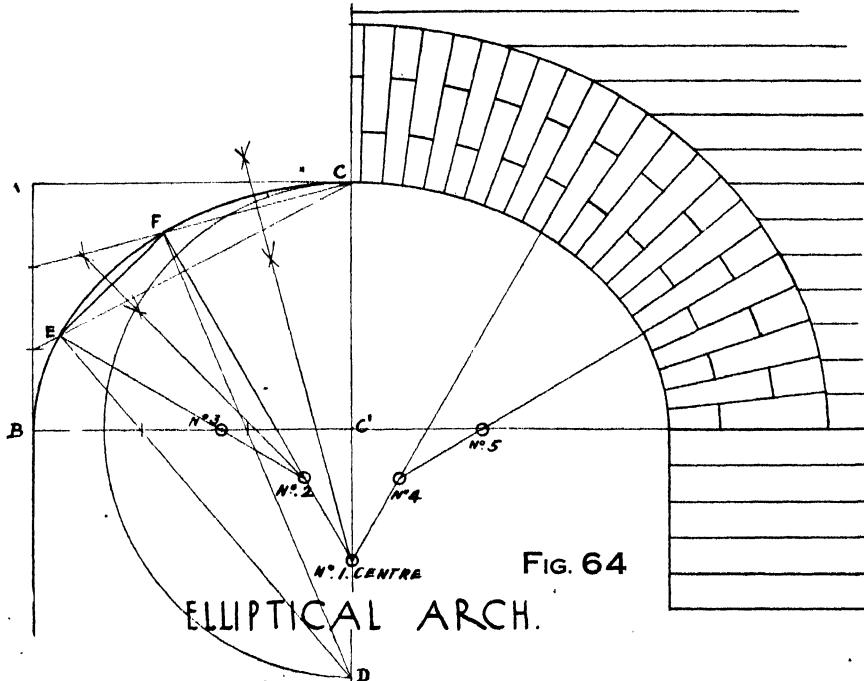


FIG. 64

bisector produced will cut the springing line at E , and the centre line at F , thus giving the centres from which one-half of the arch is drawn. To complete the arch, mark off the third centre E^1 on the springing line, the same distance from the centre line as the point E . Accuracy is very essential in setting out these arches, if the appearance of a cripple in the curve, where the sections join, is to be avoided.

When dividing the extrados for the voussoirs, it is better to make the divisions at the crown rather smaller than those at the haunches, where the curve is of small radius; otherwise, the width of the voussoirs at the intrados of this sharp curve will be much smaller than those at the crown, and the difference will be very noticeable at the junction of the sections,

Draw lines AC and AB parallel to the springing line and the centre line respectively. For a five centred arch, divide AB and BC' into three parts. (As the number of centres is increased in pairs, so the number of parts is increased by one.) Mark off D on the centre line a distance equal to CC' . Lines drawn from D through the divisions on the springing line, will intersect lines drawn from C to the divisions on AB at E and F . Bisect the line CF and produce the bisector until it cuts the centre line. This will be centre No. 1. Join F to this centre. This will be the boundary line of the section of the arch at the crown. Now join EF , and bisect this line; produce the bisector until it cuts the line F No. 1. This will be centre No. 2. Draw the intrados of these

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two sections, and join No. 2 to *E*. This line contains the second section of the arch, and the point where it cuts the springing line will be the No. 3 centre required to complete one-half of the arch.

curves and drawn from four centres, having the appearance of an ellipse at the haunches.

To set out this arch, proceed as for the semi-ellipse, by drawing the springing and centre lines. Set up the rise and half the span. Draw

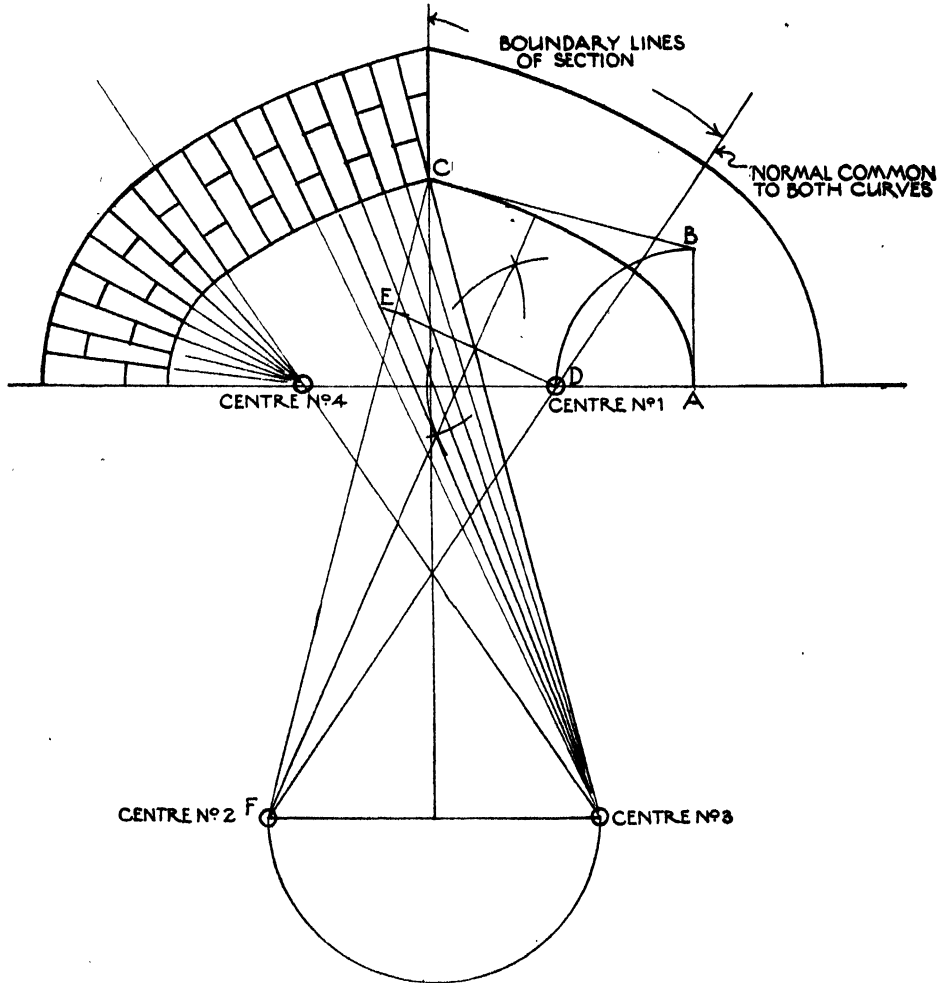


FIG. 65. TUDOR ARCH

(This method of finding No. 3 centre, though near enough for practical purposes, is not quite accurate; see the section on "Builders' Geometry.")

The remaining two centres can now be transferred to complete the other half of the arch in the manner before described.

Tudor Arch. Fig. 65 shows a pointed arch of the Tudor period; it is built up on two different

a perpendicular at *A* and mark off two-thirds of the rise on this line. Join up this point *B* with *C*. With *A* as centre and *AB* as radius, draw an arc cutting the springing line at *D*, which is centre No. 1. From *C* draw a line at right angles to *BC*. Make *CE* equal to *AB*, and join up these points by the line *DE*. Bisect *DE*, and produce the bisector until it cuts the line from *C* at *F*, which is centre No. 2.

From *F* draw a line passing through *D*. This is the boundary line of the two sections forming one-half of the arch, and is normal to both curves. With *D* as centre and *DA* as radius, draw the arc forming the haunch, which finishes on the boundary line. Complete the arcs which

the load is distributed along the foundation by means of a series of inverted arches built in half-brick rings, as shown in Fig. 66. In this case, the load is transmitted down the piers. Part of the load passes to the base of the piers direct, and part to the abutments of the arches,

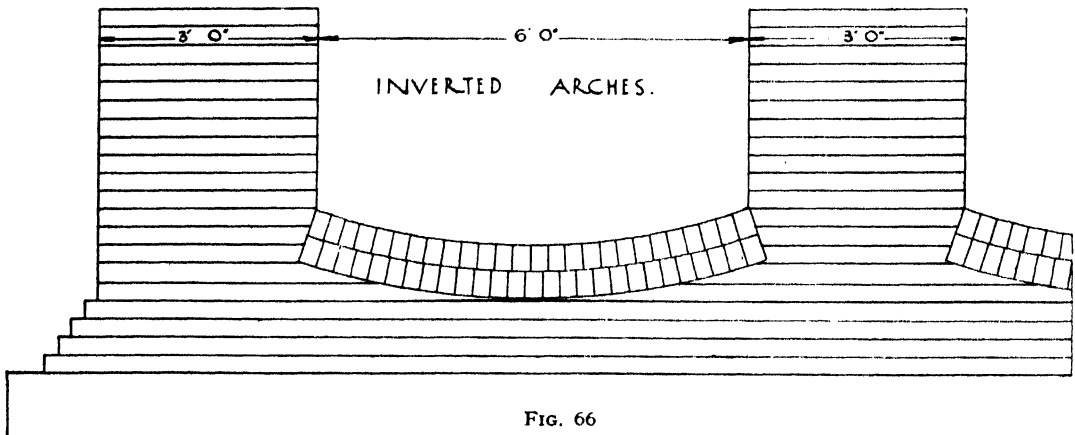


FIG. 66

finish on the centre line, using centre No. 2. These two centres can now be transferred to the opposite sides of the centre line, and the whole arch completed as before. Two templates will be required for this arch.

The foregoing examples, thoroughly under-

and from thence along the arches to the foundations. These arches act also in the capacity of cross braces to prevent shear, or sliding, movement.

The arches are usually constructed with the inverted crown resting in the top course of the

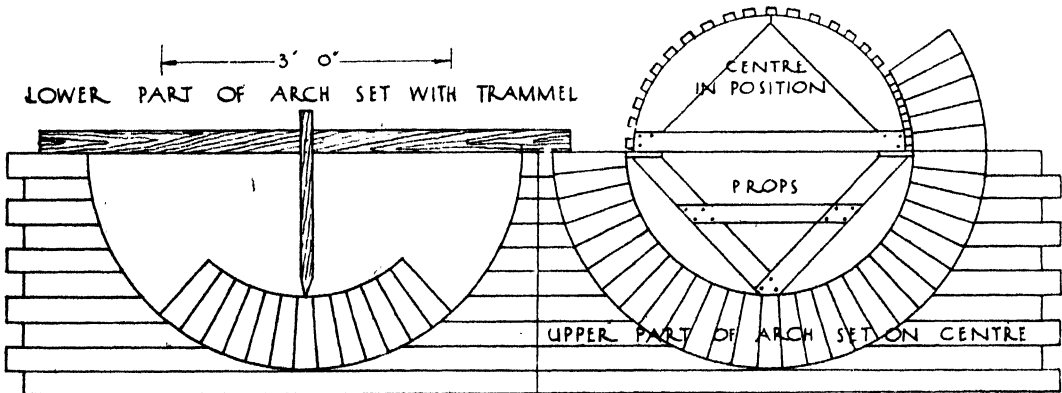


FIG. 67. BULL'S-EYE ARCH

stood, should enable the young craftsman to set out any ordinary type of arch built up on a combination of different curves.

Inverted Arches. Where a heavy portion of a building is supported on a number of isolated piers, and the foundation is a continuous beam,

footings. They are occasionally constructed in the footings themselves, but not often. The shape of the invert is cut in the bricks by means of a wooden template as the wall is built, a smaller mould being used for the arch. This mould is applied frequently to ensure that

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the arch is built symmetrical and correct in shape.

Bull's-eye Arches. Circular windows are frequently used as an architectural feature. The setting out of these is only a repetition of the semicircular arch. The building of the lower half needs some explanation. When the wall has been built level with the lowest curve of the arch, the width of the opening and its centre is marked on the wall. Each course is then racked back on either side of the centre, to allow sufficient room for the construction of the arch. A temporary timber is bedded across this rough opening, approximately half its depth above and half below the centre line of the arch. The centre of the bull's-eye is then marked on the timber, and a screw inserted to carry a trammel, or light rod. The length of this rod from the screw is equal to the radius of the extrados of the arch.

The bricks forming the inverse of the extrados are cut to shape and built in to this trammel, ready for the bottom half of the arch. The trammel is then shortened by the depth of the arch ring, or rings, as the case may be, and the lower half is built, using the trammel as a guide when bedding the bricks.

For the upper part, an ordinary semicircular centre is set in position resting on timber props, and the arch completed in the usual manner.

Fig. 67 illustrates these operations, and should be quite clear to the student. It is necessary to be very accurate in fixing the centre for the upper part, so that a perfectly continuous circle is formed by the two halves. Nothing looks worse than a crippled intrados or a flattened opening when the centre is removed.

THE NICHE

In the thick walls of many large public buildings and mansions, circular recesses, or, as they are termed, *niches*, Fig. 69, are formed. There is no doubt that originally the purpose of these recesses was to contain statues or other works of art, though it is no uncommon thing for them to remain empty.

Several very good examples of niches can be seen in the courtyard facing the entrance to the royal apartments at Hampton Court Palace, also on the right and left-hand sides of the archway leading in from the lawns, and at the sides of the terrace leading to the King's garden.

The construction of a niche in brickwork was at one time considered to be the supreme test

of a man's capabilities as a craftsman, and still remains so with many of the older men. It is somewhat difficult in this era of technical education to reconcile this idea with the methods now used in the construction of this piece of work.

The processes have been simplified to such an extent that, having mastered the simple elements of geometry and their application, the student should experience little difficulty in setting out a niche and preparing the moulds. The actual cutting is practically mechanical, and does not require a great amount of skill.

This actual piece of work has been accomplished by some of the writer's junior students,

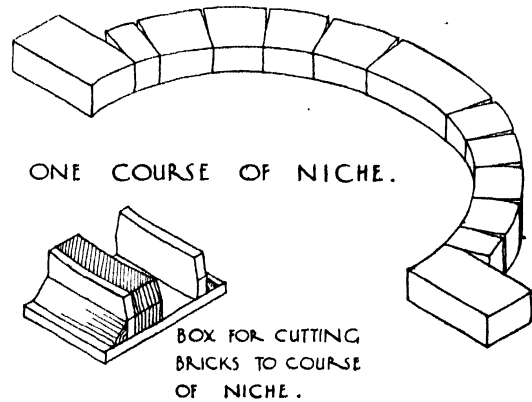


FIG. 68.

boys of from 15 to 17 years of age, in the second and third year of their training, the work being very creditably executed. At the same time, the work involved—setting out, preparation of the moulds, cutting and setting—is undoubtedly of great value to the student, giving him a clearer insight into the principles of applied geometry, accuracy in setting out, and it disposes of many of the difficulties of gauged work which present themselves to the young craftsman. Having once executed this particular job in its entirety, he is not likely to experience stage fright when confronted with even more difficult tasks in this branch of the industry. There will be few jobs that he will find himself unable to reason out and to evolve a method of executing, even if his methods be not quite orthodox.

In describing the various operations it will have to be assumed that the student has studied the geometry section of this work, or has acquired this knowledge from some other source. If not, he should do so. Simple as the explana-

BRICKWORK

tions may be, it will be practically impossible to understand them thoroughly without this knowledge.

Setting Out. In the first place, set out the plan, and arrange the bonding of the alternate courses in English, or Flemish bond, as the case may be.

As the work will be rubbed down at completion, the ends of the bricks forming the perpendicular joints will have to be cut normal to the

curve, so that a close butt joint will be formed to a depth of at least $1\frac{1}{2}$ in. from the face of the work. If it were not, these heading joints, as they are called, would become wider as the surface was rubbed away in cleaning down the work at completion, and be out of proportion with the bed joints.

From details of this plan a cutting box is made large enough to cut two stretchers at one operation, the sides of this box being cut to the

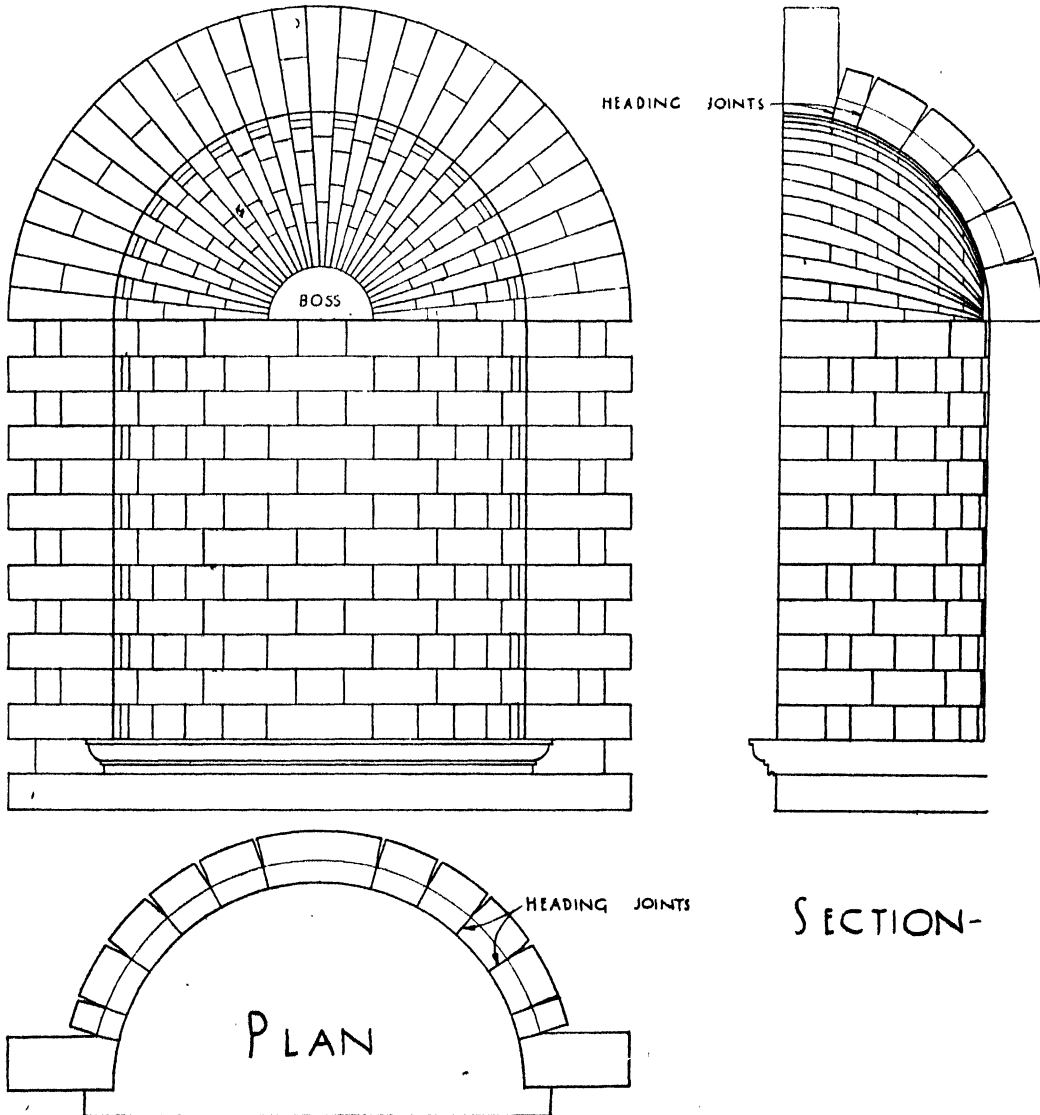


FIG. 69. A BRICK NICHE

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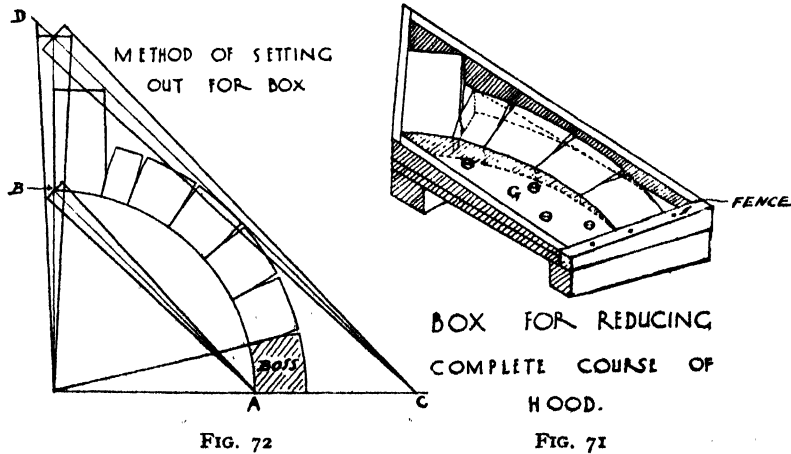
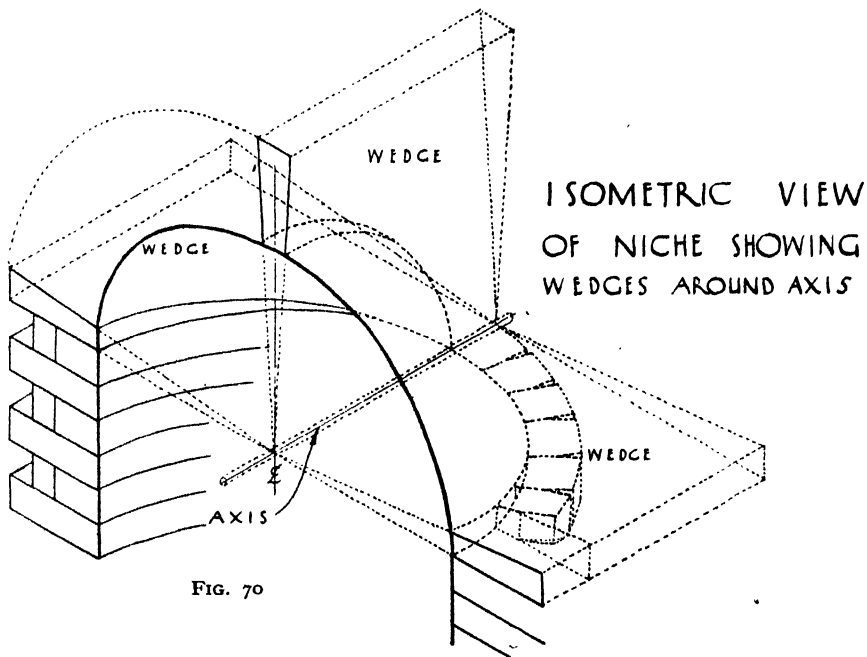
curved shape of the brick as drawn on the plan (see Fig. 68).

For the body of the niche, a parallel reducing box will be required to cut the bricks to the required depth of the course.

Cutting the Body of the Niche. Bed the bricks and square one face. Place them in the box with

circular sides, their faces resting on the base board, and their beds against the sides of the box; wedge them tightly in position, and cut to shape by working the wire saw across the two edges of the box. Headers and closers can be cut in the same box.

We have now to consider the most difficult



part of the job, the cutting of the dome-shaped hood of the recess.

Draw the elevation of the body, and at the springing line set out the face arch, which is an ordinary semicircular arch. Produce all the bed joints to meet the centre, as they are also the bed joints of each course of the hood.

It would be practically impossible to cut each course to the acute point where it meets the centre. To overcome this difficulty, a small semicircular boss is formed at the base of the hood, against which all the radial joints abut.

It is not absolutely essential for the purpose of the work to draw a vertical section through the centre of the hood, as shown in Fig. 68. By doing so, however, the student will gain considerably in his knowledge of drawing and geometry, and get a much clearer idea of what is required in the actual work.

Having drawn this elevation and section, the student will be able to see that each course of the hood is contained within a wedge, a frustum of which can be considered as the key.

Imagine this wedge standing in the position of the key of the arch, having its edge hinged to a rod set in the centre of the boss, and acting as an axis about which the wedge can rotate. This wedge will represent any course of the hood when its two sides are coincident with the radials, or bed joints, of the arch as it is rotated. Fig. 70 shows this wedge in the first position, also when it is lying on the springing line. In the latter an actual course of the arch is shown by dotted lines.

If we make a reducing box with its sides the shape of this wedge, we can reduce a complete course of the hood at one operation.

It is not necessary to make this box the full width of the wedge. Generally the size of the recess is too large to do this, as the box would be too wide to work the bow saw across its edges. If we take across the wedge a diagonal section that will just contain the required course, and construct the box to the section, as

shown in Fig. 71, the box will be narrow enough to work the bow saw across its width.

To set out this box, draw one course of the hood, and from the point *A* draw a line through the point *B*.

Draw *CD* parallel to this line, and at a distance sufficient to clear the outside edges of the bricks. Produce the lines of the key until they intersect *CD*. Through the points *B* and *D* draw lines at right angles to *AB* and *CD*.

With centres *B* and *C*, rotate the widths at top and bottom of the key on to these lines. Lines drawn from the points *A* and *C* and meeting the extremes of these widths will give the shape of the templates for the sides of the reducing box. The lines *AB* and *CD* will give the positions for fixing these sides to the base board of the box (see Fig. 72).

Fix in the bottom of the box a wedge-shaped piece of board cut to the curve of the niche, as shown at *G*. Test this with a straight-edge across the top of the box, to see that it does not stand above the edges of the sides. Fix a fence across the end where the courses finish against the boss, and the box is complete.

Cutting the Hood. Cut the curved face of the bricks in the box previously described. Set a shifting bevel to the soffit bevel, as in the case of an ordinary arch, and bed the bricks so that the curved face and the bed fit the stock and blade of the bevel, when applied in the same manner as the square when bedding and facing a brick in the usual way.

Note. The curved face of the wooden fence in the bottom of the reducing box must also have this bevel worked on its inside edge, so that when the prepared bricks are placed in the box their curved surfaces will fit against the surface of the fence.

Lay out the complete course of bricks in the box, wedge them tightly in position, and cut across the edges with the wire saw, finishing the cut surfaces with a flat file as before. Fig. 71 shows one course of the hood reduced in the box.

Chapter VII—GAUGED AND ORNAMENTAL BRICKWORK

WHERE a superior finish in the details of an important brickwork elevation is required, such as moulded reveals, arches, string courses, and other forms of ornamentation, soft rubber bricks are used for these particular features of the work. These bricks are capable of being cut with a wire saw, rubbed to a fine face with clean sharp arrises on the rubbing stone, and set with a $\frac{1}{8}$ in. joint.

For plain face work of this type, one bed is brought to a true surface on the rubbing stone, and one face worked square with this bed. The brick is then ready to be reduced to the exact length and depth required. For this purpose, a box is constructed with a base board, to which two sides, the exact length and depth of the brick, are fixed perfectly square. The width

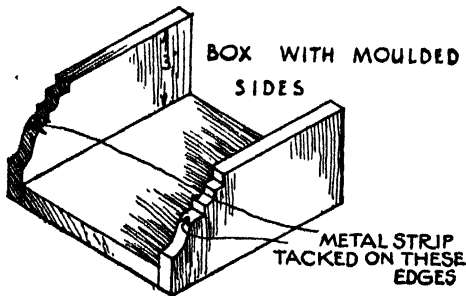


FIG. 73. BOX WITH MOULDED SIDES

of the box is usually made to accommodate two bricks with a small space between them for wedging. The prepared bricks are placed in the box, with the face resting on the base board, the surface of the bed against the sides, and wedged fairly tight. They are reduced to their true size and shape by sawing across the box with the wire saw, keeping the wire tight against the edges. The cut surfaces are finished with a flat file, care being taken to work the file towards the arrises and not away from them, otherwise clean sharp arrises cannot be obtained, as the file cuts will drag the edges away.

The operation of rubbing a true surface requires some practice, and a few hints in this respect are necessary before proceeding any farther.

The rubbing stone itself should have a per-

fectly true surface. If rounded, or hollow, accurate work is practically impossible. It should be tested for trueness with a good straight-edge before commencing operations.

The surface of the brick is rubbed on the stone with a circular motion from right to left, the whole surface of the stone being covered in the motion, otherwise the stone will wear hollow. A slight pressure, equally distributed over the whole of the brick, is exerted during the process.

The young operative, during his first experience of this work, will find some difficulty in distributing this pressure equally. The tendency will be to rock the brick slightly, producing a rounded surface, or to run the brick down at one corner. In time he will get what is called the "feel" of the brick, and will automatically vary the pressure on any particular part of the brick, according to his requirements.

The first operation of bedding is fairly simple. Test the surface from time to time with the blade of the square, until it is true along and across the bed. The second operation of squaring the face with the bed is rather more difficult, and considerable practice will be required before this process is accomplished with any rapidity.

In testing the face, the stock of the square is placed against the prepared bed, with the blade across the face. Now hold the brick above the level of the eye in a slanting position, looking along the surface of the face towards the blade of the square. Draw the square towards you; any inaccuracy of the face will be noted by light under the edge of the blade, where it does not touch the rubbed surface of the brick. A few more rubs on the stone with a slight pressure on that side of the brick, touched by the blade of the square, will be required. This operation must be repeated until the stock and blade of the square are in contact with both prepared surfaces, as it is moved along the whole length of the brick.

The next process is to reduce the brick to its exact size and shape in the box, as previously described.

It is obvious that repeated sawing across the edges of these boxes would rapidly wear away the wood, with the result that the size and

shape of the finished bricks would ultimately become inaccurate.

To prevent this, a strip of metal is tacked round these edges, and replaced as it becomes worn.

The best metal for this purpose, if it can be obtained, is a piece of an old clock spring, the temper of which can be easily removed by heating to a cherry red, and allowing it to cool slowly. Small holes for the tacks can then be punched in it with a bradawl, and it can easily

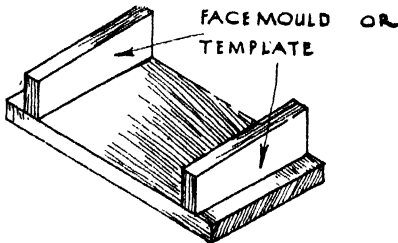


FIG. 74. TAPERING REDUCING BOX FOR ARCHES

be bent round the corners of the box, or the members of fine mouldings. See Fig. 73.

Another precaution for the young operative to observe refers to the handling of the finished bricks. The keen arrises to which the edges of the bricks are brought are easily destroyed by careless handling. In picking up a cut brick, the weight should be carried by the ball of the

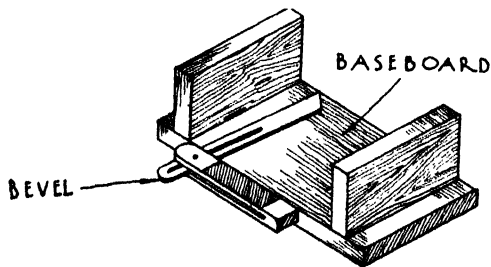


FIG. 75. MARKING SOFFIT BEVEL ON BASEBOARD

thumb and the tips of the fingers, taking care that the web of the hand—or, for that matter, any other part of the hand—between the thumb and forefinger is not touching the arris of the brick.

In the cutting of arches, the reducing box is made with its sides the exact shape of the finished voussoir (see Fig. 74), prepared from the template after the arch has been set out and traversed as described.

The operations are bedding and squaring one

face, and soffitting the brick. The latter operation means putting the soffit bevel on the prepared brick. This bevel is sometimes worked on the rubbing stone. The simplest method is to take the bevel from the template, and transfer it to the base board of the box. See Figs. 75 and 76. Now stand the bricks in the box with their faces resting on the base board, and the arris of bed and face in line with the bevel marked thereon; cut across the ends of the box with the wire saw, finishing the surfaces

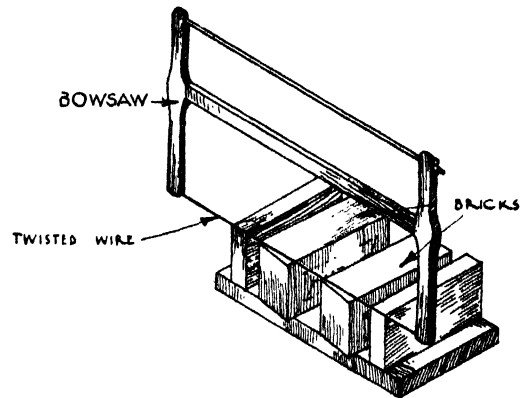


FIG. 76. CUTTING SOFFIT BEVELS IN BOX

with the file. The bricks are now ready to be reduced to the wedge-shape of the voussoirs in the same manner as described for plain face work.

SETTING

Making the Putty. Gauged brickwork is usually set with *lime putty*. This is prepared by slaking greystone lime in a tank or bin. Chalk lime should not be used for this purpose. The method of preparation is to half fill the tank with knobs of fresh lime, and cover them with water. When the slaking process commences, and the water begins to bubble and boil, stir the whole mass with a stout piece of narrow board, until it becomes a creamy fluid, adding more clean water when necessary. This *slurry* is passed through a fine sieve, the meshes of which are $\frac{1}{8}$ in., or even less, and left to stand for several days before being used, to ensure that there shall be no unslaked particles of lime.

The surplus water can be drained off as the lime precipitates. After a few days it stiffens to the consistency of lard, and can be cut out with a trowel, or clean shovel, when required for use, water being added to bring it to the

MODERN BUILDING CONSTRUCTION

requisite consistency. The tank should always be kept covered by damp sacks to prevent the surface of the putty drying, and to keep out dirt and grit.

Setting the Bricks. Small rectangular troughs, about 15 in. square and 10 in. deep, are used to hold this material. These are either placed on a small bench on the scaffold, or on a board slung between two scaffold poles, about waist high. The bricks are dipped in a bucket of water until sufficient water has been absorbed, to prevent the lime setting before they have been set in their proper position. The bed of the brick is then dipped in the lime, gathering sufficient to form the joint.

The brick is rubbed with a sliding motion into position, a final tap with the trowel being all that should be necessary. As the brick is rubbed into position, a small bead of lime is squeezed out of the joint beyond the face of the work. This bead should be left until the work is finally cleaned down. If an attempt is made to remove it while wet, the lime will spread over the face of the bricks, and the appearance of the work will not reflect any credit upon the craftsman. Apart from this, it entails much more labour to remove the traces of this smearing when cleaning the work down at completion.

At first it is somewhat difficult to judge the right amount of soaking that is necessary before dipping the brick. If it is allowed to get too wet, it will not pick up a sufficient thickness of the lime to form a bed; if insufficiently soaked, the water is drawn out of the lime, and it becomes too hard to squeeze into position. Experience only will teach the young craftsman the correct amount of soaking, but as a guide the following may be useful: When the brick, which, by the way, should always be kept dry before cutting, is first placed in the water, the absorption takes place with a violent bubbling and hissing noise. Remove it from the water when this violence subsides, and make a trial by dipping it in the lime, to see if it will pick up a sufficient bed, and note how long the bed remains soft.

In dipping, rest the forearm on the edge of the trough to steady it, and float the bed of the brick on the surface of the lime, keeping it as level as possible. If anything, the back edge of the brick should be lowest, care being taken to keep the face edge just on the surface. In removing the brick, draw it towards you, raising it at the same time. This will keep the face

clean, any dripping taking place at the back edge, which does not matter.

Before bedding the brick, scrape away a small portion of the lime from the centre of the bed, just sufficient to allow the bed to spread as it is rubbed into position.

In arch work, a rough groove, or joggle, is cut in the beds of the voussoirs. This is filled in with liquid Portland cement grout when the setting of the arch has been completed.

When setting the voussoirs, the arch should be built up from both sides, the last brick to be set being the key, which should wedge the whole of the voussoirs tightly into position.

Carved Work. Gauged brickwork that is to be ornamented by carving is usually set in a smooth paste, made by mixing dry white lead with shellac varnish, or patent knotting.

This mixture sets rapidly and soon becomes very hard, and the carving can be accomplished without fear of any small corners falling out where the carving cuts across the joints, or corners, of the bricks. This material is so tenacious that work set with it cannot be taken apart, the brick itself parting before the joint will give way.

ORNAMENTAL BRICKWORK

A few examples of ornamental brickwork are shown in Figs. 77 to 82. The old sixteenth-century chimney stacks, Fig. 77, provide a very fine example of ancient craftsmanship. Many types of these chimneys can be seen at Hampton Court Palace, which is well worth a visit. Later examples of *herring-bone*, *basket weave*, and *checkerboard* patterns are shown in Figs. 78, 79, 80, and 81, executed with plain uncut bricks. In some cases, in order to accentuate the pattern, the bricks are of various colours. The herring-bone and basket weave patterns were much used for filling in the panels between the beams in the half-timbered work of the sixteenth century, and at the present time are used as ornamental features in the panelled walls of many brick buildings, in the tympanum of arches, and in ornamental pavings.

Fig. 82 shows a quite modern example of ornamentation with plain bricks. The quoins of the reveals, the borders of the panels, the arches, and the patterns being in light-red facings, the filling being executed in a darker type of multi-coloured bricks of a purplish tone.

Innumerable examples of ornamentation could

be described. Sufficient examples have here been illustrated to give the student some idea of the possibilities of brick as a material for decoration, and with a little consideration he should be able to work out many pleasing designs for himself.

TERRA-COTTA

Terra-cotta is manufactured from refractory clays found in many parts of Staffordshire, Devonshire, Dorsetshire, Northamptonshire, and Cornwall. These clays vary considerably in their composition, which largely affects the colour of the terra-cotta, and also affects the process of manufacture. Some contain a considerable proportion of oxide of iron, which in the presence of alkalis, such as lime and magnesia, tend to fuse when subjected to very high temperatures. A large proportion of oxide of iron affects the durability and hardness of the finished material.

Terra-cotta manufactured from some of the highly refractory clays, when carefully dried and burnt, is generally good both in texture and colour. Most of them, however, require mixing with a proportion of the less refractory clays, which contain a larger proportion of lime and other alkaline impurities; a certain amount of these impurities is necessary to act as a flux, so that when the maximum temperature is reached in the kiln, the outside surface of the block will vitrify to a sufficient depth to form an efficient protective outer skin, capable of resisting the action of the acids contained in the gases of a town atmosphere.

The durability of this material depends chiefly upon this outer skin, and it should be free from fire cracks, small holes, chips, and blisters. Under no consideration should this face be chiselled, as its destruction leads to the rapid disintegration of the material in the interior of the block, the resistance of which to atmospheric influence is very small.

The greatest difficulty in the manufacture of this material is the calculation of the shrinkage that will take place during the drying and burning, and which varies with the different clays. There is also its liability to warp and twist during these processes. To overcome these difficulties, ground pottery, glass, terra-cotta waste, and sometimes sand, is added to the clay. The whole is ground to a very fine powder, mixed into a slurry with water, and finely strained. When stiffened by evaporation, it is kneaded and forced into prepared moulds.

Much labour is expended in the making of

these moulds, which have to be first modelled large enough to allow for shrinkage, and a cast taken from the model.

The cast is coated with soft soap, to make the removal of the block easy. The block is carefully dried in a uniform temperature, and then burned slowly in a kiln, the temperature of which is raised very gradually to a very high

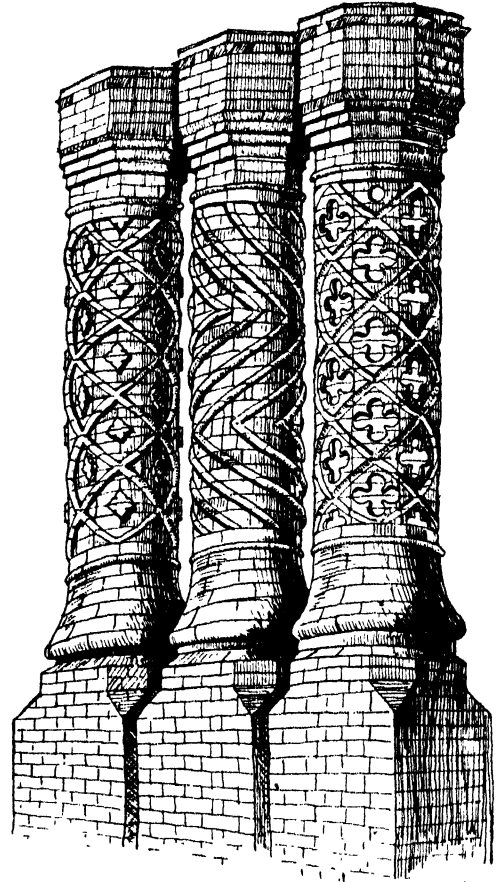


FIG. 77. ORNAMENTED CHIMNEYS
Sixteenth Century

degree. If subjected to draughts during the drying process, or if the drying be too rapid, the block will warp and twist.

The size of the blocks should not exceed 4 cub. ft., preferably from 1 cub. ft. to 3 cub. ft. The blocks are made hollow, with diaphragm partitions to strengthen them and prevent distortion, the thickness of the material varying from 1½ in. to 2 in. Terra-cotta is exceedingly strong and light and, generally speaking,

MODERN BUILDING CONSTRUCTION

is much cheaper than the best qualities of building stone, particularly when the stone is to be carved.

The colour is white, buff, light grey, and varying shades of red. Terra-cotta can now be obtained with glazed surfaces in many art colours.

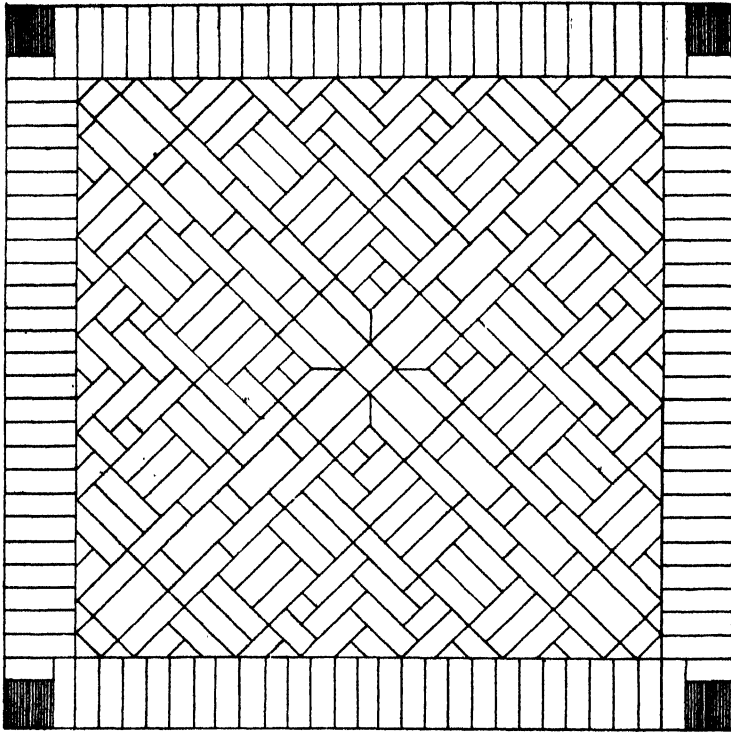
Much inferior material has been manufactured by using inferior clay, cased with a superior material. Inequality of shrinkage causes these two shells to part, forming hair cracks into which the rain and frost penetrate, destroying the face, and leaving the interior exposed to the action of the atmosphere, resulting in rapid destruction. Another reprehensible method was to paint the block with a wash of fine ochred clay previous to burning.

Fixing. The blocks are always more or less warped and twisted and their surfaces in winding. This is where the eye trained for line and level counts. The fixer will need to exercise this faculty to a large extent when the work is moulded, such as in cornices, string courses, architraves, etc., as he will find the line level and straight-edge of not much use by themselves. The excellence of his workmanship will depend chiefly upon the judgment of his vision and the amount of artistry that has been inculcated in him during his early training. In most cases, where there is any quantity of ornamental work, he will be provided with fixing diagrams for the different details, with the blocks numbered thereon.

A word of advice to the young craftsman, should he be in charge of the whole job, is to get in touch with the manufacturers as early as possible, and arrange to get the blocks delivered as they will be re-

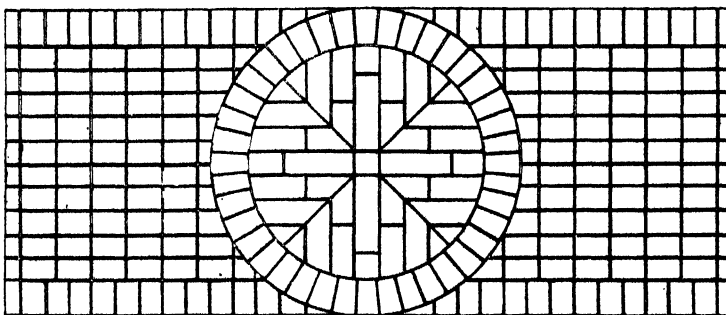
quired. Deliveries of blocks in proper order are generally very uncertain, the cause of much delay, and consequent expense.

The hollows in the blocks are filled with Portland cement concrete where any loads are



HERRINGBONE & BASKETWEAVE PANEL.

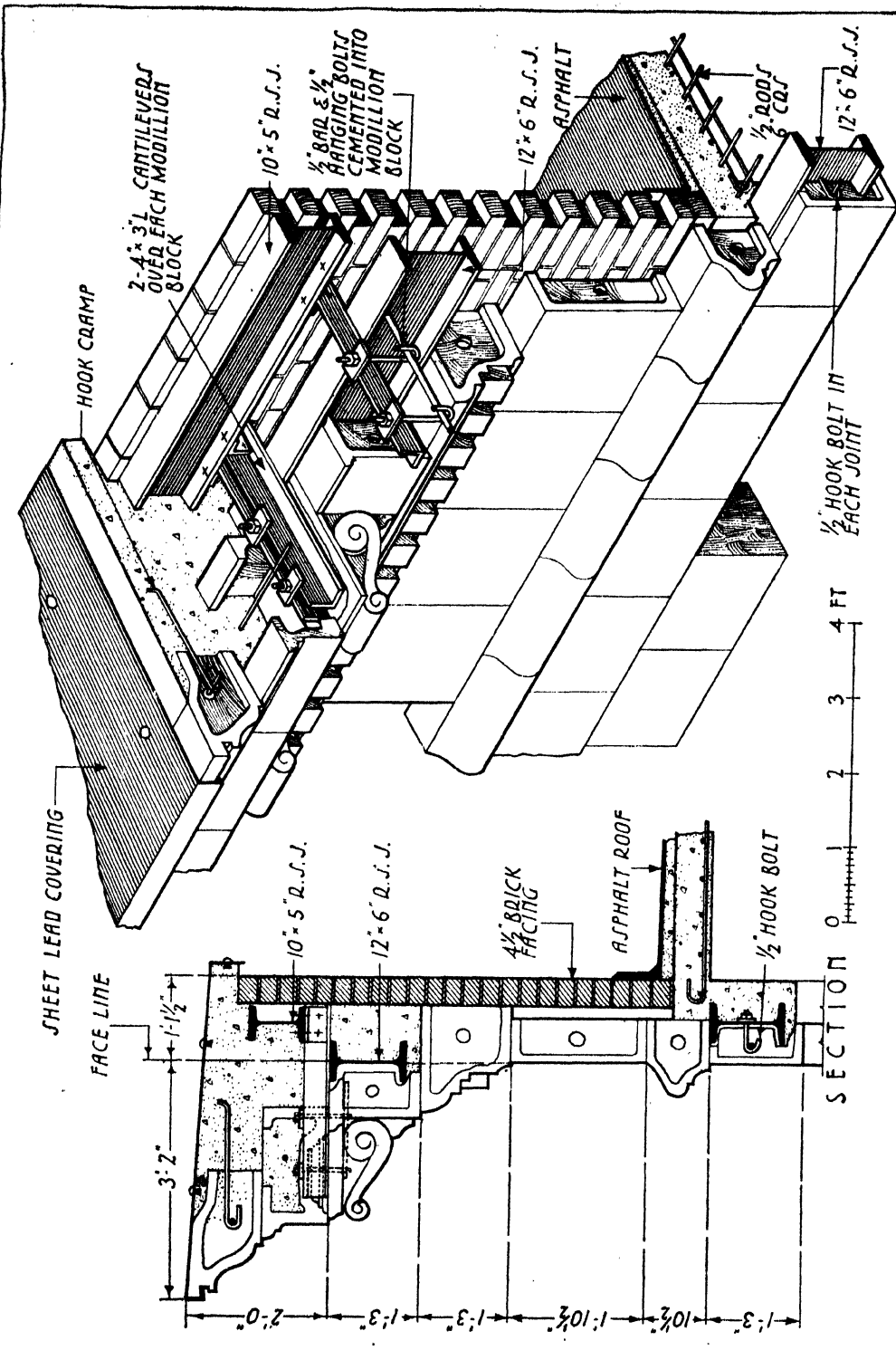
FIG. 78



CHECKER PATTERN.

FIG. 79

In designing work with much ornament, considerable economy can be effected by introducing as much repetition as possible, thereby saving the cost of constructing many different moulds.



TERRA-COTTA CORNICE

E. G. W.

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to be supported by them, or where they have to withstand any pressure. The aggregate of this concrete needs to be perfectly clean, otherwise it will cause disfiguring stains to show on the face of the terra-cotta. For this reason, broken brick, or terra-cotta, is preferable to ballast.

EFFLORESCENCE

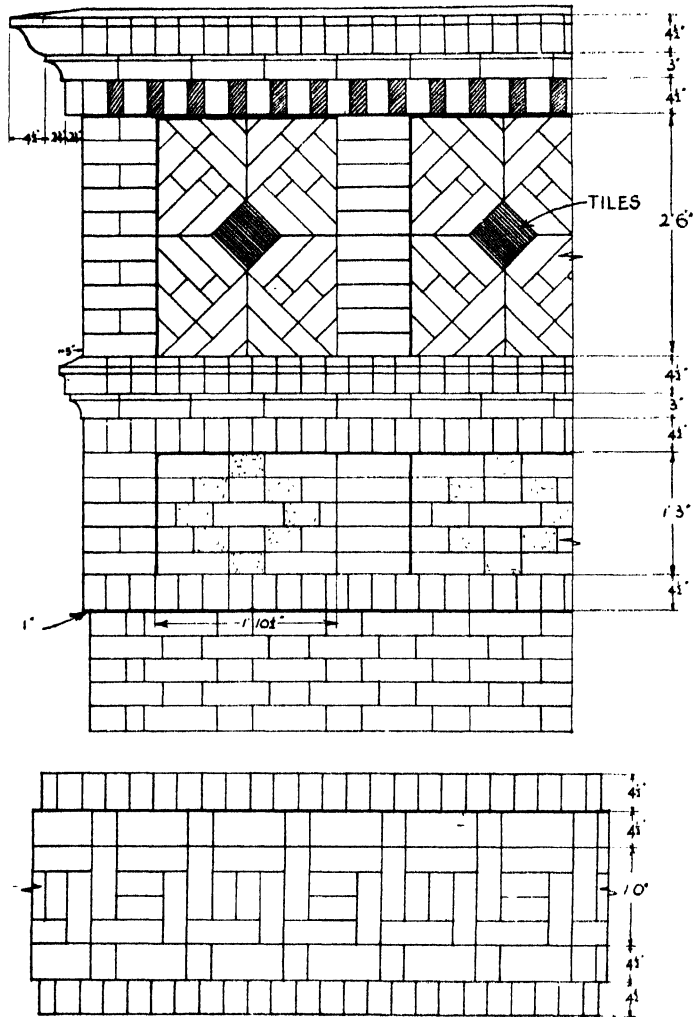
Cause of Efflorescence. The unsightly salting that occurs on the face of many newly constructed buildings, and which periodically makes its reappearance during the hot, dry weather for several years after the building has been completed, has been the subject of much controversy and research, in an endeavour to ascertain the cause, and to find a preventive, or cure. Practical experience goes to show that this salting occurs more with the porous sand-faced type of bricks than with the denser types of smooth-faced pressed bricks. It is also present in a much greater degree where lime mortar is used than it is with Portland cement mortar.

If this salting is examined, it takes the form of a dry white powder, or fibrous needle-like crystals, which on analysis proves to be composed of the following salts: Sulphate of soda (Glauber salts), sulphate of magnesia (Epsom salts), or lime, and in some cases chlorides of soda and potash.

The latter are usually present in the salting that occurs in exposed buildings near a sea-front, or where the brickyards are in close proximity to the sea. This is probably due to the presence of chlorine in the brick earth or in the atmosphere.

It would appear that these various salts are contained within the brick itself, or absorbed by the brick from the mortar. The cause is, therefore, attributable to either the composition of the mortar or the bricks, probably both. If the pores of the bricks are considered as a mass of very fine tubes, the process of salting might probably

be demonstrated on the following lines. If a fine tube is filled with a salt solution, one end of this tube being exposed to the open air and the other end in a saturated atmosphere, the



BRICK FRIEZES.

FIG. 80

surface of the solution at the open end assumes a hollow form, the solution being flush with the mouth of the tube at its edges only. It is around these edges that crystallization takes place and deposit occurs as the water is evaporated.

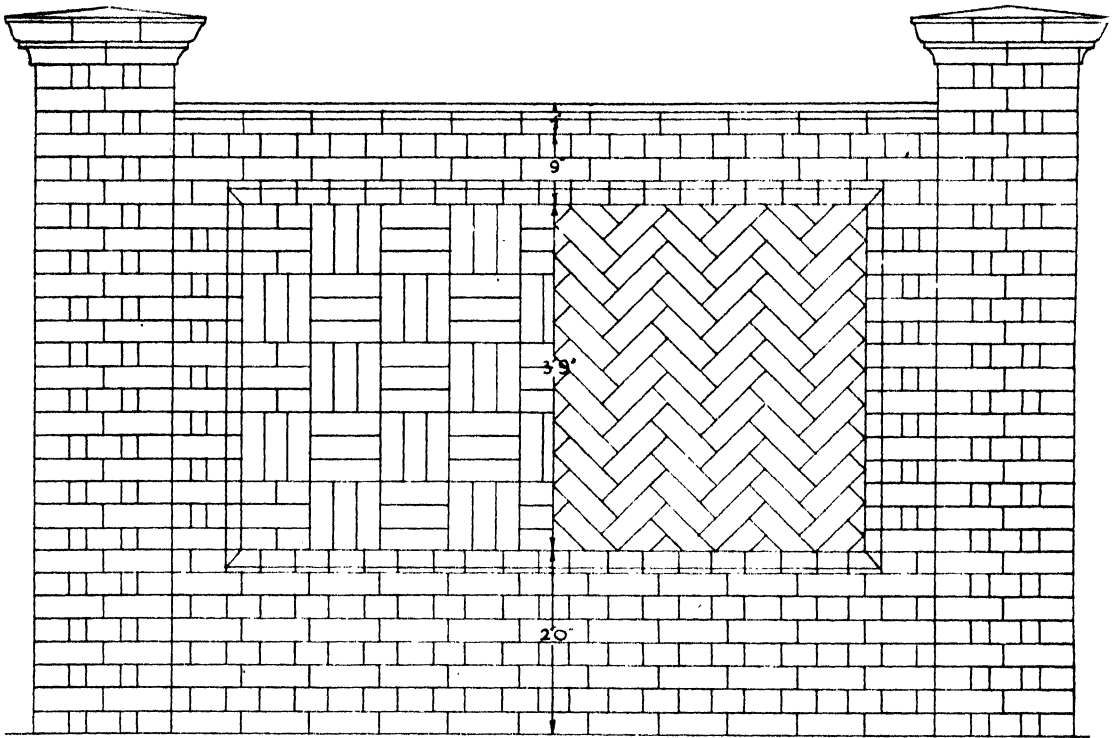
When the bricks are wetted by immersion, as

BRICKWORK

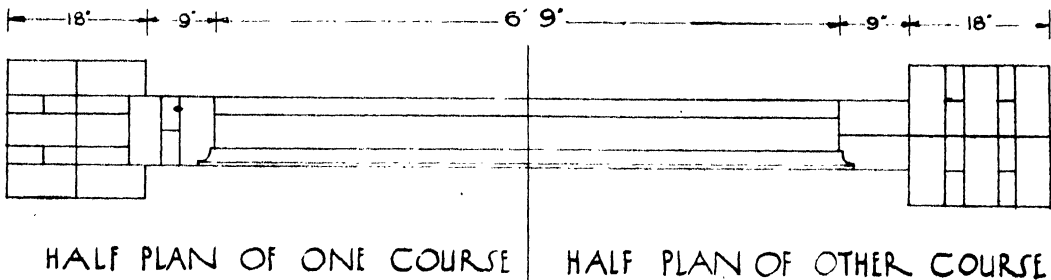
during building operations, or by driving rain, these tubes absorb and convey the water into the interior of the brick. The oxygen in the

by evaporation, and the salts deposited as described.

Brickwork at the base of walls, built in



ELEVATION SHOWING HERRINGBONE & BASKET WEAVE PANEL



HALF PLAN OF ONE COURSE

HALF PLAN OF OTHER COURSE

FIG. 81

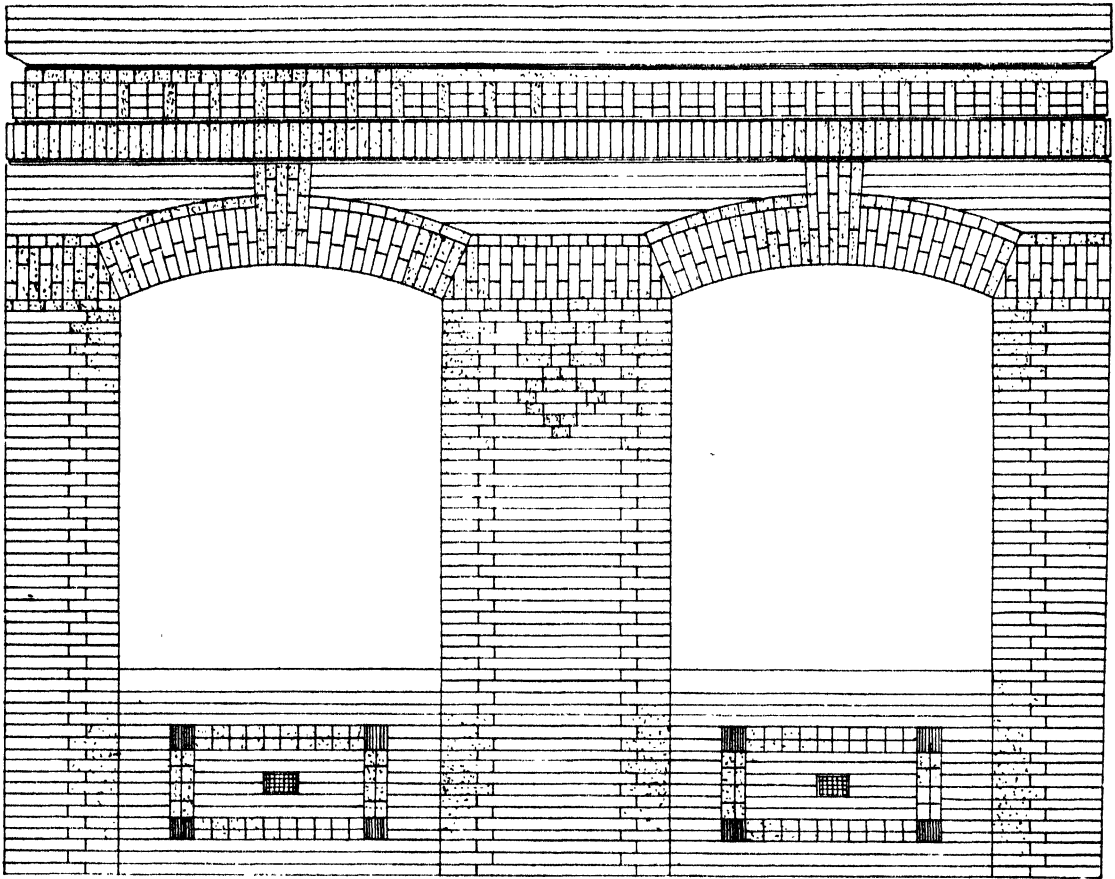
water attacks and decomposes the various salts in the interior of the brick, the water becoming saturated with them. During the dry weather the moisture is drawn to the surface of the tubes

situations where the ground water is impregnated with salts, are affected badly with this efflorescence below the damp-proof course. This goes to prove that much of the deposited salts

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have first been absorbed by the bricks. Probably this is what occurs largely with respect to the mortar with which walls are built, and would lead to the assumption that the cause lies

was the postponing of the evil, and a certain amount of damage to the face of the bricks, a portion of their surface being destroyed when the scaling took place.



MODERN BRICK ORNAMENTATION

FIG. 82

principally with the composition of the mortar. It would be very difficult to determine which of the two are the predominating cause.

Prevention. The prevention of efflorescence would seem to be in the closing of these pores before the process of crystallization takes place, and many different solutions have been tried, having this object in view, but with very indifferent results. Paraffin wax dissolved in naphtha, or petroleum, has been tried, which after a time dried and scaled off, the salting occurring at a later period. The only result obtained

Two or three washes with a dilute solution of hydrochloric acid, about 10 to 1, gives very good results. The salts are mostly alkaline and they are neutralized by the use of an acid.

Where the cause of the trouble lies in the composition of the bricks, a small proportion of barium carbonate added to the brick earth during manufacture will do much to obviate this salting.

A solution of barium in the water used for mixing the mortar will also minimize the trouble from this source.

Chapter VIII—REINFORCED BRICKWORK

REINFORCED brickwork is brickwork reinforced with steel rods, bars, mesh or steelwork of a suitable section, the object of which is to increase the stability of the brickwork.

Reinforced brickwork in its full sense means a brick building reinforced with steel, in the same way as a concrete building is reinforced. It may include constructing all the floors, beams and columns in the same way.

The construction of reinforced brickwork would appear to some as a relatively new practice; but as early as the eighteenth century, brickwork was reinforced with hoop-iron at the quoins similar to that illustrated in Fig. 31, Chapter II.

Hoop-iron reinforced brickwork was also used by Sir Isambard Brunel in the construction of the Thames Tunnel early in the nineteenth century. He also started experiments with reinforced concrete beams.

Modern reinforced brickwork, based on the same theories as those of reinforced concrete, has its real beginnings in India, where it was necessary to find some method of strengthening buildings subject to the shocks of earthquakes. Sir A. Brebner in 1918, when chief engineer to the Government of India, conducted experiments and tests with reinforced brickwork, the results of which were so satisfactory that they were immediately applied to large-scale government construction in that country. The same method was also extensively employed in the building of universities, banks and commercial buildings all over India. According to published reports of surveys taken some time after such buildings have been subjected to severe earthquake shocks their stability has been unimpaired.

Other countries were quick to appreciate the value of Sir A. Brebner's successes, and the United States of America, Canada, Japan, and later, New Zealand, were soon making a systematic investigation of reinforced brickwork. Since then, the U.S.A. and Japan have carried out a considerable amount of building in reinforced brickwork.

Reinforced brickwork does not seem to have received much recognition in this country, although the various building research departments have made systematic tests and experi-

ments. The second World War occasioned the need for blast-proof air-raid shelters, and doubtless a lot will be learned from the construction of these, and also their possibilities when this type of construction is applied to big building.

Advantages. It has been proved by the tests previously referred to that reinforced brickwork slabs and beams may be designed according to reinforced concrete theory. It can be designed accurately and is as easy, if not easier, to construct than reinforced concrete.

The advantages of reinforced brickwork are obvious. It provides its own surface finish and requires little or no maintenance, while lending itself to greater architectural expression. The formwork and shuttering required for the construction of beams and floor slabs is brought down to a minimum. Vertical shuttering will not be necessary, the bricks forming their own vertical face, and horizontal shuttering will not need to be close boarded. Columns and walls will need no shuttering at all, thus saving a great deal in labour and material.

The generally recognized fire resistance of brickwork can be utilized here to the full. In the mining districts this type of building would obviate much of the trouble caused by the subsidence of the ground, and by reinforcing brickwork with steel rods to form built-in beams (see Fig. 96) it would enable loads to be distributed more uniformly.

By reinforcing brickwork additional strength is given to it. Hence the thickness of some walls could be reduced, giving more floor space and at the same time lessening the weight of the building.

No elaborate plant is required for the erection of reinforced brickwork, only the normal scaffolding and hoisting appliances. The extra time taken in the erection of reinforced brickwork against ordinary brickwork is very small.

Bond Strength. The craftsman will not have to concern himself with the design of the reinforcement in this type of building; that is the job of the engineer or architect. What will concern the bricklayer will be the actual laying of the bricks to obtain the maximum bond strength. This means the greatest possible adhesive quality between brick and mortar.

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Bond strength is the controlling factor in erecting reinforced brickwork as it represents the resistance to shear strain. In Fig. 83 one can envisage a plain soldier arch, not reinforced, the centre portion of which is being subjected to a heavy load. The bed joints on the two sides are not adhesive enough to withstand the load, and the arch is sliding out.

It is obvious that to get this maximum bond strength there must be close contact over the

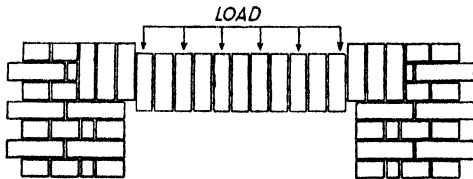


FIG. 83. SHOWING THE FAILURE OF THE BOND STRENGTH OF A SOLDIER ARCH WHEN A CONCENTRATED LOAD IS APPLIED

whole bedding surface of the brick and the mortar. This is most essential in beams and suspended floor slabs.

To obtain it there are several factors that must be considered.

If the bricks are very absorbent they will take from the mortar too much water to allow it to set properly. This disadvantage can be partly overcome by the wetting of the bricks. If the bricks are of the impervious type they will not allow the mortar to impregnate the surface to allow of good adhesion. In this case "grouting," of which more will be said later, is to be recommended. From the foregoing it is clear that a medium absorption brick would be the best type to use. The bricks generally will require wetting, but not soaking too much. It has been proved, in some cases, that if the bricks are brushed clean of dust and sprinkled with water for several minutes it will suffice.

There are already on the market special bricks for this type of work, but it is likely that the manufacture of bricks for reinforced brickwork will become even more specialized.

As to the mortar, cement mortar with the addition of lime or lime-putty has been found to be the best. A good mix would be, 3 parts of sand, 1 part of cement and $\frac{1}{4}$ to $\frac{1}{8}$ part of lime or lime-putty. The lime makes the mortar more workable and plastic; it increases the bond strength, and also enables it to be placed or squeezed round the reinforcing rods more easily. Slaked lime, with its capacity for retaining water, allows the initial set of the mortar

to take place more readily. Lime is also believed to unite with the brick itself in time, and then again cement-lime mortars show less shrinkage on drying out than cement mortars do.

Grouting has been found to give the best results. Its easily flowing nature and moisture-content give the close contact necessary for the bond strength that is not obtained by the spreading of stiffer mortar. Therefore, although grouting is not practicable for walls and piers, it would be general for floor slabs and the like. The interior joints of walls and piers would be grouted in the usual way, but more thoroughly.

The mortar must be tuckered well around the reinforcing rods to exclude the air and so prevent corrosion, and all brick joints must be filled. The mortar should be used soon after mixing, and should accordingly be mixed in quantities sufficient for immediate use.

Methods of Reinforcement. In Figs 84 and 85 simple methods of reinforcing $4\frac{1}{2}$ in. walls are depicted. In the first method "purpose-made" bricks with holes in the centre would have to be obtained, although a hollow "Cellular Fletton" which can be easily holed by the bricklayer

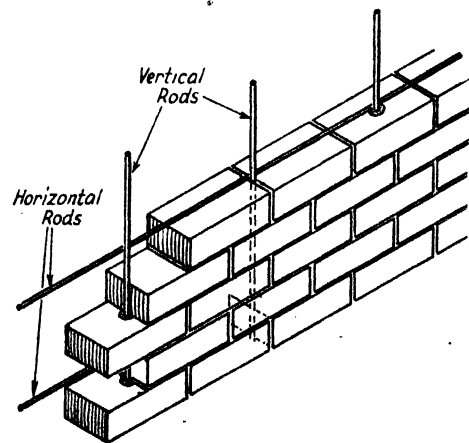


FIG. 84. HALF-BRICK WALL REINFORCED WITH STEEL ROD

can be used, provided the crushing strength of this type of brick is high enough to carry the weight, if any, for which the wall is designed. The vertical rods would have to be cut in about 7 ft. lengths and lapped about 1 ft. 6 in., as the bricklayer would not be able to reach much above 7 ft. for threading the holed bricks over.

The vertical rods would be anchored at the top to a beam, or to the ceiling, and, at the bottom, to the top of a beam or to the floor.

BRICKWORK

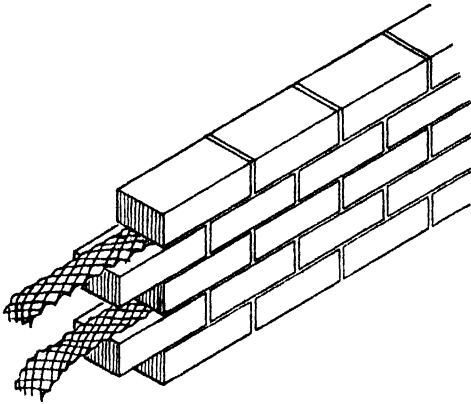


FIG. 85. HALF-BRICK WALL REINFORCED WITH STRIPS OF EXPANDED METAL LATHING

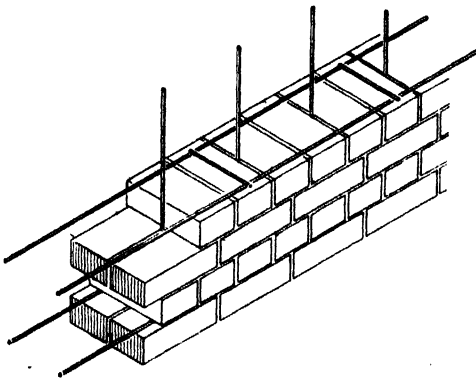


FIG. 86. REINFORCED ONE-BRICK WALL IN ENGLISH BOND

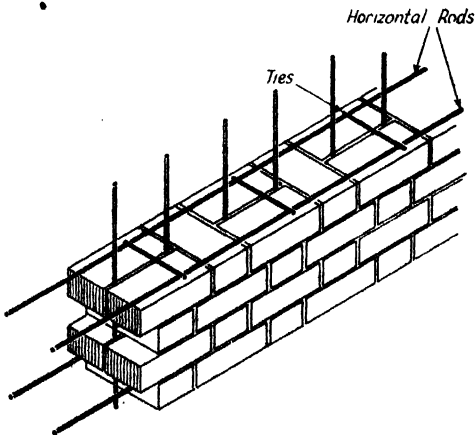


FIG. 87. REINFORCED ONE-BRICK WALL IN FLEMISH BOND

The horizontal rods will be anchored to piers or columns.

The second illustration explains itself. Strips of expanded metal lathing are laid in the bed

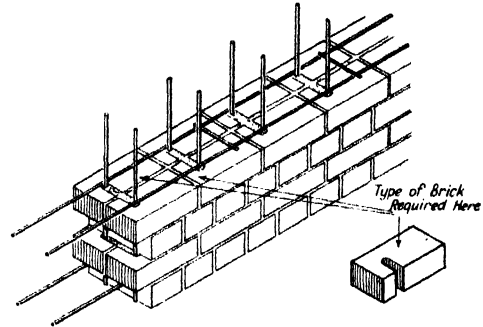


FIG. 88. REINFORCED ONE-BRICK WALL WITH SLOTTED STRETCHERS

joint of every second or third course and anchored at the sides to piers or columns.

In Figs 86 and 87 are two ways of reinforcing 9 in. walls in English and Flemish bond. In both cases the vertical rods pass through the vertical wall joints and standard bricks can be used,

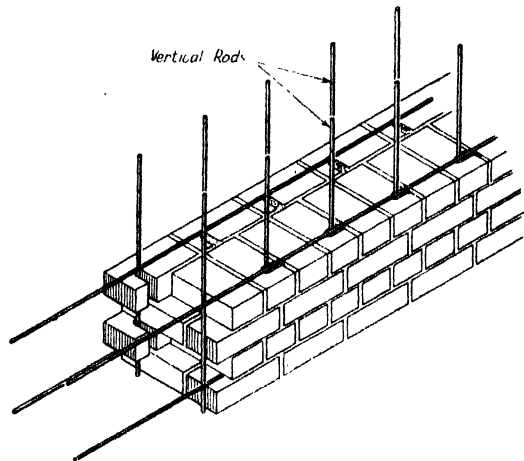


FIG. 89. REINFORCED ONE-AND-A-HALF-BRICK WALL.

(One-third of the total bricks are slotted)

although joints would have to be thicker than is usual.

When a wall or pier is designed, and the vertical reinforcing rods are required to be positioned nearer to the outside face of the wall, a slotted purpose-made brick will have to be obtained.

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Figs. 88, 89, and 90 illustrate this. In the first of these, Fig. 88, a 9 in. wall in English bond is shown, and the stretchers are the only bricks that require to be slotted.

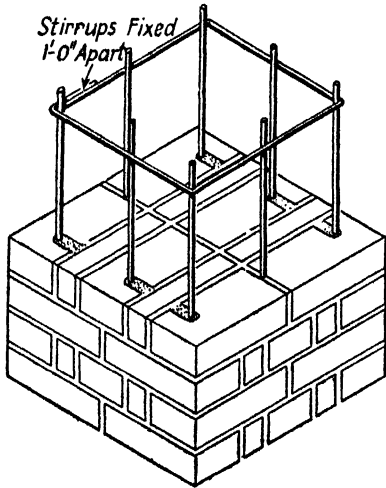


FIG. 90. REINFORCED TWO-BRICK PIER
(All bricks slotted)

Fig. 89 is a 13½ in. wall of which one-third of the total bricks are slotted, and Fig. 90 shows a 1 ft. 6 in. square pier in which all the bricks are slotted. The bricks, of course, are reversible and can be laid on either side of the wall.

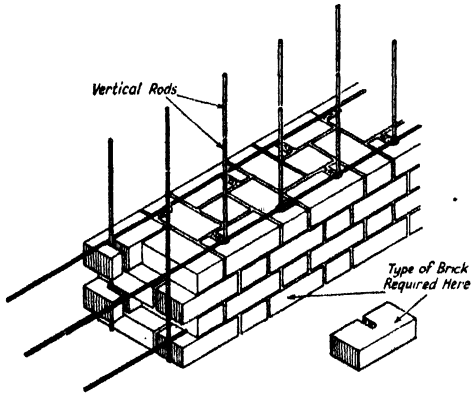


FIG. 91. REINFORCED ONE-AND-A-HALF-BRICK WALL

Fig. 91 is another illustration where slotted bricks of two different types are used.

A two-brick wall in Flemish bond is shown in Fig. 92, in which no slotted bricks are used.

From the foregoing illustrations it will be seen that bricks can easily be arranged in walls to

suit both reinforcement and face bond. Other purpose made bricks could be made to suit the various reinforcing designs, especially to

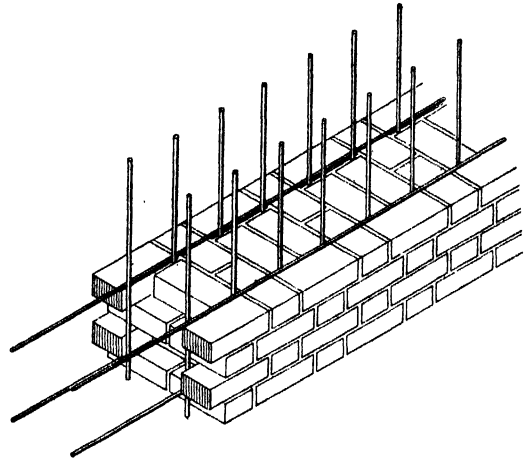


FIG. 92. REINFORCED TWO-BRICK WALL IN FLEMISH BOND

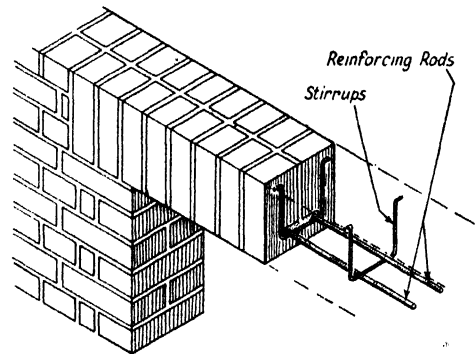


FIG. 93. REINFORCED BRICK LINTEL OR SOLDIER ARCH

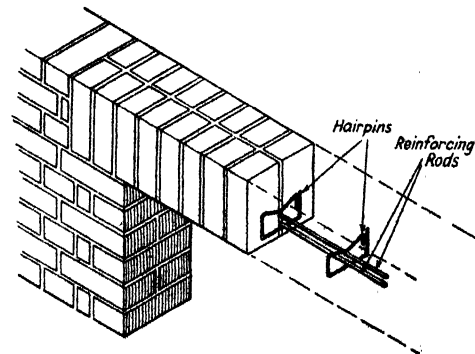


FIG. 94. ANOTHER METHOD OF REINFORCING A SOLDIER ARCH

accommodate thick rods, and save the appearance of thick mortar joints. These bricks could be standardized on the same lines as squint bricks and bullnosed bricks, etc. The reinforcing rods, in all cases where they cross or touch one another, are fixed together with wire ties.

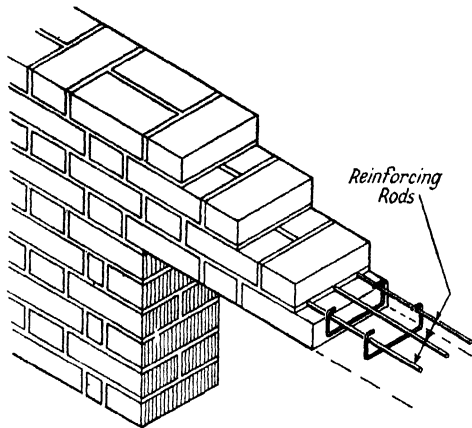


FIG. 95. REINFORCED BRICK LINTEL OR BEAM

Figs. 93 and 94 are two methods of reinforcing brick lintels or soldier arches for enclosing the heads of door or window openings, and may be used as light brick beams. Fig. 93 shows the slotted brick being used; Fig. 94 a standard brick in use.

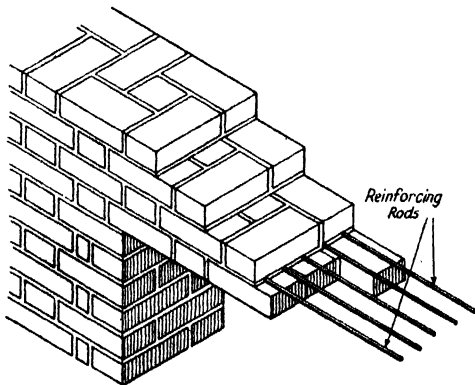


FIG. 96. REINFORCED BRICK LINTEL OR BEAM

The thickness of the rods is, of course, governed by the span of the opening. The loops of wire, or small gauged steel rod, fixed in every third bed joint are known as *hair pins*, or in heavier work, as *stirrups*.

In cases where an architect requires an opening in a brick wall to be enclosed without using

the traditional arch (where the flat courses are to run straight over the opening without breaking the face bond) the courses can be reinforced as shown in Figs. 95 and 96. This same principle can be used for the designing of load-carrying beams. A typical load-carrying beam is shown in Fig. 97. In the interior of this beam are shown flat brick courses which can be efficiently grouted in. A slotted brick could be used here.

A reinforced brick floor slab is illustrated in Fig. 98. The bottom course of the slab is formed with "bricks on edge" in between which the tension bars are laid and grouted in. To keep the bars in position, small wire hangers would have to be suspended in between the bricks. The distribution bars are laid in the bed joint of the top course, the bricks of which are laid

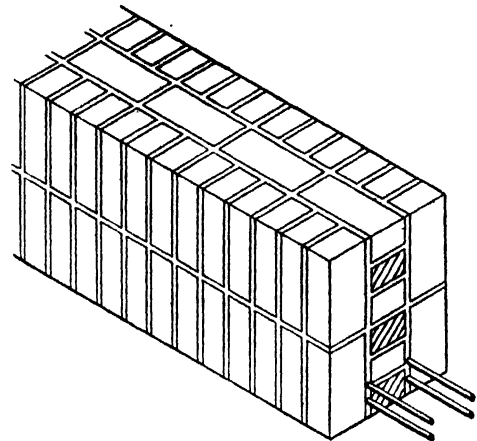


FIG. 97. SECTION OF REINFORCED BRICK BEAM

flatwise and also grouted in. Floor slabs are designed according to the span. The longer the span, the deeper the slab and the thicker the reinforcing rods.

Many types of surface air-raid shelters have been designed, and Fig. 99 shows the construction of a Quetta bond, brick and concrete air-raid shelter. This type was one that was adopted by the Ministry of Home Security. The reinforcing rods are designed to link the floor, walls, and roof into a box-like formation, and the whole is resting on a bed of ashes at ground level. The brick walls are built to form shafts or pockets wherein are vertical rods connected to the concrete floor slab and to the roof concrete. These pockets are filled with concrete as the walls are built.

Hints on General Practice. As a guide to the craftsman, a few hints on the general practice

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necessary when constructing reinforced brick-work follow.

MORTAR. The lime should be of the pure or fat type, as used for plastering work, and can be either the quick lime slaked on the job, or the hydrated lime delivered in bags ready for use. The sand should be clean and sharp, and be graded to pass through $\frac{1}{8}$ in. sieve. It should contain not more than 3 per cent of silt, loam or clay. Colour, due to organic material, may prove to be injurious.

The cement can be either Portland cement

brick for the whole of any beam, column, slab, or other member, so that any stresses thereon receive the same resistance. Second-hand bricks must not be used. The slots, grooves and holes of purpose-made bricks must be of a size to give the necessary mortar cover to the steel reinforcing rods.

The mortar cover to the reinforcing rods should be at least $\frac{1}{4}$ in. thick or half the thickness of the rod, whichever is the greater. The reinforcing rods must be kept at a distance from the face of the wall, beam or column as follows:

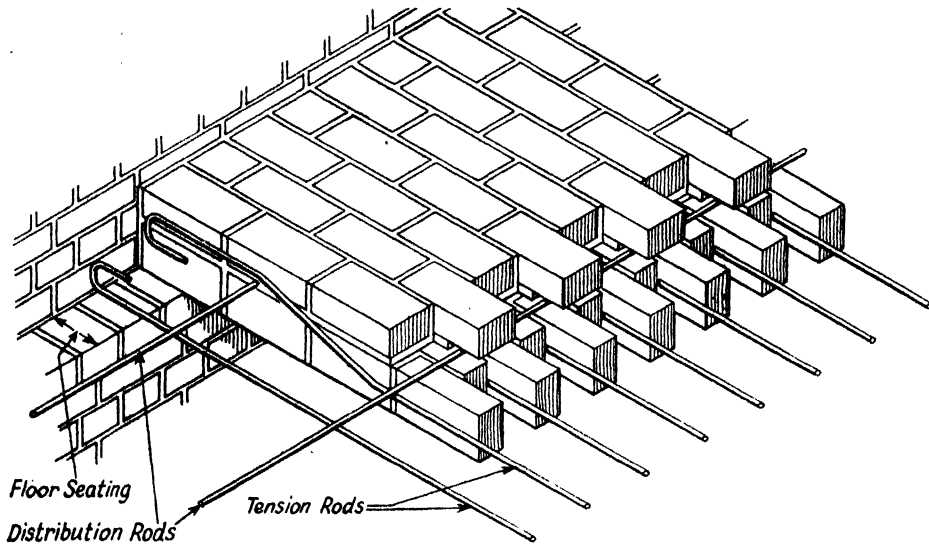


FIG. 98. REINFORCED BRICK FLOOR SLAB

or the rapid-hardening type, but, unless the work is urgent, Portland cement is the most reliable.

The lime may be added to the mixing water prior to adding the cement. No previously mixed mortar should be added to a new batch, and the mortar must be used within two hours of mixing. Grout is of the same material as the mortar but with extra water added. It should be of a creamy consistency and care must be taken that not too much water is added, otherwise segregation will cause shrinkage.

BRICKS. These should be sound, clean, and well-burned, and they should have true plane surfaces. Most of the best-quality English bricks can be used, provided that their crushing strength is not less than 1,500 lb. per square inch. The bricks when unloaded on the site should be stored on a clean base and covered with a tarpaulin sheet to protect them from dirt, dust, frost and oil. It is best to use the same kind of

The rods in all cases must be 2 in. in from any external face. From the internal face of a wall, beam, column or slab, the rods must be distanced 1 in. In the case of reinforced brick walls below ground and in contact with the soil, 3 in. of cover is necessary.

LAYING THE BRICKS. Before laying a brick, the bricklayer must first brush it clean from dust and then dip it in water. The bricks must contain enough water to prevent the suction killing the mortar, yet there must be enough suction to make the particles of mortar adhere solidly to the surface of the brick. This means that the brick should be soaked long enough to complete half of its total absorption. The weather will have to be taken into consideration and the process of soaking the bricks will have to be watched carefully. In the case of an impervious brick of the engineering type, wetting of the surfaces after brushing is all that is

necessary. Here, again, weather conditions must be considered. With these bricks, it is best to use grout for all wall joints. The spreading of mortar for the bed joints must be done with very shallow furrowing. Furrowing is the indentation formed in the mortar-bed by drawing the point of the trowel along parallel to the face of the wall about 2 inches in. Some bricklayers, although excellent craftsmen in other ways, tend to leave hollow cavities under their bricks through deep furrowing of the bed joints. This is most detrimental to the bond strength, more so in reinforced brickwork, as moisture is liable to penetrate through these cavities and start corrosion of the reinforcing rods. The horizontal reinforcing rods should be kept straight and solidly bedded in the mortar, taking care that there is the requisite amount of mortar cover under the rod. The bricks to the course covering these rods should be offered up to see that there is enough space to allow for the necessary

mortar cover on top of the rods. These bricks can then be laid so that the mortar will squeeze out at the side of each brick in turn, ensuring a solid mortar cover all round the rod. This will exclude the air and so prevent corrosion. The vertical reinforcement must be treated in a similar way, and all rods once set must be braced to prevent movement while mortar is setting. Corrosion or rust is caused by the action of water or air, or the carbon dioxide that is in the air. The addition of lime to the mortar makes it more dense and reduces the shrinkage. The lime also absorbs and neutralizes carbon dioxide. Hence, by conscientious workmanship, corrosion of the rods can be brought to a minimum. When leaving this type of work at the end of the day or for the erection of scaffolding, the wall joints of the last course should be grouted carefully, taking care that the upper surfaces of the bricks are kept clean and not smeared by mortar. Then, when the work is to be continued, these top surfaces can be well brushed and soaked prior to starting. It is important that all beams and floor slab bays should be completed the same day, as they are then virtually a monolithic member.

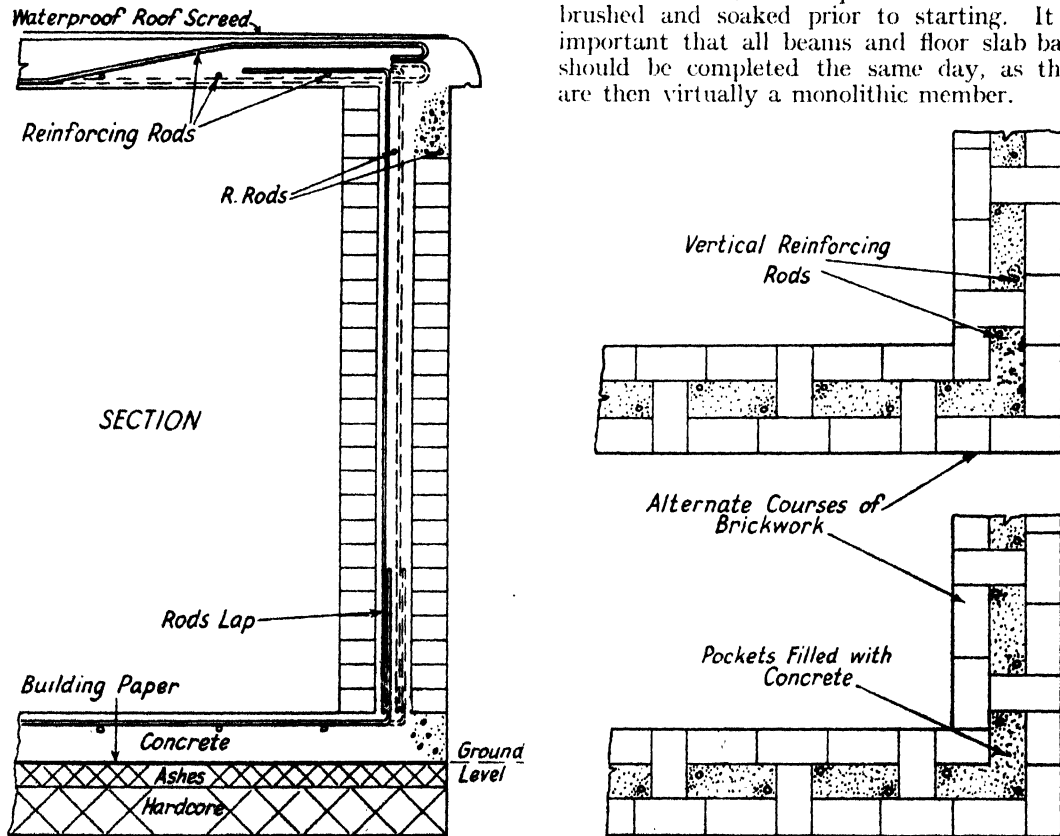
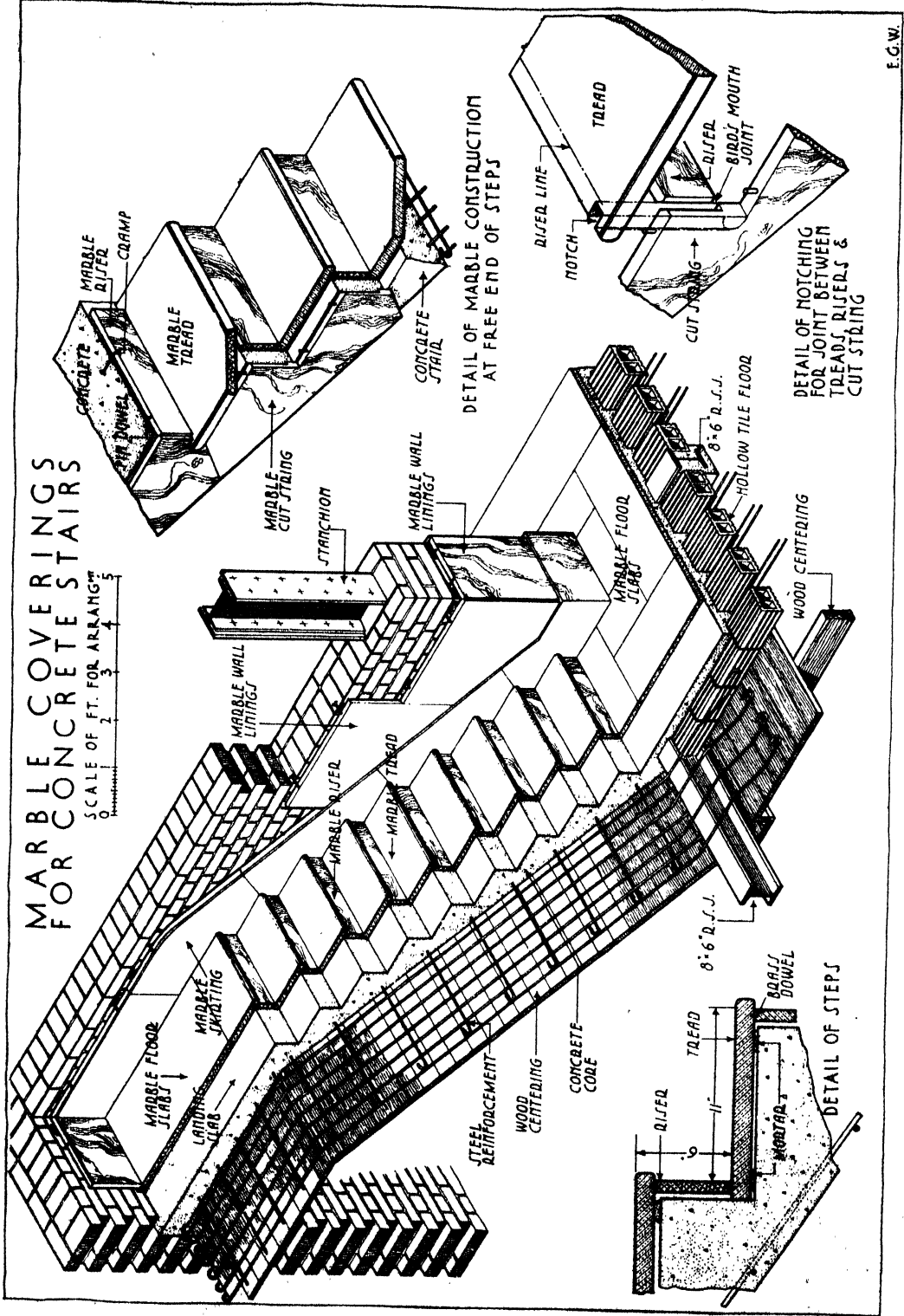


FIG. 99. CONSTRUCTION OF QUETTA BOND AIR-RAID SHELTER

MARBLE COVERINGS FOR CONCRETE STAIRS

SCALE OF FT. FOR ARRANGING



E.G.W.

Masonry

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Chapter I—BUILDING STONES

As in other branches of industry, there have been many advances in masonry during recent years. The demand for stone, together with the speed with which buildings are now being erected, has necessitated the introduction of well-organized systems of production and up-to-date appliances and machinery. Nevertheless, old methods of production are still employed in various parts of the country. This is chiefly because the local demand for the material has not justified the additional overhead costs which would be incurred by installing machinery, or because the material in these districts is more readily worked by hand-labour than by machine. It should always be remembered that the object of machinery is to cheapen costs by accelerating production.

In studying the methods of preparing blocks of stone so that they will combine to give a building maximum stability and, at the same time, satisfy architectural requirements, it is necessary that one should become acquainted with the various processes employed in completing the fabrication of the stonework, from the time the blocks are removed from the stratum in the quarry until they finally rest in their predetermined positions in one of our large buildings. Furthermore, it is not sufficient that the craftsman should understand only how to shape a piece of rough stone to the required moulds or templets. He should be thoroughly conversant with the material on which he operates: know something of its formation and general characteristics; the districts where quarries are situated; the suitability of a particular stone for a specific building purpose; and be able to tell a good weathering stone from a bad one, stating the reasons for his selection.

To the practical knowledge acquired naturally by handling and studying the various stones used in his work, the mason should strive to add a knowledge of the geology of building stones.

A craftsman is not expected to be a geologist; nevertheless he cannot fully appreciate the material on which he operates unless he has a basic understanding of the subject. It is an engrossing one, and when allied to his practical knowledge it will provide him with a storehouse of valuable information from which he can draw when faced with numerous problems connected with his work. The following is a list of books the student of geology will find helpful—

Geology of Building Stones, by J. Allan Howe.

Building Stones, by A. R. Warnes.

Weathering of Natural Building Stones, by R. J. Schaffer, B.A.

Building Stones, by J. Watson.

Builders' Materials, by B. H. & R. G. Knight.

It is not intended in this section to deal fully with the classification of building stones, but to guide the student by giving him a brief survey of the subject and leaving him to derive a deeper knowledge through study of the books mentioned, and, where possible, by visiting some of the quarries from which well-known building stones are taken.

It is not left to the craftsman to select the stone for a proposed building. The architect decides what stone is to be used, and the mason has to execute the work in the particular stone specified. The architect relies upon the integrity of the mason in the choice and selection of the blocks for the various positions in the building; especially is this so in regard to placing them on their natural bed.

There are many problems to be taken into account when selecting a building stone. If durability alone counted, the choice would certainly be in favour of granite, because this material is almost unaffected by the deleterious agencies which are to be found in town atmospheres. Cost and appearance, however, are the



**FIG. 1. GENERAL VIEW OF THE MASONRY WORKS OF THE BATH AND PORTLAND STONE FIRMS,
AT PORTLAND**

Showing railway running direct into the masons' shops, which are in the background

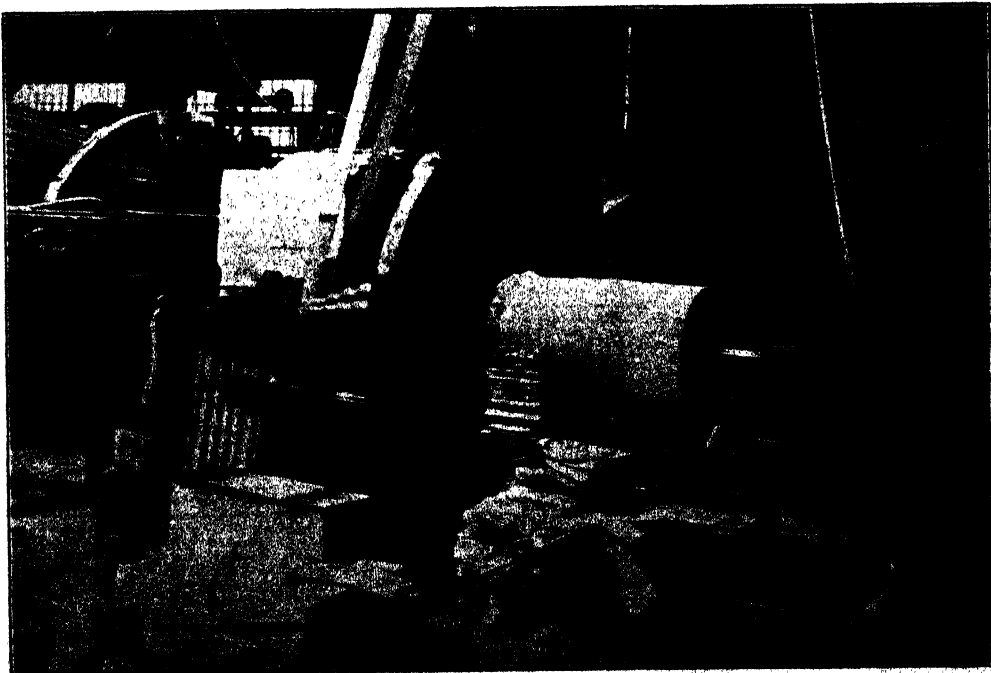


FIG. 2. DIAMOND SAW AND LATHE AT WORK AT PORTLAND MASONRY WORKS

The lathe is capable of turning stones up to 8 ft. diameter or 4 ft. 6 in. diameter, 12 ft. long

real governing factors, therefore the most important features to be considered are: the suitability of the texture of the stone for executing architectural details; the dimensions of blocks obtainable; and the limitations of the quarries from which the stone is to come.

In regard to the last-named point, if the demand for the stone should exceed the output capacity of the quarries, the building will suffer because no proper selection of the individual stones can be made, and it may be necessary to use stones of doubtful quality and durability.

It is chiefly because of the foregoing considerations that limestones are more generally used for the facing material of buildings. If adequate and proper selection has been carried out, there is no reason why limestones should not be suitable for external facings in almost any situation. The chemical analysis of a limestone may give certain information regarding its constituents, but very little useful purpose is served by such an analysis unless it is confined to a particular stone, and then it is only a guide as to its composition. The weathering quality of a limestone depends to a very large extent upon its physical structure, and not upon its chemical composition, for some limestones which are known to have good weathering qualities contain from 95 to 98 per cent of carbonate of lime.

In the selection of a building stone the student is advised to study the various buildings in the neighbourhood, and to note the condition of the stones and how they have weathered.

The chief points to notice are—

1. Situation of the building.
2. The aspect of the building.
3. Appearance and colour.
4. Possible supply of blocks of similar stone from the quarry.
5. Facility of working.
6. General characteristics.
7. Whether the stones are placed with the direction of their natural beds correct in the building.

These will be dealt with now in greater detail, especially items 6 and 7.

SITUATION OF BUILDING. This is very important to the life of a stone. Some stones are known to weather well in an inland town atmosphere, but suffer severely when exposed to sea air. This applies especially to some limestones, particularly dolomitic or magnesian limestones. The chemical constituents of rain water and the

salt bearing winds blowing from the sea, attack the calcium carbonate and magnesium carbonate. Limestones are attacked more readily in towns than in country districts, due to the air in towns containing more sulphuric acid. When rainwater containing sulphuric acid enters the pores of such stones, sulphates are formed and the physical condition thereby developed in the structure may cause the loosening and washing away of the particles. But by a careful choice of a limestone this can be minimized. Even after every effort has been made to ensure that the choice has been correctly made, a great deal depends upon the selection of the individual stones by the mason.

ASPECT. Stonework suffers severely when elevations are exposed to frequent changes in temperature, such as the heat of the sun and alternately the prevailing wet winds (chiefly south-west).

COLOUR AND APPEARANCE. The style of architecture and the various purposes for which the stone is to be used should be studied when choosing a stone. If for engineering purposes, where strength and stability should be the chief concern, colour and appearance do not matter to any great extent; but for commercial buildings in our cities, churches and country residences, colour is a very important factor. By a judicious choice of the various stones, pleasing effects can be obtained, though this is sometimes at the expense of the durability of the building.

POSSIBLE SUPPLY OF BLOCKS FROM THE QUARRIES. It is important when choosing a stone to ascertain whether quantities of block-stone of sizes suitable for the requirements of the proposed building are available. It would be fatal to commence building operations and then to discover that blocks of the size required were not obtainable.

FACILITY OF WORKING. There are several stones that would pass tests as being suitable for building purposes, but owing to the hardness and texture of these stones they would not justify the installation of the machinery necessary for their production at the rate required.

CHARACTERISTICS

Classification. Building stones are classified in a general way under the heading of *igneous*, *sedimentary*, and *metamorphic* rocks.

Igneous Rocks. These are formed by fusion below the earth's surface.

Sedimentary Rocks. All sedimentary rocks,

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which include sandstones and limestones, come under this heading. They are formed in deposits by the agency of water or winds, and are known as *stratified* rocks.

Metamorphic Rocks. These may be either of the above when changed in formation by heat and pressure. Marbles and slates come under this heading.

Granites. Granites are igneous rocks made up of granular particles, the latter being crystalline, and usually composed of quartz, felspar, and mica.

Granite has never flowed out over the earth's surface as lava, but became consolidated at a great depth under extreme pressure.

Quartz. The durability of granite depends largely upon the amount of quartz and its combination with other minerals, quartz being practically indestructible. Quartz, sand, and the chemical named *silica* may be said to be interchangeable terms.

Felspar is the most easily distinguished mineral and its colour varies considerably. The pink felspar is known as *orthoclase*, and is a potash felspar; this constituent is very characteristic in granite. Sometimes the white soda or lime felspar known as *plagioclase* is found. Felspars are commonly found with about equal quantities of quartz.

Mica is of two kinds: *muscovite*, which is potash mica (light); and *biotite*, which is a dark brown, iron and other substances being present. The light micas are more stable.

The proportions of mica should be small compared with *quartz* and *felspar*. *Hornblende* and *augite* sometimes occur and take the place of mica; the stone is then known as a *syenite*.

Iron pyrites produce oxidation and hydration either in the form of local spots, or as a uniform tinge of brown, and should always be looked upon as a fault.

The characteristics of a good granite are: fineness of grain, the disposition of the various minerals forming the mass, and the high percentage of quartz present.

In Cornish granite the felspars often look like flakes of falling snow, this appearance being caused by their flat surfaces lying in planes.

VARIETIES. Granites from Devon and Cornwall are chiefly coarse-grained, having large crystals of felspar distributed throughout. That from Penryn district is bluish grey in colour, and composed of felspar, quartz, and mica, the mica being usually of mixed colours, black and white.

The Penzance district provides a good granite, the colour of which is greenish grey. The Delank granite is of coarse grain and has a high percentage of quartz. It is a splendid weathering stone of a deep bluish grey colour, and is excellent for all types of building, engineering, and monumental purposes.

Scotch Granites. Aberdeen provides the most important granites, being light blue or grey to pink or red. The *Peterhead granite* is pink or red. *Rubislaw granite* is bluish grey. The *Sclettie granite* is grey, has a fine texture, and is a splendid weathering stone. The *Aberdeen granites* are, generally speaking, *true granites*, composed of quartz, felspar, and mica. *Hornblende* is sometimes found in place of, or in addition to, the mica. These granites are largely supplied for monumental and building purposes. They take a very high polish.

Syenites are quarried in North Wales, Malvern Hills, Leicestershire, and the Channel Islands.

Sandstones. Sandstones are formed by the disruption of pre-existing rocks due to the action of winds or moving water, the particles being deposited in beds, or strata. The chief constituents are the original quartz crystals (or grains) and the cement that binds them together. The quality of a sandstone depends upon the *cementing* material. The presence of an inferior cementing material is the chief cause of disintegration upon the exposed surfaces. The cementing materials are numerous, and may be silica, clay, iron oxides, calcite, or dolomite. Usually there is a combination of these substances, but one kind predominates. Sometimes the grains, or quartz crystals, are consolidated by heat and pressure as in *quartzite*. Sandstones vary from fine grain to coarse grit stone, whilst the colour depends chiefly upon the cementing material. Red, brown, and yellow are due to oxide of iron. White owes its colour to the combination of clear quartz with white argillaceous or clay-containing matter free from iron stains.

If the stone contains a high percentage of mica distributed along the planes of bedding it is known as a *micaceous* sandstone. Great care should be exercised in placing sandstones in the building so that the *laminæ* are horizontal. There are exceptions to this rule, as will be explained later.

VARIETIES. The following is a list of a few of the best known building stones, and will, no doubt, be of interest to the student and young craftsman.

Forest of Dean: Gloucestershire. Obtained in two colours, grey and blue. The "Grey Bed" is medium-grained slightly micaceous sandstone. The "Blue Bed" is a compact hard sandstone. Both are excellent stones for all building, engineering, and monumental purposes. They are excellent stones where strength combined with durability is required.

Grey Bed : weight 149 lb. per cub. ft.
Crushing resistance 569 tons per sq. ft.
Blue Bed : weight 151.4 lb. per cub. ft.
Crushing resistance 631 tons per sq. ft.

Red Wilderness: Mitcheldean, Gloucestershire. A stone of fine texture and suitable for all classes of external and internal work.

Weight 141 lb. per cub. ft.
Crushing resistance 695 tons per sq. ft.

Bristol Pennant Stone: Gloucestershire. A very hard fine-grained sandstone. Blue in colour. An exceedingly good stone for all engineering purposes owing to its exceptional strength. Its hardness makes it suitable for steps, landings, etc., as they do not become slippery by wear.

Weight 172 lb. per cub. ft.
Crushing resistance 1,001 tons per sq. ft.

Darley Dale: Derbyshire. Known as "Stancliffe stone." Colour is light drab to yellowish white; compact close-grained and micaceous sandstone; eminently suitable for all building and engineering work. Blocks of any reasonable size can be obtained.

Weight 148 lb. per cub. ft.
Crushing resistance 670 tons per sq. ft.

Howley Park: Yorkshire. Light brown fine-grained stone suitable for general building work, landings, copings, etc.

Weight 140.3 lb. per cub. ft.
Crushing resistance 466.7 tons per sq. ft.

Robin Hood: Yorkshire. Bluish grey, fine-grained; suitable for all general building work, copings, etc.

Weight 145 lb. per cub. ft.
Crushing resistance 574 tons per sq. ft.

Limestones. The chief characteristic of limestones is the presence of a large proportion of carbonate of lime. They were formed chiefly by the accumulation of shells or calcareous skeletons of marine or fresh water organisms, which were deposited as sediment in the waters of seas or lakes. The common or chalk limestones are more suited for the production of lime. The *Oolitic limestones* are of marine origin; they are composed chiefly of carbonate of lime, with other substances, such as car-

bonate of magnesia, silica, alumina, and iron. The *oolite* resembles the roe of a fish, and results from the accumulation of carbonate of lime around the small nuclei of fragmentary shells or grains of mud or sand. They are spherical or oval shape, and can easily be seen with the naked eye. They vary in hardness and texture; some are fairly fine, others coarse and porous.

All limestones are soft when first quarried, but harden on exposure to the atmosphere.

The stone should be uniform in colour throughout in the case of both sandstones and limestones.

VARIETIES. The following are a few of the limestones in general use for building purposes.

Ancaster: Lincolnshire. Colour is cream to buff; texture varies from a fine-grained *oolite* known as the "Freebed" to coarse and shelly, the latter being called "Rag" or "Weather Bed"; partly crystalline and of good weathering qualities. Used considerably for church work and interior decorative purposes.

Free bed—

Weight 135.3 lb. per cub. ft.
Crushing resistance 218.6 tons per sq. ft.

Bath Stones. These include a series of *oolitic* stones quarried or mined in the vicinity of Bath, and are suitable for all styles of architecture. They average cream to buff colour and are soft and easily worked. If well selected and placed upon their *natural bed* they *weather* well. There are old buildings in London constructed of this stone still in a splendid state, the stone showing very little signs of disintegration; while close at hand Portland stone buildings are showing distinctly the effects of the London atmosphere, although built considerably later. The following belong to the Bath series—

St. Aldhelm: Box Ground. A good stone and most suitable for cornices, strings and sills, and projecting members. Bedding planes show distinctly.

Weight 129 lb. per cub. ft.
Crushing resistance 107 tons per sq. ft.

Corsham Down. Fine grained, suitable for ashlars and facing stones in conjunction with Box Ground and for interior church work.

Weight 129 lb. per cub. ft.
Crushing resistance 128 tons per sq. ft.

Combe Down. Quite a good weather-resisting stone if well selected; fairly fine-grained and suitable for all positions as "Corsham Down."

Weight 128 lb. per cub. ft.
Crushing resistance 118 tons per sq. ft.

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Farleigh Down. Very soft and suitable for interior work ; does not weather well if used for exterior work.

Weight 121 lb. per cub. ft.
Crushing resistance 62 tons per sq. ft.

Monk's Park. Splendid stone for all kinds of exterior and interior work ; colour is cream, but dries almost white ; it is close-grained, and weathers exceedingly well in town atmospheres if well selected. Undoubtedly the best of the Bath series for all general building work.

Weight 137 lb. per cub. ft.
Crushing resistance 223.5 tons per sq. ft.

Hartham Park. Bedding planes more or less distinct ; suitable for exterior and interior work.

Weight 135 lb. per cub. ft.
Crushing resistance 123.5 tons per sq. ft.

Beer Stone: Near Seaton, Devon. Of the chalk series ; whitish colour ; soft. The free-stone consists of beds which lie at the junction of the chalk and the green sand. Made up of minute fragments of shells, close-grained. Suitable for internal work and lends itself to rich moulding, carvings, etc.

Weight 131.7 lb. per cub. ft.
Crushing resistance 151.2 tons per sq. ft.

Chilmark: Wiltshire. Portland *oolite* ; colour, yellowish brown ; siliciferous limestone, suitable for general building work.

Weight 135 lb. per cub. ft.
Crushing resistance 136.6 tons per sq. ft.

Clipsham Stone, Lincolnshire. Of the inferior *oolite* series, colour varies between pale cream and buff, medium grained. Used considerably for restoration work.

Doulling: Somersetshire. *Fine beds*, light brown to cream or grey, uniform in texture ; fairly soft but hardens on exposure. Most suitable for internal work. The *Chelynych bed* is a good stone for external dressings, etc.

Chelynych—

Weight 150 lb. per cub. ft.
Crushing resistance 211.6 tons per sq. ft.

Ham Hill: Somersetshire. Yellow and grey beds ; composed of fragmentary shells and high percentage of iron. Bedding planes very distinct ; hard, coarse-grained stone. A stone specially adaptable for panels as a contrast in colour to the surrounding stones, but not suitable for exposed positions.

Yellow Bed : weight 136 lb. per cub. ft.
Crushing resistance 207 tons per sq. ft.
Grey Bed : weight 141.6 lb. per cub. ft.
Crushing resistance 259 tons per sq. ft.

Hopton Wood: Derbyshire. Crinoidal limestone of the carboniferous system. Can be obtained in three colours, light, grey, dark. Takes a good polish ; suitable for monumental and decorative purposes. It is a good stone and its weathering properties are excellent.

Weight 158 lb. per cub. ft.
Crushing resistance 806 tons per sq. ft.

Ketton Stone: Rutlandshire. Even texture ; cream colour to yellowish brown ; fairly soft to work when fresh, but hardens on exposure. Quite a good stone for all external purposes.

Weight 156.7 lb. per cub. ft.
Crushing resistance 101 tons.

Portland Stone: Dorsetshire. *Oolitic* limestone. Generally speaking there are three beds of stone, Roach Bed, Whitbed, and Best Bed (*Base Bed*).

The *Roach* is chiefly suitable for marine construction, although it has been used occasionally for building purposes.

The *Whit bed* is a hard, fairly fine-grained stone, cream to light brown, but whitens when dry. Acknowledged to be one of the finest weathering limestones on the market. Suitable for all external purposes.

Base bed is a fine even-grained stone. White in colour ; suitable for fine enrichments and carvings, internal and external work.

Whit bed—

Weight 133 lb. per cub. ft.
Crushing resistance 204.7 tons per sq. ft.

Kentish Rag is a hard siliceous limestone containing a high percentage of silica.

Weight 166.6 lb. per cub. ft.

Magnesium Limestones are those containing an appreciable amount of *carbonate of magnesium* combined with *calcium carbonate*. They are usually termed *dolomites*, and vary in colour from white and cream to yellowish brown.

Anston: Yorkshire. Warm yellow colour ; suitable for exterior dressings if carefully selected.

Weight 134 lb. per cub. ft.
Crushing resistance 302 tons per sq. ft.

Mansfield Woodhouse: Nottinghamshire. Warm yellow brown colour ; suitable for internal and external dressings, etc.

Weight 145 lb. per cub. ft.
Crushing resistance 577 tons per sq. ft.

Bolsover Moor: Derbyshire. Similar to the above. A fairly good stone for external purposes, but only small blocks are obtainable.

Roche Abbey: Yorkshire. Pale grey in colour; suitable for dressings and carvings, etc.

Weight 139 lb. per cub. ft.

Crushing resistance 250 tons per sq. ft.

BEDDING AND SEASONING

Natural Bed. All stratified rocks, which include sandstone and limestones, were deposited in layers, and thus have more or less distinct bedding planes. In most sandstones the planes are easily discernible, but in some limestones it requires an intimate knowledge of the particular stone to ascertain in which direction the planes run. It is very important that the ends of the laminae should be exposed to the surface, when the stones are placed in the building. It is often suggested that cornices and overhanging courses of stonework should be placed joint bedded to prevent the drip caused by the throating falling off; but with the exception of distinctly laminated stones, such as Ham Hill stone, it is preferable to select the stones for these courses and place them in the building with the bedding planes horizontal or at right angles to the pressure. Arch stones, etc., should have their planes parallel with the centre line of the individual stone, or *voussoir*, and at right angles to the face of the arch, or as nearly as possible at right angles to the direction of the thrust.

It is very important to study the direction of the bedding of most stones, as the life of the stone depends to a great extent upon the mason rigidly adhering to this principle in the selection of each individual stone. It is not so important in the selection of Portland stone, in which it is very difficult even to the trained eye to state which way the planes run, except where shells are visible, and then in some instances one has to be very cautious in coming to a decision. Stones, such as columns, etc., for receiving weight, should be specially selected, and should always be placed with their beds horizontal.

Most stones before they are removed from the quarry have a distinct indication mark on them, or cut in, by the quarryman, for the guidance of the mason. In soft stones such as Bath stone a *kerf* is drawn with the axe through the block at right angles to the natural bed, and in other stones the numbering of the block is placed parallel with the direction of the *natural bed*, or an arrow is painted on the block indicating the *bed*. Very little benefit is obtained by a scheme of marking unless special care is exer-

cised by those who are in control of the processes of fabrication through which the block of stone has to pass to completion.

Most quarry blocks are required to be cut into smaller blocks and during this process an enormous amount of wastage may occur if the correct position of the bedding planes is maintained. To prevent this wastage, blocks are sometimes marked so that the maximum quantity of finished stonework is obtained regardless of the direction of the bedding planes. This procedure is to be condemned, and care should be taken to ensure that the stones are cut so that the direction of the planes is correct in relation to the position of the stone when it is placed on the wall of the building. To ensure against this mistake occurring after the stones have been sawn to size, the operator of each process of fabrication should indicate on each stone the direction of the bedding planes immediately the operation has been completed.

If face-bedded stones are used, the exposed surfaces will tend to flake and cause a general disintegration of the surfaces and the ultimate decay of the stonework. All face-bedded stones should be rejected before they are placed in position, but as already stated, the identification of the direction of the bedding planes calls for an intimate knowledge of the stone.

Stones should be selected to suit the particular work for which they are required, and the weight or density of the material must be taken into account. Dense stones should be used for buttresses, engineering work, etc., but for vaulting and internal decoration light stones are preferable, except where polished surfaces are required.

Seasoning. Most building stones, including granite, undergo a process of hardening upon exposure. They contain moisture, or *quarry sap*, which evaporates upon being drawn to the surface of the rock. Stones are more readily worked when freshly quarried, especially granite and the harder stones, but the softer stones such as Bath stone are best worked after being stacked for some months. The face of the stone hardens by evaporation of the sap, and if this face is removed by re-working, a weakness is caused, and the stone will not weather so well. After all labours have been finished on the stones, the clean surfaces should be slurred with stone dust and a small percentage of plaster, thus protecting all exposed surfaces and preventing a face forming.

Chapter II—QUARRYING

Methods of Quarrying. Quarrying for stone differs in various parts of the country, each district having its own methods of obtaining the rock, the methods being the best for the particular kind of stone. In some districts *electric* and *pneumatic* drilling machines are used, and the huge masses are separated by *blasting*; in others, methods which were in existence centuries ago are still in use, and the stones are obtained entirely by hand labour, these methods having proved most suitable for the production of the stone.

All sedimentary rocks, having been deposited in layers or strata, have natural divisions between them. These are termed "risings" in some districts. The "risings," together with natural vertical joints and fissures which divide the mass, are of great assistance in the quarrying operations. Reproduced photographs illustrating the quarrying methods of a few stones used in building are given, together with a short description of the local quarrying methods. Figs. 3 and 4 show Portland stone quarries.

PORTLAND STONE

This *oolitic* limestone has practically changed the appearance of London, and has been introduced into many provincial towns. It has been used for war memorials all over the country. The stone is quarried in the little peninsula jutting out into the English Channel from the coast of Dorset. Sir Christopher Wren quarried here for the material for his masterpiece, St. Paul's Cathedral, from 1675-1717. He selected the "East cliff" at the northern end of the island for his quarrying operations, where the stone was exposed owing to a landslide, and by so doing was relieved of the necessity of transporting the superimposed *Purbeck beds*, or *rubble*, which in places are forty feet deep. For some years now quarrying operations have commenced inland and from the top surface, which entails an immense amount of labour in clearing the site down to the *Portland beds*, ready for quarrying the marketable stone. From the section shown in Fig. 5 of one of the Bath and Portland Stone Firm's quarries, a general idea of the composition of the strata comprising the rubble and cap of the *Purbeck beds* can be obtained, although in each district there is

some difference in the way the deposits are arranged.

There is a thin layer of soil averaging 1 ft. deep, then a bed of shivered stone, or *slat*, from 3 ft. to 8 ft. deep; this *slat* can be split into quite thin slabs. A *tier*, or layer of clay, is next, but is entirely absent in some districts. Then another bed of *slat* averaging 3 ft. 6 in. deep is reached; this is composed of a compact hard limestone useless for building purposes. Next we come to three thin layers, which in order are termed *Bacon tier*, *Aish*, and *Soft burr*. Under these is the *Dirt bed*, which is of great interest to geologists. This bed contains numerous trunks of silicified trees, proving this layer to have been at one time at the surface and covered with a dense forest.

Immediately under the *Dirt bed* is the *Top cap*, which varies in its structure but is chiefly a very compact mass of stone 6 ft. to 8 ft. deep; it has to be removed by blasting. Although it is a compact hard stone it is quite unsuitable for building purposes, and except that it has been used occasionally for marine construction such as breakwaters, etc., it is a waste product. The last bed of the "Purbeck stone" is the *Skull cap* about 3 ft. deep, also a waste product, which in turn lies upon the *Portland beds*.

It will be noticed from this description, that an enormous amount of waste material must be transported to another part before any marketable stone can be obtained. Indeed, this does not complete the sum of the waste material, for the *Roach bed* upon which energy must also be expended, is again not suitable for general building purposes, being a very porous stone and full of cavities formed by the moulds of shell fish, etc. It has been used for *rock-faced work* for plinths, etc., and is well suited for that class of work. It has also been used for marine construction, but there is no great demand for it; hence the major portion becomes a mass of waste to be removed and deposited with the rest of the rubble. The *Roach* is about 2 ft. 6 in. in depth, and is usually attached to the *Whit bed*; this contains the stone which is in such great demand for external work of every description. This bed varies from 3 ft. to 10 ft.



FIG. 3. PORTLAND STONE: PERRYFIELD QUARRY
Showing depth of stone compared with the amount of waste or rubble



FIG. 4. PORTLAND QUARRY: CLOSE-UP VIEW OF BEDS OF STONE
Showing the method of cutting the blocks from the strata

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deep, and is generally of a light brown colour, containing numerous shells which lend a variation and charm to the finished stone; some architects object to these shells showing in the finished faces.

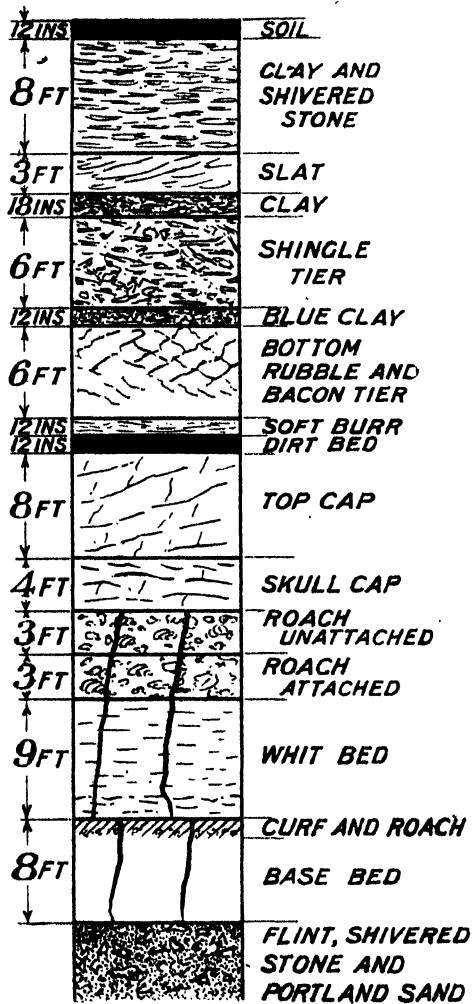


FIG. 5. TYPICAL SECTION THROUGH A PORTLAND QUARRY

Under the *Whit bed* is often a tier of *flint* and *rubble* which has to be removed. We then come to *curf*, which is sometimes attached to the *Base bed*. This bed varies in thickness and quality. It is a nice white, clean, and even-grained stone, often softer than *Whit bed*. Usually, if a good deep *Whit bed* is obtained, the

Base bed is rather poor, and if the *Whit bed* is thin and of poor quality, a very good deep hard *Base bed* is usual. It is then excellent for monumental and building purposes and will withstand the atmosphere of towns remarkably well.

When the *Roach bed* is reached, natural vertical joints appear, dividing the mass of rock into huge blocks. These joints are named by the quarrymen according to the direction they run, such as *Southers*, *East-wester*, *North-easter*, *North-westers*, or *Raingers*. Large fissures, termed by the quarrymen *gullies*, run approximately "Southern." They are from 6 in. to 2 ft. wide, and from 70 ft. to 90 ft. apart. It is from these gullies that the quarrymen work, starting from the gully on the left, and moving towards the gully on the right, so that the rock frees itself; the huge blocks of stone are *reamed* or wedged away from the natural joints; slots are cut half on each side of the joint, and *pigs* are inserted. *Pigs* are pieces of iron 15 in. \times 6 in. \times 3 in. These are placed face to face, 2 or 3 ft. apart, and large *wedges* are driven down between the *pigs*. The wedges are each struck with a sledge hammer at the same time until the joint opens. This process is termed *reaming the rock*. The blocks are also lifted from the *risings*, which are the horizontal divisions of the stratum. If the *rising* is too far down, the blocks are *lifted* through a bed of shells called a *Cockle bed*, through which the stone will readily split. Fig. 7, which is a reproduced photograph, shows a lift through a cockle bed. A groove is cut with the *twible* or *pick*. *Scales* and *small wedges* are inserted close together in the groove, as shown in Fig. 4; the *wedges* are struck with the hammer, thus causing the block to split along its bed.

The blocks when reamed weigh anything up to 100 tons. When the blocks are cut they are squared up with the *kivel*, an instrument 6 lb. to 18 lb. in weight, and hammer faced at one end (with surface slightly concave) and pointed or *broached* at the other. They are then *axed* over. After the stones are roughly squared they are measured, and the cubical contents, together with the number and trade-mark, is painted on them at the same time.

The quarrymen are paid according to the cubical contents of the measured block, and the railway companies accept the marked measurement for rail charges.

The blocks are lifted by the cranes on to trolleys and hauled direct out of the quarries by motor wagons to the railway sidings, or loaded direct into railway trucks from the quarry. A

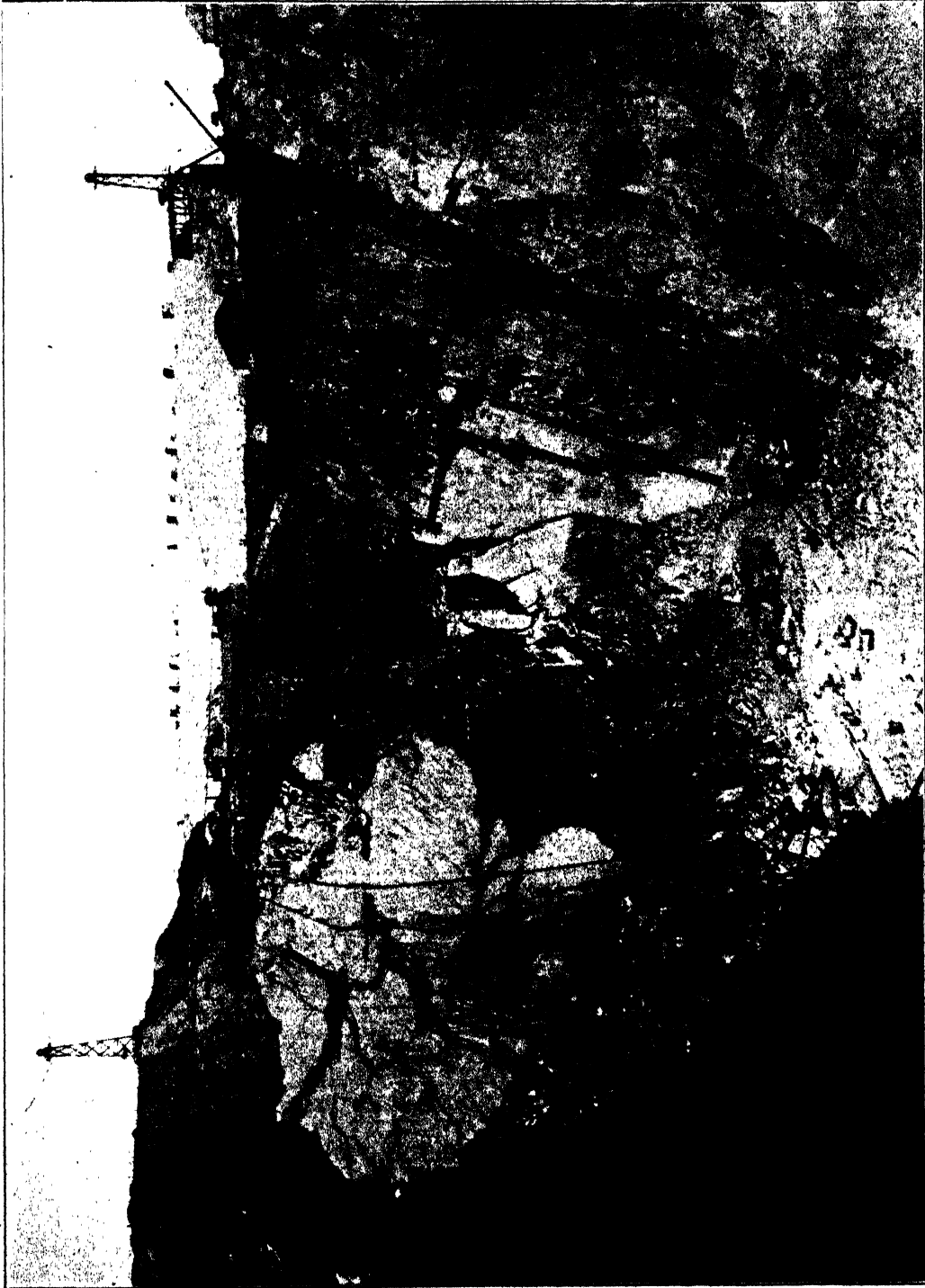


FIG. 6. ABERDEEN GRANITE: SCLATTIE QUARRY
By kind permission of Messrs. A. & F. Manuclie, Ltd.

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large quantity of block stone is conveyed by means of an inclined railway to the loading pier, and shipped into barges.

ABERDEEN GRANITE

The granites found in the immediate vicinity of Aberdeen are grey, and include *Sclattie*, *Rubislaw*, and *Kemnay*. The red granite comes from Peterhead, which is thirty miles farther

enough a *sump* is formed, and a powerful pump is installed for draining the quarry; during a wet period as much as 50 tons of water per day may have to be pumped out. The pump is a vital unit in big deep quarries, and is, therefore, very carefully protected against accidents during blasting operations.

After the *sump* is formed the new *dip* is then worked outwards across the whole floor of the



FIG. 7. PORTLAND STONE QUARRYING. VIEW SHOWING "LIFT"

north. These districts supply a building and ornamental material unsurpassed for beauty and durability.

The quarries are from 800 to 1,000 ft. long, by 400 to 600 ft. wide, and 300 to 400 ft. deep, which increases year by year.

The quarrying operations have a tendency to deepen rather than to expand, owing to the fact that the overburden of boulder clay and sand, and top rock, which extends from 5 to 20 ft. deep, is very costly to remove.

The granite for commercial use is found in isolated masses divided by "bars" of very inferior rock and by *natural vertical joints*; usually, these "bars" lessen in extent, and the quality and texture of the granite improves as the quarry deepens.

The quarries are deepened by sinking a shaft about 40 ft. in a corner, and the quarryman always tries to take advantage of some inclined vertical joints which will facilitate the blasting out of the shaft. When the hole is made big

quarry, the direction being determined by the natural vertical joints. As the *dip* extends, stones are quarried along the whole working face.

The sides of the Aberdeen quarries are almost perpendicular, and are not worked in galleries as sandstone and other quarries where there is danger of "caving" and the sides collapsing.

The Blondin Cable lifting apparatus is in general use and is admirably adapted for such deep workings, but is not so suitable for shallow quarries.

The Blondin at Sclattie—the most modern and efficient of the kind in the country—lifts 10 tons. The winding machine is fitted with friction clutches, flexible couplings, and helical gear; the rope drums are 6 ft. diameter. One of the masts is 60 ft. high; the main cable is 700 ft. between masts fixed on each side of the quarry; this cable is $7\frac{1}{4}$ in. circumference, and the breaking strain is 190 tons. The time required to lift a load from the bottom of the

quarry to mast-head is 90 sec. The Blondins are often served by fixed cranes on the floor of the quarry.

The Scattie quarry is now worked entirely by electricity, thus accelerating the output of good stone for all building purposes, the removal of waste, and reducing the quarrying costs. The quarry is shown in Fig. 6.

The mass of rock is moved by boring and blasting. Holes 3 to 4 in. diameter are drilled 20 ft. deep into the rock, by rock drills fixed on tripods. Hand drilling in quarries is now obsolete, and all boring is done by steam or compressed air at a pressure of about 80 lb. to the square inch. Air mains are carried from the compressor station round the quarry and down the face of the rock to the point required; from the mains, pipes lead to the stones to be drilled. A flexible rubber hose is then connected from the pipe to the drill. The modern rock drill is a wonderfully efficient tool, and from 3 to 6 ft. per hr. (of the large-size holes) can be bored in granite.

Black Powder only is used when quarrying stone for building and ornamental purposes, as the high grade explosives fracture and shatter the stone too much, though they are very suitable for roadstone quarries.

When blasting, the holes—usually three to six, according to the weight of the blast—are lightly charged at first and fired several times in succession, with half-hour intervals for cooling off. When it is seen that the cracks are forming satisfactorily and that the vertical joints are yielding, a heavy and final "charge" of powder is given to blow the rock clearly away from the face. This charge may be anything from 50 lb. to 150 lb., or even more.

After the rock is blasted out and the blocks lie loosely round, they are split up into the shapes and sizes required by the quarrymen. A straight line of holes about 4 in. deep and $\frac{3}{4}$ in. diameter is drilled by *pneumatic plug drills*. Wedges are now inserted between two *halfrounds*, or *feathers*, and after a little driving the block breaks in two pieces. The quarry blocker then roughly squares and straightens the stone, and soon it is ready to leave the quarry to be dressed in the mason's yard. The blocks are graded according to colour, the perfect ones being reserved for polishing and ornamental work, the others are cut up for local building purposes and road or paving setts.

Some of the quarry waste is crushed by stone-breakers for road metal, while some is used in the

construction of side-walk slabs, and for concrete blocks.

For slabs and blocks the stone passes through a $\frac{1}{4}$ in. screen; it is then mixed with Portland cement, placed in moulds, and subjected to a pressure of about 400 tons per sq. ft.

Great difficulty is often experienced owing to the fact that the masses of rock are interrupted by natural joints and *faults*. These *faults*, or *bars*, are nearly always discoloured rock, which is valueless for polishing and ornamental purposes, and sometimes thousands of tons have to be removed before stones of important sizes can be obtained. This accounts for the relatively high costs in Aberdeen quarries compared with those of Norway and Sweden. However, when good blocks have been secured, no stone yet discovered in Scandinavia equals the Aberdeen granite in beauty, high polishing gloss, and durability.

NORWEGIAN GRANITE

Quarrying in Norway and Sweden is very different from quarrying in England and Scotland. In Scandinavia no quarry is sunk below the surface level, as huge masses of rock are exposed free from soil and rubbish.

The quarryman therefore sees at once what his quarry is like and how it can be developed, and he has not to engage in the speculative work of exploring and developing in the way the British quarryer must do.

The *ice period*, which left huge deposits of boulders, clay, and sand on Scottish quarries, performed a wonderfully important work for the quarries in Norway and Sweden, where the movement of the glaciers scoured off the disintegrated rock on hill tops and left the sound rock below fully exposed.

This explains why many of the quarries are free from "top-rock," and why the term "deep quarry rock" found in many building specifications has not much significance in Norway.

Though almost the whole of Norway is Granite and Syenite, not a millionth part of the rock is suitable for commercial purposes. About 90 per cent of all exported granite comes from the south-east side of the Christiania or *Oslo* fjord, in the county of Ostfold.

The most famous quarry in Norway is *Bakke* on the Iddefjord, a few miles from the town of Fredrikshald. This property has 400 acres of exposed rock, and the principal quarry lies down by the edge of the fjord where steamers up to 4,000 tons can load direct from the quarry



FIG. 8. NORWEGIAN GRANITE : BAKKE QUARRY
By kind permission of Messrs. A. & F. Mannell, Ltd.

cranes. A reproduced photograph of Bakke quarry, Norway, is given in Fig. 8.

The beds of this rock lie parallel, averaging 20 ft. deep, and the face now being worked is 65 ft. high. Blocks of almost any size can be obtained; in fact, the sizes of the quarried



FIG. 9. FOREST OF DEAN STONE QUARRYING

blocks are only restricted by the loading and discharging facilities.

In three successive blasts in this quarry over 9,000 tons of whole and unfractured blocks were secured, so that an ample and continuous supply is to be relied upon for generations to come. The quarry is electrically equipped, the current being obtained from a waterfall. All drilling is done by compressed air, though this is not general in other neighbouring quarries.

Blasting and splitting of the rocks is carried out in the same way as in Scottish quarries, but naturally all the expense of *tiring* (removing overburden) and pumping of water is obviated.

This quarry produces the well-known granite called *standard grey*, and its fine grain, purity, and freedom from mica spots, has made it the most popular grey granite on the market where large blocks are required quickly for building purposes. It is what masons call a *safe* stone, and because of this reliability in working it is greatly used for carving and fine mouldings, and very few fractures happen during the masoning. The popularity of this granite and variety of purposes for which standard grey is used, have caused several substitutes to appear, but no stone equals it in texture, freedom from black spots, and safe working.

It is almost chemically free from iron, and this fact has led to its use for modern paper rolls,

some of which are 16 ft. in length, and 2 ft. in diameter. It is also used for rolls for cocoa grinding, and for grinding of various chemicals. Fig. 11 shows the *rock face* of a granite quarry in America. The marketable stone is quarried at the surface, as in Norway. In Fig. 12 the drill is seen at work boring, preparatory to blasting. The effects of a recent blast are seen on the right of the picture.

FOREST OF DEAN STONE

The colours are grey, blue, and red. Grey and blue are generally to be obtained from the same quarry, but some quarries yield a preponderance of grey, others of blue.

In the red stone quarry there is sometimes an admixture of grey stone, the two colours being mingled in the same layer of rock. This stone is known as *wilderness*.

The first operation is the excavation and clearing away of the top soil and loose rubble, which is termed "ridding"; the depth of the "rid" varies, but is chiefly made up of a top layer of vegetable soil, peculiar to a forest district, then a layer of sandy soil and loose rubble.

The situation of a quarry is usually chosen so that the "rid," which is of no commercial value, can readily be disposed of with the minimum amount of labour. The quarries are thus usually situated upon a hillside, and it is here



FIG. 10. PAINSWICK STONE QUARRYING

that the accessible rocks are to be found. The "rid" having been removed, some thin layers of stone are obtained, but of low value. The layers vary from 2 to 8 in. thick, and are used for paving, cover stones for manholes, etc. The thickest stones, if of suitable grit, are often used

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for the manufacture of grindstones. These layers are readily quarried; the chief instrument used for so doing is the *crowbar* for dislodging them from their beds. The faces of these thin slabs are fairly true and require very little dressing when used for pavings, etc., hence the term, *self-faced*, by which they are known in the trade. After the thin layers have been quarried the thick beds become accessible; they are from 5 ft. to 6 ft. thick. Usually the lower the position of the bed in the quarry, the better the quality of the stone. The depth to which a quarry may be worked is usually limited by the cost, and also by the presence of coal in the stone, indicating the close proximity of coal measures or strata.

For quarrying the larger beds, explosives are



FIG. 11. WINNSBORO BLUE GRANITE QUARRY FACE, RION, SOUTH CAROLINA

necessary, especially for clearing the tight corners to allow freedom of movement of the large masses. High explosives are used as a lifting agency to dislodge heavy benches of stone, but this method requires great experience and judgment, for an unwise use of high explosive would result in the shattering of the rock, rendering it unsuitable for masonry work of importance.

When the top of the large beds of stone have been laid bare and the freedom of movement obtained, the quarrymen begin to cut up the rock into convenient size blocks, the sizes being determined by the lifting capacity of the crane, and the purposes for which the blocks are intended. The large beds of stone are now converted into blocks with the aid of drills driven by compressed air. The old method of splitting the rocks by working a V-shaped groove and inserting plugs is now discarded, owing to up-to-date improvements. Drill holes about

5 in. apart are put in to a depth of 9 in., with every twelfth hole bored to the bottom of the bed of stone. Into all the holes are driven plugs and feathers with a sledge hammer, which causes the stone to split in the desired direction, Fig. 9.

The blocks are then conveyed to the masonry works, which are all situated close to the railway tracks and station. These works are equipped with machinery suitable for dealing with stone of this structure and are capable of the production of wrought-stone to meet all requirements.

MARBLE

Marble quarrying methods differ very little from those which are adopted for the extraction



FIG. 12. WINNSBORO BLUE GRANITE, RION, SOUTH CAROLINA, DRILLING FOR BLASTING AT QUARRY FACE
Position of latest blast can be seen on the right

of other stones. The rock is found either in the form of boulders or as a homogeneous mass without layers of stratification.

The Italian quarries are mostly situated on the sides of mountains, and in many instances several thousand feet above sea level.

When the rock is found in the form of boulders, these are removed from their position in the quarry and transported to their required destination, but usually the blocks have to be sawn from the mass. This sawing process is carried out by endless wire saws.

The cut is made by the abrasive action of the wire passing over the surface of the rock, the wire being kept in contact with the surface of the rock by an arrangement of pulleys.

Blocks of marble of almost any size can be cut with wire saws, in fact, the size of the blocks is determined only by the lifting appliances available.

Chapter III—TECHNICAL TERMS AND STONE FINISHINGS

FIG. 13 is the sketch of the angle of a building indicating the terms used for the various stones.

The term *Face* is applied to the surface of the stone exposed to view, and is usually the vertical surface shown on elevation.

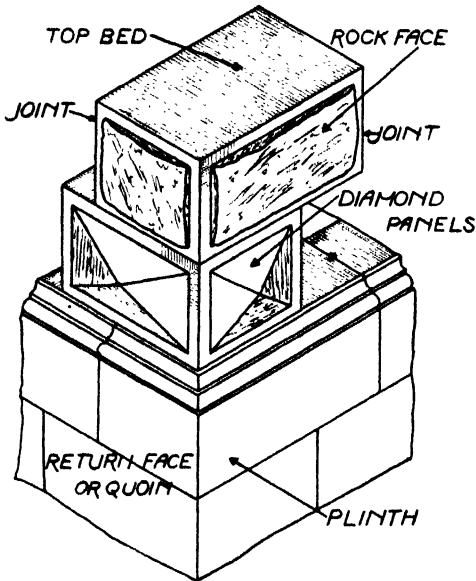


FIG. 13. SKETCH OF ANGLE OF BUILDING, SHOWING MOULDED PLINTH AND QUOIN STONES Finished alternately with diamond panels and rock-face chisel drafted margins

The *Return Face* is the vertical surface exposed to the side elevation, and is generally at right angles to the face.

Beds are the lower surface upon which the stone rests, and the upper surface which supports the stone above. They may be either horizontal or inclined.

Joints are the surfaces prepared to receive other stones butting against them

Back, or *Rough Back*, is the term applied to the vertical surface entirely hidden in the thickness of the wall, and the surface is usually left from the punch or saw.

Clean Back is the term used for the inside vertical surface of stones extending through the thickness of the wall, and forming a face on the inside.

Quoin Stone is a block of stone placed at the angle of a building, the faces being finished in several forms. Fig. 13 shows the *quoin stones* finished alternately with *rock-faced chisel-drafted margin* and *diamond panels with chisel-drafted margin*.

Plinth is the lower courses of stonework projecting from the main wall face. The top course is usually moulded or chamfered.

Break (Fig. 14). This term is usually applied to a recess from the main wall face. When a joint is in line with the *break*, the stone is worked

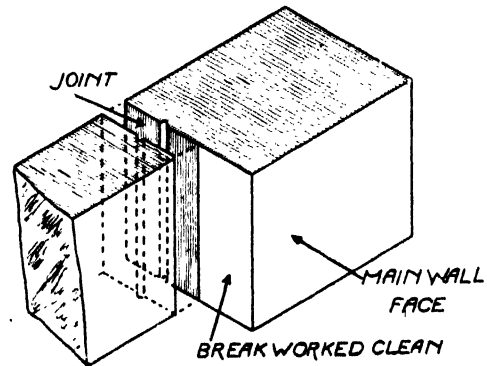


FIG. 14. BREAK STONE

clean for the depth of the break, and a hard line is marked on the stone, showing the face line of the recessed wall, the remainder of the surface being worked as a joint. In the sketch the abutting joint is kept away from the joint for clearness.

The *Arris* of a stone is the edge made by the intersection of two surfaces forming an external angle.

A *Closer* is the last stone to be placed in a course, being jointed to the correct length so as to close or fill the gap.

External Mitre, Fig. 15, is the line formed by the intersection of two mouldings at an "external angle" of a building.

Internal Mitre, Fig. 15, is the line formed by the intersection of two mouldings at an "internal angle" of a building, the moulding making an angle less than 180°.

Ashtar Stop (Fig. 16). The moulding is

MODERN BUILDING CONSTRUCTION

mitred and returned on to an ashlar face, forming an abrupt finish to the moulding.

Ashlar is the term applied to finally dressed stone worked to fit in the general face of the

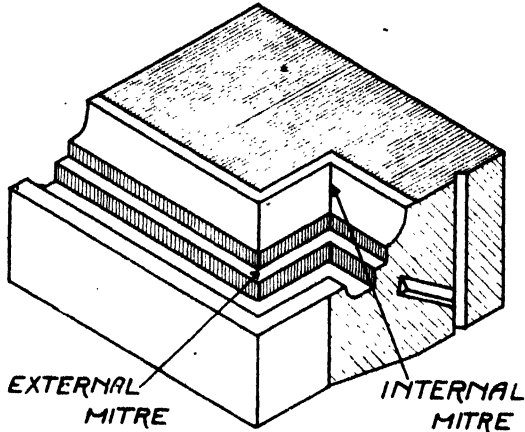


FIG. 15. EXTERNAL AND INTERNAL MITRE

wall, either projecting from the *wall face* or *flush*, and is described according to the finish of the face of the stone.

Plain Ashlars are stones with rubbed, dragged, or polished plain surfaces.

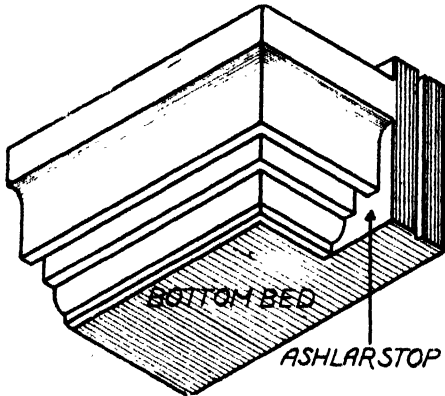


FIG. 16. STRING COURSE WITH ASHLAR STOP

Boasted Surfaces, Fig. 17, are finished with a 2 in. *boaster* in fairly even tool marks. The regularity and angle of the chisel marks depend upon the style of the craftsman.

Tooled, or Batted, Surfaces, Fig. 18, are left with regular chisel marks vertically across the face of the stone, and are cut with a "batting"

or "broad" tool after the surface has been rubbed true. The "bats" are usually specified so many bats to the inch. The faces of York stone used as *padstones* (*templates*) are usually batted, or tooled.

Rusticated Ashlars are the courses of stonework projecting from a wall and finished in several ways. The back of the "rustication"

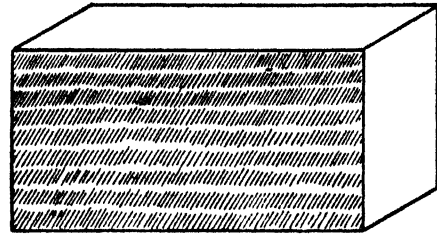


FIG. 17. BOASTED ASHLAR

should always be the face line of the wall. The following are some methods of treating the rustication: *chamfer*, Fig. 19; *chamfer-fillet*, Fig. 20; *rebated*, Fig. 21.

For Rustic Work in Granite the faces are left rough and should be entirely free from punch marks.

Pitched-Faced Ashlar (Fig. 22). The beds and joints are worked true and the lines for the

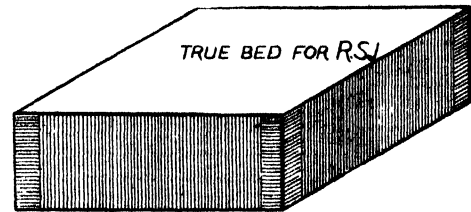


FIG. 18. TOOLED, OR BATTED, TEMPLATE

face of the wall marked on the beds and joints. The lines are then "pitched" with a hammer and "pitching tool." The rough surface of the stone should extend over the surface, no punch or chisel marks being shown.

Punched, or Broached, Ashlar, Fig. 23, is left from the punch in furrows across the surface, usually between chisel-drafted margins.

Furrowed Surfaces, Fig. 24, consist of small *flutings* either horizontal or vertical across the face of the stone, the "flutes" being $\frac{1}{4}$ in. centre to centre.

Reticulated Ashlar (Fig. 25). The surface is worked true with a series of sinkings cut into the stone about $\frac{1}{4}$ in. deep, the sinkings being

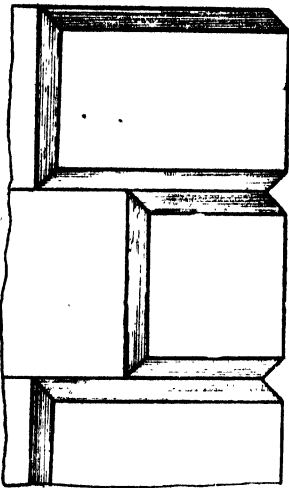


FIG. 19. CHAMFERED JOINTS

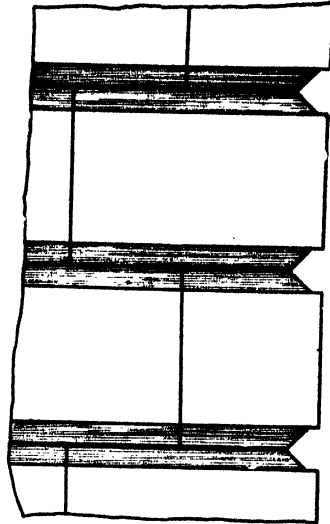


FIG. 20. CHAMFER-FILLET JOINTS

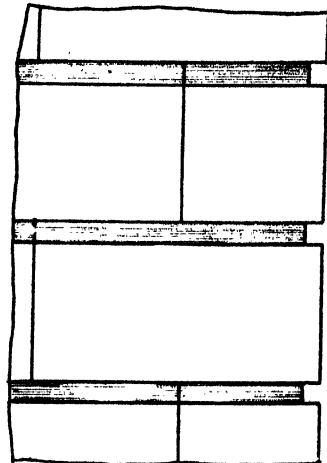


FIG. 21. REBATED JOINTS

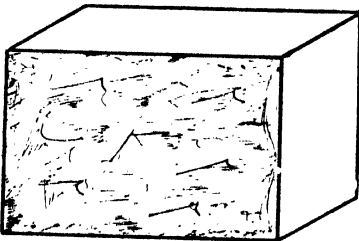


FIG. 22. PITCHED-FACED ASHLAR

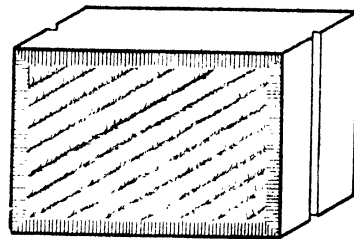


FIG. 23. PUNCHED, OR BROACHED

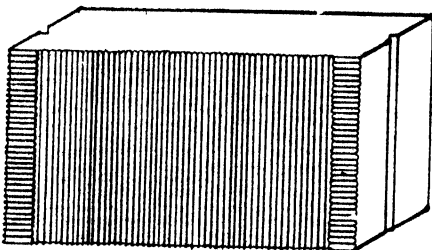


FIG. 24. FURROWED SURFACES

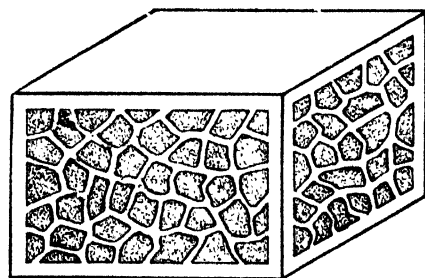


FIG. 25. RETICULATED ASHLAR

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separated by bands of regular width. The sinkings should be worked true to a gauge, and "picked" with a fine *mallet-headed point*.

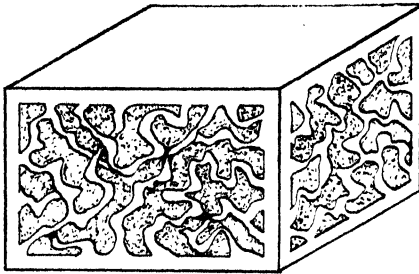


FIG. 26. VERMICULATED ASHLAR

Vermiculated Ashlar (Fig. 26). This style of finish is different from the former. The bands separating the sinkings are irregular in width

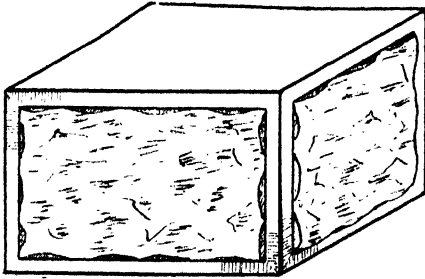


FIG. 27. ROCK-FACE, CHISEL-DRAFTED MARGINS

and form. They are often worked to interlace, giving a worm-eaten appearance.

Chisel-drafted Margins (Fig. 27). True drafts are worked around the face of the stone, and the

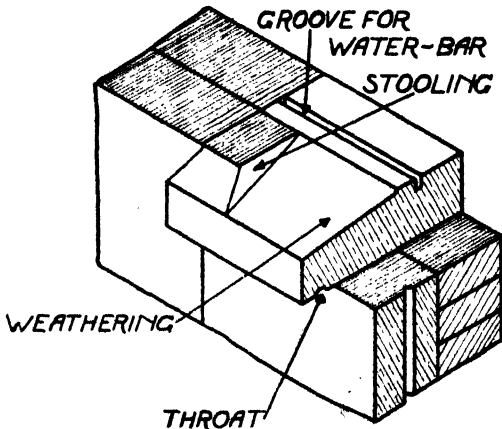


FIG. 28. PLAIN STONE SILL, SHOWING WEATHERING, THROATING, STOOLING AND GROOVE FOR WATER-BAR

centre is either left "rough," "punched," or "picked."

WINDOW OPENINGS

Sills. The term applies to the lower horizontal member of a window or door opening.

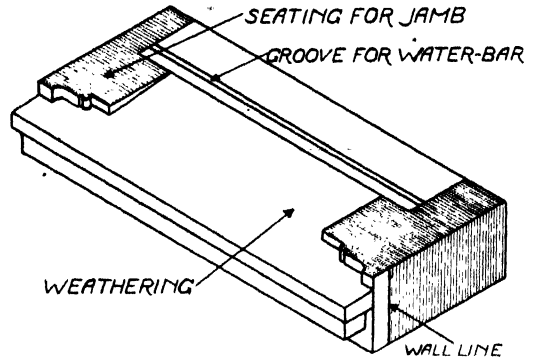


FIG. 29. SKETCH OF MOULDED WINDOW SILL
Showing moulded jambs worked direct on to weathering

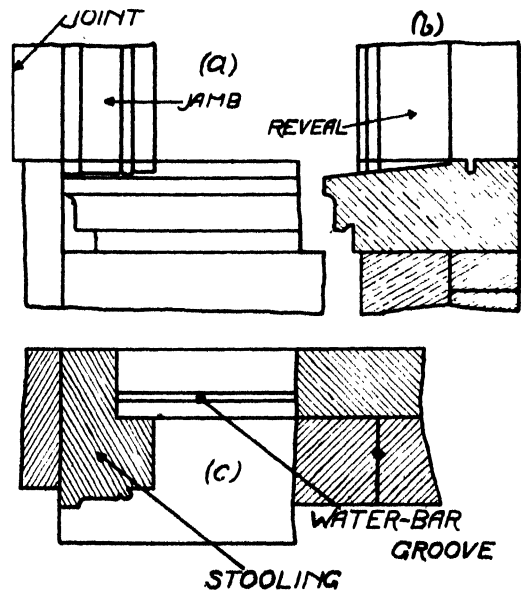


FIG. 30 (a) ELEVATION, (b) SECTION, (c) PLAN OF MOULDED SILL

Window Sills, Fig. 28, are constructed to throw the water clear of the wall, and keep the moisture from penetrating under the wood sill which is attached to the frame. To meet these requirements they should be *weathered, throated, and grooved*.

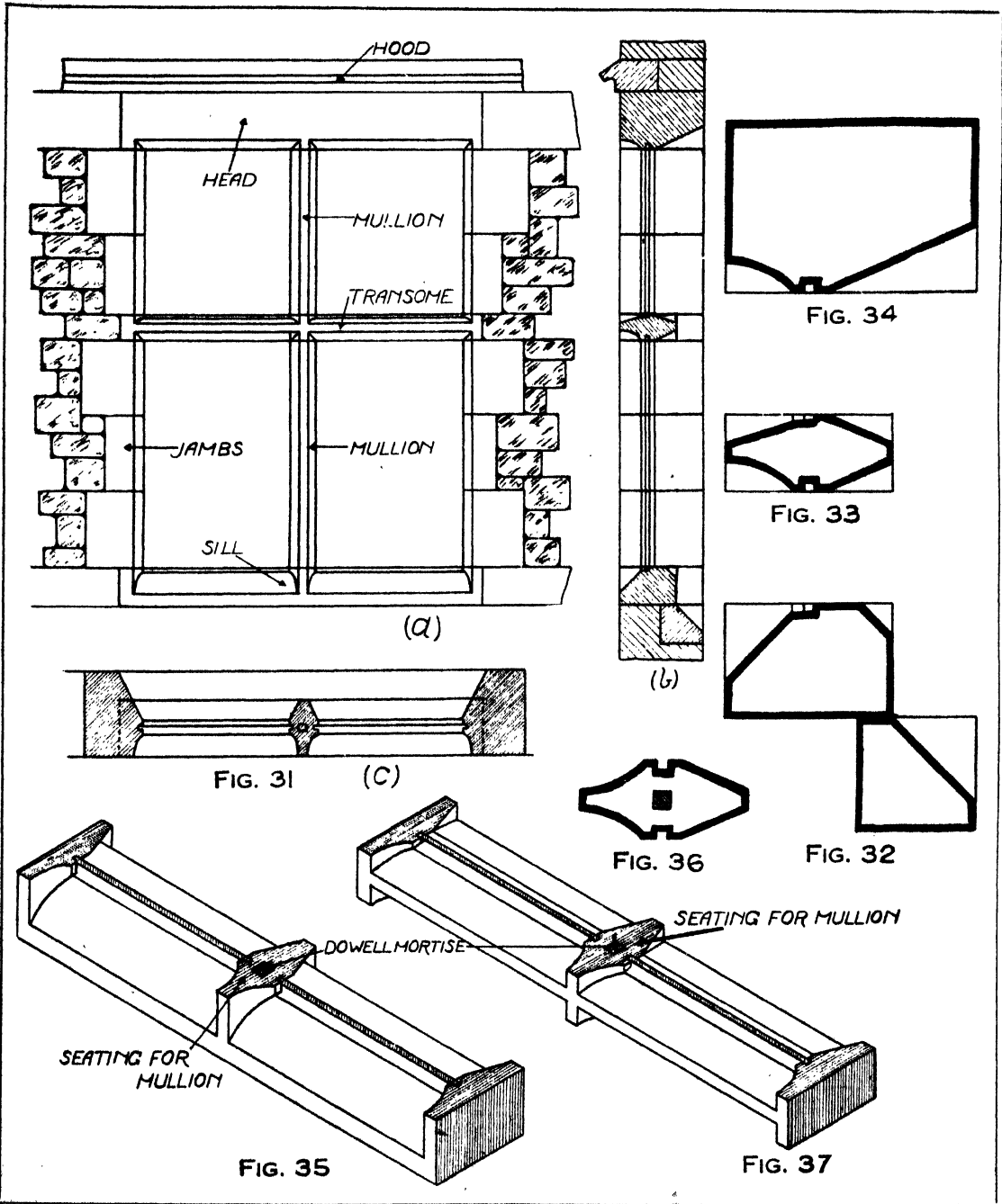


FIG. 31. (a) ELEVATION, (b) SECTION, (c) PLAN, SHOWING TREATMENT OF FOUR-LIGHT WINDOW
 FIG. 32. DETAIL SECTION THROUGH SILL AND SUB-SILL
 FIG. 33. DETAIL SECTION THROUGH TRANSOME
 FIG. 34. DETAIL SECTION THROUGH HEAD
 FIG. 35. ISOMETRIC SKETCH OF SILL
 FIG. 36. DETAIL SECTION THROUGH MULLION
 FIG. 37. ISOMETRIC SKETCH OF TRANSOME

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The *Weathering* is the exposed top surface, and should be worked inclined to the horizontal, the angle depending upon the projection of the sill and the *reveal* of the window jambs.

Stoolings. Horizontal portions should be left at each end of the sill, forming seatings for the jambs to rest on; the weathering is usually mitred away from the stoolings, or the jamb moulding is cut direct down to intersect the slope of the weathering.

A horizontal seating should also be left under *mullions* where the window has two or more "lights."

Throat. Sills should have a projection from the wall line, thus allowing an undercut groove to be worked, forming a *drip* so that the water from the sloping surface is allowed to drop clear of the wall.

Water-bar Groove. A groove should be cut in the top bed of the sill behind the back edge of the weathering, and carried past the reveal line of the opening, to receive a *metal strip*, 1 in. \times $\frac{1}{2}$ in. in section, which should be bedded in red lead, half in the *stone sill* and half in the *oak sill*, to prevent the water percolating through the joint between the two sills. Sills should not be allowed to run too far under the jambs, as they are then liable to fracture, owing to unequal settlements of the building.

The throating should not be worked right through the length of the sill but returned to the wall, forming a drip at each end.

Fig. 29 is a sketch of a moulded sill; the moulded jambs are cut direct on to the weathering.

Fig. 30 shows the sill in (a) elevation, (b) section, (c) plan.

Jamb Stones are the stones employed at the sides of openings, forming the reveals to the openings. They should be well bonded through the wall and on the face.

Fig. 31 shows the treatment of a four-light window, (a) elevation, (b) section, (c) plan; with detail sections through the *sill*, and *sub-sill*, Fig. 32; *transome*, Fig. 33; and *head*, Fig. 34. The sill in this case has no projection, but usually a moulded *drip stone* is provided under the sill, in separate course. Fig. 35 is a sketch of the sill showing the rebate instead of a glazing groove.

Fig. 36 is a section through the mullion (*vertical bar*, or *post*) which divides the window into several lights.

A sketch of the transome is shown in Fig. 37; this is an *horizontal bar* separating a window into two lights in height. The top portion of the

transome is worked as the sill with weathering, rebate, etc., but the underside is worked as a head, or *lintel*; this is shown clearly in detail section of *transome*.

Dowells. Either copper or slate is used in the beds of *jambs*, *mullions*, *columns*, *balusters*, etc., to prevent lateral movement of the stone. For this purpose they should not be more than 2 in. long, but for *finials*, *terminals*, etc., as long as the individual case requires.

A *Joggle* is the indentation made in the joints of stones to prevent sliding, the cavity so formed being filled with *liquid cement*, or *grout*. Sometimes an indentation is cut in the joint to receive a projection on the next stone.

STRING COURSES

String courses are the horizontal bands of stonework projecting from the face of the wall. They are usually moulded, and placed to accentuate the horizontal divisions of the building; sometimes they are in the form of a plain face projecting only a few inches from the face of the wall. A drip should be formed by working a throat underneath the projection, and the top surface of the projection should be weathered.

See Fig. 16, which shows a sketch of a moulded stone suitable for a string course.

Cornice. The term *cornice* is usually applied to the moulded projecting course crowning the part of the building to which it is affixed. Fig. 38 shows a section through a stone cornice in one bed.

Fig. 39 shows a section through a stone cornice built up in two beds of stone. The weathering is shown inclined towards the wall face, with channel provided for carrying off the rain-water; the channel is inclined towards certain points, where holes are cut through the cornice to the face of the wall below, and a lead pipe inserted, discharging into a *rain-water head*; or the channels are carried through to the back of the wall and run direct into a *rain-water pipe* running down a chase cut in the inside of the wall. The exposed upper surfaces of cornices should be covered with some impervious material. *Sheet lead* is the finest covering for stonework, but rather expensive. This covering is shown in Fig. 38. A saddle joint is shown as an alternative to covering.

Asphalt is very often used, as shown in Fig. 39. The asphalt is spread on the surface while hot, *trowelled* to the correct *falls*, and rounded off at the nosing of the cornice. A *dove-tailed groove* is worked in the stone a few inches

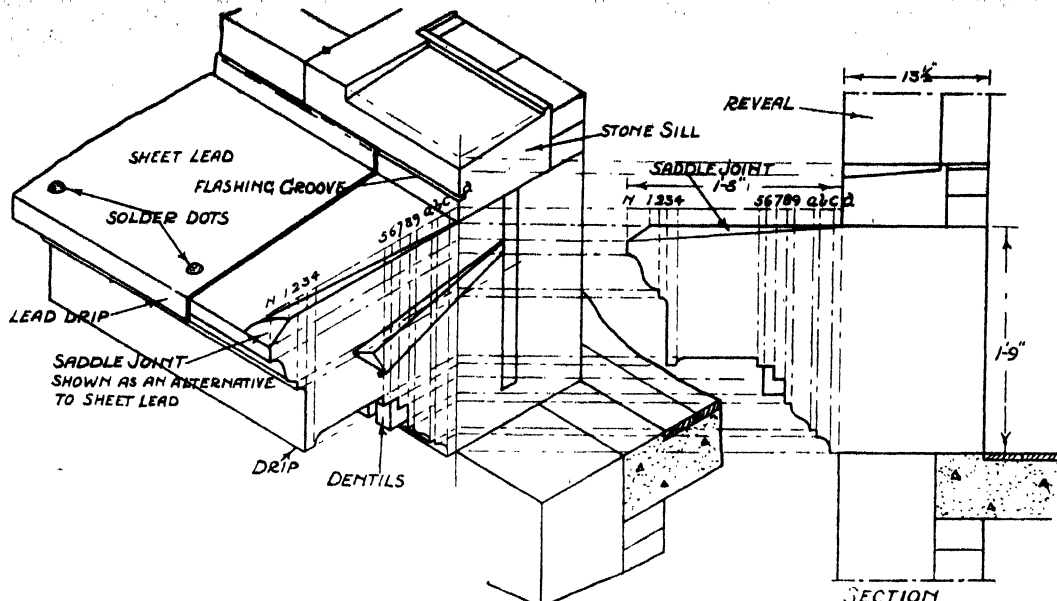


FIG. 38. DETAILS OF STONE CORNICE

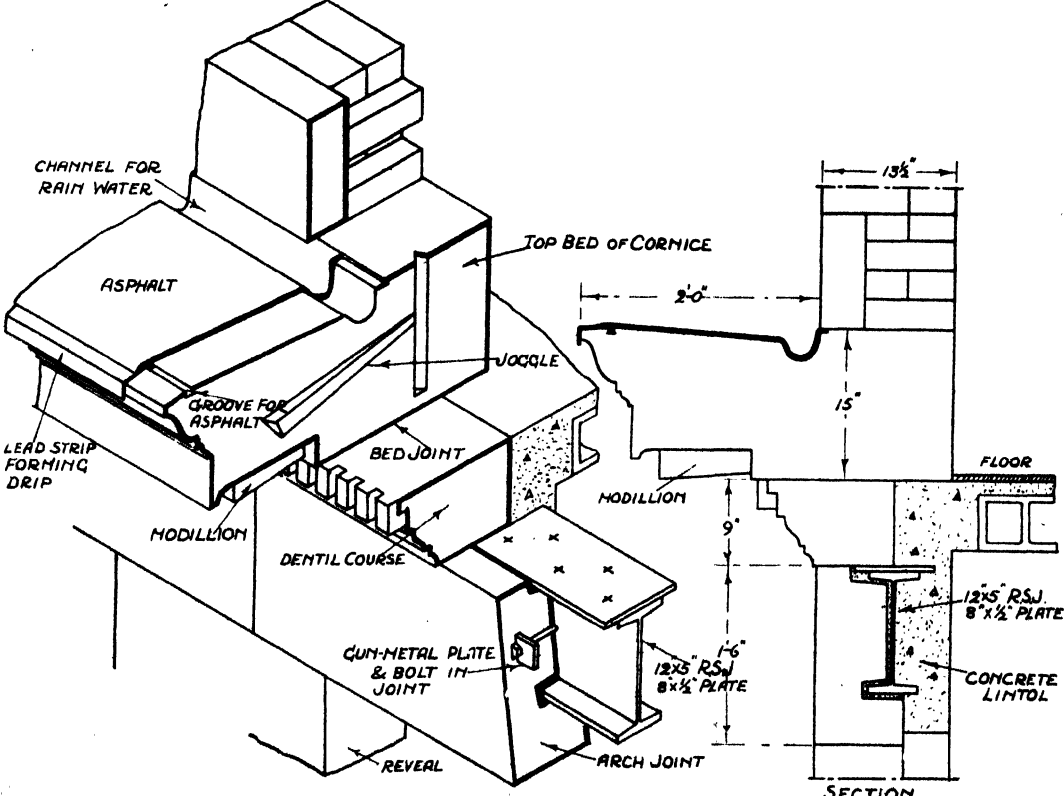
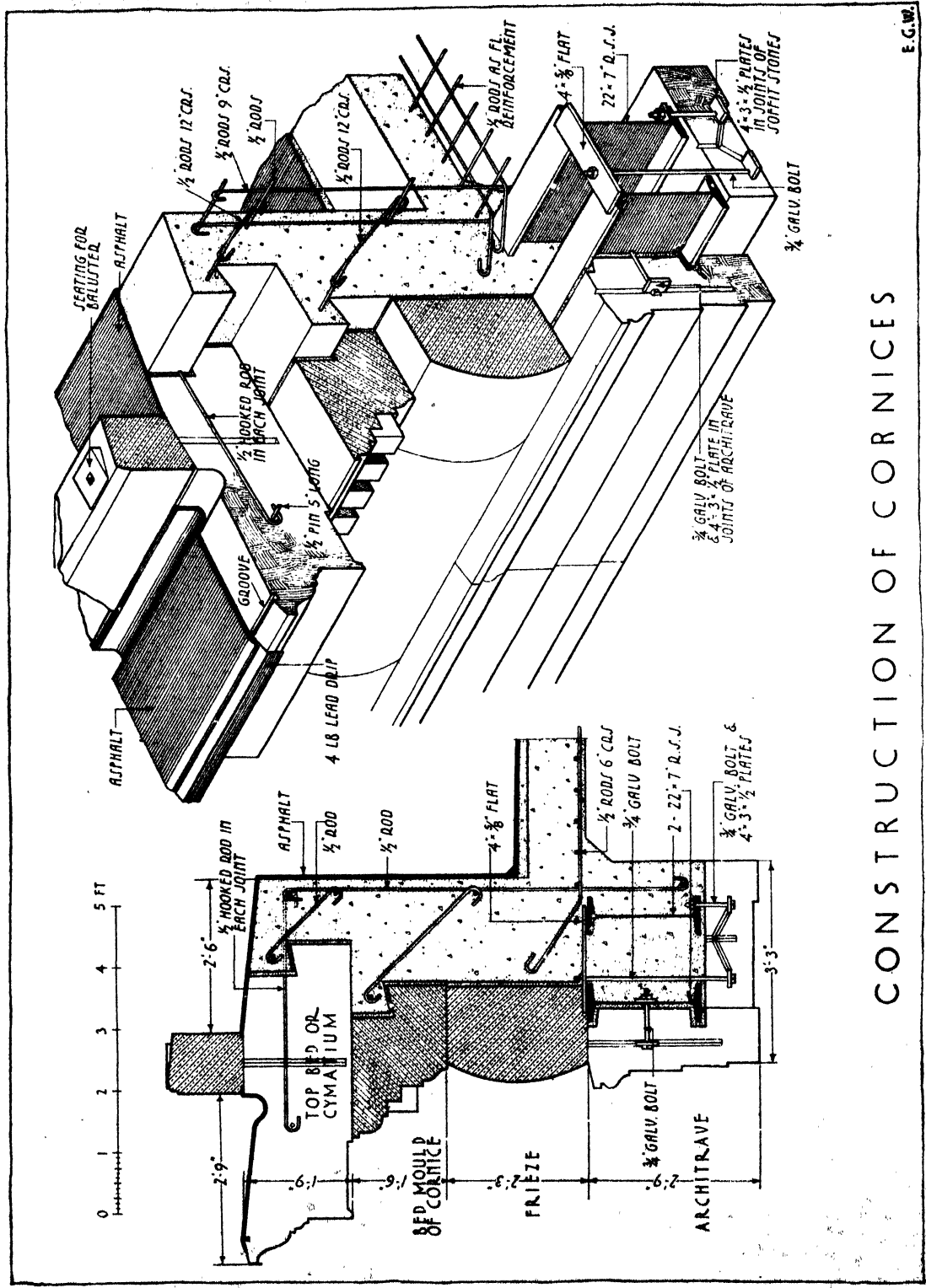


FIG. 39. STONE CORNICE AND LINTOL



CONSTRUCTION OF CORNICES

E. G. W.

from the nose line, to form a key for the asphalt. This is not a good finish for the covering, as the rain-water is allowed to run down the front members of the cornice, soon causing discoloration of the stone-work in the form of dark streaks. A drip should be formed by a strip of sheet lead worked over the nosing and turned into the dove-tailed groove, the asphalt being finished on top of the lead strip, as shown in Fig. 39.

COPINGS AND GABLES

The term *coping* is used for the top course of masonry covering a wall. Copings are designed

designed according to the particular period of architecture required.

Gables. Fig. 45 shows (a) elevation and (b) side elevation of a gable, or the vertical triangular piece of wall at the end of a roof, showing *springer*, *kneeler*, *apex* or *saddle stone*, and *coping*, the section of which is the same as shown in Fig. 40.

Plain ashlar *bands* are sometimes placed at various levels, usually at the level of the springer and kneeler. If the gable is large, two or more kneelers should be provided, to help resist the thrust of the *coping*, which should be cramped at each joint with a metal or slate

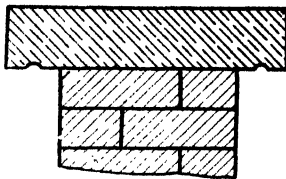


FIG. 40. FLAT COPING

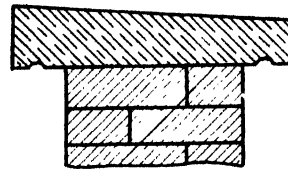


FIG. 41. FEATHER-EDGE COPING

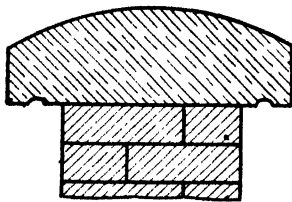


FIG. 42. SEGMENTAL COPING

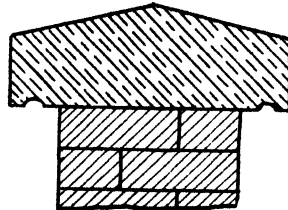


FIG. 43. SADDLE-BACK COPING

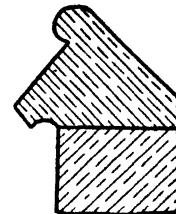


FIG. 44. GOTHIC COPING

to keep the wall dry. They should have projections from the wall face on either side, and be provided with a drip formed by working a groove on the underside of the stone.

Fig. 40 shows a section through a *flat*, or *parallel*, *coping* suitable for gables and inclined surfaces, but it is not recommended for horizontal wall coverings.

Fig. 41 is a section of a *feather-edge coping*, which is quite an economical covering for brick walls, etc. The top surface should slope towards the inside face of the wall.

Fig. 42 is a section of *segmental coping*, which is also suitable for horizontal wall coverings.

Fig. 43 shows a section of *saddle-back coping* suitable for the same purposes as above mentioned. The top surface is weathered both ways from the centre.

Fig. 44 is a section of one form of *Gothic coping*. There are various forms which are

cramp. The cramp should grip the two stones tightly, after which it is necessary to fill in with Portland cement, entirely covering the metal.

RUBBLE WALLS

Rubble Walls are unlike those built with *wrought masonry*, because the resulting appearance and stability of the wall depends upon the skill and artistic taste of the mason or *waller*. The stones are placed in the wall in their rough state or roughly squared with the hammer, the interstices being filled with mortar. The bonding of the stones is a very important factor and entirely rests with the mason, who should select the stones to form as good a bond as possible; bonders or headers should be placed at intervals to provide a bond transversely through the wall. All uncoursed rubble walls are required by the London Building Act to be one-third thicker than walls built of wrought-stone or brick.

MODERN BUILDING CONSTRUCTION

Coursed Rubble Wall. Fig. 46 is from a photograph of this type of walling. The stones are roughly squared to suit the height of the courses required.

graph of this type of wall, the stones being built in the wall any shape, or pitched to fit the adjacent stones.

Flint Walling, Fig. 49, shows a piece of

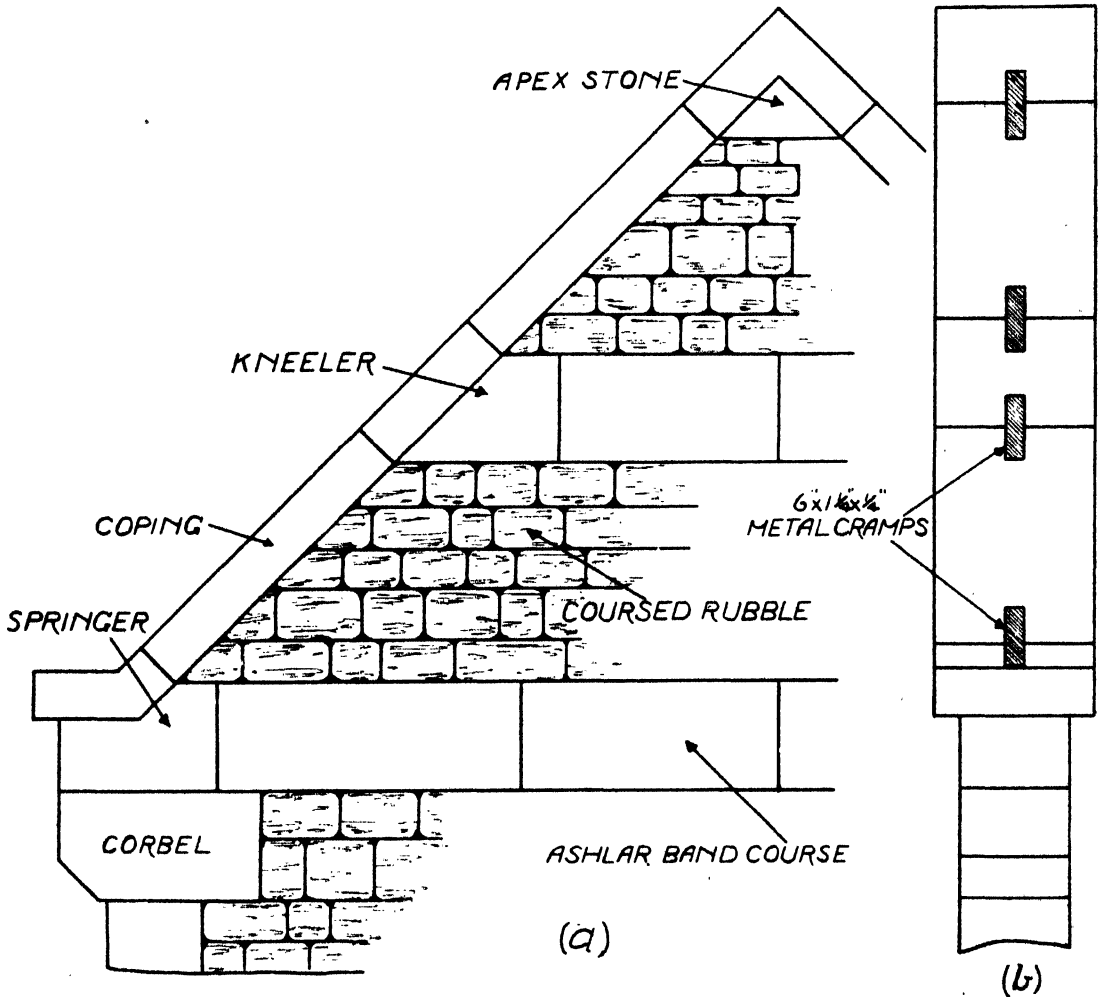


FIG. 45. GABLE IN COURSED RUBBLE WALL

A *Random Rubble Wall* built to courses is shown in Fig. 47. Small square stones called *snecks* are introduced to level up, to the height of the adjacent stones.

Polygonal Wall. Fig. 48 is from a photo-

polled flint walling. The flints are split and the broken surface forms the face of the work. This class of work is generally arranged between wrought stone quoins and horizontal courses.

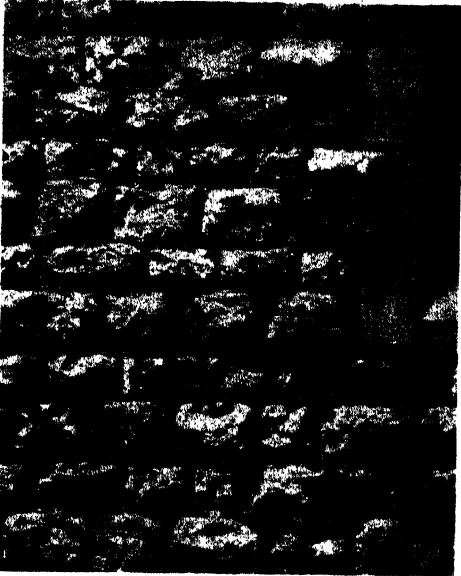


FIG. 46. COURSED RUBBLE WALL

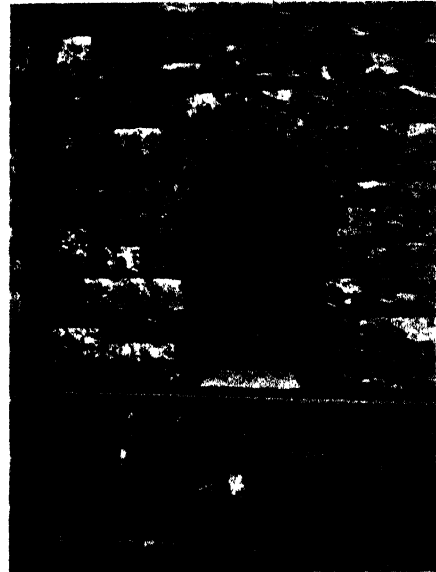


FIG. 47. RANDOM RUBBLE WALL, BUILT TO COURSES, WITH SNECKS INTRODUCED



FIG. 48. POLYGONAL WALLING



FIG. 49. FLINT WALLING, WITH WROUGHT-STONE QUINS

Chapter IV—TOOLS AND APPLIANCES

THE tools used by masons vary according to the particular rock or stone upon which they are to operate. Every mason, like other craftsmen, accumulates quite a host of various little devices to suit his own particular way of working, and to facilitate the execution of difficult intersections and undercut members of mouldings. Masons' tools have not undergone any fundamental change for a great number of years. A few devices have been added, but the principal tools remain the same. They should be made from the best *tool steel*. Some are, however, made from *mild steel*, but these are very inferior, and when sharpened lack that cutting edge which is necessary to the clean cutting of the stone.

The following are some of the tools in general use by masons—

Fig. 50. A mason's *Mallet* is usually made of beechwood, hickory, or a well-selected piece of applewood.

Fig. 51. The *Hammer* is made of cast steel, from 1 lb. to 5½ lb. in weight. The faces of the hammer should be inclined at an angle to receive the impact squarely.

Fig. 52. The *Dummy* is used by "soft stone" or "Bath stone" masons in conjunction with wood-handled chisels. It is made of zinc and lead, and varies from 2 to 4 lb. in weight.

Fig. 53. The *Pitching Tool* is used in conjunction with the hammer for reducing the stone to the working lines.

Fig. 54. The *Punch*, which is hammer-headed, is used in conjunction with the hammer for working off the superfluous stone.

Fig. 55. The *Mallet-headed Point* is used chiefly in furrowing the stone preparatory to chiselling the surface.

Fig. 56. *Hammer-headed Chisels*, with cutting edge varying from ½ in. to 1½ in. wide, are used for drafting or chiselling granite and hard sandstones.

Fig. 57. *Mallet-headed Drafting Chisels* are about ¾ in. wide for working the marginal drafts. Similar chisels of various widths from ¼ to ¾ in. are employed for working mouldings. Sometimes the cutting edge is rounded to the curve of the moulding.

Fig. 58. The *Claw-chisel*, usually from 1½ in. to 2 in. wide, is used in conjunction with the mallet in making drafts over the stone surface, the teeth being formed to prevent the stone *plucking* or *lifting* in holes.

Fig. 58A. In the *Patent Claw-chisel* (Fauld's patent), the cutting edge is inserted and removed when blunt or broken. These tools are excellent on "Grit stones." The shells in Portland readily break the teeth. The use of these tools means a great saving in forging.

Fig. 59. The *Boaster* is a mallet-headed chisel about 2 in. wide, and is used after the *claw chisel* to straighten the surface in drafts.

Fig. 60. *Mallet-headed Gouges* are of sizes varying from ¼ in. to 1½ in. wide, and curved to suit curves of mouldings. The cutting edges are concave.

Fig. 61. The *Mallet-headed Waster* is a chisel similar to the claw-chisel, and from ½ in. to ¾ in. wide. It is used on Bath stone instead of the punch for removing the waste stone. The cutting edge is split, forming teeth similar to the claw chisel.

Fig. 62. The *Batting*, or *Broad Tool*, usually from 4 in. to 4½ in. wide, is used for "batting" or "tooling" sandstones.

Fig. 63. *Lewisings Chisels* are formed specially for cutting mortises for the insertion of the *lewises* for lifting stones. They are from ¾ in. to 1¼ in. wide.

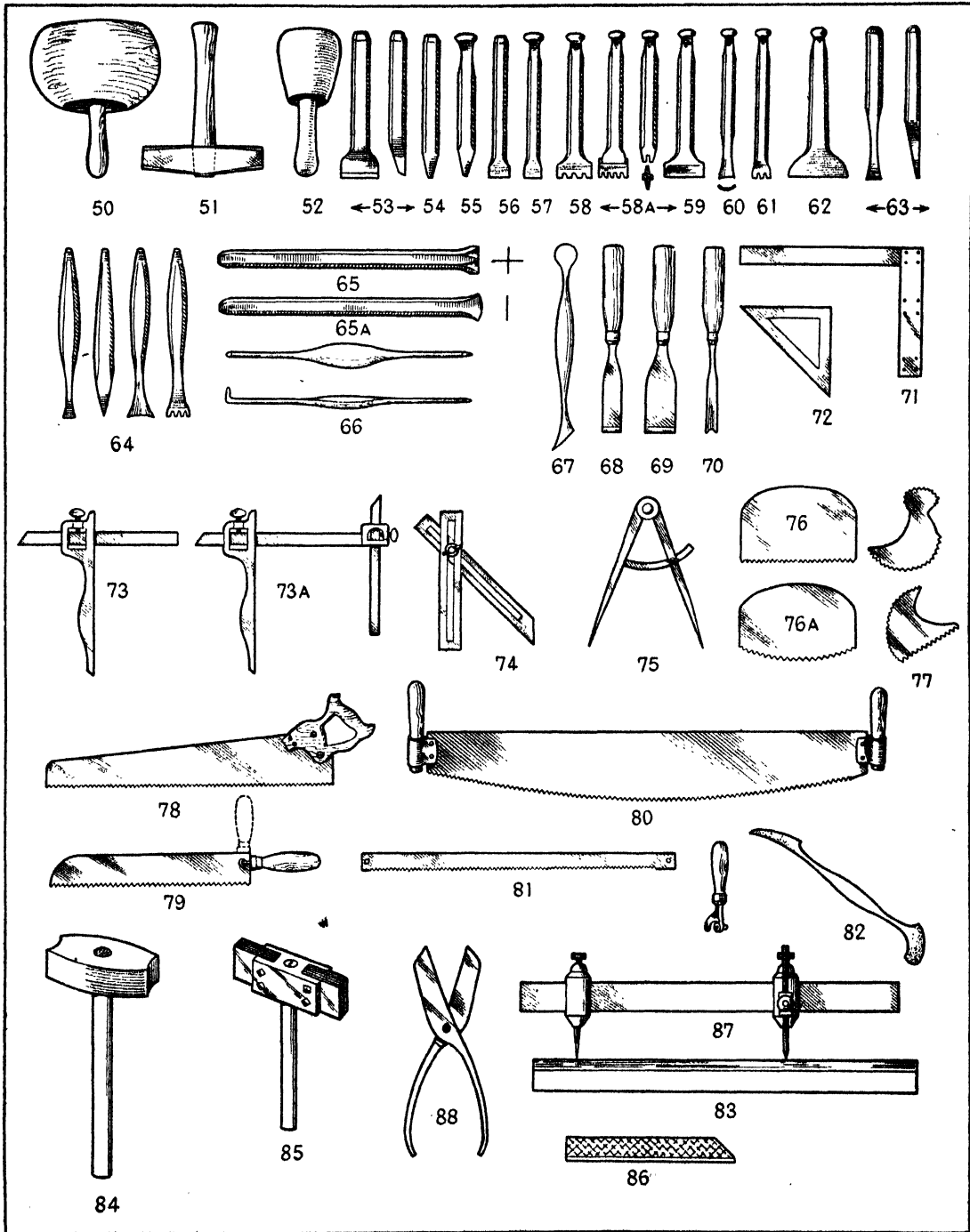
The *Quirking Tool* is similar to the lewising chisel. It is from ¾ in. to ¾ in. wide, and is used for cutting grooves in sills, also grooves for lead flashings, etc.

Fig. 64. *Cup-headed Tools* are used in conjunction with an iron hammer. They comprise chisels of various sizes, and are chiefly used for letter cutting and carving.

Fig. 65. The *Diamond Jumper* is made from octagonal steel, with a cutting edge in the form of a cross. These tools are used for boring holes and are made in various sizes and lengths.

Fig. 65A shows another form of *Jumper*. It is used for the same purposes as the diamond jumper.

These are used in quarries for drilling holes



FIGS. 50 TO 88. MASON'S TOOLS

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for blasting. When used for this purpose they are from 5 to 6 ft. in length; they are not struck with a hammer, but lifted and allowed to fall, being slightly turned whilst being lifted.

Fig. 66 shows a *Trammel and Scriber*. The ends are drawn out to a point, one end being bent at right angles. The centre of the tool is widened out to a concave surface to fit over a chisel handle. When being used, both are held tightly together and the head of the chisel is passed along the edge of the stone, the bent point of the trammel making a line parallel to the edge at the required distance apart. The *scriber* or *point* at the other end of the tool is used for marking lines and moulds on the stone.

Fig. 67. The *Mitre Tool*, having a cutting edge at each end, is made to various shapes and used for "truing-up" mitres and internal angles of mouldings.

Fig. 68. A wood-handled *Drafting Chisel* used in conjunction with the *dummy* for working drafts on Bath stone.

Fig. 69. The *Driver* is used for the same purposes as the booster, but on Bath and similar stones.

Fig. 70. *Wood-handled Gouges* of various sizes and curves are used for working mouldings, etc., on Bath and similar stones.

Fig. 71. *Double-stocked Squares* are used when squaring the stones to shape to test the accuracy of the surfaces that are intended to be at right angles to each other. The square should be tested from time to time and kept correct to the angle of 90°.

Fig. 72. *Set Squares* are made of steel plate. The one shown has both angles 45°. Another with angles 60° and 30° is also used.

Fig. 73. The *Sinking Square* is an adjustable square, and is used as a depth gauge; also for testing square sinkings of small dimensions.

Fig. 73A. The *Double-sinking Square* is used in cases where direct squaring or gauging is impossible. For instance, the raking moulding of a pediment springer as shown in Fig. 144.

Fig. 74. *Bevel*, or *Shiftstock*, is used for obtaining and testing angles and for working chamfers, etc.

Fig. 75. *Compasses* are for drawing circles and measuring distances, etc.

Fig. 76. *Drags* are used for finishing surfaces of Bath and similar soft stones; they are of

various grades and are known as *coarse*, *second*, and *fine*, and are used in rotation to secure a fairly smooth surface.

Fig. 76A. *Circular Drags* are used in rotation as the former, but on concave surfaces.

Fig. 77. *Cocks' Combs* are used for combing mouldings. They are made in various shapes to suit all curves. The teeth are cut around the curved and straight edges. The combs are usually made in the form of French curves.

Fig. 78. The *Hand Saw* is used for sawing soft stones. It is usually called a *banker saw*. The teeth are cut at an angle of about 60°.

Fig. 79. The *Fillet Saw* is used for sawing down neat to the line for fillets, etc., the handle being adjustable in order to prevent damaging the corners of the stone.

Fig. 80. *Cross-cut Saws* are used for sawing the large blocks of Bath stone into slabs or to required sizes. Large *Single-handed Saws* called "Frig-bob" saws are used in the Bath stone mines for releasing the stones from the strata.

Fig. 81. *Whip Saws* are of various lengths and very pliable. They can be bent to suit whatever curve is required when working circular mouldings, etc. The handle is shown detached.

Fig. 82. *Riffler Rasps* are made to suit any curve, and are used for rasping and cleaning in difficult positions, such as at intersections, etc.

Fig. 83. A *Straight-edge* is a piece of wood or steel of any length, with both edges "shot" (planed) straight and parallel, usually with one bevelled edge. Used for testing the surfaces, etc.

Fig. 84. A *Spall Hammer* is used for removing the superfluous stone when in large quantity. The faces are concave, forming two cutting edges.

Fig. 85. The *Patent Bush Hammer* is for finishing surfaces of granite. The plates, which are detachable, vary in thickness according to the work specified.

Fig. 86. *Mason's Fillet Rasps*. These are made to various shapes with one edge smooth, so that when rasping a fillet the edge of the rasp will not cut the surface at right angles, and thus make a groove.

Fig. 87 shows a pair of *Beam Compasses* for setting out or drawing large arcs, etc.

Fig. 88 shows a pair of *Snips*. These are used for cutting zinc moulds.

Chapter V—MACHINES

THERE are various types of machines now in use for the production of worked stone, and much depends upon the adoption of the best type of

Fig. 1 (Chapter I) is a reproduced photograph of a modern masonry works which is capable of producing several thousand cubic feet of worked

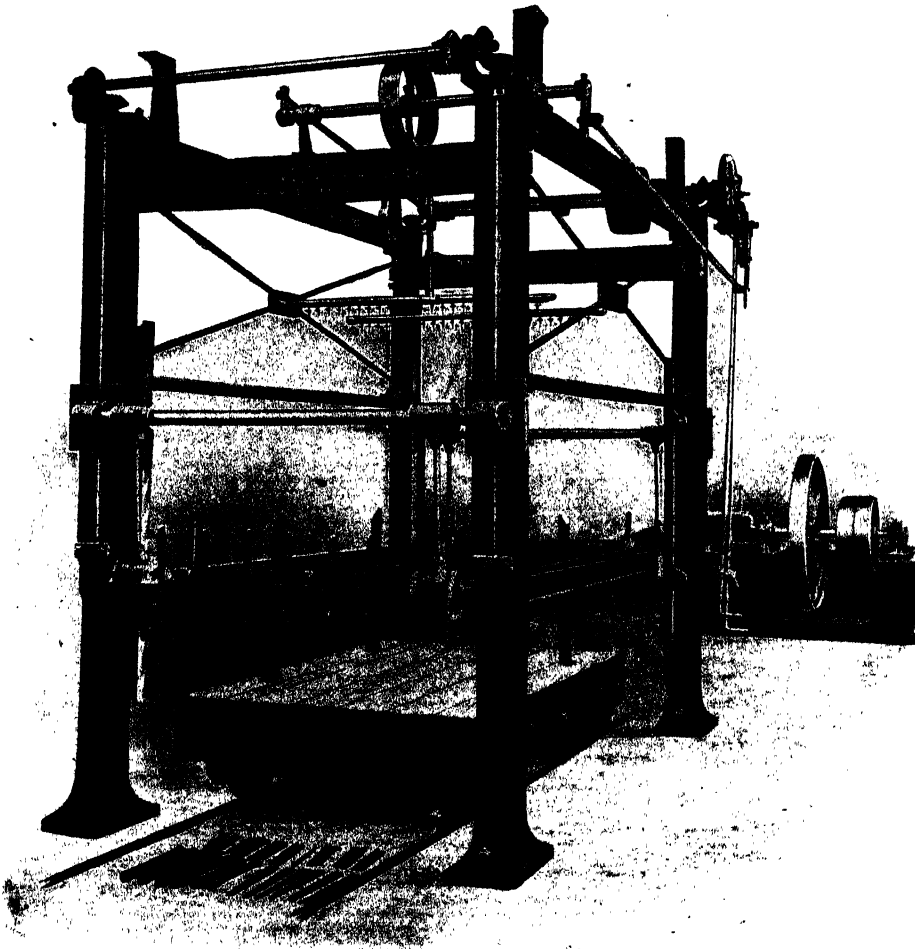


FIG. 89. FRAME SAW

machine, incorporating the various devices suitable for the class of work to be executed. Proper organization and lay-out of the works are essential if the full benefits of the machines are to be obtained.

Portland stone each week. The machines are laid out or grouped in series so that a minimum amount of time is taken up in conveying the stones from one part of the works to the other. The machines and the masons' bankers are

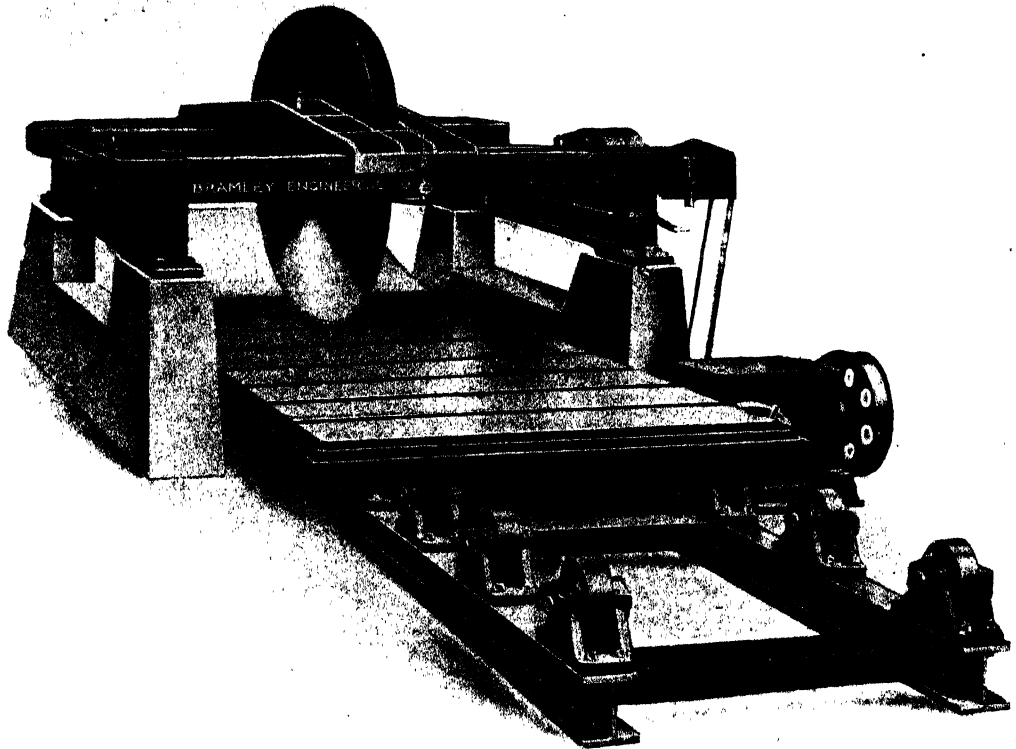


FIG. 90. AN IMPROVED PATTERN OF THE USUAL TYPE OF DIAMOND SAW

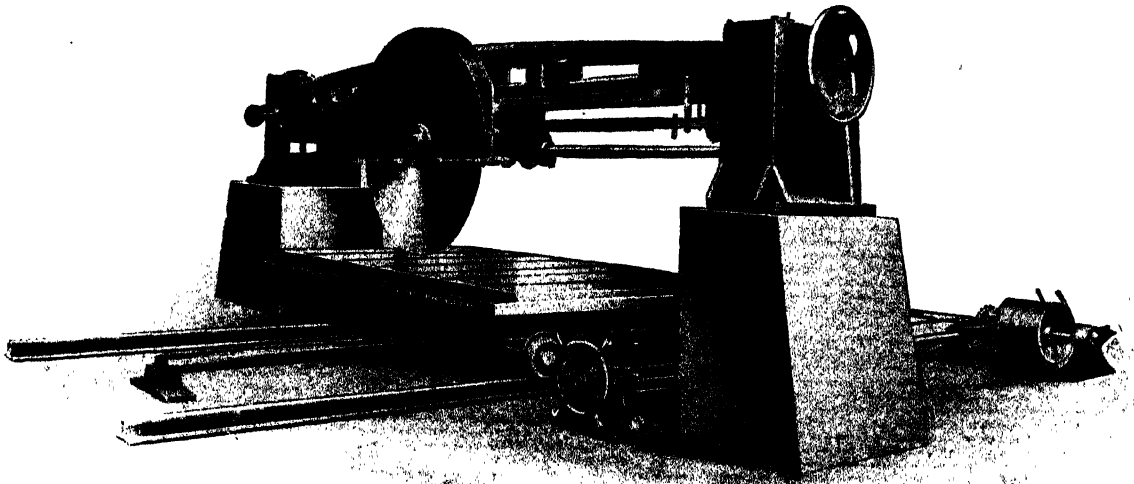


FIG. 91. DIAMOND SAW, BEAM-TYPE

arranged so that they can be served with electric travellers capable of lifting 10 tons, and which travel 200 ft. per min. The railway track runs direct into the works.

The following is a list of some of the machines in use for general masonry. It is not intended to cover the whole of the range of the machines in use, as there are many different types for the

These are driven tight, making the blades rigid. The best blades for Portland stone are the "corrugated" or "ribbed" blades, about 5 in. wide. The frame is raised or lowered by means of a *worm* connected to the overhead gearing, the speed of which can be regulated or governed by means of the attachment at the side to suit the hardness of material being cut.

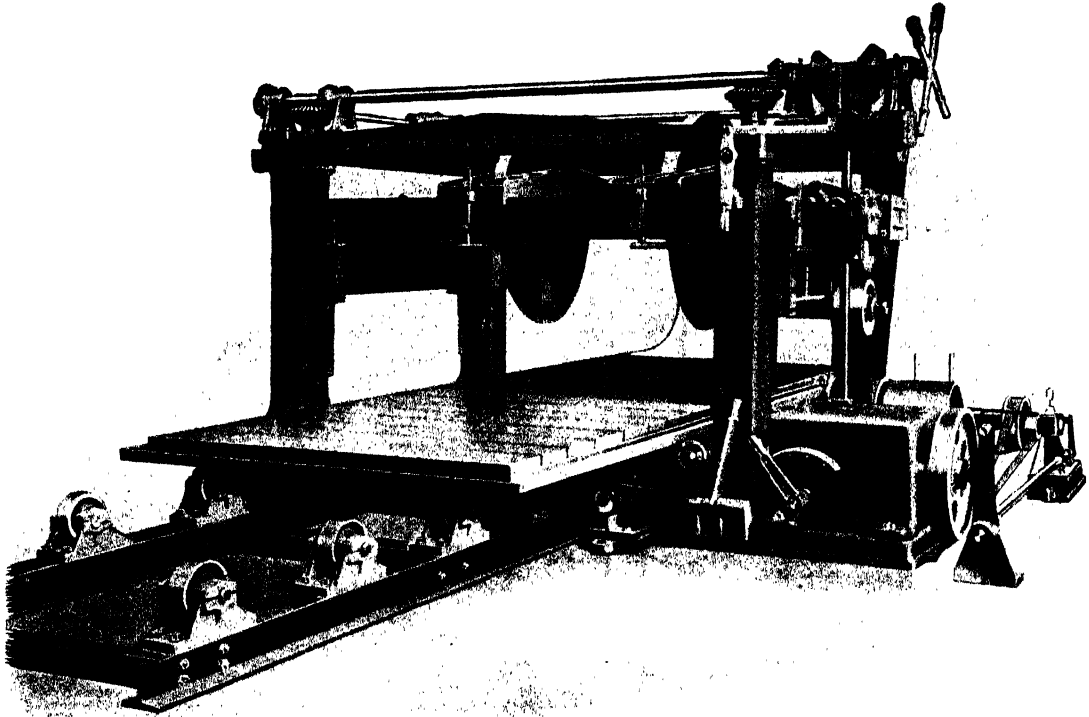


FIG. 92. THE "BRAMLEY" TWIN-BLADE DIAMOND SAW

various branches, the type and grouping of the machines being somewhat different in marble and granite works from that of a Portland stone works.

SAWING

Frame Saw. Fig. 89 shows a good type of machine, and is an essential unit in masonry works, irrespective of the class of work to be done. The table is loaded with blocks of stone, and run under the frame. *Saw blades* are fixed in the frame at the required distance apart by means of the wedges shown in the foreground.

Swinging jets are provided for the distribution of the water over the top surface of the stone.

Bridport or some other sharp sand (and *steel grit* for granite, etc.) is placed on top of the stone; the sand must be allowed to enter freely the *kerf* made by the saw. A channel should be formed in the floor to convey the slurry resulting from the sawing into a pit. The water is allowed to drain away, the sand and other solids forming a sediment.

Diamond Circular Saw. These machines are generally included in the equipment of a masonry works dealing with Portland or similar stones.

MODERN BUILDING CONSTRUCTION

Fig. 90 shows the type of diamond saw in general use in masonry works. After the blocks of stone are slabbed in the frame saws they are turned over and cut to size, or possibly to shape, under the diamond saw. The resultant surface is fairly true, with very few waves, so that the surfaces only require rubbing to the necessary finish. These machines are made with

the saw while the blade is rotating. The speed is arranged to suit the hardness of the particular stone to be cut. Only water is used as a cutting medium, apart from the *diamonds*, which are attached to the rim of the blade.

Fig. 91 shows the beam-type diamond saw. In this type of machine the length of the stone is not limited, and the saw blade travels through

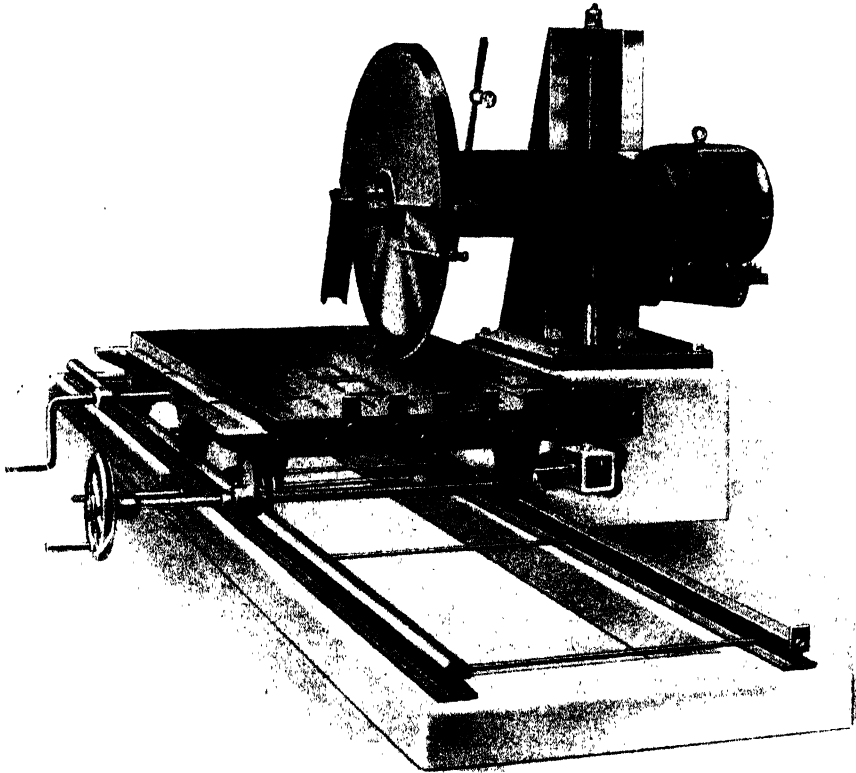


FIG. 93. JOINTER SAW

rising and falling motion, so that the blade can cut at any height from the table (within the limits of the machine), thus making it possible for the saw to cut "checks" in the stone if necessary. The blade, which is from 5 ft. to 6 ft. in diameter, travels laterally along the spindle, thus allowing cuts to be made at different parts of the block without shifting the stone. The stone rests on the table, which travels under

the stone, cutting in both directions. It is a splendid machine for jointing large stones, such as cornices, etc.; also for slabbing, turning out extremely accurate work.

The rising and falling motion, which is incorporated in the machine, enables "checking" work to be done. To suit the cutting of material of different hardnesses and thicknesses, different speeds are provided. The "beam"

has a locking device to minimize vibration while sawing.

Fig. 92 shows an improved type of saw, called the *Bramley twin-blade diamond saw*. Blades can be used up to 8 ft. 4 in. diameter, allowing a

and wheels of other dimensions used, to suit all requirements. The carborundum is pressed on to the outside rim of the blade and slightly bevelled towards the centre, thus allowing the saw to *clear* in the cut.

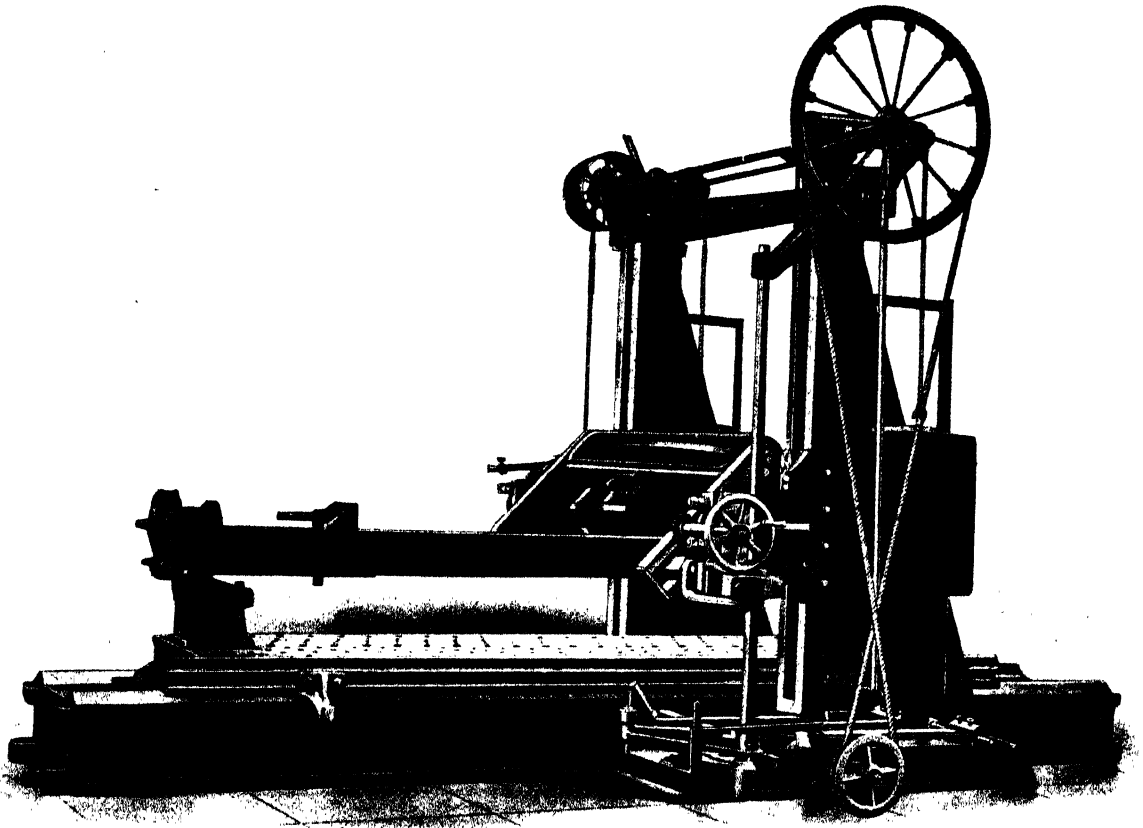


FIG. 94. MOULDING MACHINE, PROVIDED WITH TURNOVER TOOL HEAD AND ROCKING TABLE

depth of cut up to 3 ft. 6 in., and having approximately 200 sockets for diamonds.

Jointer Saw. Fig. 93 is from a photograph of a *jointer saw*. This is a handy machine and a great asset in a modern masonry works, as stones of small dimensions can be readily cut to the correct sizes required. If the machine is worked by a skilful operator, scarcely any finishing to the stone is necessary. The machines are provided with *rising and falling motion* and fitted with *carborundum-rimmed steel-centred blades*, which can easily be attached or detached,

PLANING AND MOULDING

Planing and Moulding Machine. Fig. 94 shows the usual type of machine used in various masonry works. For light mouldings, strings, cornices, etc., it is excellent. The *rocking table* enables the stone to be machined at top and both sides at one setting, and is specially advantageous for working deeply cut mouldings as the stone can be tilted at an angle, thus shortening the tools necessary for working the mouldings and minimizing the vibration.

MODERN BUILDING CONSTRUCTION

The *turn-over motion* of the *tool head* enables the stone to be cut upon the return of the table.

Fig. 95 shows a *rigid head type* of planing machine which is most suitable for planing large surfaces and heavy work in general; for

Turning Lathes are used considerably for turning bases, columns, caps and balusters. They should be designed to meet the requirements of stone turning, although engineers' lathes can readily be adapted. *Gap lathes* should be installed for turning bases, etc., of

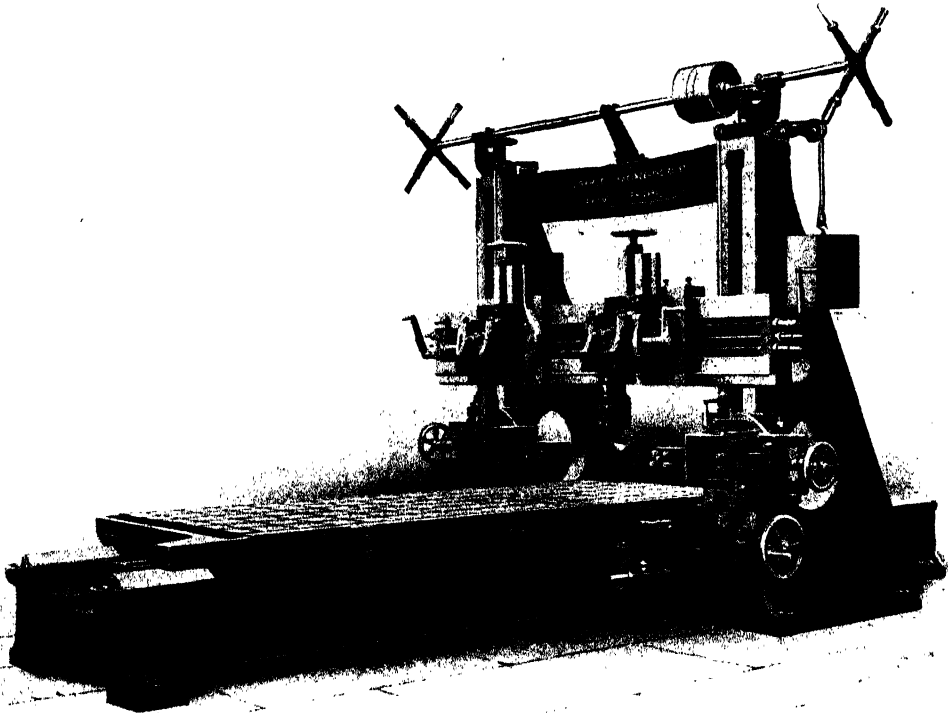


FIG. 95. PLANING MACHINE

although this type of machine will only cut in one direction, the apparent loss of time is recovered by the quick return of the table. Abrasive profiling machines are now being developed for the execution of mouldings, etc., in Portland and similar stones. Carborundum discs shaped to the reverse profile of the desired moulding are fitted to a machine, the arrangement being to allow the disc to revolve at a high velocity over the surface of the stone gradually wearing away the material until the desired profile is obtained. A constant flow of water being maintained.

large diameters. Machine tools are now in general use in marble and granite works, but though much benefit would result by their use in Portland stone works, they are not at present used to any great extent.

Fig. 2 also shows a column stone being turned in a lathe in the masonry works of the Bath & Portland Stone Firms Ltd., at Portland. This lathe is capable of turning stones up to 8 ft. in diameter. The gap of the lathe is 5 ft. It is also capable of turning a shaft 12 ft. long, by 4 ft. 6 in. diameter. A diamond saw is also shown at work.

Chapter VI—STONE CUTTING

Coping a Block of Stone. The stone blocks are usually roughly squared in the quarries by means of an axe and pick, and are sent in this state to the masonry works. If no machinery is used and all labours are to be done by hand, it

under the cut and the block allowed to rest on the iron bar, so that one end of the block is free, the other end being wedged up to keep the block level.

The line is then stabbed in with a hammer

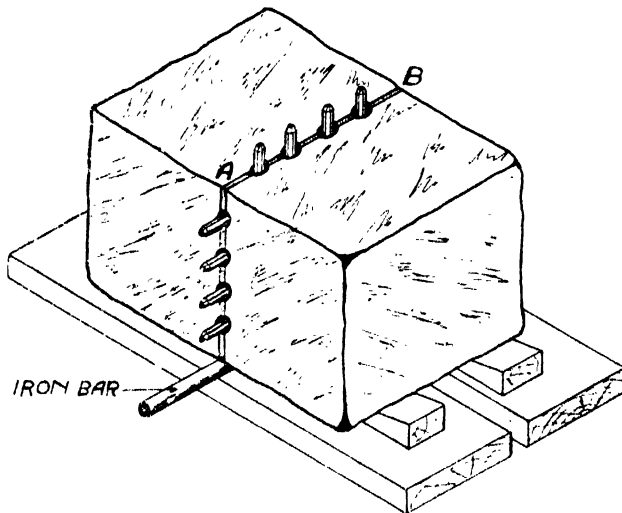


FIG. 96. METHOD OF COPING A BLOCK OF STONE

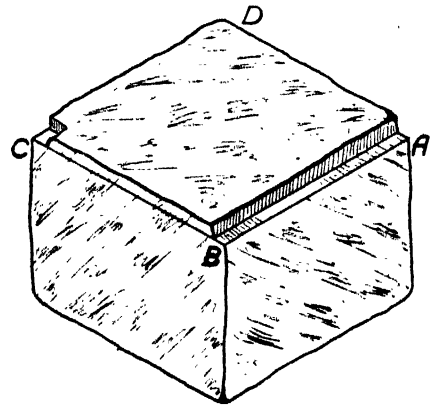


FIG. 97. WORKING MARGINAL DRAFTS

is occasionally found necessary to *split*, or *cope*, a block of stone to the sizes required.

This operation is done in the harder stones by the method shown in Fig. 96.

The mason makes a line on the top surface of the block at *AB*, the position where the stone is to be split, and roughly squares a line down the side from point *A*. A straight-edge should be held or fixed to this line, and another straight-edge held down the other side from point *B* and *sighted* through; when the two straight-edges are parallel with each other the position for the cutting line on the side of the block from point *B* is obtained.

If the ground is soft where the stone is to be coped, it is advisable to have planks placed under the stone, as shown in sketch, but these are not necessary if the ground is hard. The block should be lifted and an iron bar placed directly

and pitching tool. Sometimes a *V*-groove is cut, the centre of the *V* corresponding with the cutting line. Holes are cut in at intervals along the top and sides about $1\frac{1}{2}$ in. deep, and short punches are inserted square with the surface of the block and in line with the required cut. The punches should grip as soon as they are tapped with the hammer.

When all the punches are in position they should be struck in rotation, when they should ring. If it is a large block that is being coped, it is sometimes better to allow the block to remain for a while after the punches have been inserted, and a little water poured into the holes will often assist in the splitting.

Surface of Operation, or Working Surface. This surface is selected according to the particular piece of work required. Sometimes it is the



CUTTING THE STONE TO WORKING-LINE
Showing method of using hammer and pitching-tool



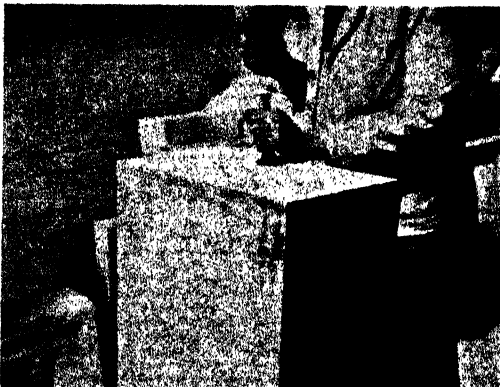
WORKING MARGINAL DRAFTS
Showing method of using mallet and drafting-chisel



POINTING OFF THE SUPERFLUOUS STONE WITH HAMMER AND PUNCH



AFTER SURFACE IS POINTED, DRAFTS ARE WORKED ACROSS THE SURFACE WITH A MALLET AND CLAW-CHISEL



THE SURFACE IS NOW BOASTERED IN DRAFTS WITH MALLET AND BOASTER, EACH DRAFT BEING WORKED TRUE TO THE STRAIGHT-EDGE



THE STONE IS THEN WORKED TO THE SHAPE OF THE MOULD, THE SUPERFLUOUS STONE BEING REMOVED BY THE HAMMER AND FITCHING-TOOL

face, and at other times one of the beds, usually the largest surface being selected.

The mason measures the stone, and, knowing the size required for the finished stone, marks

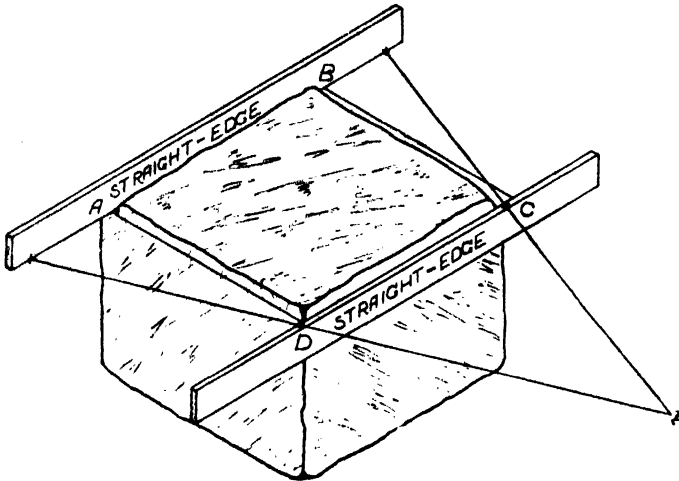


FIG. 98. BONING THE DRAFTS

on a guiding line *AB*, Fig. 97. This line is pitched up with a hammer and pitching tool. The corners are next cut in with a drafting chisel. This is done to prevent losing the corners. The draft is worked straight through between the points *A* and *B* with a drafting chisel, making a draft about $\frac{3}{4}$ in. wide, which should be tested with a straight-edge, and reworked unit straight. Next cut in corner *C* approximately square with the block, and work draft between points *BC*.

As the surface when finished should be in a true plane and out of *winding*, or *twist*, it is necessary to cut in corner *D* so that it is true with, or in the same plane as, the corners *A*, *B*, *C*. A straight-edge is placed on draft *AB*, and another is held on the side of block opposite *AB*, so that the straight-edge is level with corner *C* and sighted through, as shown in Fig. 98. The left-hand end of the straight-edge is raised or lowered until both straight-edges are in line with

each other. The operation is called *boning* and is very important, for if the surface is not *out of winding* it is impossible to square the stone true to shape from the surface. When the straight-edges are parallel, a line should be drawn on the stone and the corner cut in almost down to the line. The draft should then be worked between *C* and *D*, and the straight-edges applied as in Fig. 99. These should be sighted through, and the draft *CD* corrected until both are parallel. It now only remains for the last draft to be worked straight between *D* and *A*.

Having completed the *four marginal drafts*, they should not be interfered with. If in subsequent working of the stone between the drafts it is found necessary to touch any of the drafts, it is best to re-work the drafts to the required depth, and go through the *boning operation*

again. Sometimes *boning blocks* are used at the corners of the rough block; they are made from hardwood about 2 in. cube. The corners are cut

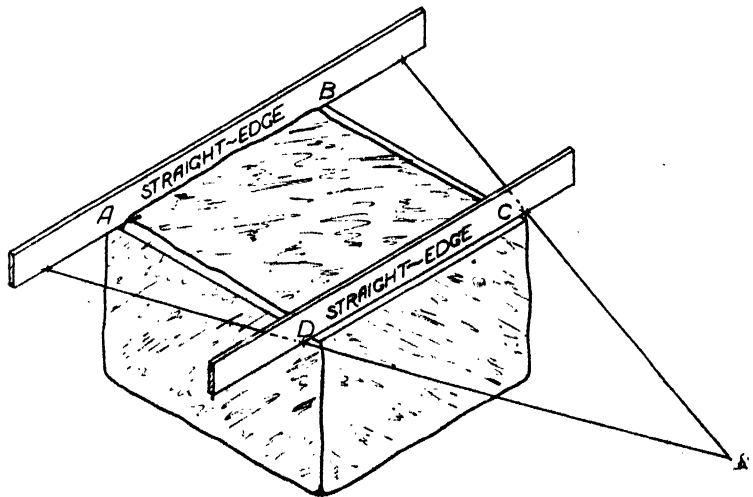


FIG. 99. TESTING THE DRAFTS

in and the *boning blocks* are placed on the positions cut, and the two straight-edges held on top and sighted through; corner *D* is then cut until the two straight-edges are parallel. This method is mostly used in surfacing granite and similar

MODERN BUILDING CONSTRUCTION

stones. The surface between the drafts should now be worked. If there is a lot of waste or superfluous stone to be removed, this should be punched off from the top, roughly down to the surface. By this method the punch is cleared and the stone bursts readily. Furrows may

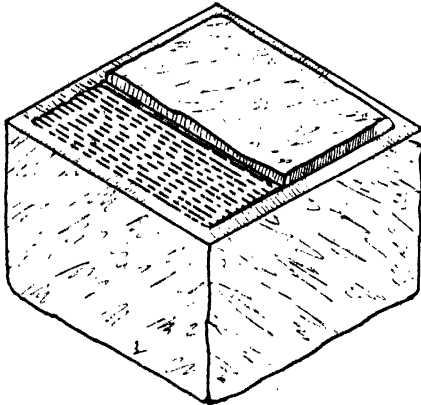


FIG. 100. POINTING

then be made along the surface with a "punch" or "point" fairly close to the required surface, and a straight-edge applied occasionally (see Fig. 100). Drafts should be worked with a claw chisel in the same direction as the furrows, each draft being tested and finished almost straight, to allow for chiselling over with a boaster. Next chisel over surface with a boaster. Each draft should be worked true to the straight-edge. When commencing another draft allow the boaster to overlap the preceding draft just a little. Repeat this process right across the surface, the tool marks being inclined at an angle approximately 60° .

Some writers suggest working drafts diagonally across the surface; but the young craftsman will find that it makes no difference what the superficial area of the surface may be, provided it is worked in series of drafts, each being worked true: the first draft *AB*, being straight, is a guide for the second draft; this draft when straight is a guide to the third, and so on across the surface, the draft before, being a guide to the next. The disadvantages of working diagonal drafts are: (1) It is more difficult to work or plough the centre of the surface without a guide. (2) The diagonal draft is longer. (3) The probability that one side of the diagonal draft is below the surface, which would necessitate re-working the marginal drafts.

When the surface is finished a straight-edge

should be applied diagonally across the surface. If the marginal drafts were boned correctly and the drafts across the surface worked true, then the surface should be straight between corners *AC*, and *BD*, when tested with the straight-edge. If round in one direction and hollow in the other when the straight-edge is applied diagonally, it is proof that the marginal drafts are not "out of winding."

Squaring a Surface. (Fig. 101.) The first surface having been worked true, it is now necessary to work the stone to the required shape. If the stone has to be worked to a *templet* (sometimes called *template*) or *zinc mould*, this should be applied on the "finished" or "working" surface.

The shape of the mould should be marked on the stone with a "scriber" and then with a pencil, so that the exact position of the mould remains during subsequent working. The stone may now be shaped to the mould by squaring the surfaces from the one already finished. One side is first selected and the stone is pitched near to the line, which is then cut up with a boaster. This line becomes a guide for working the front draft. The corners are again cut in correct to the line and the draft straightened between. A

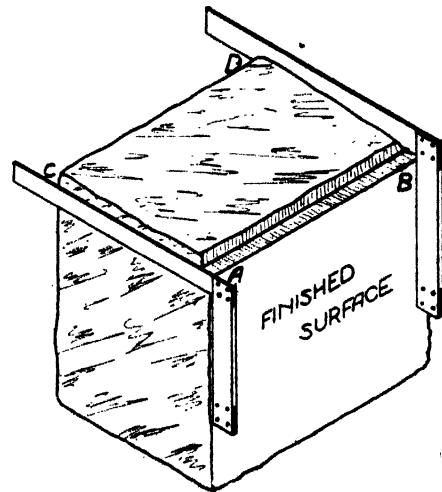


FIG. 101. SQUARING A BLOCK OF STONE

square line should be marked on the stone by the aid of the square, as shown in sketch, remembering that the stock of the square must always be held at right angles to the surface to be squared. Work the draft between *A* and *C*, and apply the square continually, this being repeated until the draft is exactly square. The failing of the beginner is in trying to make the

square fit the stone and not the stone fit the square. The square should be gradually brought down on to the draft by holding the stock of the square, the blade being left free.

When this draft is correct, square in draft at *BD*, as was done for draft *AC*. If the first surface has been worked true, the two drafts squared from the surface will be "out of winding." Next work draft straight between *CD*. The centre of the surface should be worked off as previously explained. All the remaining surfaces of the stone are worked as described, until the stone has been shaped according to the mould applied, or to the sizes given.

Working Springer Stone to Gable. Assuming the springer stone, Fig. 45, is to be worked from a rough block of stone, begin by working the face surface as previously explained and illustrated in Figs. 97-100. When this has been accomplished, place the face-mould on the prepared surface and mark the outline of the mould on the stone. Next work the bottom bed surface; this surface must be worked square from the surface of operation, as previously explained and illustrated in Fig. 101.

The bed-mould should now be applied to the bed surface, and adjusted to coincide with the surface of operation and the position of the face-mould as marked on the surface of operation. The bed-mould determines the width of the stone. The joint surface, and the return end surface, should now be worked square to the surface of operation.

Next work the back surface parallel to the surface of operation. Although the greater portion of this surface will have to be cut away at a later stage, it is better to work the entire surface so that the face-mould can be applied *lines down* on the surface.

When the back surface has been worked, the rebated joint and the top surface of the coping can be worked, thereby producing the true outline of the springer.

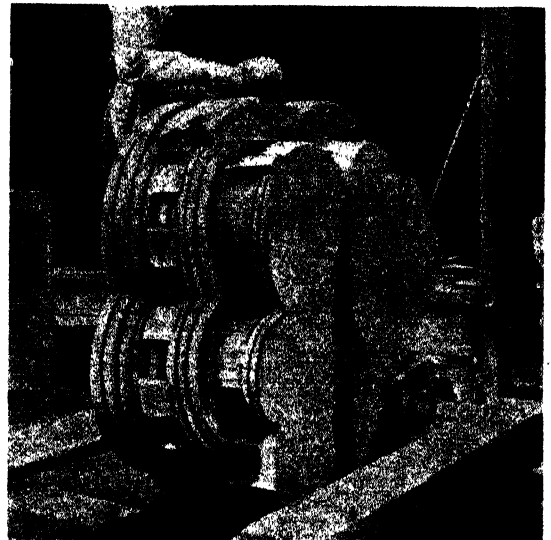
Next apply the section-mould of the coping to the rebated joint, thus determining the position of the wall lines and the throatings. Trammel the wall lines along each surface measuring from the front and back faces, and then work the front and back sunk surfaces, leaving the coping portion projecting from each surface.

The sunk surface on the return end should now be worked to the wall line already marked on the bottom bed surface. The stone can now be completed by working the throating along the under-surface of the coping, and a joggle

can be formed in the joint surfaces if desired. These joggles are best formed while the stone is on the banker, but this operation is usually



WORKING INTERSECTIONS



WORKING A GOTHIC CAPITAL

left until the stone is on the site and ready for fixing into position.

A mortise may be cut in the top surface, but room for adjustment must be allowed so that when the cramp is inserted in the mortise it will fit tight.

Chapter VII—CURVED WORK, MOULDINGS AND JOINTS

CURVED WORK

Working a Circular or Convex Surface. Fig. 102. In this case, should the stone be in a rough state when *bankered*, the first step would be to

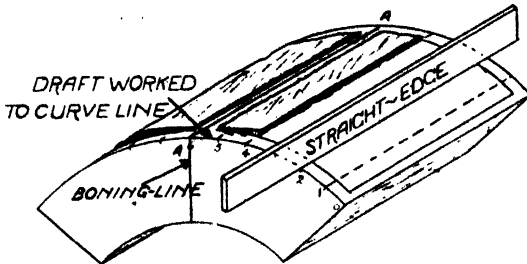


FIG. 102. WORKING CIRCULAR SURFACES

work one of the *beds*, making this the *working surface*. When this step is completed, the *bed mould* giving the required curve and position of joints should be marked on the surface. The bed mould should have a *boning line* marked on, which should be transferred to the stone when applying the bed mould. Next, square a draft down the face of the stone at *A*. Mark off height of stone required and work the second bed parallel to the first and square with draft *AA*. Square down the boning line on the draft *AA*, and bone line on second bed. Apply the bed mould, lines down, to the boning line and line *AA*. Next work off joints to position given on bed mould.

The circular face should now be worked. Work drafts at each joint, making sure that they are straight; then pitch up the circular lines along the beds, and work the drafts

true to the curve. Sometimes a *reverse temple* is supplied for testing these curved drafts, but it is not necessary. Next work surface off as shown in the figure, making sure that the straight-edge is applied parallel to the joints for each draft. It is best to mark the divisions on the beds, also marking them across the surface in proceeding.

To work the *concave surface*, proceed the same as the convex surface; but if curve is very sharp, the surface should be chiselled with a *round-nosed tool*, and finished by boasting at right angles to chisel marks.

Working a Column with Entasis. This is usually done by mechanical means, the stone being roughed to shape by hand and turned in a centre lathe, as Fig. 2; but it is important that the student or young craftsman should know how to work a column stone by hand, should he at any time be called upon to do so.

The stone is selected according to the height of the required finished stone and roughly squared to the diameter of the bottom bed. A bed mould is cut to the diameter of the column forming the bottom bed of the stone, with the

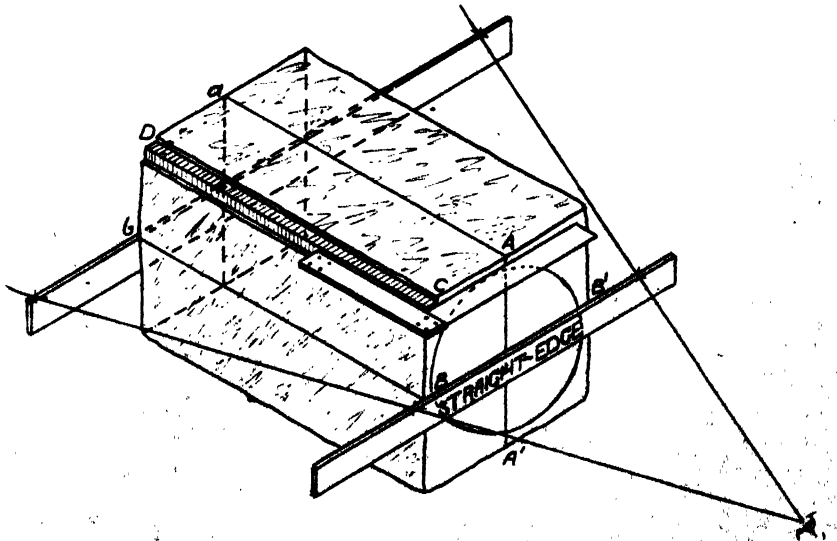


FIG. 103. BONING A COLUMN STONE

top bed line marked on the same mould. It will be noticed that the centre for the top bed mould is exactly over the centre for the bottom

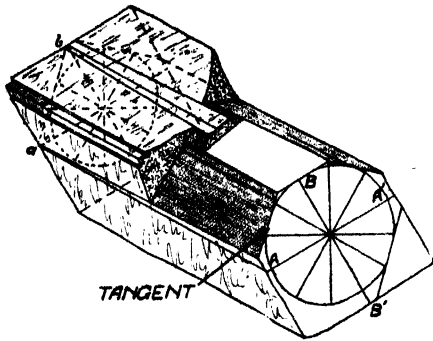


FIG. 104. WORKING A COLUMN BY MEANS OF TANGENTS

bed mould, that is, the circles are *concentric*, and so on up through the stones forming the shaft, so that the centre for the circle describing the top bed of the column is perpendicularly above that describing the bottom diameter. This being so, care must be taken in working each stone to make sure that the centres on each bed are exactly above each other. Fig. 103 explains the method of procedure.

The first operation is to work two angle drafts through the stone at *CD*. From these drafts both beds can be worked square and to the required height. Then apply bed mould on one

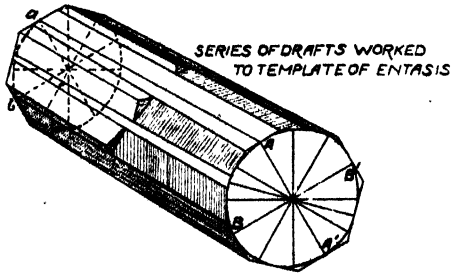


FIG. 105. COLUMN STONE WORKED BY MEANS OF TANGENTS

of the beds, mark on the diagonal lines *AA'* and *BB'*, which should be continued to the rough edge of the stone. Then measure the distance *CB* and transfer same to the other bed from point *D*. Draw a line between these two points; the line should be parallel to angle draft *CD*. Hold a straight-edge to line *BB'*, and sight a line through the other bed of the

stone from point *b*, by means of the two straight-edges; then scribe this line in. We have now to fix the exact position on this line for the centre

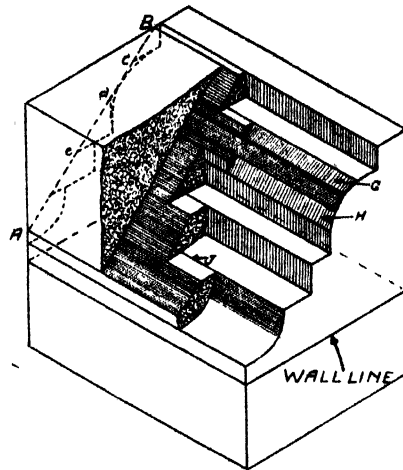


FIG. 106. SHOWING STAGES FOR WORKING MOULDING

marked on the first bed. Repeat the operation of boning. Measure the distance *CA* and transfer it as before, marking it at *Da*. Sight through

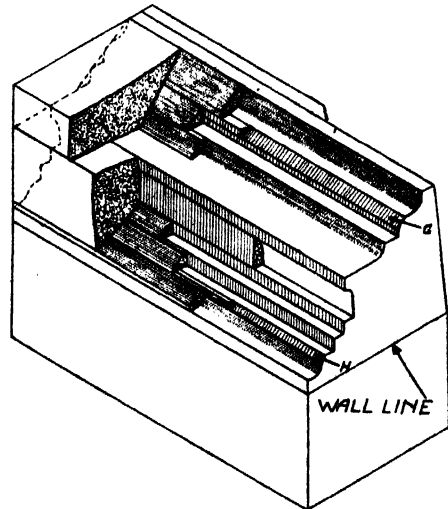


FIG. 107. WORKING A PIECE OF CORNICE

the straight-edge held at *A* and *A'* and join the two points obtained with a line on bed, cutting the line *bb* already marked, thus giving the centre required. Apply top bed mould to the diagonal lines, or describe circle to the required radius.

MODERN BUILDING CONSTRUCTION

We have now to work the curved surface of the shaft. This is done by series of tangents as shown in Fig. 104.

More diagonal lines can be marked on the beds to ensure accuracy in working, and could be numbered if desired.

As there is to be an entasis to the column, these tangents would be worked true to a

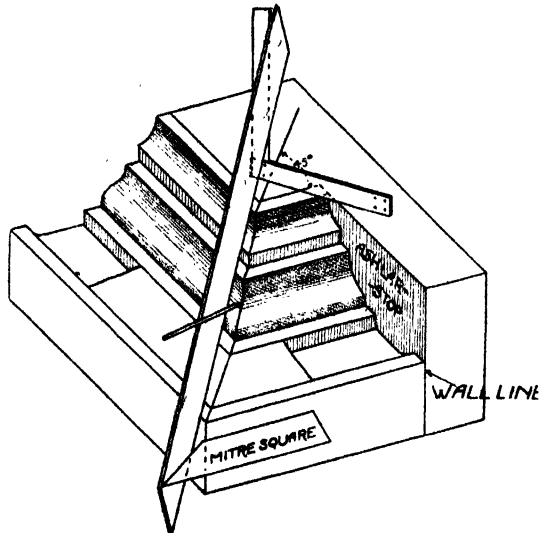


FIG. 108. METHOD OF SCRIBING A MITRE

reverse template of the entasis. Fig. 105 shows the stone almost finished by means of the tangents.

MOULDINGS

Working Mouldings by Hand. It is not possible to lay down any fixed rule for the working of mouldings by hand, as each craftsman, by actual practice, creates a method convenient to his style of working. The general principles are, however, the same, and the young craftsman is advised to encourage the habit of being methodical in his work; then later, when skilled in his craft, he can adopt "short-cut" methods. Fig. 106 shows a stone with the section of moulding marked on. A simple group of mouldings has been chosen—ovolo, fillet, and cavetto.

The following description is suitable for Portland and stones of similar texture. Mark on chamfer line *AB*, forming a *tangent* to the curve of the ovolo. The chamfer line should be marked on the other end of the stone by boning, which would touch the ovolo curve at the same point. The chamfer should be worked off and

finished with claw tool; but the portion in contact with the ovolo could be worked true, thus finishing that portion of the curve. The fillet lines should next be extended to meet the chamfer as at *c*, *d*, and *e* (in dotted lines), and lines drawn on the stone as guide lines for working the fillets. Cut in correct to section at each end with a drafting chisel; then work through

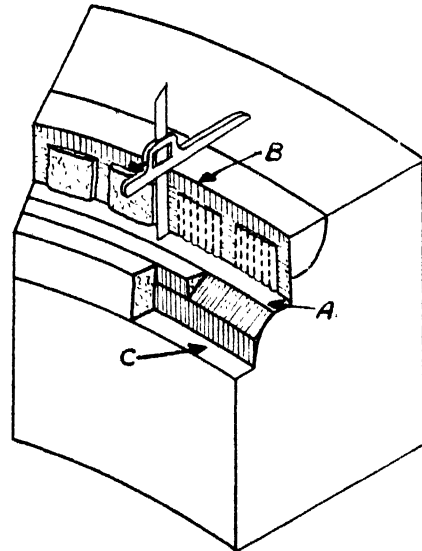


FIG. 109. WORKING CIRCULAR MOULDING

the stone in series of drafts until the fillet is straight. The fillet should be cut with a boaster direct into the angle, making the angle sharp and straight. After the fillets are worked, proceed with chamfers or tangents as shown in the figure, these chamfers being marked on the ovolo as at *G* and *H*. Guiding lines should be drawn through the stone, thus ensuring that the curve is true from end to end. Next mark on the lines for the cavetto at *J*, cut in the ends with a drafting chisel correct to section, and work the hollow.

Great care must be taken to keep the work correct to section, so that when butted against the next stone the lines of continuity will not be broken.

Fig. 107 shows process of working a piece of cornice by hand. The wall line should be boned on each joint, and the mould or section applied to the wall line.

Scribing a Mitre. Mitres in constructional stonework are worked out of the solid stone and the detail is known as a *Mason's Mitre*.

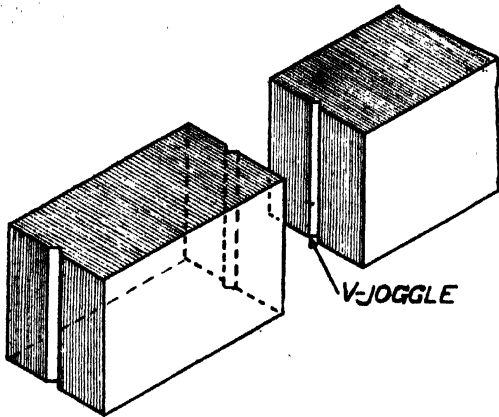


FIG. 110. BUTT JOINT

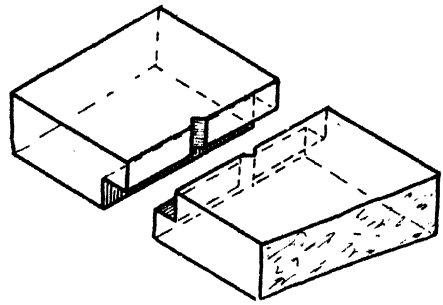


FIG. 113. REBATED JOINT

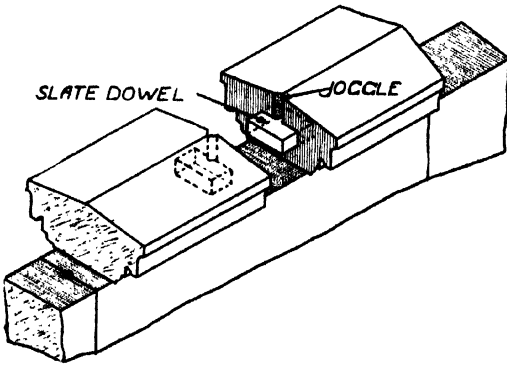


FIG. 111. DOWELLED JOINT

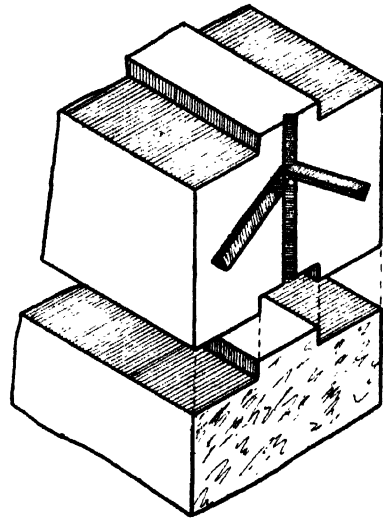


FIG. 114. TABLE JOINT

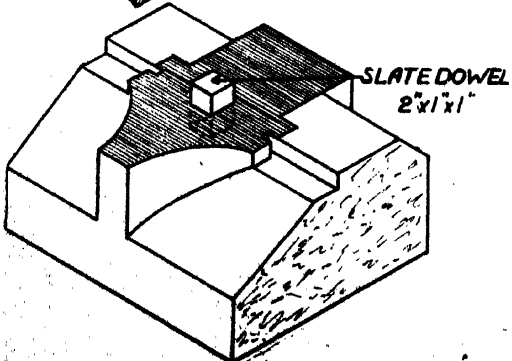
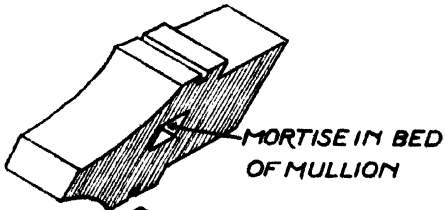


FIG. 112. SLATE DOWEL IN TOP BED OF SILL

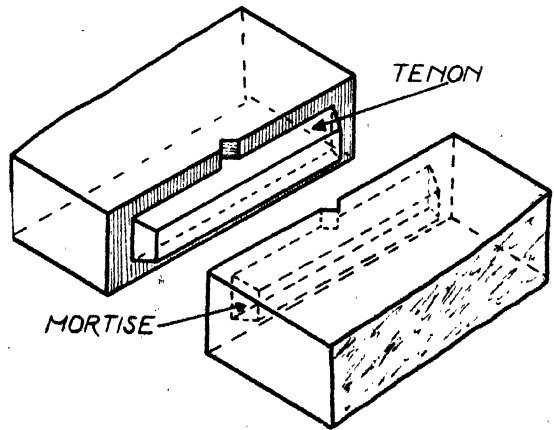


FIG. 115. TENONED OR MORTISED JOINT

MODERN BUILDING CONSTRUCTION

Mitres are occasioned by changes in the direction of the straight wall line and they occur at breaks, angles, recesses, and projections from the wall line.

In modern masonry production, straight through mouldings are executed by machines and the stones are cut to correct length by machines, the return mouldings, breaks and stops being worked by hand.

In preparation for working a return moulding, the first operation is to determine the exact position on the stone for the return moulding—this position is usually obtained from the bed-mould—and then to mark a line across the moulding representing the intersection of the two mouldings. This operation is called "Scribing the Mitre," and it must be carried out with great care and accuracy because the profile of the return moulding is determined by the position of the scribed line. Fig. 108 illustrates a piece of cornice with *ashlar stop* worked, showing clearly the method of *scribing*, or *marking* on the "mitre line." If the stone is being worked with bottom bed up, the best method is to use the square as in sketch; but should the nosing of the cornice be on top, it will be found more convenient to use the *mitre square*, as shown in the figure, having an angle of 135° , which, if held on a surface, such as the nosing of a piece of cornice, produces an angle of 45° . The mitre square can only be used when the return angle is 90° , or at right angles with the face. If the return moulding is to make an acute or obtuse angle, that is, any angle other than a right angle, the wall lines on the bottom bed surface should be divided and the mitre line should make a continuous straight line with this dividing line.

When scribing the mitre, a wide board is held against the blade of the *square* or the edge of the *mitre square* as shown in Fig. 108. The board must be held tight against the square while the shaft of the pencil is moved along the face of the board and at the same time marking the mitre line across the mouldings.

A piece of brass tubing with a pencil fixed in the end is a convenient tool for marking the mitre line on the deeply undercut members of a cornice. When working a return moulding, throatings and all undercut members must be left for the last operation, otherwise the throating or undercut member will cut through the return members and the stone will be spoiled. This is clearly shown in Fig. 108.

Soft stones such as Bath, Beer, etc., are worked

by a method different from the above. As the stone is soft, the superfluous stone is removed with the hand or fillet saw, in checks. It is usual to saw quite close to the *neat line* and finish with a drag and cockscomb. Marble and the more brittle stones should be worked in series of chamfers as far as possible, the stone being liable to fracture by stabbing into the angles.

To Work Circular Moulding. (Fig. 109.) The stone should be worked to the face mould, and the joint mould or section applied and marked with scribe. As previously explained, the contour of the moulding is obtained by a process of working the stone in a series of checks or rebates, each being worked in turn until the required profile is obtained.

Circular mouldings are worked in a similar manner, but it is necessary to trammel the lines for the rebates from the extrados or intrados curves and then to cut the rebates from these lines in stages along these curves.

First work out the notch for the fillet *A* between ovolo and cavetto. Trammel the lines of the fillet from the concave or convex edge of the stone. Cut in the draft at edge *B*, either to template of curve or to the line trammelled; then work drafts at intervals square from face, testing with a *sinking square*, which also acts as a depth gauge. Several points are thus found for the curve of the fillet *A*. The portion between the drafts should be pointed, and clawed and finished with a chisel to the correct curve. Next work the fillet *C*. Trammel line round parallel to concave edge at notch *A*, gauging with a sinking square from concave surface.

Work off tangents to ovolo; the guiding lines must be trammelled as before. Then work the cavetto section. A *reverse template* of the cavetto section should be cut in zinc, and applied at intervals.

MASONRY JOINTS

Butt Joint. Fig. 110 shows a butt joint used generally in *wrought masonry*, the two stones being butted together and a joggle or V-groove cut into each stone, forming a cavity for the cement grout to be poured in. A deep furrow cut with a punch is an excellent method of forming a joggle because it provides a roughened surface for the cement to hold. When the course of stones is complete and the stones are in their correct position, the joint spaces between the stones are pointed with mortar along the front and back edges of the stones, and the joint

spaces filled by pouring a semi-liquid mortar into the cavity. The semi-liquid mortar is known as *grout*, and the process is known as *grouting*. When the grout has set and has become hard it will act in a manner similar to a dowel and thereby assist in resisting lateral stresses.

Dowelled Joint. Fig. 111 shows a dowelled joint for the capping of a dwarf wall. A piece of slate 6 in. by 3 in. by 1 in., is shown let half in the joint of each stone, and the two stones butted together; the joint is pointed and the cement grout poured into the joggle, filling all the interstices around the slate. This is a good method of dowelling when the stones are subject

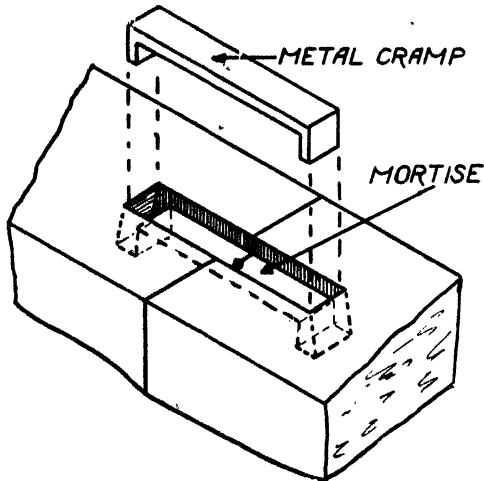


FIG. 116. METAL CRAMP

to a side strain or lateral pressure. Fig. 112 shows a dowelled joint between a sill and a mullion. The *dowel* should not be longer than 2 in.

Many instances occur in constructional masonry where the insertion of dowels in the joint surfaces of stones is essential for the purpose of resisting lateral stresses. Column stones should have at least two dowels fitted in each bed surface, and tracery stones require dowels, but it is inadvisable to use dowels in the bed surfaces of cornices, etc.

Dowels may be made of any non-corrosive material such as slate, brass, and copper.

Pebbles from ballast make good dowels and they are very suitable for use as dowels for tracery stones.

Rebated Joint. Fig. 113 shows a rebated joint. It is used for copings to gables or inclined surfaces to prevent the rain percolating through the joint to the wall beneath.

Secret Joggled Joint. The secret joggled, or secret radiating joints, Fig. 121, are used for flat arches comprising several stones, when vertical joints are desired on the elevation.

The surface of the recessed portion is formed so that the direction of the surface converges to a common centre in a manner similar to the radiating joints of an arch.

In some instances, a horizontal seating is formed at the bottom of the recess, but this practice is not a desirable one because the horizontal seating will tend to prevent the wedging action of the radiating joints; also, when the lintel, or arch, is subjected to extra loading, the portion of stonework below the horizontal seating is liable to fracture. A

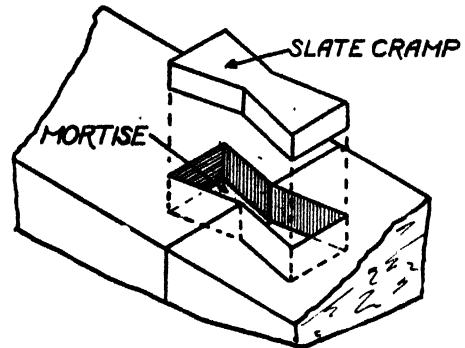


FIG. 117. SLATE CRAMP

deep recess will not produce extra strength; in practice it will be a cause of weakness. Deep recesses require extra labour in cutting away the stone and increase the quantity of material.

Table Joint. Fig. 114 shows a table joint. This is an expensive method of forming beds or joints, and is used chiefly for marine constructions, and in a modified form for spires, etc. Fig. 115 shows another form of tabled joint known as a *mortise and tenon joint*; it is chiefly used for landings, etc.

Cramps. Stones that are liable to be pulled apart or are in tension, should be strengthened by means of a *metal* or *slate cramp*. Fig. 116 shows a metal cramp. This should be fitted tightly across the joint, so that the cramp would tend to draw the two stones together; it should be made of copper or galvanized iron, and completely covered with cement. Fig. 117 shows a *slate cramp*; it is placed across the joint in the mortise, which is afterwards filled with cement grout.

Chapter VIII—ARCHES

FIG. 118 shows a moulded head which is the term for a flat arch or lintel made of one stone. The moulding of the jamb is here shown mitred and worked through the head. In large openings it becomes necessary to make up the lintel by

introducing several stones, for which an odd number of stones should always be used, the centre one forming a keystone.

Flat Arch, or Lintel. Fig. 119 shows the moulding running through the keystone, and the joints converging to a centre.

Fig. 120 is a flat arch over an opening in a rusticated ashlar wall having skewbacks, or springing stones. The keystone is shown projecting from the wall face, with the top of the keystone forming a stop to the lower members of the cornice above. A good method for obtaining the rake of the skewback is to allow 1 in. fall for every foot of opening on a face 12 in. high. Produce the line of skewback until it meets the centre line; the intersection will be the centre for all the radiating joints.

Fig. 121 shows a flat arch or lintel in three stones with vertical joints on the face, and secret radiating joints behind the face line. The construction is clearly shown in the sketch.

Semi-arch. Fig. 122 shows two methods of bonding a semi-arch in an ashlar wall; (a) is the most economical and the best method, all the archstones or voussoirs forming a wedge and closing the arch, thus distributing the weight on to the abutments. The method of jointing shown at (b) has a portion of the ashlar worked

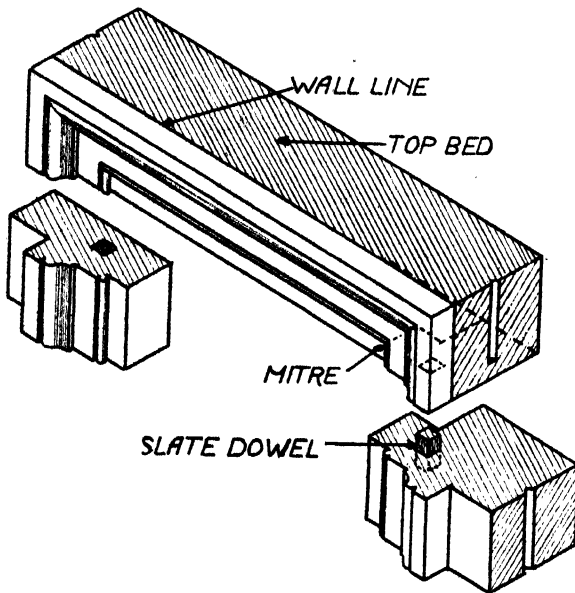


FIG. 118. MOULDED HEAD

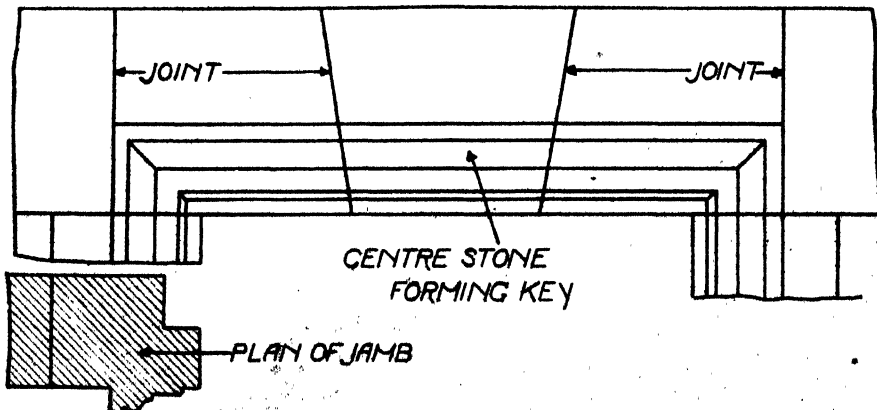


FIG. 119. FLAT ARCH OR LINTEL

on the archstone, forming *horizontal seatings*, which are termed *crosettes*. These tend to hold up the individual voussoir should an unequal

settlement of the abutments occur, thus preventing the stones sliding on their joints towards the centre of the arch. Should the pressure be too

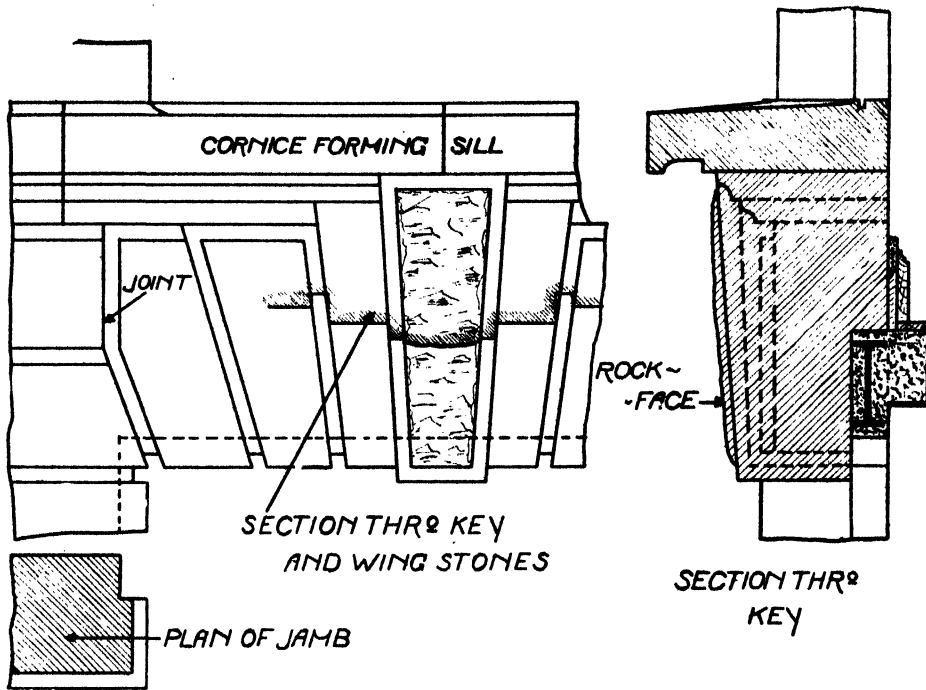


FIG. 120. FLAT ARCH IN RUSTICATED-ASHLAR WALL
Showing keystone and wing-stones

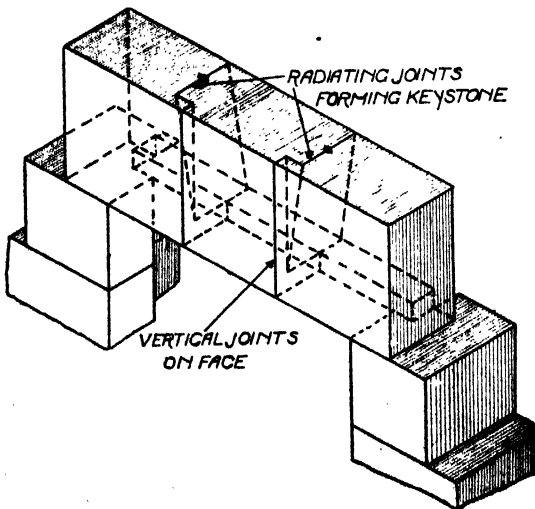


FIG. 121. FLAT ARCH WITH SECRET-JOGGLE JOINTS

great, the stones are liable to fracture at the angle marked *c*. The names of the various stones in the arch are indicated as *springer*, *voussoir*, or *archstone*, and *keystone*.

WORKING THE KEYSTONE. The method of working the keystone and one of the archstones is shown in Figs. 123 and 124.

The face and joint moulds are required for this. Select a piece of stone large enough to suit the face mould and joint mould, then work a true surface of operation and apply the face mould. Shape the stone to the face mould, squaring all the surfaces from the face already worked.

The method of obtaining the *joint mould* is shown in Fig. 122. This mould is applied on the joints, the face of the keystone being worked to the required slope, or *detail*, from the joint mould.

Segmental Arch. Fig. 125 shows a segmental stone arch over an opening in a brick wall. It

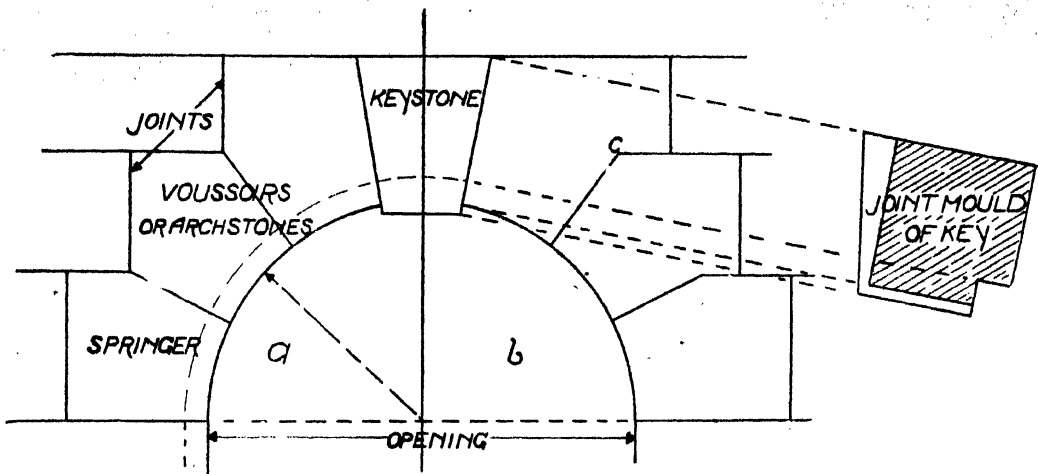


FIG. 122

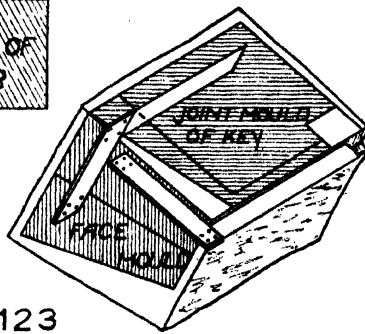
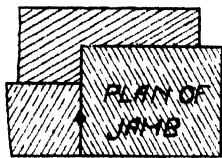


FIG. 123

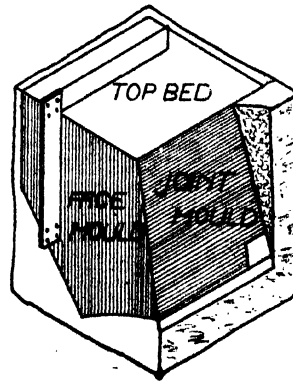


FIG. 124

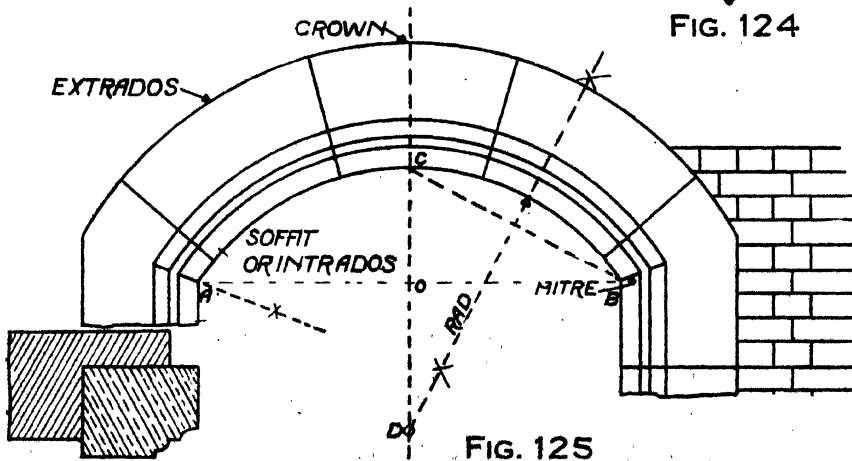


FIG. 125

FIG. 122. SEMI-ARCH, SHOWING ALTERNATE BONDING AND METHOD OF OBTAINING JOINT-MOULD FOR KEYSTONE
 FIG. 123. METHOD OF WORKING KEYSTONE
 FIG. 124. METHOD OF WORKING A VOUSSOIR
 FIG. 125. SEGMENTAL ARCH IN A BRICK WALL

is comprised of three arch stones and springers, the centre arch stone forming a keystone, the springers having a portion of the arch worked on them. The intersection of the jamb moulding

Then, $V = R - \sqrt{R^2 - \frac{C^2}{4}}$, and any ordinate Y , at a distance X from the centre of chord $= \sqrt{R^2 - X^2} - (R - V)$.

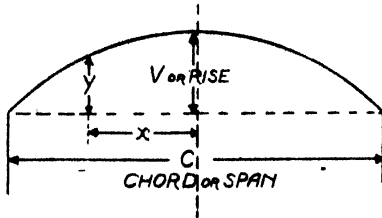


FIG. 126

with the arch, moulding forms an internal mitre.

The terms connected with the arch are illustrated in Fig. 125. The *soffit* or *intrados* is the name given to the underside of the arch. The outer surface is called the *extrados*, and the top of the arch is termed the *crow*n. The centre D for striking the curve is obtained by bisecting a line drawn through BC . Where the *bisector*

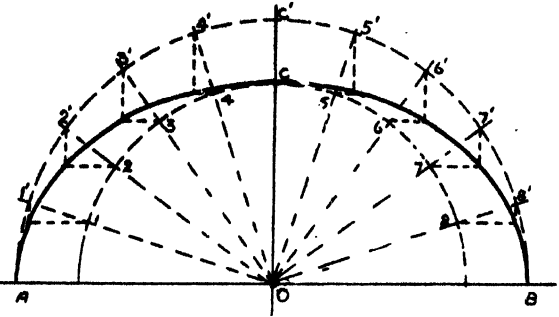


FIG. 128. METHOD OF DRAWING SEMI-ELLIPSE

This formula is very convenient should the *rise* of the arch also be given, as portions of the curve can be plotted to suit the size of the setting-out board. If the span, or opening, and the rise are given, the radius can be obtained by

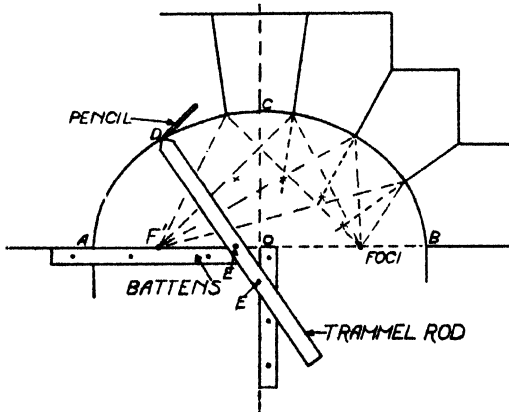


FIG. 127. SEMI-ELLIPTICAL ARCH
Showing trammel method of drawing the curve and normal bed-joints

cuts the centre line at D is the centre for the curve ABC . All the bed joints should converge to this centre.

Should the arch span a large opening, it is often necessary to plot portions of the curve because it would be impossible to obtain the centre from which to draw the curve. The following formula can be adopted as Fig. 126.

Let, V = rise
 R = radius
 C = chord, or span

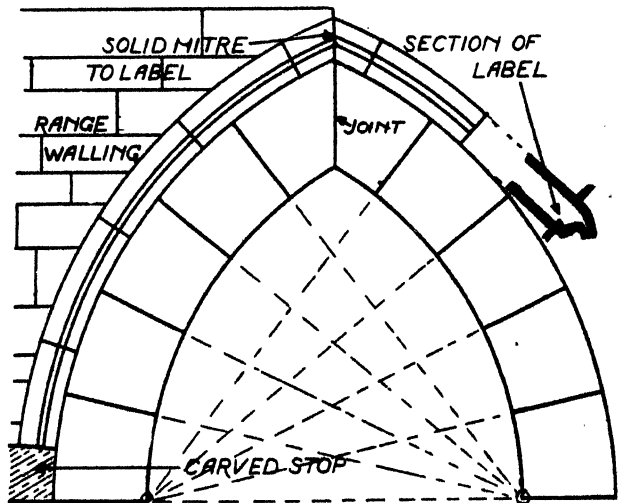


FIG. 129. EQUILATERAL ARCH SHOWING LABEL AND STOP, ALSO RANGE WALLING

calculation, and portions of the arch or curve laid down, by the following formula—

Let, A = rise
 B = half the span
 Then, $R = \frac{B^2 + A^2}{2A}$

Semi-Elliptical Arch. Fig. 127 shows a

semi-elliptical arch bound with ashlar walling. Although there are several methods of drawing the ellipse, the trammel method shown in Fig. 127 is quite good. Plot the springing line AB and centre line OC . Extend OC below the springing line, and nail to these lines pieces of battens as shown. Mark on a rod the distance OA (half major axis) and OC (half minor axis) from the same point of the rod. Pins or nails should be put through the rod at the points marked E and E' . These nails are allowed to slide along the edges of the battens (as sketch), and a pencil held at D gives the curve required.

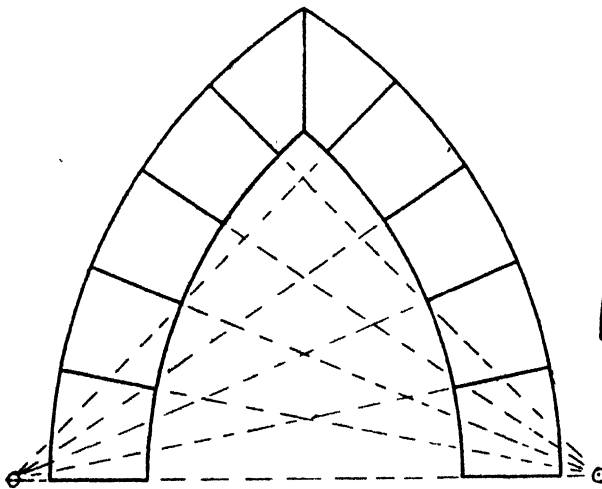


FIG. 130. LANCET ARCH

Fig. 128 shows another method of drawing the curve. Draw the springing line AB and the centre line OC , and mark off the span and the rise. With O as centre and OA radius, draw the semicircle $AC'B$; and again with O as centre and OC radius draw another semicircle. Divide the semicircle $AC'B$ into any number of parts, and through these points draw lines to the centre O . At the points where these lines cut the inside semicircle, draw horizontal lines; and from the corresponding points on the outside semicircle, drop vertical lines. The points of intersection of these lines are the points through which the semi-ellipse is to be drawn.

TO OBTAIN THE BED JOINTS. Divide the arch Fig. 127, into the number of stones required. With radius OA and centre C draw an arc cutting the springing line or major axis at FF' . From these points, which are termed *foci*, draw lines cutting the arch at the point required.

Bisect the angle made by these two lines, and the bisector will be the normal required. The lines for mouldings around the arch (should they be required) are drawn by trammelling from the line of the arch already drawn.

Approximate Elliptical Arches. In some instances approximate elliptical curves are used in preference to true elliptical curves. Preference is usually given to the former when curves for brick arches are struck because of the number of small units that are required to complete the arch and the number of different templates required for the process of brick cutting.

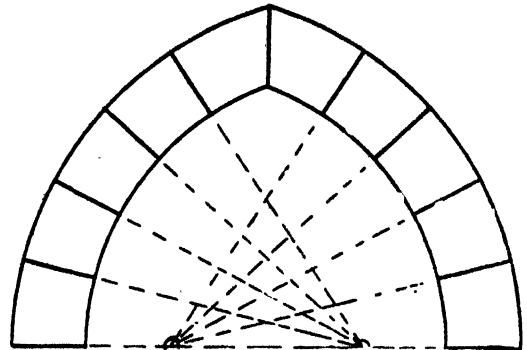


FIG. 131. DROP, OR OBTUSE, ARCH

Approximate elliptical curves are usually struck from five centres and made up by a series of tangential arcs.

To obtain the curve, several points on the true ellipse are determined and the arcs between these points are struck from the centres.

In masonry, nothing is gained by substituting the approximate ellipse for the true elliptical curve and the latter should be adhered to unless the architect requests otherwise.

Gothic Arches. Fig. 129 shows the setting-out of an *equilateral arch*. In pointed arches it is best to arrange a vertical joint through the centre of the arch instead of having a key-stone. A *label*, or *drip course* is shown in the figure, the top or crowning piece of label forming a *saddle stone* over the vertical centre joint, to keep the rain from percolating to the joint.

Fig. 130 shows the outline of a pointed arch known in Gothic architecture as a "lancet arch." The curves are struck from centres outside the curves.

Fig. 131 shows the outline of a *drop*, or *obtuse arch*; the curves are struck from centres situated within the curves.

Chapter IX—STONE STAIRS

ARRANGEMENT. The design or arrangement of stone stairs is not often left to the discretion of the mason, but a few hints in regard to the principles underlying the construction will, no doubt, be of use to the student. Suitability, directness, and light are the chief principles which govern stair planning; suitability or harmony with the style of architecture, directness for ease in ascending or descending from one level to another. The beginning of the stairs and the bends and landings are vital points where the maximum light is required. The *headway* is also a very important factor, and should be not less than 6 ft. 6 in. to 7 ft.

TERMS. The following terms are used in connection with stairs—A *Staircase* is the chamber or the apartment which contains the stairs. A *Flight* is a continued series of steps without a landing. A *Landing* is the flat resting place at the top of any flight of steps. *Half-space landings* extend right across the width of the staircase. *Quarter-space landings* are usually the same width as the steps or flight. *Rise* is the vertical height between two treads. *Tread* is the horizontal upper surface of the step. *Riser* is the vertical face or front of the step. *The going* is the horizontal distance from one riser to the next riser. *Winders* are steps of triangular form on plan and used for turning the corners or around the curved portions of the staircase in a continuous flight.

DIMENSIONS OF STEPS. The dimensions of the steps should be considered. The wider the tread, the less should be the rise, to give easy ascent. The following rule is often adopted—the width of *tread* multiplied by the *rise* equals approximately 66 in.

Another very good rule or formula to adopt is : $2 \text{ risers} + 1 \text{ tread} = 23 \text{ in.}$

The tread should not be less than 9 in. When spacing for *winders*, measure the width of tread 18 in. from the free end, as this distance from the handrail forms the *line of tread*.

A **STRAIGHT STAIR** is a straight flight of steps. The steps are either built into the wall at both ends, or one end of the step is left free. The London Building Act provides that all hanging,

or free end, steps should be supported at the free end by rolled steel joists to minimize risk of collapse in case of fire.

DOG-LEGGED STAIRS, Fig. 132, are composed of hanging steps built into the wall at one end. The free ends of one flight of steps are immediately over those of the flight below. A half-space landing is arranged midway from floor to floor.

OPEN NEWEL STAIR. Fig. 133. These are arranged around a rectangular staircase, with an opening, or *well hole*, in the centre between the flights of steps.

GEOMETRICAL STAIR. Fig. 134. The flight of steps follow the shape of the wall. The bends are formed by winding steps called *winders*, the handrailing being continuous from floor to floor.

The *circular newel*, or *turret*, stair is now seldom used. A section of the newel is worked on the narrow end, the wide end of the step being built into the wall.

STEPS. These may be of at least three forms—

1. *Rectangular step.* Fig. 135. These should be rebated on the bottom front edge, to resist the thrust.

2. *Spandril steps,* Fig. 136, are used chiefly where *head room* is desired, also to obtain a good appearance from the flight below, the lower surface being cut away so as to form a *raking soffit*. This is also done to lighten the steps.

3. *Treads and risers.* Fig. 137. These are chiefly in marble, as an ornamental covering to a concrete core, which is usually built in situ.

Great care must be exercised when fixing a stone stair to ensure that each step is fixed correct to the *height rod*, which should be fastened to the wall from floor level at a convenient place. The rod should have the height of each step clearly cut and numbered.

Each step should be level from its corresponding mark on the rod. Another rod should be fixed to the wall for testing the *going*; the width of each tread should be marked on this rod.

Fig. 138 is a sketch of a *spandril step* showing the soffit and horizontal seating at the wall end, also the *rebate* to fit on the next step.

Fig. 139 is a sketch of a *winder step*.

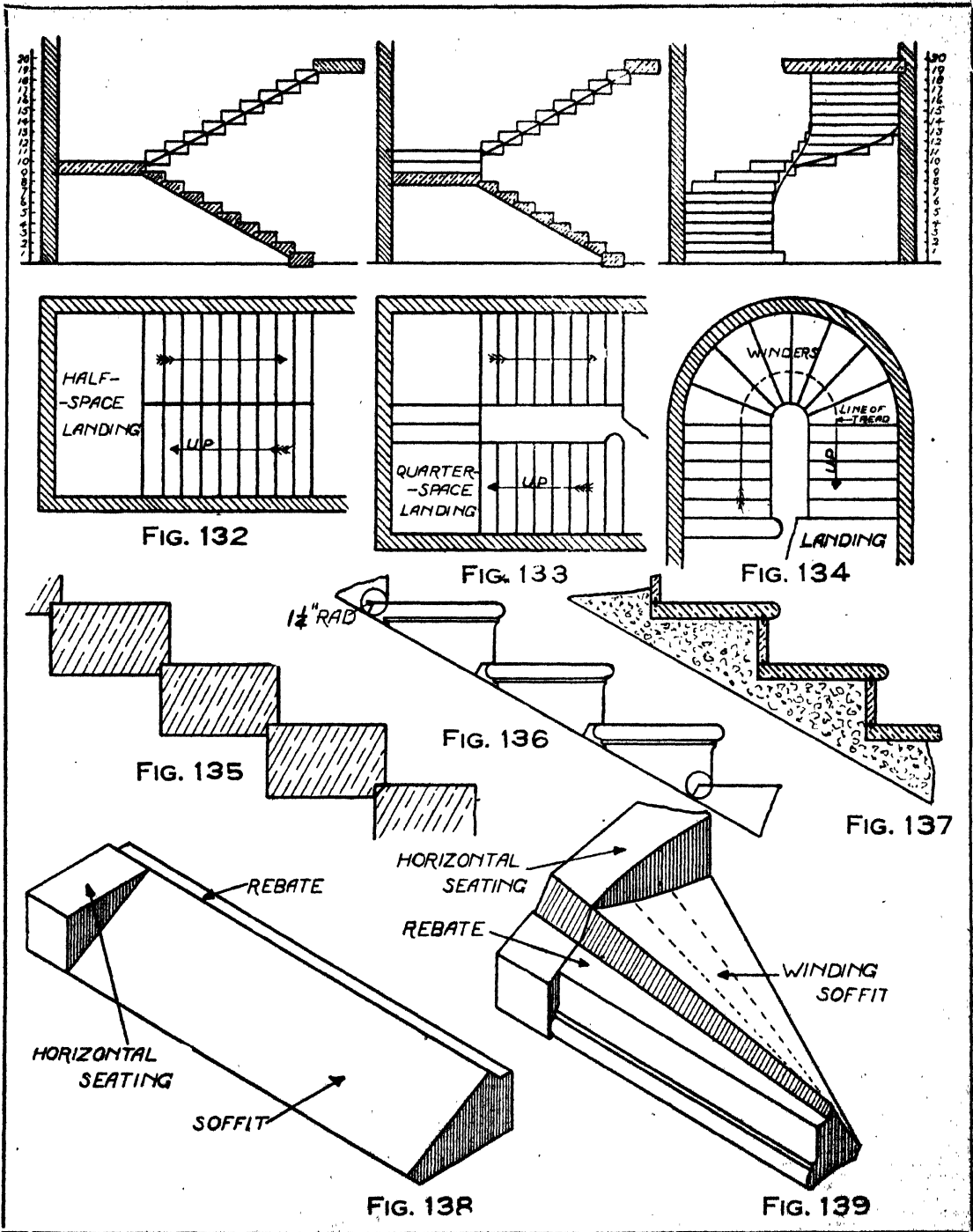


FIG. 132. DOG-LEGGED STAIR FIG. 134. GEOMETRICAL STAIR FIG. 136. SPANDRIL STEPS
 FIG. 133. OPEN-NEWEL STAIR FIG. 135. RECTANGULAR STEPS FIG. 137. TREADS AND RISERS
 FIG. 138. SKETCH OF SPANDRIL STEP, SHOWING SOFFIT AND HORIZONTAL SEATING
 FIG. 139. SKETCH OF WINDER STEP

Chapter X—SETTING-OUT

THE setting-out, or drawing, office connected with masonry plays a very important part in masonry production. An efficient practical draughtsman is in the position of being able to economize in material and save much labour in the execution of the work. Bad setting-out entails expense in rectifying errors in finished work, and re-working, to make the stones fit in their respective places. Stones on which quite a lot of labour has been expended sometimes have to be replaced by new ones, because of errors in draughtsmanship.

A good knowledge of practical applied geometry is an essential qualification, and a great saving of material and labour can be effected by the application of the principles of geometry, especially in the execution of the complicated problems in masonry.

EQUIPMENT OF OFFICE. The office should be equipped with a large table, or drawing board, measuring several feet in each direction, according to the size of the office, and about 2 ft. 6 in. high. A roof light is an advantage. It is advisable to cover the board with sheets of thick brown paper, which can be purchased in rolls 60 in. wide. The setting-out should be done on these sheets; the advantage of this method over drawing direct on to a whitened board is that, when the particular piece of setting-out is finished, it can be kept for reference until the work has been completed on the site. The setting-out should not be taken out of the office, especially into damp atmospheres, as the paper is liable to expand or contract according to changes in the humidity of the atmosphere.

It is also convenient to cut the zinc moulds from the paper. The zinc is placed under the portion of setting-out required, and the main points are pricked on to the zinc with a sharp instrument direct from the setting-out. The zinc is then taken out, and the lines for cutting are marked on the zinc with a scribe and straight-edge, between the points which have been transferred from the drawing to the zinc.

INSTRUMENTS FOR SETTING-OUT. The following instruments are required: *Pliable steel straight-edges*, of various lengths with bevelled edge, preferably with inches and divisions marked; *two*

pairs of beam compasses, Fig. 87, one heavy pair to take a stout rod for large radii, and a delicate pair for smaller work; *two set-squares*, one 45°, Fig. 72, one 30° and 60°; *a pair of winged compasses*, (steel) for marking on zinc; *a pair of snips*, Fig. 88, for cutting the zinc to the shape of the various moulds; *several fine files* of various shapes for finishing the zinc moulds; *a set of drawing instruments* of good make is essential.

LAY-OUTS. The architect's drawings are handed to the draughtsman, who makes a complete set of scale drawings of the stonework, with each stone distinctly marked and numbered.

The architect often leaves the placing of the

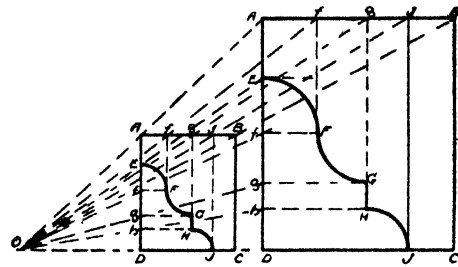


FIG. 140. METHOD OF ENLARGING MOULDINGS

joints and beds of the stone to the mason; if this is the case, when the draughtsman receives the drawings he makes a complete *lay-out* to scale, placing the beds and joints, and numbering each stone in rotation. The correct size of each stone should be indicated on the lay-out. Three blue prints should be taken; one is for the works' foreman, and one is sent to the fixer on the site, as a fixing sketch, the other retained for office use. Certain parts as shown on the scale drawing require setting-out full size before correct sizes can be obtained.

Full-size sections and details should be supplied by the architect, but if this is not done, the draughtsman will be required to enlarge the mouldings and sections to full size, and submit these to the architect for approval. Fig. 140 shows a method of enlarging mouldings.

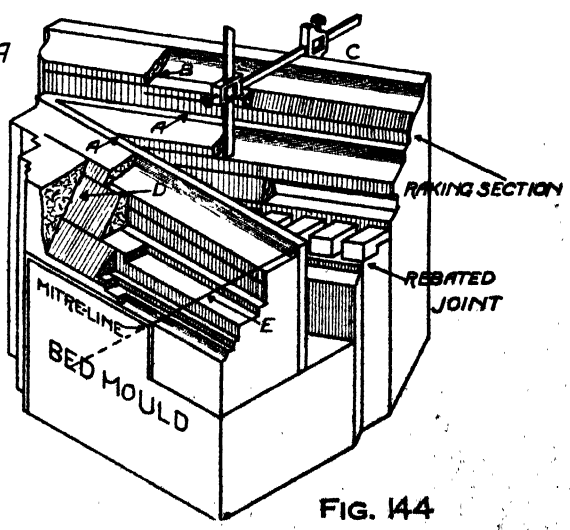
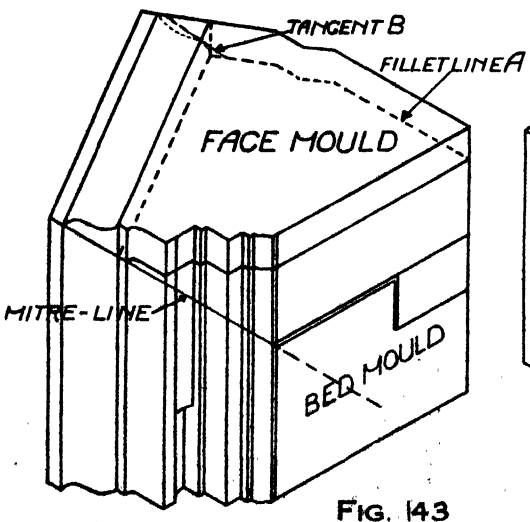
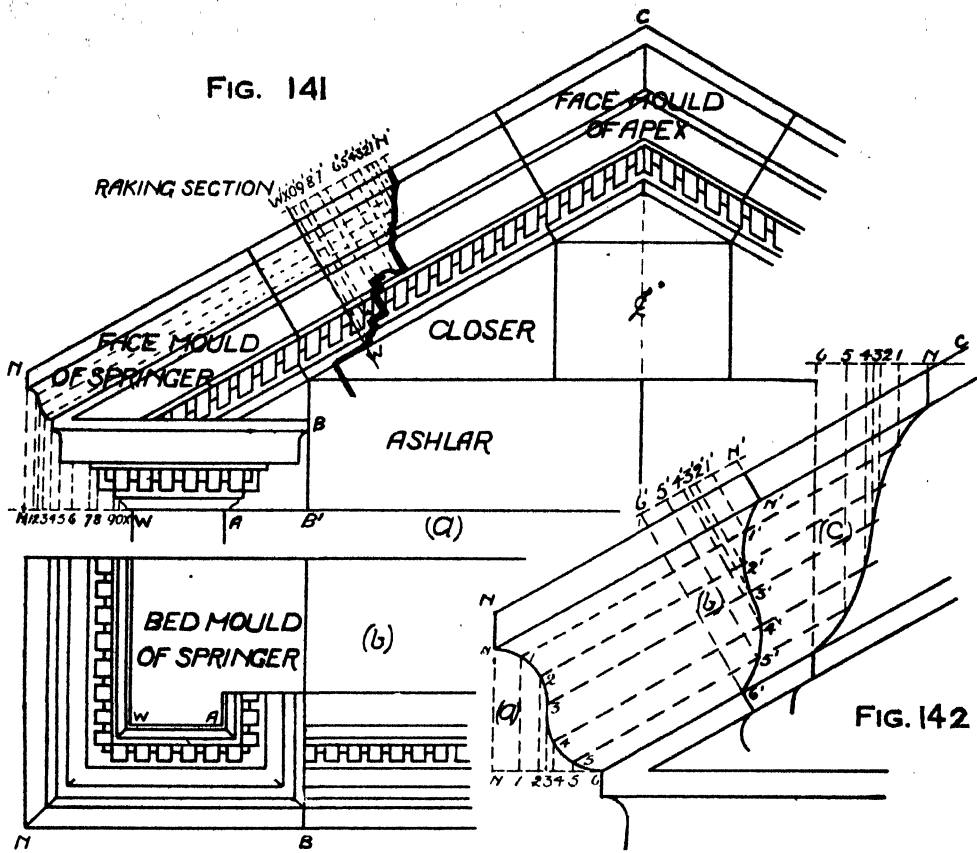


FIG. 141. (a) LAY-OUT OF ELEVATION AND (b) PLAN OF STONE PEDIMENT
 FIG. 142. METHOD OF OBTAINING RAKING SECTION, ALSO SECTION FOR BROKEN PEDIMENT
 FIGS. 143 AND 144. METHOD OF WORKING PEDIMENT SPRINGER

The draughtsman should be well acquainted with construction, and be able to arrange his jointing and bonding to the best advantage, giving good construction, and at the same time keeping in mind ease and saving of labour in working, and the convenience of handling the material on site.

Setting-out a Stone Pediment. Fig. 141 (a) is the elevation and (b) the plan of a stone pediment. In setting out full size it is only necessary to lay down sufficient beyond the centre line to obtain the *face mould* for the *apex stone* and the *bed mould* of the *springer*.

Draw the base line in elevation to correspond to the bottom bed line of the springer, and draw the centre line at right angles to the base line. Mark off point *A* and the width of the pilaster *WA* on the base line, *W* being the wall line for the return horizontal cornice mould. Transfer the full-size section of cornice *NW* from the architect's full-size detail, thus obtaining the point *N*, which is the point of intersection for the raking nosing. From *N* draw *NC*, cutting the centre line at *C*. This has been drawn to the angle of 30° in the figure for convenience, but the rake is usually determined by the architect's drawings. From the points forming the *nosing* of the horizontal cornice and the *fillet* at the base of the *ogee* (*cyma-recta*), draw lines parallel to *NC*, cutting the centre line; also, from this fillet, draw horizontal lines representing the lower members of the cornice, and plot the return moulding at *AB*. The top member *B* determines the position for the vertical joint line of springer.

To obtain the elevation of the *raking* cornice, draw a line *WW'* perpendicular to *NC* at any point on *NC*, and set out the distances along *W'N'* equal to the distances along *WN*. From the fillet line at base of ogee, mark off heights (or distances) corresponding to the horizontal lines representing the members of the moulding between *A* and *B*. Transfer these to *WW'* from the line of the raking fillet already drawn. Draw lines from the points thus obtained parallel to *NC*, cutting the centre line, the intersection of which forms *internal mitre* of the *apex stone*. Mark on joint line for raking moulding, making the portion of joint vertical which cuts through the dentils. Next set out dentils as shown in drawing, and fill in jointing of *ashlar* or *core*, allowing for a portion of the ashlar to be worked on the closer.

It is now necessary to draw sufficient of the plan to obtain the *bed mould* for *springer* as

shown in (b). Set out the thickness of wall on plan and depth of *break* at *A*, and project down the members of the moulding, also the joint lines, from the elevation; then set out the dentils on plan, and project them up to the elevation. The plan should be drawn looking up.

Next obtain the section of the raking moulding; the height of the *ogee* varies according to the angle the raking moulding makes with horizontal, the projection remaining the same. The method of obtaining the section for the *raking moulding* is clearly shown in Fig. 142, (a) and (b); this is necessary if a *true mitre* is desired at the intersection of the *raking ogee* with the horizontal mould. This raking section is required for working the *springer*, *closer*, and *apex stone*. Fig. 142 (c), also shows clearly the method for obtaining the required section of the return moulding for a *broken pediment*.

Working the Pediment Springer. The moulds required for working the springer, Fig. 141, are face mould, bed mould, raking section and section at *BB'*, Fig. 143. A piece of stone of the size required having been selected, make the face of the springer the surface of operation. Work this surface true, and apply the face mould. Next work bottom bed square with the face and mark on bed mould; then work joints and the raking top surface correct to face mould.

The return moulding should then be worked, with the exception of the undercut throating. Now scribe the mitre line and mark on raking section and true section on the joints. Work a surface level with the fillet at the base of the ogee moulding; this can be done by working square down from the surface of operation to the line of the fillet *A* and the raking ogee, or to a tangent line *B*, touching the ogee.

Mark on the surface now worked the lines *AA*, Fig. 144, representing the horizontal fillet and the raking fillet, and finish working the ogee moulding in stages as shown in sketch at *B*. In working the members of the raking moulding which dies on to the surface forming the top of the horizontal moulding or *cap*, it is necessary that each step should be worked parallel to the top raking surface. This is tested by using a double-sinking square from the top surface, as sketch at *C*, Fig. 144; the depth of the sinkings are also tested by using the double sinking square. Next work the horizontal moulding in stages as shown at *D*, and *scribe* the mitre line *E*; return the moulding on to the ashlar face, then set out the dentils as shown on bed mould. The last operation is the working of the throating.

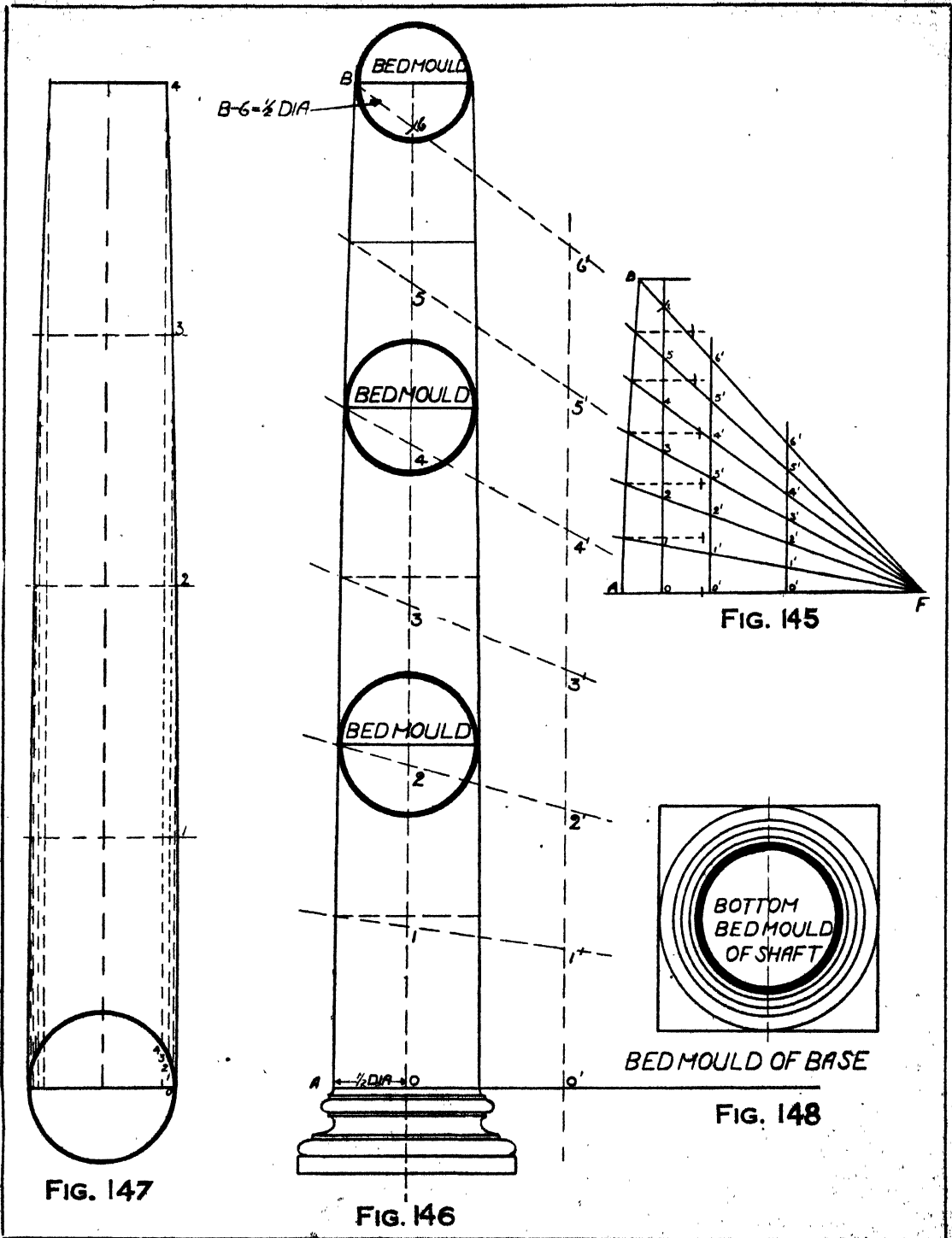


FIG. 145. DIAGRAM SHOWING METHOD OF OBTAINING ENTASIS

FIG. 146. SETTING-OUT OF ENTASIS

FIG. 147. ALTERNATIVE METHOD

FIG. 148. BED MOULD OF BASE

Setting-out the Entasis of a Column. The *entasis* of a column is the delicate swelling worked on the shaft. The swell may commence from the base line or about one-third of the height up from the base line. The curve generally used is known as the *Concoid of Nicomedes*. The diagram, Fig. 145, shows the method of setting-out this curve. Draw the base line AF , and erect the centre line perpendicular to it. Mark off on the base line on each side of the centre line a distance equal to half the *lower diameter* of shaft AO . Measure off on the centre line the height of the shaft, and draw the top bed line parallel with the base line. Mark off distance equal to the top diameter of shaft, as at B . With distance AO as radius and centre B , describe an arc cutting the centre line at 6. Through $B6$ draw a line, extending it until it cuts the horizontal base line projected at F . Divide the height between $O6$ into any number of equal parts; in this instance the distance $O6$ is divided into six equal parts. Draw lines from point F through these points and produce beyond the centre line. Mark off on each line the distance AO (*half the lower diameter* of shaft) from the centre line. The curve required passes through these points. To obtain the curve on the opposite side of the shaft, draw horizontal lines cutting the centre line, making the distance equal on each side of the centre line.

For large columns the above method requires a large surface to obtain the point F , but actually this point is not required, as shown in diagram, for if any line is drawn parallel to $O6$ cutting the triangle $O6F$, it will be divided into the same number of equal parts, and lines drawn through their respective points, as $5\ 5'$, and $4\ 4'$, will meet at point F .

Fig. 146 shows the setting-out of the shaft by the method described. The line $O'6'$ is drawn close up to the centre line; the line $B6$ is produced, cutting the parallel line in $6'$. Divide $O'6'$ into six equal parts and draw lines $5\ 5'$ and $4\ 4'$ etc., and on these mark off from centre line distance equal to AO . Mark off the heights of the individual stones forming the shaft, and on these describe circles, which represent the *bed moulds* of the stones at the various bed lines of the shaft.

Fig. 147 shows another method of drawing the entasis. Set out the shaft as previously described, and draw a circle representing the bottom diameter of the shaft; then divide the height into any number of equal parts. From

the top diameter of shaft draw a line parallel with the centre line, cutting the circumference of the lower diameter of shaft in point 4; divide the arc $O4$ into the same number of equal parts as the height, and erect perpendiculars cutting the corresponding horizontal lines. The intersections of these lines are the points through which to draw the curve.

Fig. 148 shows the bed mould for the moulded base.

Setting-out Niche with Spherical Head. Fig. 149. The example chosen should offer no difficulty to the student, and when mastered, the more intricate examples of niches can be approached by methods similar to that shown.

It is only necessary to set out slightly more than half the elevation and plan; the section can be omitted. Draw the wall line $A'B'$ on plan, and the centre line $O'C$ at right angles to it. Mark off on each side of the centre line distances $O'A'$ and $O'B'$. With O' as centre and radius $O'A'$, draw the semicircle $A'DB$ representing the outline of the niche on plan. At a convenient distance from the wall line $A'B'$ draw the springing line AB parallel to $A'B'$, and project the points $A'B'$, cutting the springing line at points AB . With O as centre and radius OA draw semicircle ACB .

To draw the elevation of the hood of the niche, divide the elevation into the number of stones required, and draw the lines for the bed joints normal to the curve, bonding them with the ashlar walling. The bed joints are conical in form, being portions of a true inverted cone having O as apex.

Project point E down to plan, cutting the wall line $A'B'$ at E' . With O' as centre and $O'E'$ radius, draw the semicircle which is the plan of the bed line EE . Divide the plan into the number of stones required, five in this case, and draw lines representing the vertical joints, which give the outlines of the bed moulds required for the first course. The point of intersection of the conical bed and the horizontal bed marked F should be projected to plan, cutting the wall line at F' . A semicircle drawn from this point with O' as centre, gives the line of intersection on plan, which should be marked on the bed mould. The line representing the semicircle at A' , which is the bottom bed line for the curve of the niche, should also be marked on the bed mould.

The bed moulds for the other courses of the niche are obtained in a similar manner and are clearly shown in the figure. The *centre*, or *key*,

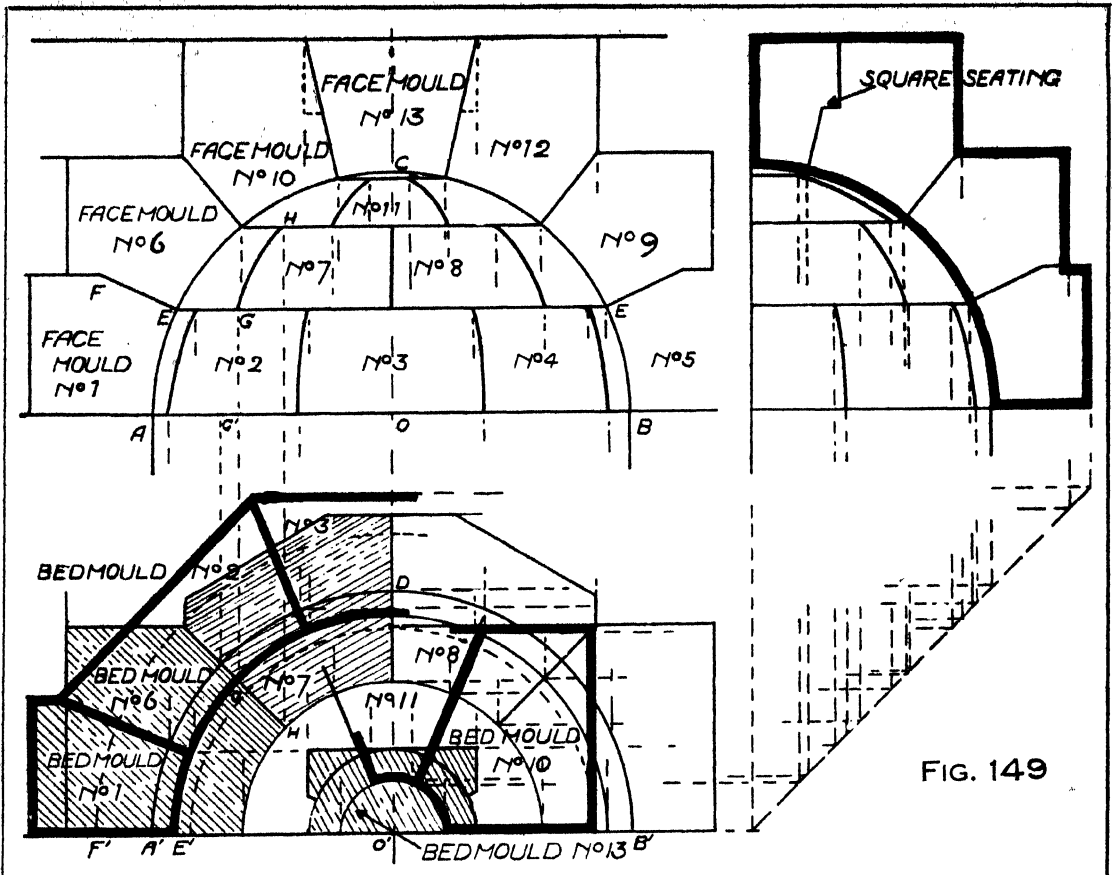


FIG. 149

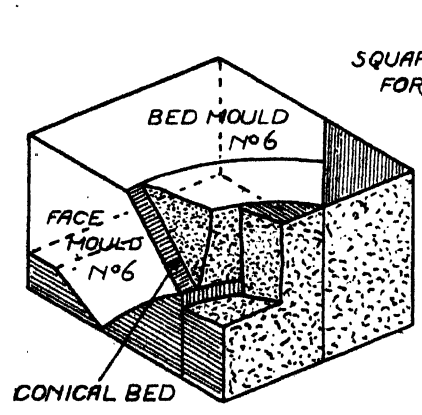


FIG. 150

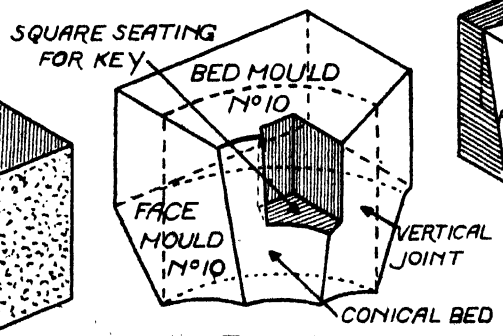


FIG. 151

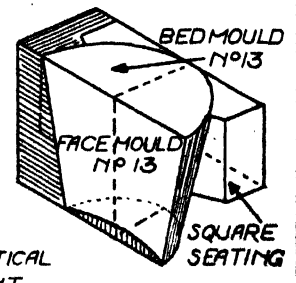


FIG. 152

FIG. 149. PLAN, ELEVATION, AND SECTION OF SPHERICAL NICHE
 FIG. 150. SKETCH OF No. 6 STONE
 FIG. 151. SKETCH OF No. 10 STONE
 FIG. 152. SKETCH OF KEYSTONE

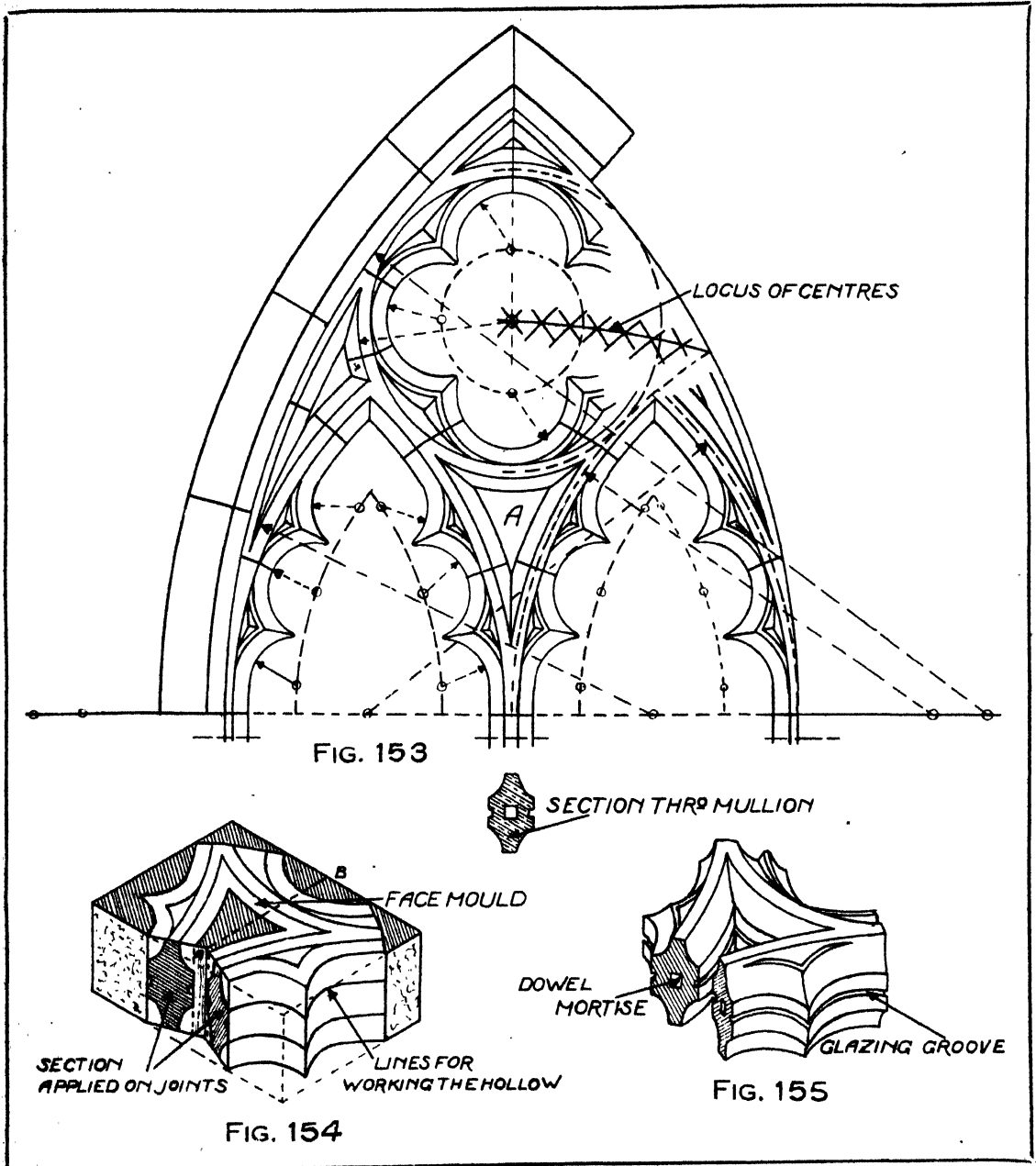


FIG. 153. SETTING-OUT OF GEOMETRICAL TRACERY

FIG. 154. METHOD OF APPLYING MOULDS TO STONE MARKED A

FIG. 155. SKETCH OF FINISHED STONE

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stone is shown with a *square seating* or *joggled joint*, which is provided to prevent the key stone slipping out.

The elevation of the vertical joints is obtained by projecting the intersection of the joint lines and the bed lines from the plan to the elevation, as at *GH*. In elevation they are seen as portions of an ellipse, and can be drawn as such with *OC* as the semi-major axis and *OG'* as the semi-minor axis. These lines are not required in the setting-out.

Fig. 150 is a sketch showing the application of the bed mould and face mould for the working of No. 6 stone.

Fig. 151 is a sketch of No. 10 stone showing the conical bed and square seating provided for the key stone, also the bed mould and face mould applied.

The application of the moulds for the working of the keystone is shown on Fig. 152.

Tracery Window. Tracery is a characteristic and ornamental detail in Gothic architecture. It may be the decorative treatment of windows or wall surfaces, but in whatever form it has been used it has always been considered as exemplifying the craft of masonry. From medieval times, the history of the craft has been woven round the development and execution of traceries, and many interesting and instructive examples of craftsmanship can be seen in the Gothic buildings which have been handed down to us as a legacy.

All traceries are based upon geometrical form and the correct method of setting out or drawing traceries can be accomplished only by those who have a knowledge of the fundamental principles of plane geometry.

The true outline of the interlacing curves is obtained by applying these principles in the form of tangents to curves, circles in contact, and tangential arcs. The points of contraflexure must be determined in a geometrical manner, and the centres of circles defined correctly, if good results are to be achieved.

Assistance in the process of setting out of traceries will be obtained if the following geometrical theorem is memorised and applied: "When two circles touch one another, the straight line which joins their centres, or that line produced, passes through the point of contact."

Many examples of the setting out of traceries could be given, but if the foregoing suggestions are carried out it will be found that the most complicated piece of tracery can be drawn by a

simple process of building up and a strict adherence to geometrical principles.

Fig. 153 is an example of *geometrical tracery*. Commence the setting-out by drawing the springing line, which forms the lower limit of the tracery, and project the width of openings or lights and positions of jambs and mullion, up to the springing line from the plan. The fillet of the jambs should represent half the width of the nosing of the mullion. The best method to adopt is to take the centre of the nosing for working out the geometrical pattern. These lines are shown dotted on the right-hand side of the figure. The centre for drawing the *quatrefoil* is found by obtaining the *locus*, or *path*, of all points equidistant from the two curves that the quatrefoil has to touch. The intersection of the locus with the centre line of the window gives the centre of the quatrefoil. Having completed these centre constructional lines, mark on either side the width of half the mullion. The centres for the *cusplings* are now decided upon, but no general rule for this can be given as they must be found by trial and error. The contour of the curves on either side of the cusplings are generally similar in form. The jointing of the tracery is very important and should be arranged so that the joints are normal to each main curve through which the joint passes; great care must be exercised to ensure that each stone supports the next stone above so that there is no tendency for individual stones to fall out.

Fig. 154 is a sketch of the piece of tracery marked *A* in the figure, and shows the application of the *face mould* and *joint mould*, also the method of working the stone.

Working Stone A. After the surface of operation is worked, mark on it the face mould (including the centre *AB*); then work the back face correctly to the depth of the mullion section and parallel to the surface of operation. From point *B* square a line to the back face; bone in the centre line *AB* and apply the face mould lines down. Next work off the superfluous stone to the exact shape of the face mould, and apply the section on the joints. Trammel the lines for the hollow moulding and the glazing groove around the cusps, etc., from the face. As the moulding is being worked, a reverse templet should be applied at intervals. The fillet of the cusps should be worked after the moulding is finished. Fig. 155 shows the finished stone with *dowel mortise* cut in the joints. A pebble forms the best dowel for tracery of this description.

Chapter XI—RAMP AND TWIST WORK

ALTHOUGH this particular form of masonry has always been considered as one of the most difficult problems, the problem resolves itself into one of common sense, provided the subject is approached in a proper manner.

There are various methods which may be adopted in the solution of this problem, but the writer suggests that the one most suitable for masonry production is that known as the *cylindrical method*. It is most practical because the setter-out is required to draft the setting-out so that all lines necessary for the complete working of the stones may be transferred to zinc moulds. The working of the stones by the banker mason may then be done in a mechanical manner by transferring the lines from the moulds to the stone and working to these lines. Also, the cylindrical is most suitable because it is usually desirable for one course of the stones to be bedded upon the twisted surfaces of the course below. This can only be possible providing the bed surface of each course has been worked to a definite form.

TERMS. A *Ramp* is a surface which is curved in elevation and straight in plan.

Ramp and Twist is the term used when referring to stones the surfaces of which rise and curve at the same time.

Right Circular Cylinder. In geometry, a right circular cylinder is defined as a solid described by the revolution of a rectangle about one of its sides which remains fixed.

A *Right Elliptical Cylinder* is one in which a section made by a plane passing through the solid at right angles to the axis of the cylinder is an ellipse.

A *Helix* is the curve generated by a point which moves along the surface of a cylinder in such a way that a constant ratio is maintained between its travel round the cylinder and parallel to its axis.

A *Helicoidal Surface* is a surface generated by a straight line which slides along the helix, always remaining perpendicular to the axis of the cylinder, and radiating from it whilst at the same time revolving about that axis at a uniform motion. Any point in the radiating line will generate a helix.

Fig. 156 is the part plan of a geometrical

stone stair. A solid stone plinth is to be supported at the free end as indicated by the lines *AB* in plan. It is required to obtain the moulds necessary for working the plinth stones.

Setting-out. Draw the plan of the plinth (Fig. 156), and place in the normal lines representing the risers of the steps. Project from plan the elevation of the plinth by first marking off a series of divisions equal to the height of the risers, as at points 0, 1, 2, 3, etc., Fig. 157. Then draw lines from these points representing the riser heights in elevation, and project into elevation lines from the intersection points of the risers and the plinth in plan. These projectors will determine the elevation of the top and bottom arrises of the face *A* of the plinth in elevation.

Continue the normal lines to the face *B* of the plinth in plan and project these points in a similar manner, thus obtaining the elevation of the four helices and the outline of the helicoidal solid.

Next draw the centre line *C* in plan, and obtain its development; also the true surfaces *A* and *B* by stretching out on a straight line the arcs of each plan division. The rise of each division is equal to a riser height, as shown in Fig. 158.

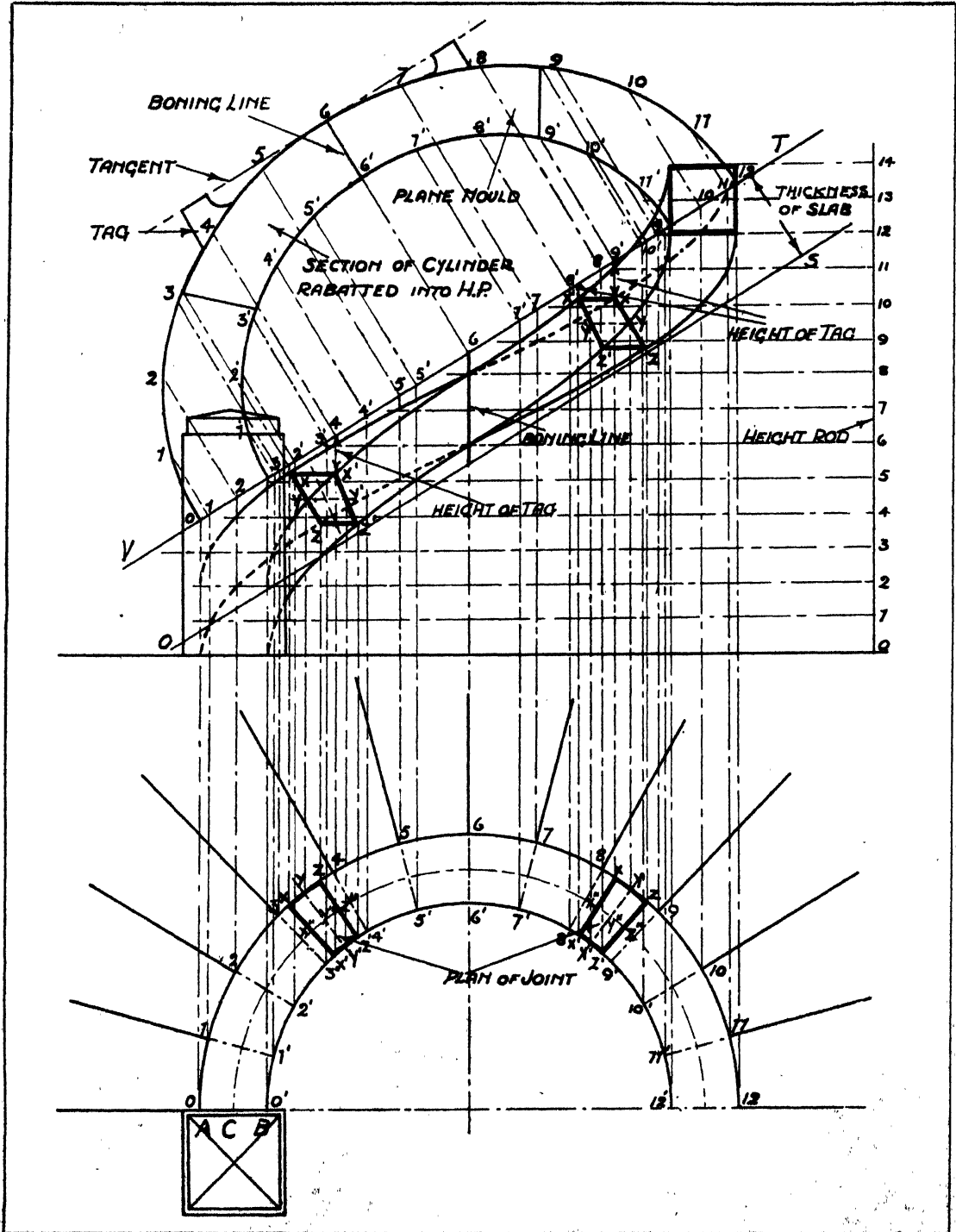
Next determine the length of the individual stone by dividing the total length of the development into a suitable number of stones. The complete length of the development has not been drawn, but a suitable length stone has been chosen.

As the joint surfaces should be twisted or helicoidal they are most conveniently determined at right angles to the pitch in the centre line development. These lines may be drawn in the centre line development as at *X" Y" Z"*. Project these points down to the stretch out line and transfer them to their correct position in plan as shown at *X' Y' Z'*.

Through these points draw lines converging to the centre *O*, cutting the surfaces *A* and *B* in points *XYZ* and *X'Y'Z'*. The plan of the joint surfaces is now determined.

The elevation of the joints may be obtained by projecting from the plan of the joints as shown.

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FIGS. 156 AND 157. OBTAINING MOULDS FOR PLINTH STONES

To obtain the joints in the development of surfaces *A* and *B*, it must be remembered that all straight lines in a helicoidal surface must be at right angles to the axis, which in this instance is vertical; therefore the top and bottom arrises of the joint surfaces will be horizontal lines and of the same vertical height

is obtained by continuing the projectors from plan to the V.T. and drawing them perpendicular to V.T. and measuring the length of the ordinates in plan from the line 0-12, and transferring these lengths so as to obtain points for drawing the two elliptical curves which determine the form of the plane mould.

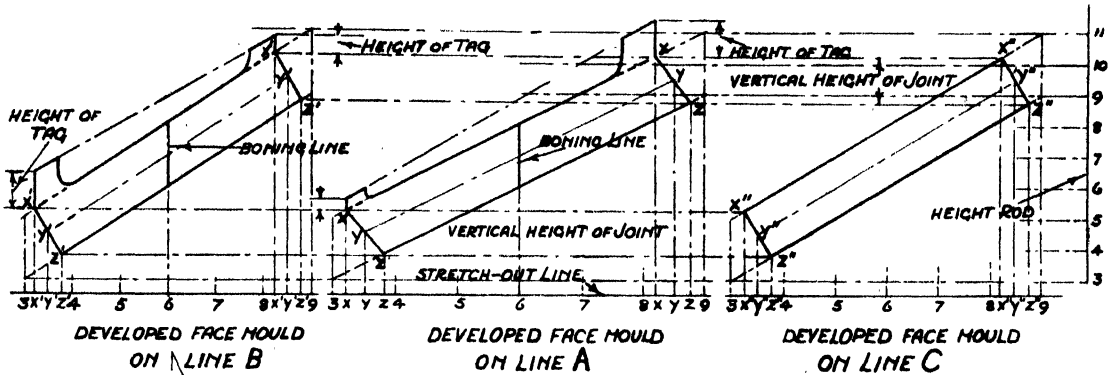


Fig. 158

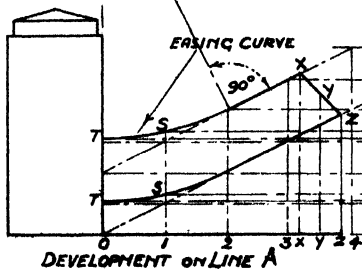


Fig. 159

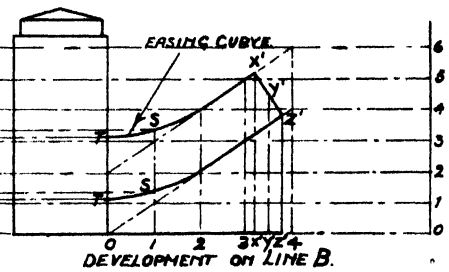


Fig. 160

on the plan lines *A*, *B*, and *C*. Transfer the distances shown on the plan of the joint surfaces to their respective development lines and project these points vertically to cut the developments as shown.

Next place in elevation the V.T. of the cutting plane to clear all extreme points of the solid, and determine the section made by this cutting plane passing through the hollow cylinder by rebating it into the V.P. This plane is revolved about the axis V.T.

Draw the line *OS* parallel to V.T. to clear the solid, thus determining the *cover mould* and the thickness of the slab required.

The boning line should be marked upon this mould as shown in Fig. 157. The plane mould

Line 66' will be the boning line, and tags to assist the adjustment of this mould may be added by drawing a tangent to the ellipse at point 6 and arranging the tags as shown in the drawing. To obtain the correct bevel for the tags for the adjustment of the developed face moulds, measure the vertical height between the top of the stone and the top edge of the cover mould in elevation, and transfer this height to the correct position in development as shown. Fig. 159 shows the method for obtaining an easing curve which often becomes necessary for the commencement of a ramp twist wall; it also shows the development of the easing stone on line *A*, and Fig. 160 is the development of the same stone on line *B*.

Chapter XII—MARBLE WORK

Composition. True marble is a limestone which, as a result of the application of heat and pressure, has undergone recrystallization accompanied by a complete alteration of the original

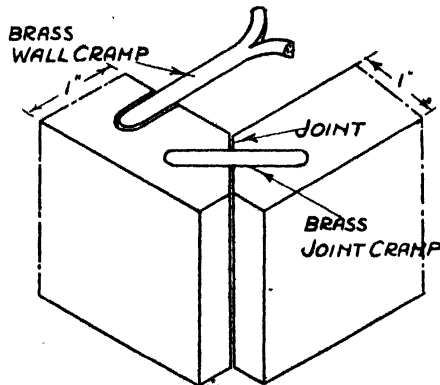


FIG. 161. BIRD'S MOUTH MITRE JOINT FOR MARBLE

texture. Such a rock is a mass of crystalline calcite.

There are many fairly hard and semi-crystalline limestones which exhibit a distinct

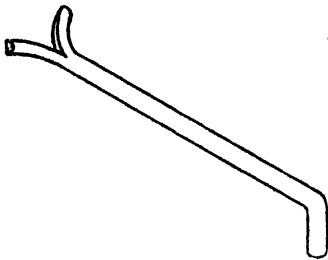


FIG. 162. BRASS WALL CRAMP

readiness to receive a polish, and as such are commercially classified as marbles. Ancaster stone, Hopton stone, Travertine, Perrycot (polished Portland stone) might be mentioned as examples. A list of varieties is given in the next column.

The beauty of polished marble depends upon the nature of the colouring matter and its disposition in streaks and veins throughout the rock.

The veinings, markings, and the various

colours of marbles are due to the inclusion of such foreign substances as carbonate of magnesium, silica, clay, carbonaceous matter, and metal oxides. Thus, a pure limestone when converted into marble becomes a white crystalline mass, as, for instance, the Carrara marbles.

The black marbles result from the presence of organic matter, such as decayed vegetation.

The presence of iron oxides produce yellow, red and brown colourings, while the green colourings are due to the inclusion of ferro-magnesium silicates or copper carbonates.

For many years coloured marbles have been favoured for decorative purposes, but this tendency appears to be giving way to the use of uncoloured marbles. All decorative marbles should be used discriminately so as to avoid a cheap and gaudy appearance.

VARIETIES. Marble is classified under such headings as—

Unicoloured Marbles. These are entirely black or white.

Variiegated Marbles. These are veined and include the breccias.

Madreporic. Those marbles which contain fossil remains of organisms.

The term marble in the following list includes any fairly hard stone, crystalline in structure, capable of taking a polish and used for interior decorative purposes. The list chiefly deals with marbles from Britain and European countries, and no attempt is made to include the marbles from America which are to be found in that continent in great abundance.

BRECCIAS. This term includes those marbles which contain fragments of older rocks in a conglomerate mass and an absence of veining. Breccias are named according to their colour or the district where they are quarried. They include such marbles as *Breche Rose*, which is quarried in Norway, and *Breche Violette*, quarried in Seravezza, Italy.

BELGIUM BLACK, a unicoloured marble taking

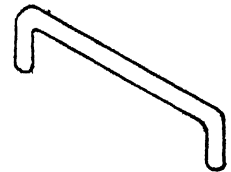


FIG. 163. BRASS JOINT CRAMP

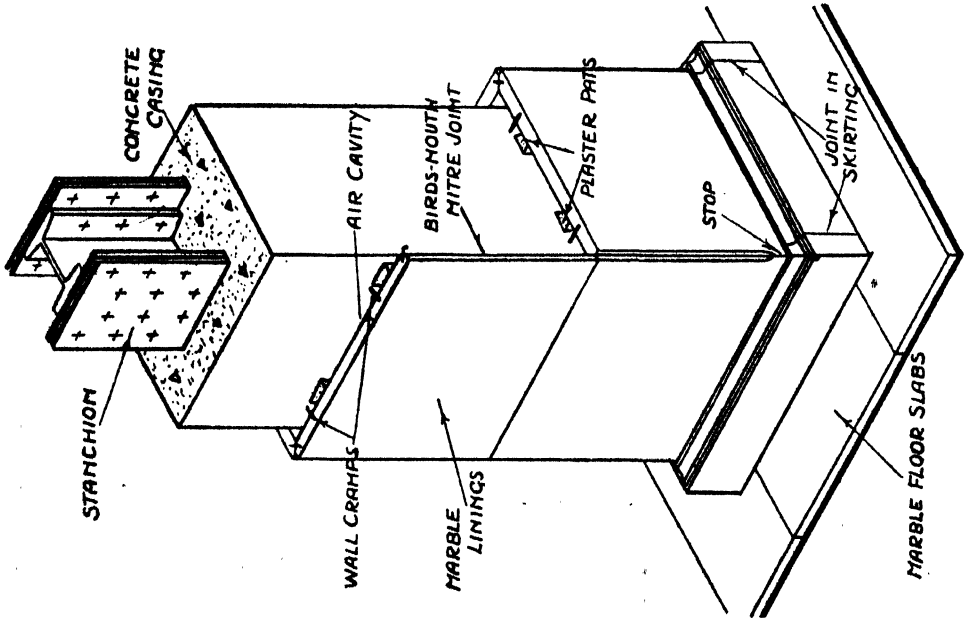


FIG. 164. MARBLE LININGS TO CONCRETE PIER

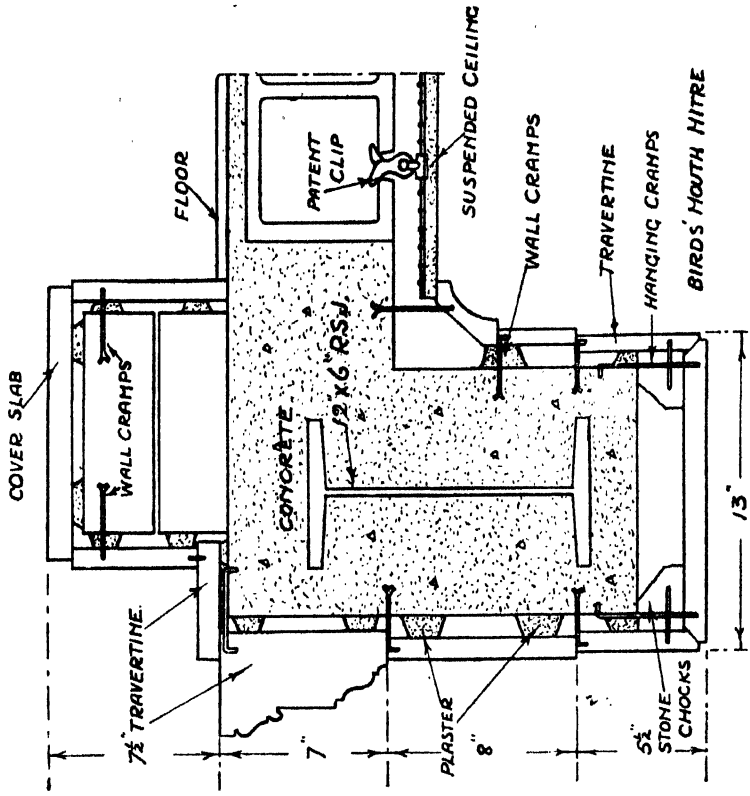


FIG. 165. MARBLE SOFFIT AND BEAM COVERING

MODERN BUILDING CONSTRUCTION

a high polish. It is quarried in the Province of Namur, Belgium.

BLACK AND GOLD, also known as *Portor marble*, black in colour with yellow veins; quarried in Italy and France.

BOTTICINO, colour light brown to cream; quarried in Lombardy, Italy.

CARRARA. This term includes marbles such as Statuary and Sicilian; quarried in Italy.

CAMPAN ROSE marbles are coloured pink with a white mottling which changes to red and

ONYX. There are two principal varieties, "Veined" and "Ribbed." It is formed in deposits as stalactites or stalagmites. Its colour varies from almost pure white to green, and rose and golden yellow. It is obtained in Algeria, Egypt, and Arizona.

PERRY-COT is a crystalline limestone, light grey in colour. It contains a quantity of shelly fragments and is quarried at Portland, Dorset.

PIASTRACCIA is similar in many respects to Carrara marble. It is hard and contains dark veins; quarried close to Seravezza, Italy.

PURBECK is a crystalline limestone, light grey in colour and shelly; quarried at Swanage, Dorset.

SERPENTINE. Olive green in colour with rich brown and dark green veins. It includes many so-called marbles such as *Connemara*, *Levanto Rosso*, *Swedish green*, and *Tinos*.

SWEDISH GREEN. Colour light to dark green; quarried in Sweden.

TINOS. Colour dark green with light veins and markings; quarried in Greece.

TRAVERTINE. Similar to Onyx in formation. It has a straw colour with pitted surfaces; quarried in Italy.

Jointing. Interior marble work is usually constructed in thin slabs forming a veneer, and is only intended as a covering to the rough brick walls and framework of the structures.

The arrangement of the jointing requires a great amount of skill in preparation, while the form of

the jointing surfaces should be arranged similarly to those usually found in joinery. The working of mason's mitres is not common practice in marble work, mitre joints being used instead. Slabs meeting at angles are usually mitre-jointed, whilst the sharp edge at the junction of the slabs is obviated by forming a recess called a "birds-mouth" mitre as shown in Fig. 161.

Return ends for mouldings are usually worked in the solid, while internal mitres are jointed at the mitre.

It is usual to box up steel stanchions, and beams, etc., with thin slabs of marble and to secure the slabs to structures by means of brass wall-ties and cramps as shown in Figs.

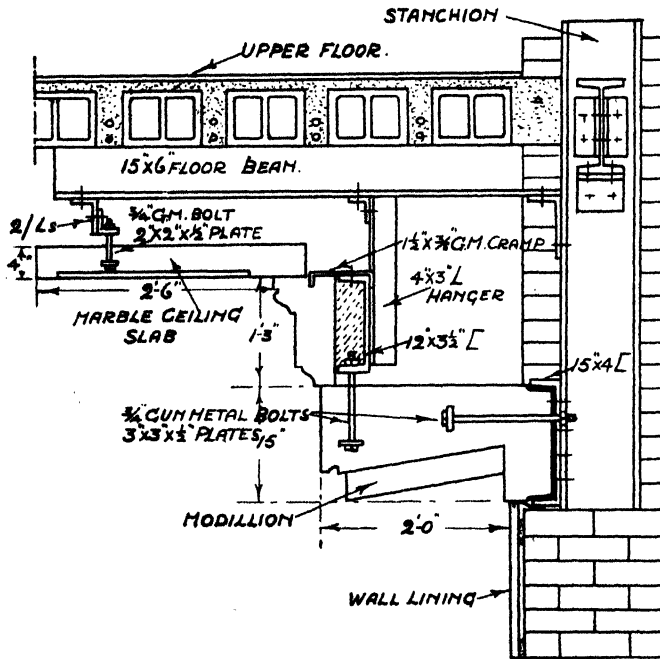


FIG. 166. CONSTRUCTION OF MARBLE CORNICE AND CEILING

violet; quarried in the Valley of Campan, France.

CIPOLLINO. Its colour combines alternate bands of green and white; quarried on the Island of Eubœa, Greece. *Swiss Cipollino* is a similar marble which is quarried at Canton Valais, Switzerland.

DEVONSHIRE MARBLE includes such stones as *Ashburton*, *Ipplepen*, *Ogwell* and *Petit-Tor*. Its colour ranges from black grey to red.

HOPTON WOOD. There are two varieties, "Dark" and "Light," both quarried in Derbyshire.

IRISH MARBLE includes *Connemara Green* and *Irish Black*, the former quarried in Connemara and the latter in county Galway.

FIG. 167

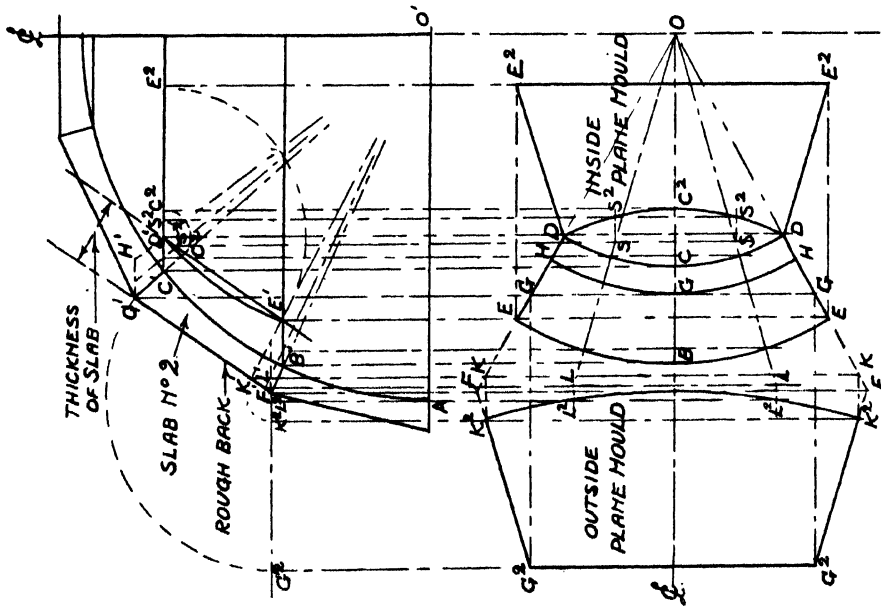


FIG. 168. SETTING-OUT FOR MARBLE DOME

FIG. 170

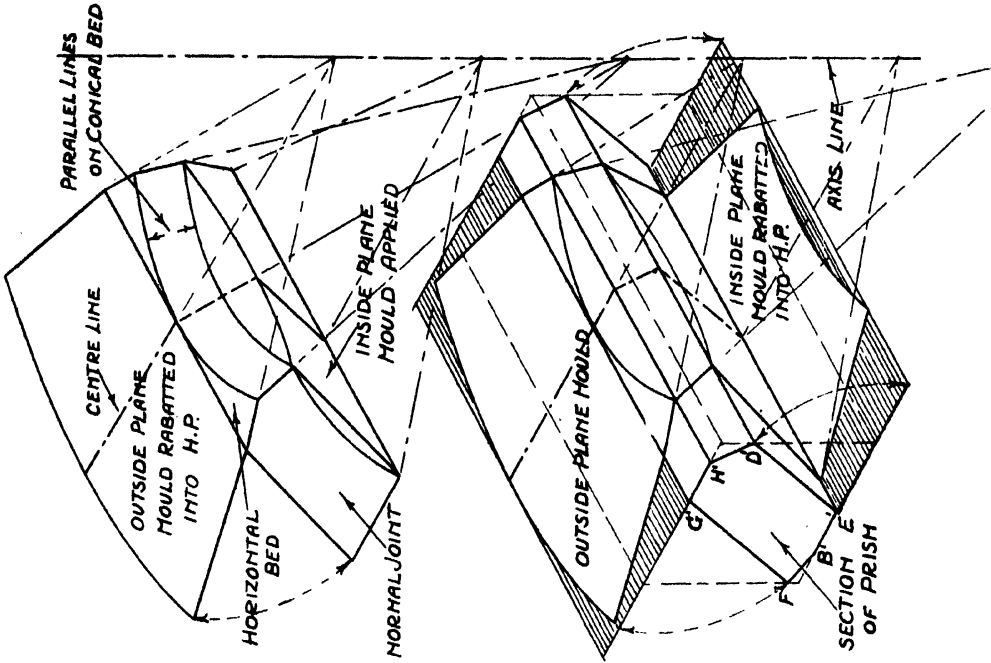


FIG. 169. SKETCHES SHOWING APPLICATION OF MOULDS ON SLAB

MODERN BUILDING CONSTRUCTION

162 and 163. Sketches showing the boxing up of a pier and a beam are given in Figs. 164 and 165.

In modern construction, marble cornices and ceiling slabs are attached to, and suspended from, the steel framework in the walls and floors of structures. A suggestion for such construction is given in the sketch (Fig. 166).

Concrete stairs are formed in situ, the concrete being covered with marble in the form of treads and risers, and notched strings and skirtings. A detail drawing of marble coverings for concrete stairs is given on page 258.

Working Marble. The manufacture or fabrication of marble-work differs from stone-work production.

Marble is worked and polished almost entirely by machinery, the blocks are slabbed in framed saws, the slabs afterwards being cut to size and shape by carborundum circular saws.

Large slabs for wall linings are placed under a rotary or Jenny Lind polishing machine, where the faces of the slabs are brought to a polished surface by a process of abrasion.

Mouldings, etc., are profiled by carborundum wheels shaped to the profile of the section required. These wheels revolve at a high velocity, while the marble makes contact with the revolving wheel by being fixed or clamped to a moving table which passes under the profiling wheel.

During the profiling operation a constant stream of water is directed on to the surface of the profiling wheel.

Flexible abrasive wheels are also used in the production of marble-work. Abrasive wheels, which are attached to flexible tubes and held in contact with the surface of the marble, wear away the superfluous material until the desired form is obtained.

Circular work can be executed by these machines including the polishing of the surfaces. Very little labour is executed by hand, that is by using the hammer and chisel. Pneumatic and electric machine tools are used by marble masons for executing intersections and those details which are necessarily classified as banker work.

Setting-out for marble work is similar to ordinary stone-work setting out. Economy in

material is an important factor, and ways and means in avoiding waste should be carefully studied.

All work should be executed from the smallest slab containing the required finished unit; therefore the setter-out should become acquainted with the fundamental principles of geometry, and be able to apply this knowledge to the problem in hand.

The setting out of a *marble dome* is given as a typical example. Fig. 167 is the sectional elevation of the dome, the outside surfaces being left sawn.

Taking one of the pieces of marble in course No. 2, draw projectors into plan from points $F'B'$, $C'G'$ and obtain the plan of these horizontal arris lines, and the plan of the slab, by placing in the normal joint lines in plan as shown where the horizontal arris lines cut the normal joint lines; project these points into elevation, thus obtaining the elevation of the joint line $D'E'$.

Draw a line joining points $D'E'$, and a line parallel to this line, thus determining points $F'G'$. These lines determine the thickness of the slab, whilst points $G'H'D'E'B'F'$ define the outline of the prism containing the stone.

To obtain the moulds for working the stone, with F' as centre, or axis, rotate the inclined surface $F'G'$ into the horizontal plane, thus determining its true shape.

The bottom bed of the slab is conical in form; therefore to obtain the true shape of the intersection of this bed with the inclined surface $F'G'$, draw normal lines from the horizontal arris line $B'E'$ to cut the inclined surface $F'G'$ at point K' , and draw vertical projectors from these points to cut the joint lines in plan at K . Draw horizontal lines from K to cut a line projected from K' , after being turned or rotated into the horizontal plane as shown.

Point G' is projected in a similar manner, while intermediate points can be obtained by drawing a normal line in plan as at LO and projecting as before described. The inside plane mould is obtained in a similar manner, the projection being clearly indicated on the drawing (Figs. 167 and 168).

Figs. 169 and 170 show the sketch of the stone and the application of the moulds.

Chapter XIII—CAST STONE

It is usual to consider the manufacture, finish, and use of cast stone entirely from a masonry point of view, so that the facing blocks may, when combined in the façade of a building,

Building Research Station, will no doubt overcome this defect.

Cast stone, which is really a development of artificial stone, sometimes has a facing of natural

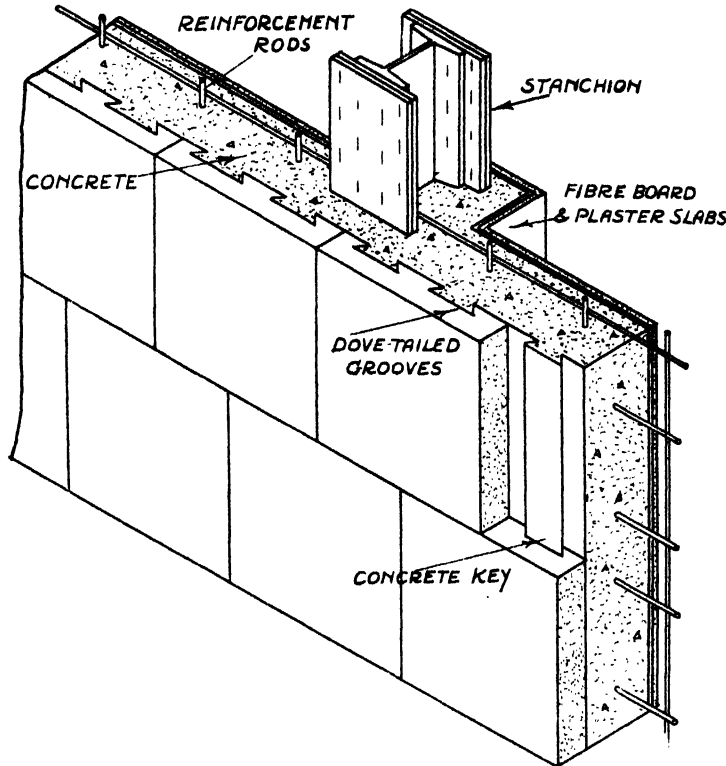


FIG. 171. SKETCH SHOWING CONSTRUCTION FOR CAST STONE FACINGS

resemble as closely as possible natural stone facings.

The successful manufacture of cast stone largely depends upon scientific research. Unscientific methods of mixing an unknown quality and quantity of Portland cement with an unsuitable aggregate, so as to form a solid mass is doomed to failure, and *crazing*, which is a serious defect in some cast stone products, results from such methods.

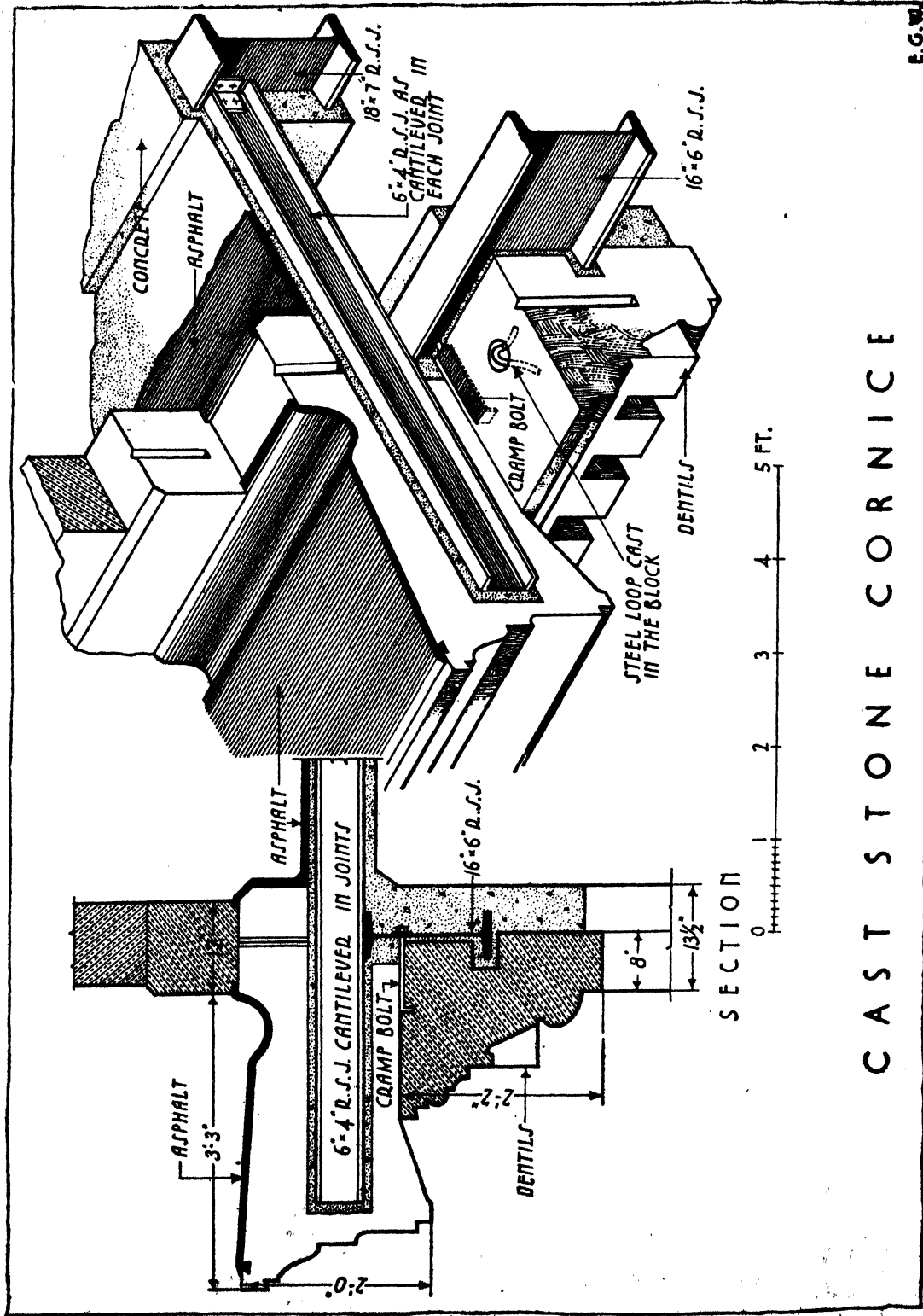
The problem of preventing crazing has not been definitely solved, but scientific investigations, especially those being carried out by the

crushed stone and cement, the core of the material being ordinary concrete.

The crushed stone facing material is first placed in the moulds which are then filled with the concrete core.

Another method is to make the blocks entirely of crushed stone and cement. Such products may be worked in a similar manner to natural stone, the blocks being cut with diamond or carborundum saws, chiselled and carved to the required form and detail.

Methods of Casting. There are three chief methods of casting: (1) Wood moulding;



C A S T S T O N E C O R N I C E

(2) Sand moulding; (3) Metal moulding. The two latter methods produce the best results.

Sand Moulding is accomplished by preparing wooden replicas of the required units and covering them with specially prepared loamy sand, which is spread over the floor area of a shed.

After the sand has been pressed tightly around the wooden duplicate of the unit required, it

or machines, sufficient height being allowed in the casting for this dressing.

It is preferable to cast mouldings face downwards so that any shrinkage that results during setting, may occur at the back surface of the block. Good moulds are essential if good results are desired.

Great care must be taken to ensure that the moulds are true to shape and that they are

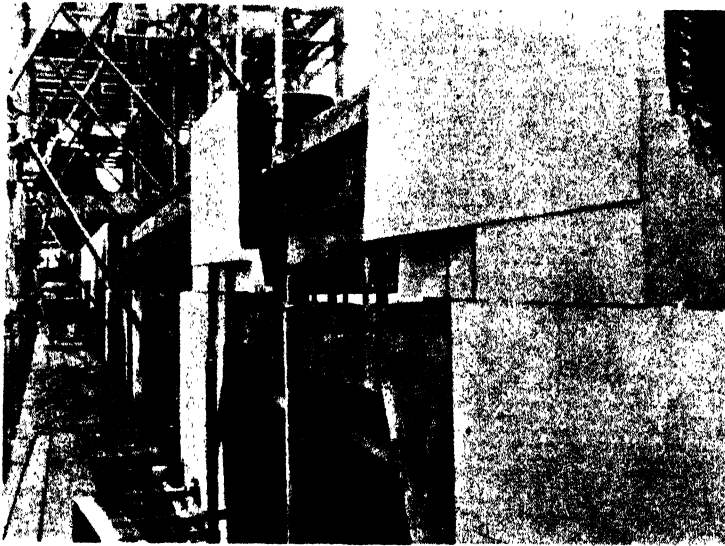


FIG. 172. CAST STONE FACINGS AT UNILEVER HOUSE

is lifted clear of the sand, thus leaving a true impression of the required unit formed in the sand. This impression is afterwards filled with the admixture of crushed stone and cement and allowed to set hard.

The block is then lifted from the sand and stacked until it is thoroughly dry, the sand being allowed to remain on the face surfaces of the block. The face surfaces are finished by being rubbed, tooled, or chiselled as desired.

To assist in lifting the blocks from the sand, and for hoisting purposes on the site, steel loops are cast in the mass, thus saving time in cutting mortises and fitting lewisies.

Ashlars should be cast with their bed surfaces top and bottom, so that any irregularity due to shrinkage may be corrected by being dressed or cut off to the desired height by banker masons

constructed so that they may be easily removed without injuring the cast.

The elimination of notchings requisite when facing steel framed structures, is one of the reasons why cast stone is often adopted in preference to natural stone.

The repetition of units, such as can be turned out from one mould is another reason for the economical use of cast stone.

The plate on page 330 shows the construction of a cast stone cornice, and Fig. 171 shows a method of construction when cast stone is used for slabs facing external walls which are formed in concrete. The facing slabs act as permanent shuttering for the concrete filling.

Fig. 172 is from a photograph showing cast stone in modern construction.

Chapter XIV—HOISTING AND FIXING

DURING recent years, methods which were used in this department of masonry have changed considerably. This change is due to the different types of structures now being erected; and the general use of *derrick*, or *jib*, cranes. This applies chiefly to the larger buildings, but as the old methods are still in use on buildings other than steel-framed structures, a general survey of both methods will be of interest to the student.

The *mason*, or *fixer*, as he is termed, does not

usually suggest the type of scaffolding, as the erection of the necessary hoist is usually left to those who are specialists in this work. It is only necessary for him to give the approximate weight of the heaviest piece of stone and state his requirements.

In towns a staging, known as a *gantry*, of baulk timbers, should be erected over the footway, the scaffolding being erected from this.

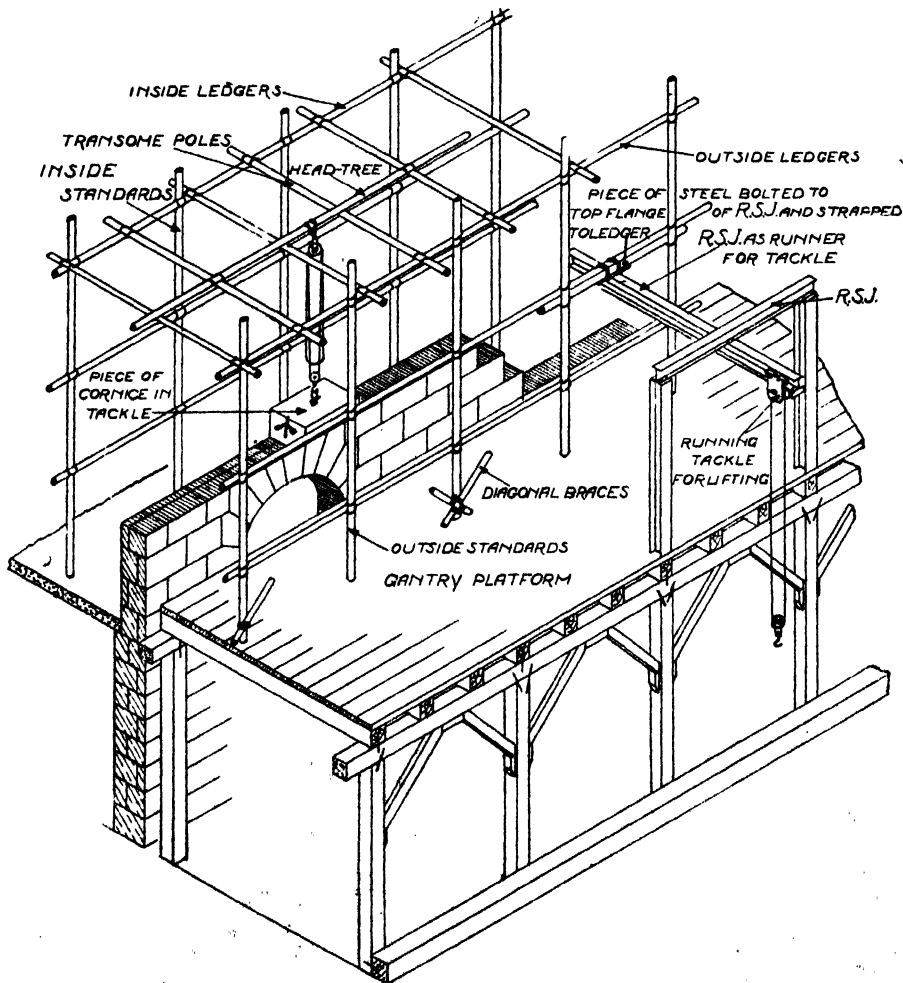


FIG. 173. SKETCH OF MASON'S HOIST, SHOWING METHOD OF LIFTING STONES FROM ROADWAY

HOISTING

Shear Legs. For this operation it is usual to erect a pair of *shear legs* on the front edge of



FIG. 174. CORNICE BEING FIXED WITH THE AID OF A DERRICK CRANE

the gantry. This device consists of two strong poles, spread out at the bottom and inclining towards each other and overlapping at the top, forming a *crutch*, and securely fastened at the crossing. The butt end of a stout pole is placed in the crutch, projecting sufficiently over the roadway, the other end being lashed to the scaffolding.

From the overhanging end of the pole are suspended *pulley blocks*, through which a steel cable is passed, down through a snatch block, secured at the foot of one of the legs, and thence to the *crab*, or *winch*, the latter being anchored down to the gantry.

Steelwork is sometimes erected at the front edge of the gantry, as shown in Fig. 173, and to this steelwork is bolted a R.S.J. cantilever. Hoisting tackle, provided with runners, is suspended from the bottom flange of the cantilever, and worked by a motor or hand power. By these means the stones are hoisted direct out of the cart in the roadway and landed on the gantry, ready for distribution to the required position on the building.

Mason's Hoist. This is shown clearly in Fig. 173. The *ledgers*, or horizontal poles, of the scaffolding should be carried up at least two stages above the platform upon which the workmen are engaged. Across the ledgers, from the outside to the inside scaffolding, *transome poles* should be laid. On top of these, spanning several and parallel with the face of the building, should be placed a *head-tree*, the head-tree

forming a beam to which the tackle or blocks are suspended for the purpose of lifting. The main hoist should be built out from the scaffold, so that there is no necessity to raise the scaffold board for the stone to pass through. The hoist is lifted scaffold by scaffold as the work proceeds.

Steel tubular scaffolding is now in general use in modern building construction. Ease and speed in erection and the avoidance of waste in material appear to favour this type of scaffolding.

Suspended scaffolding is sometimes adopted and used to advantage. This form of scaffolding is shown in Fig. 175.

Derrick Cranes. On large buildings derrick cranes are fixed to stagings, called *lower gantries*, supported on three legs, or towers, either constructed of timber or steel work, and erected high enough to clear the roof of the building. These cranes are usually placed to lift material from the road and carry same over the greatest area possible. Sometimes they do all the lifting necessary, including the setting of the stones. Fig. 174 shows a piece of cornice being fixed with the aid of a derrick crane. This system is not



FIG. 175. SUSPENDED SCAFFOLDING

to be recommended because, directly the stone is lowered on to its bed, the hook of the crane is detached, and the crane employed in lifting other materials. The fixer is thus left to place the stone finally into its correct position, and often finds that it is necessary to relift the stone, with the consequent respreading of the mortar

MODERN BUILDING CONSTRUCTION

or putty bed, and therefore a loss of time is incurred. Then, again, if the crane cannot be



FIG. 176. CRANE FIXED TO FACE OF STEEL FRAMEWORK

readily obtained, the fixer is tempted to resort to wedging up, which is often fatal when the stonework is required to receive a heavy load. Where derrick cranes are used, it is advisable,

both for economy and good work, to provide *hand jib cranes* anchored down to the steelwork, or hoists should be provided, for the fixing of stones. To accomplish this, should the building be a steel-framed structure, cantilevers may be fixed from the steelwork above, supporting a R.S.J., fixed parallel with the wall face. An endless tackle, provided with runners, to fit over the bottom flange of the R.S.J., is fixed to the underside of the cantilevers, so that the stone after being lifted may be moved longitudinally with the face of the building. Jib cranes are sometimes fastened to the face of the steel framework at convenient intervals and used for hoisting the stones to their required height. Fig. 176 is from a photograph of one of these cranes in use.

Appliances. Wrought stonework is lifted by means of *lewises*, *sling chains*, *chain dogs*, and *skips*, or *trays*.

THREE-LEGGED LEWISES (Fig. 177). These consist of two wedge-shaped pieces of mild steel or iron and a centre parallel piece, which are connected by a shackle and pin. A dovetailed mortise is cut in the top bed of the stone, at a slightly less angle than the wedge-shaped piece, and about the length of the two wedge-shaped pieces placed together. These two are inserted into the mortise, and the parallel piece placed between them, spreading them apart and filling the mortise. The lewis should be fairly tight and grip at the bottom of the mortise, the shackle being placed in position and the pin inserted. Fig. 178 is a sketch of the lewis in position.

CHAIN LEWISES (Fig. 179). Chain lewises are not suitable for heavy stones, as they are liable to draw unless carefully inserted. They consist

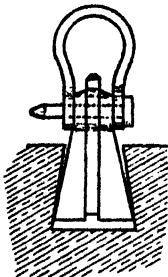


FIG. 177. SECTION THROUGH MORTISE SHOWING THE CORRECT FITTING FOR THREE-LEGGED LEWIS

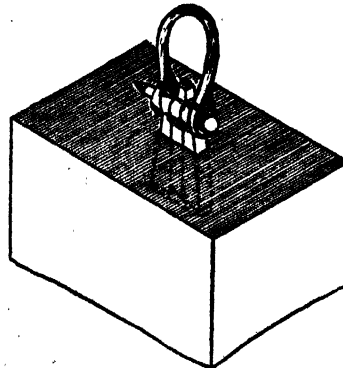


FIG. 178. SKETCH OF THREE-LEGGED LEWIS IN POSITION

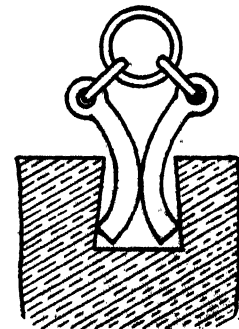


FIG. 179. CHAIN LEWIS IN POSITION

of two curved iron legs, about 8 in. long, grouped together by three rings. The legs are inserted loosely into an almost square-cut mortise. The pull, caused when the weight is felt

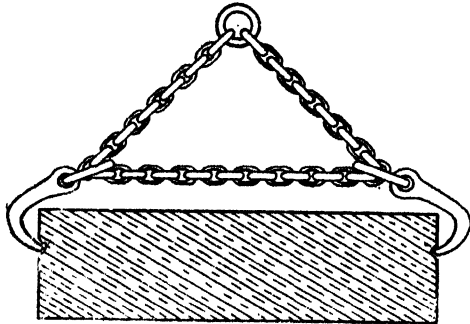


FIG. 180. CHAIN DOGS

in the centre ring, tends to draw the other rings together. These pull the top portion of the legs, which in turn spreads the lower part of



FIG. 181. PEDIMENT BEING FIXED BY MEANS OF CHAIN DOGS

the legs, thus gripping the sides at the lower part of the mortise.

Care should be taken to ensure that they are quite free at the upper edge. If the mortise is cut too large, a thin iron wedge should be placed between the legs of the lewis.

CHAIN DOGS (Fig. 180). These are excellent devices for lifting stonework, especially jointed stones and rough blocks. A small hole is cut in the ends of the stone about $\frac{1}{4}$ in. deep with a hammer and punch, and the dogs inserted. These are attached to a chain, forming a triangle

over the top of the stone. As the pull is vertical, the dogs draw together in a horizontal direction, thus gripping the stone. Fig. 181 shows a stone pediment being fixed by means of chain dogs.

SLING CHAINS (Fig. 182). The chain is placed round the centre of the stone and passed through the hook end, the ring being attached to the hook of the lifting apparatus. Care must be taken to ensure that the clean arrises of the stone are protected with pieces of wood, thus allowing the chain to *bite* into the wood without injuring the stone. The hook, when the weight is received, should point down towards the stone.

SNIPS, OR SCISSORS. These are used for lifting rough blocks, gripping the stone in a similar manner to the chain dogs, but they are cumbersome, especially when required for lifting large blocks.

SKIPS, OR TRAYS. These are timber boxes provided with iron straps underneath and continuing above the sides, with holes for the insertion of the hooks of the *skip chains*, which consist of four chains, about 3 ft. in length,

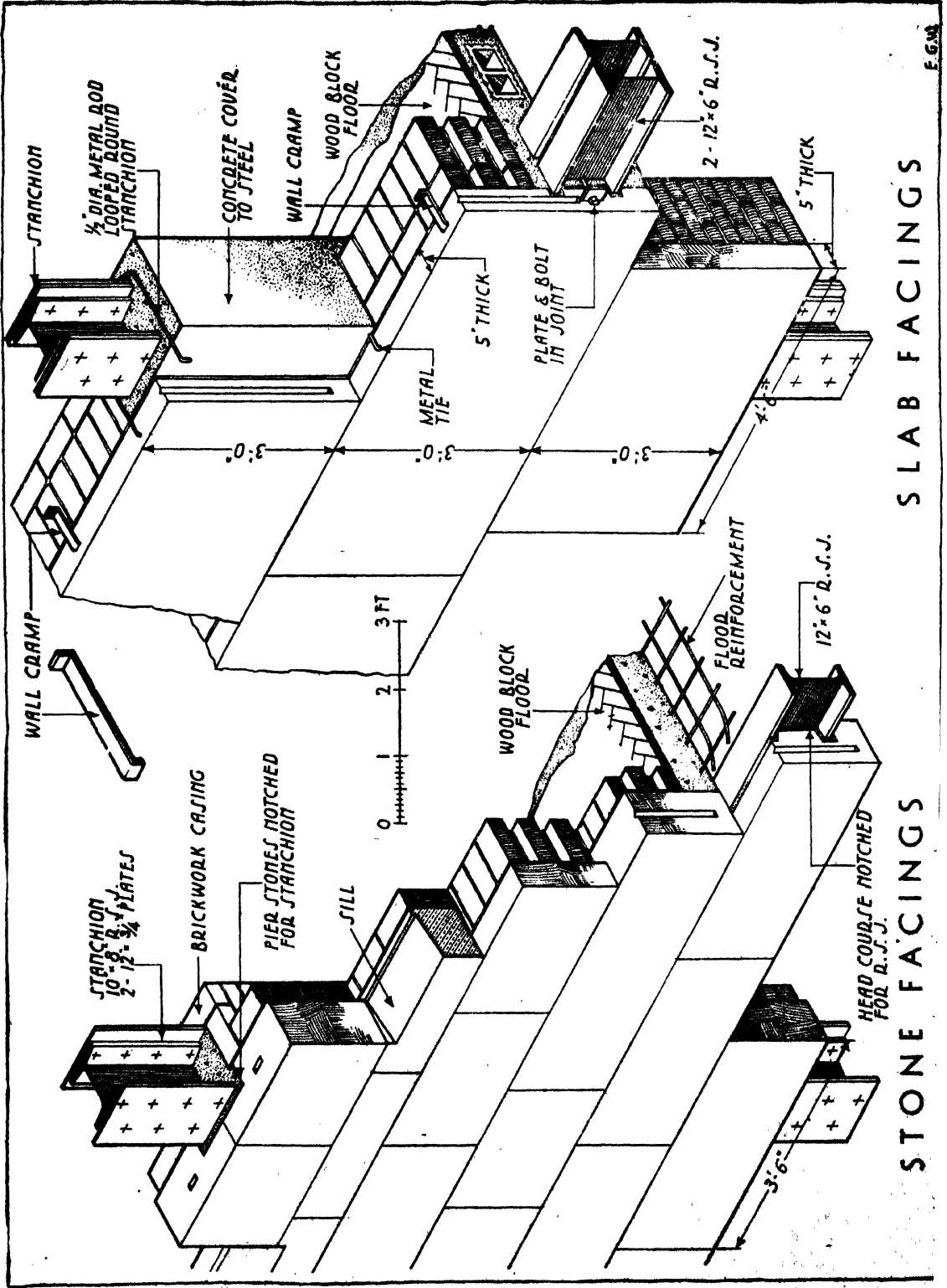


FIG. 182. PIECE OF CORNICE IN SLING-CHAIN READY FOR HOISTING

terminating with hooks and grouped together at the top by a large ring.

ROPE TACKLE. This comprises a rope made either of steel or hemp wreathed about a *two- and three-sheaf block*.

ENDLESS CHAIN TACKLE. Either the "Western" or "Morris" pattern. It is an excellent device for lifting individual stones, and is fastened to the head-tree or jib-pole by a collar chain about 3 ft. in length, provided with rings at each end, one ring being oval, so that it may be passed through the ring at the other end.



SLAB FACINGS

STONE FACINGS

LIFTING PINS. Fig. 183 is a sketch of a pair of lifting pins. Two holes, inclined towards the centre for the insertion of the pins, are drilled in the top bed of the stone.

JACK SLINGS. Rough blocks of stone are often lifted by passing a long sling chain (or rope) round the four sides of the block, looping the chain so that it can be attached to the lifting apparatus directly over the centre of the top surface. When the pull is applied, the sling bites into the side edges, thus gripping the stone. It is occasionally necessary to lift wrought stonework by this means; this circumstance usually occurs when it is impossible to pass a sling chain under the stone and lewis cannot be used. Great care must be exercised in protecting the arrises with pieces of wood, allowing the sling to bite into these.

FIXING

The tools used by the fixer are similar to those mentioned as being used by the mason, with the addition of the following—

THE LINE. This should be made of *whipcord*, and is used for stretching between two fixed points, so that the intermediate stones can be adjusted to their correct position, or set to the line.

PLUMB-RULES. (Fig. 184.) These are used to test whether the stones are set upright or vertical. When held vertical, the line to which the *plumb-bob* is attached should coincide with the line on the rule. A reproduced photograph showing the use of the plumb rule is given in Fig. 198. The *plumb-bob* is usually made of lead or a mixture of lead and zinc; its weight is about 2 lb.

To test battering walls, as in the case of a spire, a plumb-rule as shown in Fig. 186 is used. It is provided with one edge cut to the angle or bevel of the work.

To determine a point down from a datum line or from any fixed point, *centre-bobs* (Fig. 185) are used. These are made of brass or gun-metal. They are provided with a screw-on cap for fastening to the line, and have a steel point at the lower end.

LEVELS. All horizontal surfaces should be tested with a spirit level, both parallel and at right angles to the face of the wall. Fig. 187 shows the usual type of level used by a fixer.

These levels should not be fitted with brass ends, as in the case of a bricklayer's level, as they are likely to damage the sharp arrises of the stonework. A level (Fig. 188), about 3 ft.

long, and fitted with a vertical spirit level, is sometimes used. These levels are very useful for testing, or plumbing, the stones during windy weather, or in positions where it is impossible to use the plumb-rule.

TROWELS. Fig. 189 shows the usual type used by fixers. These craftsmen usually prefer a trowel of medium size and slightly rounded at the end for spreading the mortar beds. Fig. 190 shows a handy trowel usually to be found amongst the fixer's tools. These trowels are used for inserting between the beds for finally adjusting the stones to their correct positions. *Pointing trowels* (Fig. 191) are used for pointing

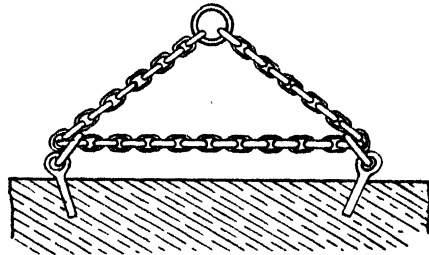


FIG. 183. LIFTING PINS FOR GRANITE

the joints of the stone preparatory to grouting with liquid cement.

PINCH-BAR. (Fig. 192). These bars are used for *prising*, or *lifting*, the stones off their beds, also to assist in adjusting the stones to their correct positions.

STEEL-FRAMED BUILDINGS

Remarkable changes have occurred in building operations during the last few years. At one time masonry was entirely constructional, designed to support the heavy loads of the building, but now, owing to the introduction of steelwork, in the form of steel-framed buildings, stonework is used as a means of decoration, or as a casing for the framework of steel. Steel stanchions form the core to piers, and the stones are notched to fit round the steelwork, sometimes to within a few inches of the face of the work. *Fasciae*, *cornices*, *soffit stones*, etc., are held in position by the steelwork (see Figs. 194, 195, 196, 197, 199).

At one time, large openings were spanned by stones of considerable size, and where the span was too large for one stone, several stones were introduced, with *radiating* or *secret-joggled joints*. These joints are still used in a modified form in conjunction with steelwork. A rolled steel joist of a section suitable to carry the calculated load

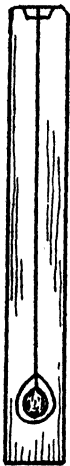


FIG. 184
PLUMB-RULE

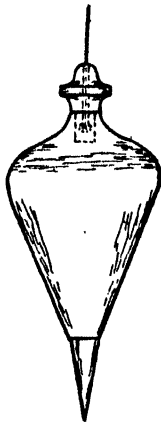


FIG. 185
CENTRE-BOB



FIG. 186
PLUMB-RULE FOR
BATTERING WALLS



FIG. 187
MASON'S LEVEL

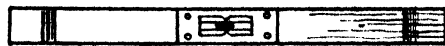


FIG. 188
MASON'S LEVEL FOR TESTING
VERTICAL FACES



FIG. 189
MASON'S SPREADING TROWEL



FIG. 190
LIFTING TROWEL



FIG. 191
POINTING TROWEL

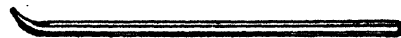


FIG. 192
PINCH-BAR

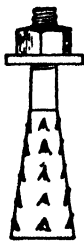


FIG. 193
RAG BOLT

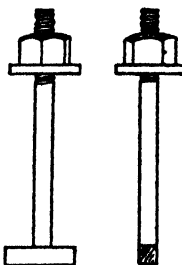


FIG. 194
ANCHOR BOLT

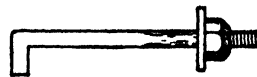
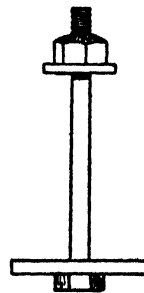


FIG. 196
PLATE AND BOLT

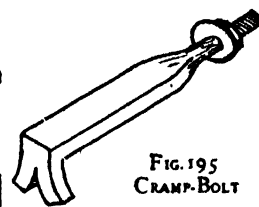


FIG. 195
CRAMP-BOLT

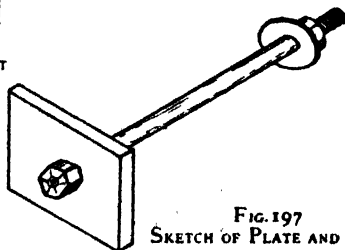


FIG. 197
SKETCH OF PLATE AND BOLT

TOOLS AND APPLIANCES USED IN FIXING STONEMWORK

is now placed across the opening, and the stones are notched and bolted to this joist, giving the

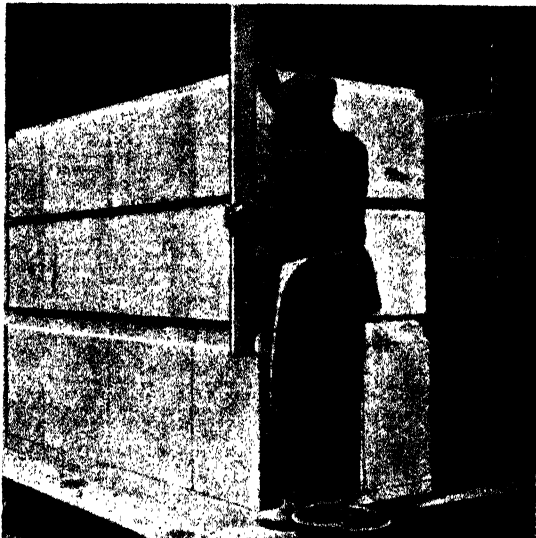


FIG. 198. TESTING STONES WITH A PLUMB-RULE

appearance on the elevation of solid stones. There are several methods of fixing stonework to steelwork, each with its own particular merit. The following are some of the methods in use.

RAG BOLTS. (Fig. 193.) These are metal bolts, dovetailed and jagged at one end, the other end being threaded to take a nut. A dovetailed mortise is cut into the stone, the mortise at the surface being slightly larger than the dovetailed portion of the rag bolt; the latter is then inserted into the mortise, which is filled with molten lead. The disadvantage of using this method for securing fasciae, etc., is that the holes drilled through the girders do not always coincide with the position of the bolt in the stone. As the stone must be placed directly into position, it is necessary, should the holes be drilled wrongly, to ease the bolt, which creates a weakness impossible to rectify after the fixing of the stones has been completed.

ANCHOR BOLTS. Fig. 194 shows this type of bolt, which is shaped at one end in the form of a T, and threaded at the other for the nut. A mortise is cut in the joint of each stone. The first stone having been placed in position, the bolt is passed through the girder and inserted half in the stone, the remainder protruding from the joint, the next stone being butted against the first stone. The bolt is then tightened

by means of the nut on the other end of the bolt.

CRAMP BOLTS. (Fig. 195.) These are used for connecting stonework to steelwork. They are generally inserted in the top bed of the stone, the lewis hole being utilized for this purpose.

PLATES AND BOLTS. Plates and bolts are the best means of securing stonework to steelwork. Figs. 196 and 197 show the plate and bolt in detail. They should be made either of gun-metal or galvanized iron. A mortise for half the plate is cut into the joint of each stone and into this mortise the plate is inserted, the bolt being passed through the rolled steel joist, or girder, and tightened by means of the threaded nut at the other end of the bolt.

When fixing a length of fascia, it is best to start at the left-hand end and work to the right, the stones being butted against each other after the plates and bolts have been placed loosely in position. When the length of fascia is complete, all the bolts should be slightly tightened; then the joints of the stone pointed, and the whole grouted with cement, the cement being allowed to fill all the spaces



FIG. 199. SHOWING METHOD OF CASING STEELWORK WITH STONE

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between the back of the stone and the steelwork. When the cement has almost set, the nuts should be tightened with the aid of a spanner.

It is necessary, if fixing a closer, to cut a

inserted from the inside. The nuts are run on to the bolts at the plate end, in the joints of the stones. The bolts in this case should be tightened before the joints are grouted. Fig. 204



FIG. 200. ATTACHING FASCIA COURSE TO STEELWORK

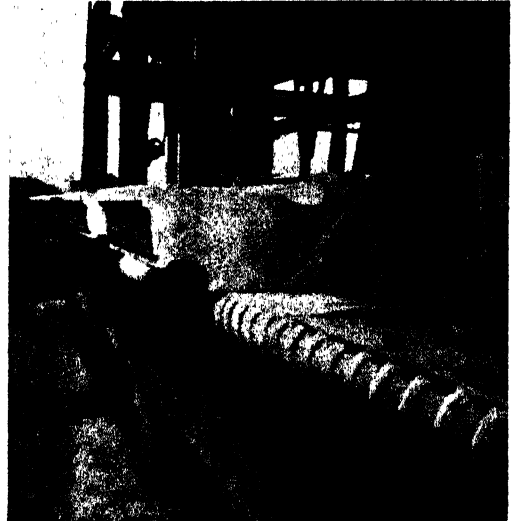


FIG. 202. FIXING CORNICE WITH THE AID OF A CHAIN TACKLE

mortise in each joint, and in the joint of the stone butting against the closer, to the top bed. The plates are then placed into the mortise after the stone is in position, the bolts being

shows the piece of fascia stone notched ready for fixing into position, and Fig. 205 shows the piece placed in position and with the *bolt* and *plate* inserted.



FIG. 201. ATTACHING CORNICE TO STEELWORK



FIG. 203. CENTERING SUPPORTING MASONRY ARCHES

CENTERING

The fixer should be in a position to state his requirements for all kinds of *centering* and *head-trees* necessary for the fixing of arches, groins, ceilings, hanging fasciae, domes, etc., which require supporting until the piece of work has been *keyed*, or the unit completed. The cement-

completed, the folding wedges should be slackened, thus allowing the arch to settle before any great weight is superimposed. A reproduced photograph showing the centering for a stone arch is given in Fig. 203.

Centres for groins, domes, etc., are best built up by a series of ribs, to enable the fixer to get at



FIG. 204. FASCIA STONE, NOTCHED, BEING PLACED INTO POSITION

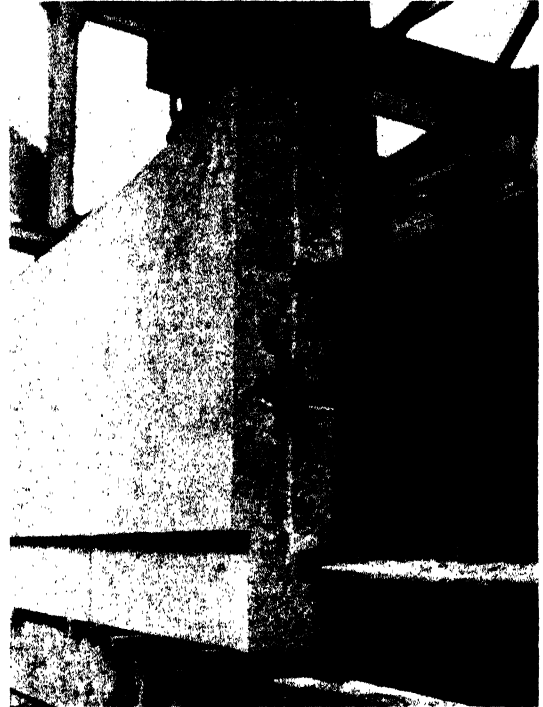


FIG. 205. PIECE OF FASCIA FIXED TO STEELWORK BY BOLTS AND PLATES

ing material should have sufficient time to set before the *centres* are struck.

For fixing stone arches, *laggings*, or cross pieces, should be nailed on the centering at intervals to suit the size of the individual voussoirs, or arch stones, preferably two laggings under the soffit of each stone. The *centre* should be made with a distance of at least an inch between the stone and the top surface of the laggings, and a radius rod provided for testing the accuracy of the curve of the arch. Folding wedges should be supplied, so that the fixer is able to adjust the stone by means of the pairs of folding wedges, resting on the laggings, each stone being tested with a plumb-rule as shown in Fig. 198. When the arch is *keyed* up and the abutments, or spandrels,

all the surfaces of the individual stones in each course. Space should be provided between the centres and the stones for wedging; but in the case of rib-vaulting and Gothic arches, it is best to have the centres fixed to the correct line of the soffit of the arch or ribs, and the stones placed direct on to the laggings or the centres without wedges.

Great care must be exercised to ensure that large folding wedges are placed immediately under the ends of the centres, on top of the uprights supporting the centres, so that the centres can be easily struck without disturbing the work.

Head-trees, for supporting hanging fasciae, should be fixed so as to allow for folding wedges between the soffit of the stones and the *head-trees*.

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SETTING-OUT PREPARATORY TO FIXING

In setting-out a building, care must be taken to ensure that the first course of stonework is placed in correct position, to dimensions given on the fixing sketch plan, which is supplied to the fixer by the setter-out.

BEDDING AND POINTING

Mortar for Stone-setting. The bedding material used for setting stonework will vary in composition according to the kind of stone to be set and the structural requirements of the work. The ultimate success of stone facings

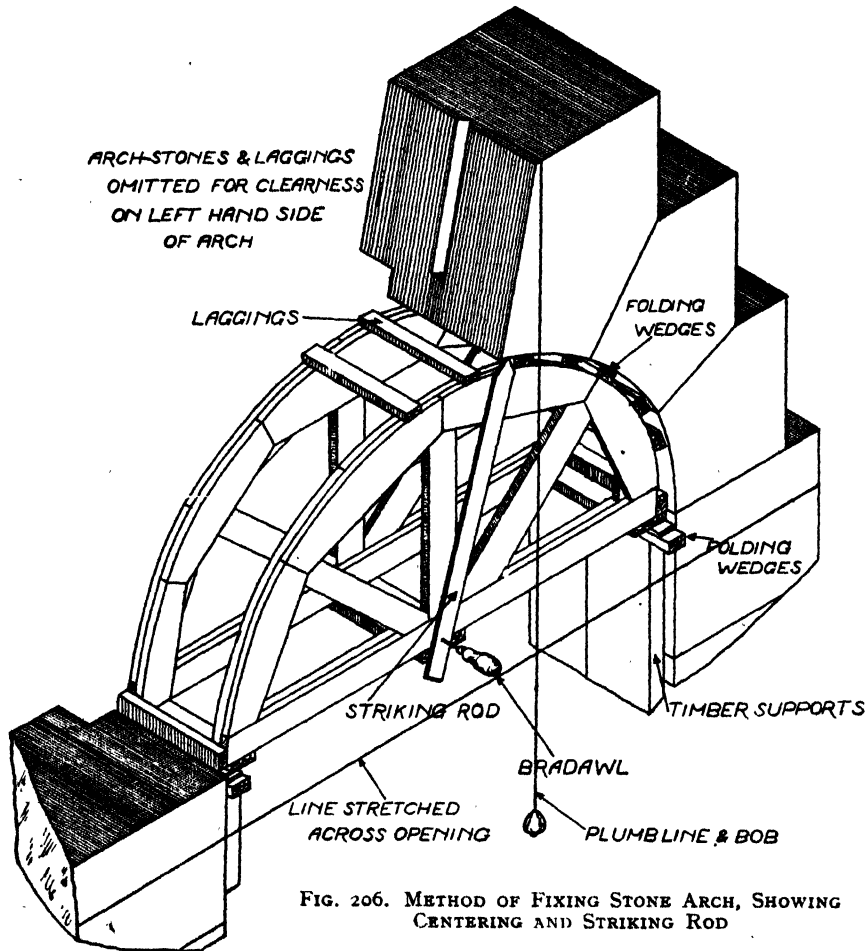


FIG. 206. METHOD OF FIXING STONE ARCH, SHOWING CENTERING AND STRIKING ROD

All levels are taken from a *datum line*, or fixed level, and the top bed of the first course of stone is either measured up or down to *datum line*, as the case requires.

Openings and breaks must be carefully checked, together with overall dimensions, before the work is allowed to proceed. The *wall-line*, or *building-line*, is always fixed, so it is important that all recesses and projections are measured from this line.

will depend to a very great extent upon the composition of mortar used. Unsuitable admixtures will cause unsightly stains to appear on the exposed surfaces and these stains are often accompanied with the crystallization of salts which will tend to cause a rapid decay of the stones.

The stability of wrought stonework does not depend to any great extent upon the strength of the mortar, which is merely intended to act

as a cushion between the stones, thus allowing each stone to settle on its bed so that it may take its full bearing and load.

For rubble walls a mixture of cement and sand, or lime and sand, is used, because the strength of these walls depends upon the cementing material. The beds and joints are large in comparison to wrought stonework, which does not depend to the same extent upon the mortar for its strength, but on the bonding and jointing. The bedding of wrought stonework should ensure an evenly distributed pressure over the whole of the surface. The size of the beds and joints range from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. in thickness. The bedding material used for setting Portland and similar limestones is called *mason's putty*, and is composed of lime putty and stone dust of the same stone as that being set, in the proportion of three parts of stone dust to one of lime putty. Great care must be taken to ensure that no particles of unslaked lime are allowed to remain in the mortar. To avoid this occurring, hydrated lime, the composition of which should conform to the standard test of the Building Research Station, should be used. The stones are set and jointed against each other; care being taken to keep all the beds and joints at equal distance apart. To ensure this, they should be measured or tested with a *gauge*.

The beds and joints should be pointed when the stones are in their correct position and the joints grouted with liquid cement. When stones are to be supported by or attached to steelwork, as is often the case in the construction of fascia and soffit courses and heavy cornices, it is advisable to grout the interstices between the stones and the steelwork with a mixture of stone dust and Portland cement. For structures where great strength is required, it is best to use Portland cement, but for buildings faced with Portland or similar stones, an admixture of "white" cement is an excellent material for grouting the stones. The cement should be made into a thick liquid and poured into the joggles, filling all the interstices, at the same time dropping a few pebbles or washed shingle into the joggles.

Where stonework is backed by brickwork in cement, or where it encases steelwork, each stone should be painted at the back with bituminous paint, or coated with lime mortar.

All stonework after being fixed should be well slurred, or covered with a mixture of stone dust and a small quantity of plaster, to keep the face of the stone clean. This prevents a face or film

forming on the stone, which if removed during the process of cleaning down would tend to shorten the life of the stone. If the work is slurred it also presents a more uniform appearance upon completion.

All slurry on the faces of the stonework should be cleaned off before fixing, so that the quality of the stone can be inspected and passed by the clerk of works. This often saves great expense and annoyance in cutting out bad stones during the process of cleaning down.

A suitable mortar for setting sandstones can be made from a mixture comprising 3 to 5 parts washed sand and one part Portland cement.



FIG. 207. POINTING THE JOINTS OF A PIECE OF CORNICE AFTER BEING SET CORRECTLY IN POSITION

Lime should not be used in conjunction with sandstones.

For setting granite, a mixture comprising 3 to 5 parts crushed granite and one part Portland cement will make a suitable mortar. For setting interior marble-work it is preferable to use plaster of paris, but for setting external marble-work of the white variety, white Portland cement should be used.

Stains in Stonework. Stains on the surfaces of stones usually occur in close proximity to the beds and joints. The cause of these stains can often be attributed to the materials which comprise the composition of the mortar. In some instances the fault is occasioned through constructional defects and lack of supervision during building operations.

Pointing. When flush or weathered joints are required, it is better to finish the pointing of the stonework during erection, as shown in Fig. 207.

Chapter XV—CLEANING AND RESTORING STONEMWORK

CLEANING

THE method of cleaning stonework will depend upon the circumstances, the type of stone, and the condition of the stonework. There appears to be no legitimate reason for the customary practice of giving a new appearance to the surfaces of the stone facings of old buildings. Such cleaning may result in an early decay of the stonework, a condition which is more harmful than a dirty appearance.

There are several methods of cleaning stone, and briefly they may be summarized as follows—

(1) *The dry method*, in which the surfaces are brushed with a wire brush or rubbed with grit stone or carborundum blocks.

(2) *The wet method*, in which the surfaces are washed with clean water only, or rubbed down with sand, grit stone or carborundum in combination with water.

To assist in the cleaning process, chemicals such as caustic soda or compounds containing caustic soda in a diluted form are often applied to the surfaces. The use of such chemicals will facilitate the removal of the dirt and sooty accumulation, but this advantage is more than counterbalanced by the acceleration of decay which will result and become apparent after a short lapse of time.

Damage to the stonework may be caused by the physical action of caustic soda, which action will result in the change of molecular volume, due to the formation and crystallization of new chemical compounds, and a consequent exfoliation or crumbling of the stone. Cleaning solutions or patent processes should not be used or employed unless they are free from damaging chemical substances.

Steam Cleaning. In this method, steam is generated under a pressure of about 60 lb. to the sq. in. and applied to the surfaces of the stonework in the form of a jet of steam through the medium of a steam brush. The application of the steam is not injurious to the stone and a clean surface will result, but care must be exercised to ensure that chemical substances are not used in combination with the steam.

The best method of cleaning is the application of clean water accompanied with a thorough

brushing of the surfaces with a hard stiff brush.

Whenever the cleaning of the surfaces of stonework is contemplated it should be remembered that the stains and discoloration are less to be worried about than decay.

DECAY

The bad condition of stonework of buildings is due very largely to the omission on the part of those responsible in obtaining expert advice in the selection of the kind of stone at the time the building was designed.

Building owners are often left with a legacy of faulty material because the wrong kind of stone, or stones of poor quality, were selected for the building, the result of which becomes apparent some time after the completion of the building. In such cases the particular building stone is condemned and classified as a stone having poor weathering qualities, whereas the fault lies with those who were responsible for the selection.

Unfortunately it is not until the decay in stonework is noticeable that any attempt is directed to the means available for the arrest of the process of decay. At this stage it is often found that the disease is chronic and will yield only to the most drastic treatment.

Causes. Decay in stonework may be caused by chemical processes, physical processes, or a combination of both. Decay through constructional faults, structural and natural defects, come under the heading of those caused by physical processes.

The principal chemical agents which affect building stones are: carbon dioxide, sulphuric acid, and chemical salts. Carbon dioxide, which is a normal constituent of the atmosphere in towns, will under certain conditions readily act upon stones containing calcium carbonate. The particles of calcium carbonate will dissolve in a solution containing carbon dioxide, the particles being taken into solution and gradually washed away, thus resulting in an eroded surface.

Sandstones containing an appreciable quantity of lime, or calcium carbonate, are liable to be attacked by carbon dioxide and by sulphur gases, Fig. 208.

Decay caused by physical processes may be

due to the effect of fluctuating temperatures, particularly when the change is accompanied by excessive moisture, this condition resulting in

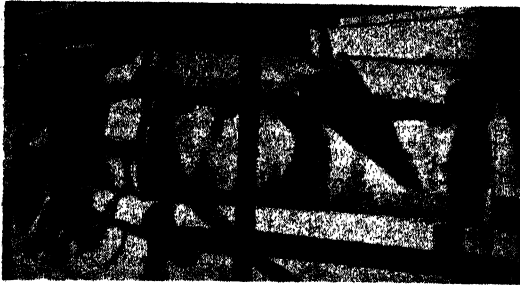


FIG. 208. STONework AFFECTED BY SULPHURIC ACID IN SOLUTION

the expansion or contraction of the particles comprising the stone. The stresses which occur in the material cause the cementing material to fracture, cracks forming over the surface, thus allowing salts and acids to be deposited in the cracks.

Frost is associated with temperature changes and when united with the foregoing will cause the surface of the stone to disintegrate.

STRUCTURAL DEFECTS may assist in causing, or accelerating, the process of decay in stonework. The defects may occur by the settlement of the structure, in which case the joints between the stones will be opened, or the stones cracked, thereby allowing access to rain and acids.

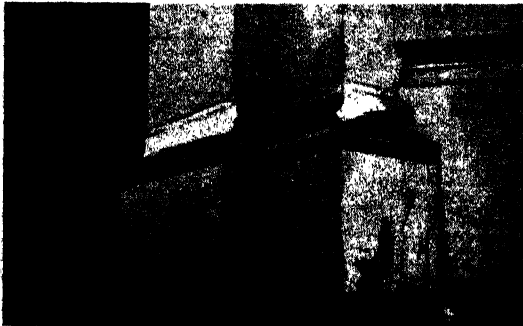


FIG. 209. DAMAGE TO STONework CAUSED BY FAULTY FIXING

Fractures and a breaking away of stonework details often occur through faulty fixing. See Fig. 209.

INEFFICIENT DAMP-PROOF COURSES will permit moisture containing salts to travel into the walls of the buildings, the moisture eventually evap-

orating and leaving a deposit of salt crystals which will readily act with a deleterious effect upon the stones.

FAULTY SURFACES. The absence of weathered or inclined exposed surfaces of stonework will tend to allow rain-water to lodge on the exposed top surfaces of stonework instead of being quickly discharged from these surfaces.

INEFFICIENT DRIPS formed on the underside of projecting stonework will permit rainwater to run down the wall surfaces, with deleterious effects upon the stonework.

METAL CONNECTIONS. When iron, or steel, is used in connecting devices, unless special precautions are taken to prevent moisture from coming into contact with the metal, corrosion takes place and layers of rust are formed on the

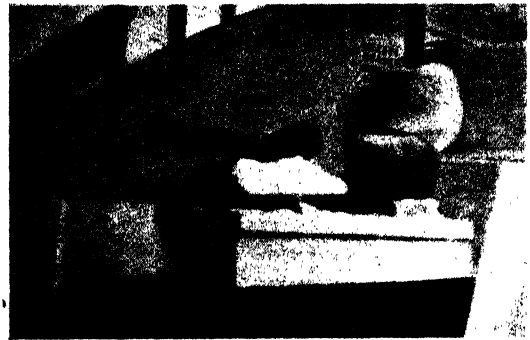


FIG. 210. BURSTING OF STONework CAUSED BY IRON DOWEL

surface of the metal, thereby causing expansion to take place and a resulting bursting of the stones and later decay. See Fig. 210.

BASES OF WALLS. Sand-bags or rubbish deposits when placed at the base of walls will ultimately permit the transference of salts in solution to the stones, thereby accelerating the process of decay.

RESTORATION AND REPAIR

The restoration of stonework which is in a bad condition owing to the presence of decay, is an operation demanding expert advice. It is not just a simple matter of building up the contour of the details with mastic or other compounds and then to imagine that the defect has been righted.

Decay in stone is a disease and an antidote must be applied if a cure is to be obtained. Many so-called methods of restoration and repair are advertised, and some, when applied,

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have produced excellent results, but in many instances a great deal of money has been wasted by the application of ineffective methods and unsuitable materials.

between a good and a bad stone. The stones should be cut out by a skilled mason, and templates cut to the contour of the existing mouldings and details so that the new stones can be



FIG. 211. CONDITION OF STONEWORK BEFORE RESTORATION



FIG. 212. DECAYED STONEWORK CUT AWAY

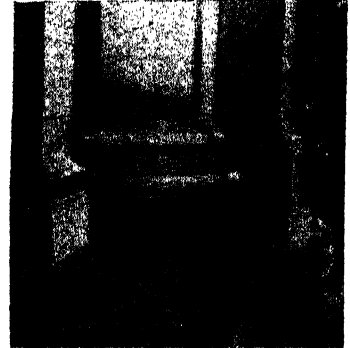


FIG. 213. RESTORATION COMPLETED

The most effective method is to cut out all the stones which are affected and replace them with new stones of the same variety. This is an expensive method, but it is the only real cure. It is because of the cost that this method is not generally adopted and cheaper substitutes introduced.

worked to these templates. See Figs. 211, 212, and 213.

It is not always necessary to cut away to the extreme depth of the stone or bed. A depth of approximately 5 in. is usually sufficient. See Fig. 214. In many instances it is necessary to remove complete architectural features and



FIG. 214. DECAYED STONE REMOVED FOR THE INSERTION OF NEW STONE

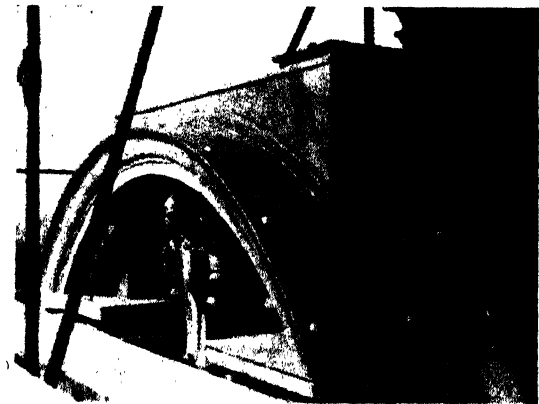


FIG. 215. DECAYED STONWORK OF PEDIMENT

To facilitate the removal of the decayed stones or stones damaged through bombing, and to replace with new ones, scaffolding often has to be erected. This is an expensive item but well worth while if the stonework of an expensive building is desired to be preserved.

All affected stones should be marked by a competent person who is able to discriminate

replace them with new stones as shown in Figs. 215 and 216.

The new stones should be bedded in a mortar comprising stone dust and hydrated lime and a small percentage of Portland cement (if limestone is being replaced).

The joint surfaces around the stone should be pointed with the same mortar, and in some

instances a portion of the top joint may be left open for grouting purposes.

To grout the stones a dam or funnel can be formed in front of the aperture into which liquid grout, comprising the same mix as the bedding mortar, can be poured. To assist the flow of the liquid around the embedded surfaces of the stone, a weep hole may be formed at the bottom of each joint.

When the process of replacing is completed the whole of the surface of the stonework should be washed down with clean water.

Mastic Repair. Restoration of decayed stonework may be carried out by building up the decayed portions to the required details with a cement mixture or a mastic compound.

To obtain the best results with either of these methods of restoration, only skilled men should be employed. It is essential that all the decayed portions should be cut away and a key or a dove-tail formed in the recesses so that the cement or mastic will obtain a secure hold. Unless this is done, the applied material will soon fall away.

All admixtures which include chemicals in their composition should be avoided because they are liable to develop cracks. Rainwater will soon enter these cavities and result in the breaking away of the material. Mastic compounds can be used with good results providing they do not contain any deleterious substances such as silicate of soda, or hydrochloric or sulphuric acids.

The original lines and profiles of mouldings should be made up with the repair material, but care must be exercised to ensure that the mastic is properly wedged to the stone, and a specially prepared mastic should be employed for each variety of stone. It is very important, when executing plastic repairs, to provide an efficient key for the cement. The decayed portions should be cut away to a depth which will allow the edges or side surfaces of the sinkings to be under-

cut. Also the mastic may be assisted in its adherence to the stone by drilling holes in the stonework at differing angles in the lower surfaces of the sinkings.

When making up the profiles of mouldings, etc., the plastic material should be reinforced with brass wire and a system of dowelling should be introduced.

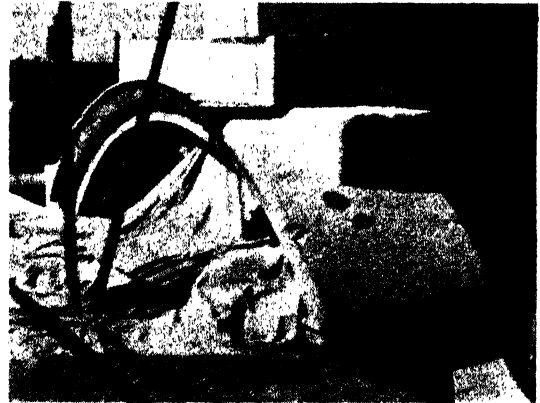


FIG. 216. STONWORK OF PEDIMENT AFTER RESTORATION

Top surfaces of stones covered with sheet lead

Renovating Stonework. When new additions are made to old buildings, it is often desired to make the old stonework assume a similar appearance to the new work. For such purposes cleaning or washing may not be sufficient.

To obtain the required result, specially prepared renovators are used. A preservative liquid, tinted to the required shade, is applied in the form of a wash so that the old stonework will accord in colour and appearance with the new stonework.

Providing the preparation is free from acids and alkalis no harmful effects will result from the use of such preservative solutions.

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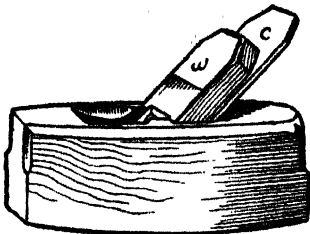


FIG. 1. SMOOTHING PLANE

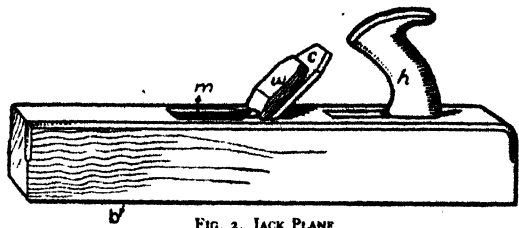


FIG. 2. JACK PLANE

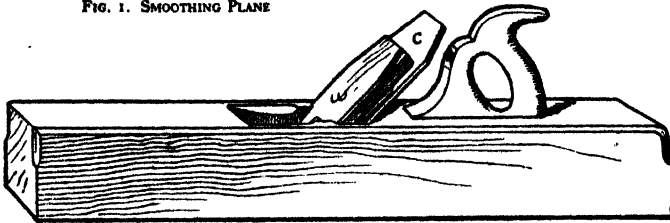


FIG. 3. TRYING PLANE

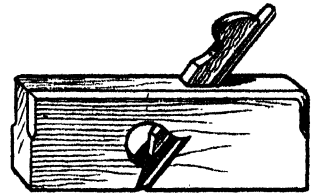


FIG. 4. REBATE PLANE

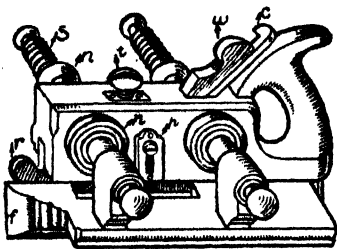


FIG. 5. PLOUGH

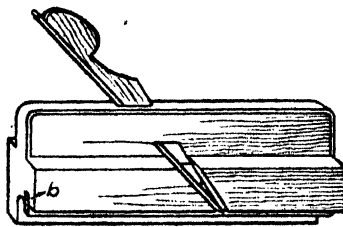


FIG. 6. BRAD PLANE

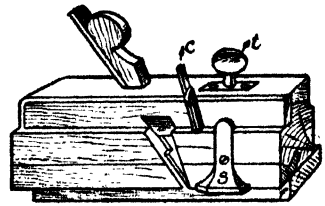


FIG. 7. FILLISTER PLANE

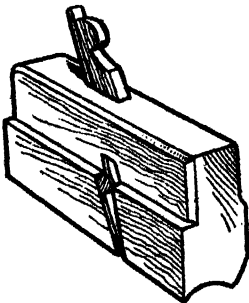


FIG. 8. HOLLOW PLANE

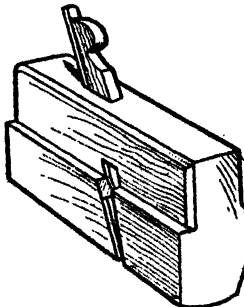


FIG. 9. ROUND PLANE

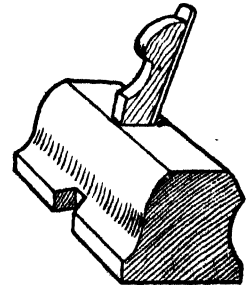


FIG. 10. ROUTER PLANE

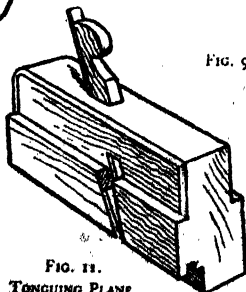


FIG. 11. TONGUING PLANE

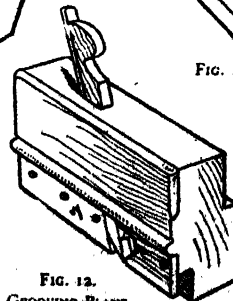


FIG. 12. GROOVING PLANE

Joinery

By T. CORKHILL, F.B.I.C.C., M.I.STRUCT.E., *Double Medallist*

Chapter I—TOOLS

THIS section, together with the sections on "Carpentry," "Stairs and Handrails," and "Geometry," is intended to give the joiner an insight into the intricacies of his craft. In it he will find all that he requires to make him competent to face the problems with which he may have to contend. The problems are not new; they have always been associated with the working of wood; but the increasing use of machinery has given many of them a new aspect. There are very few materials which give so much pleasure and satisfaction to the craftsman as timber. An artistic and well finished piece of woodwork is an abiding joy to the maker; and nearly everyone who strives patiently can attain the satisfaction of producing the very best results. Most boys, whilst still at school, are filled with a desire for woodworking; but only a few of those who eventually follow the craft remain sufficiently enthusiastic to equip themselves thoroughly and efficiently with knowledge as well as with tools.

It is often contended that the joiner of to-day is not so capable as those of previous generations. Certainly many of them have not the same opportunities of learning their craft whilst at work, but there are many joiners of to-day as capable as any in the past. This is however, not sufficient; *every* joiner should strive to make himself competent. Some men will always excel, but everyone has the ability and power to improve himself by careful study. If the student conscientiously works through this section he will feel better equipped and more confident to face the various problems met with in the course of his work.

The first thing the joiner requires is a knowledge of the tools and materials used in his work.

Buying and Care of Tools. With regard to the tools, the joiner is entirely responsible and it behoves him to make a very careful selection. The finish of a job depends nearly as much on the tools as upon the craftsmanship. Good quality tools are essential; inferior tools are

dear at any price. It is not the quantity but the quality of the tools that tells in the production of good work. The beginner should buy from a reputable firm, and should seek the advice of an experienced joiner when purchasing. He should avoid combination tools as a general rule; "one tool one job," is a good maxim. When he has obtained the tools, he should take a pride in them and keep them in good condition, clean and sharp. He is then on the highway towards making a good job.

The tools shown have been illustrated from the catalogues of R. Melhuish, Fetter Lane, E.C.4, and S. Tyzack & Son, Old Street, Shoreditch, E.C.

PLANES

Wooden Planes. Planes are the most important and expensive part of the equipment, but it is not necessary to have a large assortment at first. It is essential to have what are usually called the *bench planes*, that is, the *jack plane*, *smoothing plane*, *try plane*, and *rebate plane*; the others are added as the occasion requires them. The usual types of wooden planes are shown in Figs. 1 to 12; they are all made of best quality beech wood.

JACK PLANE. This is used in rough work for *planing up* the stuff as it comes from the saw, and for planing off large quantities to reduce the size or straighten the surface. It is very convenient to handle, the body or *stock*, being about 17 in. by 3 in. by 3 in. The handle is glued into a slot in the body of the plane. The wedge *w*, Fig. 2, fixes the *irons c*, and the *mouth* and *throat m* allow the shavings to escape. The *sole b* of the body should be at right angles to the medullary rays to give the best resistance to wear.

PLANE IRONS. A longitudinal section through the mouth of the plane is shown in Fig. 13, with an inverted plan of the *sole b*. The *irons, C*, consist of two parts, the *cutting iron*, or blade, and the *back iron*. The cutting iron is shown in Fig. 14, and the back iron in Fig. 15. The

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former is made of iron with a steel facing *a*; this makes the blade easy to grind and sharpen. The grinding angle *g* is about 25 degrees and the sharpening angles about 35 degrees; but both angles depend upon the nature of the work,

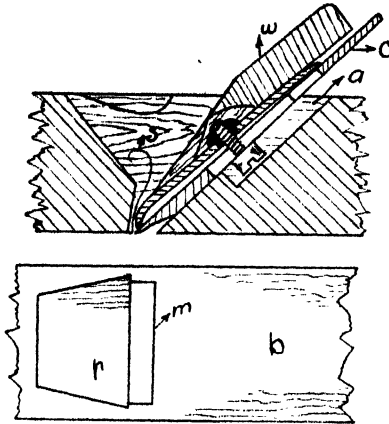


FIG. 13. SECTION OF PLANE

as will be explained later. It is usual to sharpen the jack plane iron slightly round as shown at *b*, because of the thick shavings which it has to remove. For the smoothing and try plane irons the edge should be straight, with the corners sharpened off to prevent *plane marks* being left on the stuff.

The *back, cap, or cover, iron* is made of steel; the brass nut *a* is fixed to the steel and receives the screw *b*. Fig. 13 shows the two irons in position. For the smoothing and try planes the back iron is *set back* from the cutting edge about $\frac{1}{16}$ in., and for the jack plane, about $\frac{1}{8}$ in. For hardwood or cross grain these distances should be halved. The action of the back iron is to *break* the shaving *s* as it is cut, and to bend it over, thus preventing the fibres from splitting along the grain in front of the cutting edge. To assist the action of the back iron it is necessary that the mouth *m*, Fig. 13, should not be too open in front of the cutting edge. When the plane is new the mouth is often too close, but it soon wears more open, and eventually it has to be closed by letting a boxwood mouthpiece *p* into the sole. The plane irons are usually $2\frac{1}{4}$ in. wide. The cutting iron generally tapers in thickness, but a *parallel iron* is preferable because it does not require refitting after repeated sharpening, and does not open the mouth when worn down.

Successful planing depends upon a sharp edge,

well-fitted irons, and a straight sole. It is generally the second feature which gives trouble. It is impossible to give too much attention to the fitting of the irons, both in the body and one to the other. Badly fitted irons cause *chattering*, or vibration, and *choking*. The irons should be *set fine* for hardwood, that is, the back iron should be close to the cutting edge; and there should not be much *hook* on the plane, that is, the plane should *remove* thin shavings.

SMOOTHING PLANE. This plane, Fig. 1, is used for *finishing off* the surface preparatory to scraping or sandpapering. It is about 8 in. long, and made from a piece of 3 in. by 3 in. beech. A metal front, Fig. 16, is usually fitted to the smoothing plane when the mouth is too open. The front *s* is let into the sole of the plane, and carries a slot to receive a small nut *n*. A screw *a* passes through the nose of the plane and engages with the nut to fix the plate *s*. The screw head rests in a cup *c*.

TRYING PLANE. The trying plane, Fig. 3, is the largest of the bench planes. It is similar to the jack plane except for the closed handle, and is used for straightening surfaces. The body is about 23 in. long, and it is usually about $3\frac{1}{2}$ in. square, with a $2\frac{1}{2}$ in. iron. A *jointing plane* is similar to the trying plane but longer; it is used for making long joints, but very few joiners possess one.

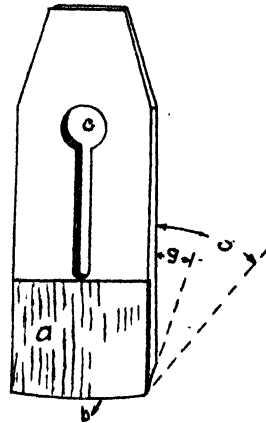


FIG. 14
CUTTING IRON

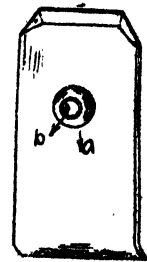


FIG. 15
BACK IRON

Care of Planes. All the wooden planes should be well soaked in raw linseed oil before being used. This lengthens the life of the plane, reduces the friction on the sole, and improves the appearance. They should be wiped occasionally with an oily rag for the same reasons. Some

joiners mix a little burnt ochre with the oil for wiping the surface; this gives a darker and more mature appearance to the planes. The wedges should be *eased* and the irons *knocked back* when the planes are not in use.

REBATE PLANE. The rebate, or *rabbet*, plane, Fig. 4, is intended for planing in corners; hence the iron, which is a single iron, is the same width as the body. The iron is placed on the *skew* to give a shearing cut and clearance for the shavings. The usual thickness is $1\frac{1}{2}$ in., but they may be obtained in various thicknesses up to 2 in.

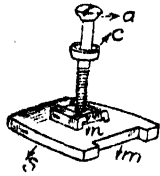


FIG. 16
METAL FRONT

The *badger* is similar to a jack plane in size and shape, but the irons are arranged as a rebate plane on the off side of the stock.

The Stanley metal rebate plane is about 2 in. wide, and fitted with double irons like the smoothing plane. It is easily adjusted and makes a good finish.

PLOUGH. The plough, Fig. 5, is used for making grooves. The fence *f* is adjusted to the required distance by the wooden nuts *n*, which run on the two spindles *s*. The depth of the groove is regulated by the stop *p*, which is adjusted by the thumb-screw *t*. The metal runner *r* is screwed to the body. There are usually about eight bits, or irons, *c*, of different sizes supplied with the plane. The bits have a projection at the top for adjusting for "hook," and are fixed in position by the wedge *w*. The plough may be obtained with or without handle.

FILLISTER. This is a rebate plane with an adjustable fence *f*, Fig. 7. The fence is slotted and is fixed in position by two screws underneath. The depth of the rebate is regulated by the stop *s*, which is adjusted by the thumb-screw *t*. A side cutter *c* marks out the rebate in front of the cutting iron.

The *sash fillister* is like a plough in shape, and cuts the rebate on the back edge of the stuff whilst working from the face side. The fillisters are seldom used because rebates are conveniently made by the plough and rebate plane, even where no machines or circular saws are available.

BEAD PLANES. Fig. 6 illustrates a bead plane; it is so often required that nearly every joiner possesses two or three different sizes. The most common sizes are $\frac{1}{4}$ in., $\frac{3}{8}$ in., and $\frac{1}{2}$ in., but

they may be obtained much larger. The strip *b* is made of boxwood to prevent wear.

HOLLOWS AND ROUNDS. These planes are shown in Figs. 8 and 9; they are used to plane up convex and concave surfaces. They may be obtained in various sizes and are usually sold in pairs. A complete set consists of eighteen pairs.

MATCH PLANES. Matching planes, or tonguing and grooving planes, are shown in Figs. 11 and 12. They are sold in pairs and are used to form the tongues and grooves on match-boarding, etc. The grooving plane, Fig. 12, has a metal plate *p* to run in the groove; the iron is not adjustable, so that the groove is always the same distance from the face side.

MOULDING PLANES. There are many other forms of moulding planes, such as *ovolo*, *lamb's tongue*, *ogee*, *reed*, *torus*, etc., but they are not so often used as formerly, because of the increased use of machinery. It was customary at one time for every joiner to have thirty or more moulding planes of different descriptions; but to-day very few joiners possess more than one or two beads, *ovolos*, and hollows and rounds.

ROUTER. Fig. 10 shows the router, or Old Woman's Tooth. It is used for cleaning out trenches to the required depth.

TRENCHING PLANE. This is in the form of a rebate plane, but it has two side cutters because it is intended for grooving across the grain.

SPOKESHAVE. This is shown in Fig. 17; it is

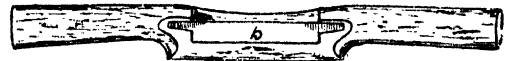


FIG. 17. WOODEN SPOKESHAVE

used for planing small circular work. The blade *b* is fixed in position by two tapered tangs, cast on the blade, which pass through the body. It is adjusted by tapping the blade for less "hook," or the ends of the tangs for more "hook." The body is made of beech or boxwood.

Other forms of wooden planes have for the most part been superseded by metal planes. *Thumb* planes, however, are usually of wood. They are very small planes of various shapes and are mostly used for wreathed handrailing and *circle-on-circle* work.

Metal Planes. Most forms of wooden plane are duplicated in metal but not all are popular with the joiner. The jack and try planes are

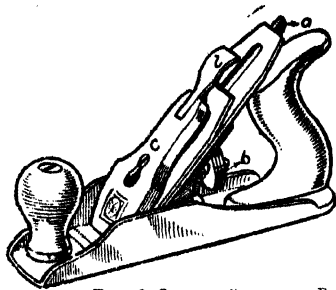


FIG. 18. STANLEY SMOOTHING PLANE

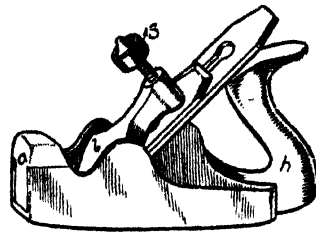


FIG. 19. SMOOTHING PLANE

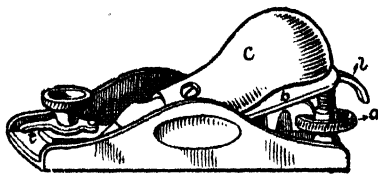


FIG. 20. BLOCK PLANE

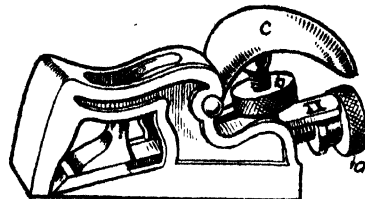


FIG. 21. BULLNOSE PLANE

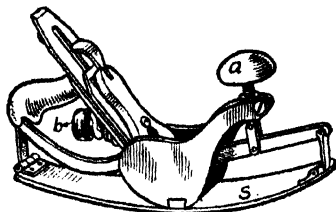


FIG. 22. COMPASS PLANE

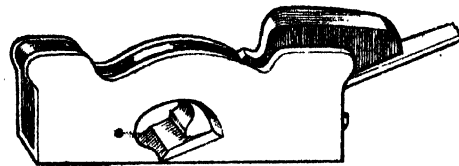


FIG. 23. SHOULDER PLANE

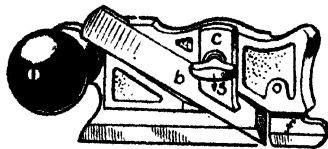


FIG. 24. SIDE-REBATE PLANE

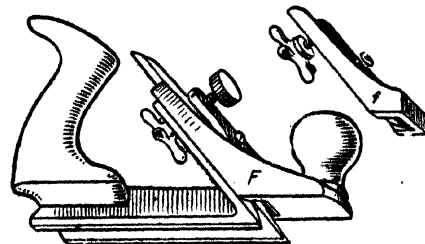


FIG. 25. CHAMFER PLANE

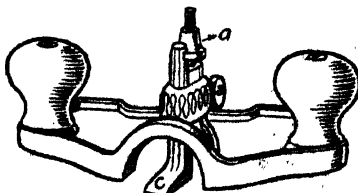


FIG. 26. ROUTER PLANE

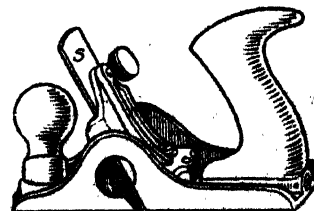


FIG. 27. SCRAPER PLANE

not so satisfactory as the wooden types; but most joiners include an iron smoothing plane in their kit, and one or more of the smaller types of planes. The planes are made in various metals, including cast iron, malleable iron, cast steel, and gun-metal. Cast-iron planes are cheap, but should be avoided because they are easily broken.

SMOOTHING PLANES. The Stanley smoothing plane shown in Fig. 18 should be of the "bed-rock" type, otherwise it is apt to *chatter* on hardwood, knots, etc. It is a very useful plane because the irons are easily adjusted, and with care is a very serviceable plane. The sole must be kept clean, and occasionally smeared with oil to ease the friction, which is greater than with the wooden soles. The irons are fixed by the cap *c* which is adjusted by the lever *l*. The lever *a* adjusts the irons sideways, and the milled nut *b* adjusts for thickness of shaving.

The English pattern of smoothing plane is shown in Fig. 19. This is a strong and serviceable plane, but is not adjustable except as an ordinary plane. The irons are fixed by the lever *l* by means of the screw *s*. It is the best plane for hardwoods and across the grain because of its rigidity. The mahogany handle *h* is continued to form the bed for the irons. Some forms of metal planes have corrugated soles to ease the friction; theoretically these are good, but in practice the corrugations are apt to clog, especially on resinous timbers. Other good types are the "Norris" and "Sargent" planes. All these planes produce a straight and highly finished surface.

BLOCK PLANES. Fig. 20 shows a useful type of block plane, especially for fitting mitres and other small work. The blade *b* is held by the cap *c*, which is fixed by the lever *l*, and adjusted by the milled nut *a*. The throat is adjusted by the lever *t*. This type of plane has no back iron, but the cutting edge is supported by turning the iron over so that the *bed* is carried up to the cutting edge. The bed is also very flat where a single iron is used, that is, the angle between the sole and the iron is very small.

Some types of block planes have the iron close up to the nose of the plane for working into corners; these are often called *chariot planes*. Sometimes the type shown in Fig. 20 has a removable front for the same purpose.

BULLNOSE PLANES. This is a similar type to the block-plane, but it is arranged as a rebate plane. Fig. 21 shows a useful type. The

blade is held by the cap *c*, which is fixed by the milled nut *b*, and it is adjusted by the nut *a*. It is an indispensable plane for working into corners, especially in hardwoods.

COMPASS PLANE. Fig. 22 shows a very useful plane for circular work. The sole *s* is adjusted by the screw *a* for either concave or convex surfaces. The principle of the plane irons is the same as for the Stanley smooth plane. The quickness of adjusting both the irons and the curvature has given this plane first place, although the "old-time" joiners still stick to the wooden type, which, generally speaking, is now obsolete. For "flat" concave work, however, it is a common practice to plant an auxiliary sole on an ordinary smoothing plane, the false sole being shaped to the required curvature.

SHOULDER PLANE. This rebate plane, shown in Fig. 23, is excellent for planing across the grain, such as the shoulders of rails, and for ordinary rebates in hardwoods. It is a perfect plane for this class of work owing to its rigidity and close mouth.

SIDE-REBATE PLANES. Fig. 24 shows the usual type of side-rebate plane. They are useful for cleaning up the sides of plough grooves, etc., where no other tool is applicable. They are sold in pairs, right and left hand, but usually the joiner is contented with a right-hand plane only. The front *f* is removable for working up into corners. The blade *b* is held in position by the cap *c*, which is fixed by the thumb screw *s*.

CHAMFER PLANES. These planes are not a necessary part of the equipment but they are very useful where machines are not available. Fig. 25 shows the usual type, but they may be obtained in wood; in fact, many joiners make their own. The metal plane is supplied with two fronts so that *f* may be substituted for *F* when required for stop chamfers.

ROUTER. Fig. 26 shows the metal form of Old Woman's Tooth. The nut *a* adjusts the cutter for depth and the milled nut *s* fixes the cutter.

SCRAPER PLANES. The scraper plane, Fig. 27, is seldom used by the joiner unless he is constantly working on hardwood; but it is a common plane for the cabinet maker. The joiner uses the hand scraper, which is explained later. The scraper *s* may be substituted by a toothing iron and used for preparing the surface for veneering, to give a key for the glue. This blade is grooved on the back so that when it is ground, the cutting edge is serrated like saw teeth.

SPOKESHAVES. The iron spokeshave shown in

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Fig. 28 is an improvement on the wooden type, because of the adjustable cutter and mouth-piece. The cutter can also be sharpened on an

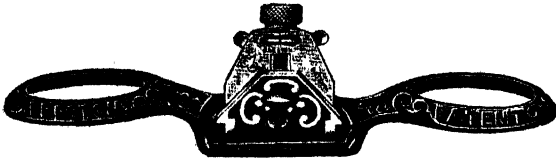


FIG. 28. METAL SPOKESHAVE

oilstone like an ordinary plane iron; but it is usual to fix it in a slot in a wooden holder for convenient handling.

CIRCULAR ROUTER. The circular quirk router shown in Fig. 29 is indispensable for working

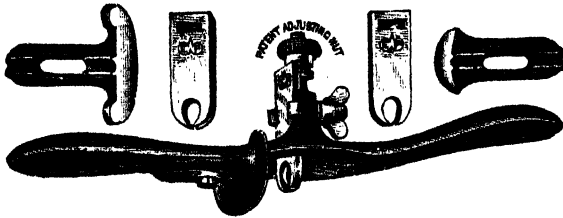


FIG. 29. CIRCULAR ROUTER

mouldings by hand on circular work. It is supplied with three thicknesses of blades, which are adjusted by the milled nut. The thumb-screw fixes the blade in position. Three different fences are supplied for straight and curved work of different radii.

STANLEY UNIVERSAL PLANE. This plane is an ingenious contrivance to take the place of the many moulding planes used by the "old-

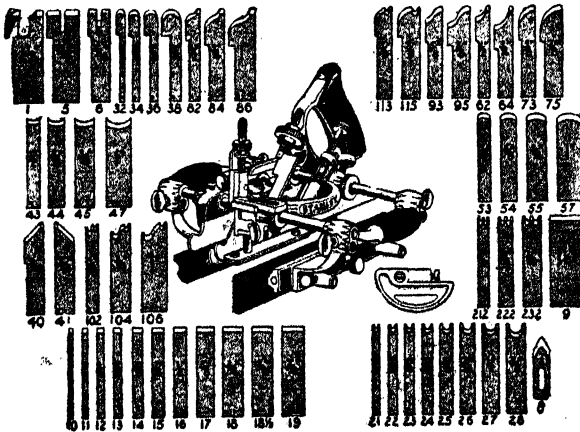


FIG. 30. UNIVERSAL PLANE

time" joiner. It is often called the "55" plane because it is supplied with that number of cutters. The difficulty of this plane lies in the *setting up* for the various operations, but it is useful for small jobs when it is not worth while setting up the machines. The expense, however, makes it more of a *shop* tool than an individual tool. Almost any moulding may be *stuck* by this plane because blank cutters may be obtained and cut to any required shape.

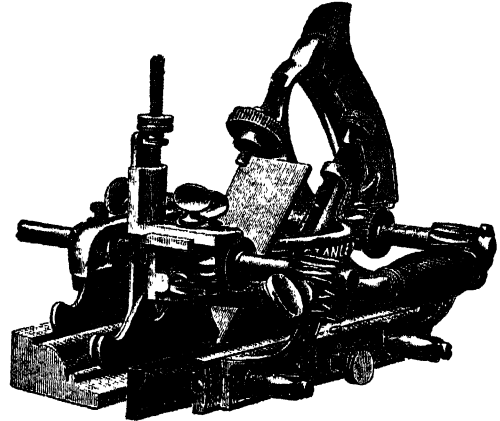


FIG. 31. UNIVERSAL PLANE IN USE

A general view of the plane surrounded by the cutters is shown in Fig. 30, and in Fig. 31 the plane is *set up* for moulding an architrave.

SAWS

CROSS-CUT SAW. The "cross-cut," or *hand saw*, has the position amongst saws that the jack plane has amongst planes. It is intended for cutting across the grain, but it is often used with the grain as well, and many carpenters use it for nearly all purposes. The saw is usually about 26 in. long, and has about 6 *points*, or teeth, to the inch. Fig. 32 shows the usual pattern. The hollow back is supposed to have a better appearance than the straight back and to give a better clearance in the cut. The clearance, however, depends upon the *set* of the saw, and all blades are thinner at the back to assist the clearance. The best quality saws are of silver spring steel, and should spring back to the original shape, no matter how they may be bent. The handle is made of beech or applewood, and it is fixed to the blade by brass screw rivets. Once a saw is *buckled* by careless handling, that is, it has assumed a permanently bent shape, it is useless

for good work; but if the saw is of good quality it can be *hammered* straight again by an expert.

RIP SAWS. The rip saw is very similar to the cross-cut except for the size and shape of the

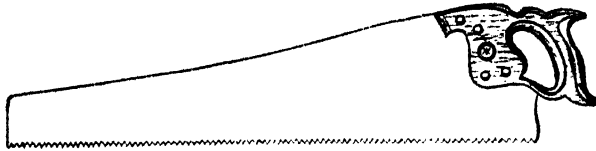


FIG. 32. CROSS-CUT SAW

teeth. These are usually four points to the inch, and have a different cutting action. The saw is usually 28 in. long, and is used only for cutting along the grain as shown in Fig. 33. It does not require so much *set* as the hand saw.

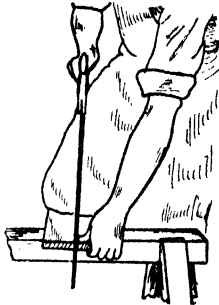


FIG. 33. USING RIP SAW

PANEL SAWS. This is a small cross-cut, about 20 in. long, and having 10 points to the inch. It is very useful for bench work, and for taking the place of the tenon saw where it is necessary to cut *through* wide stuff, such as panels, etc.

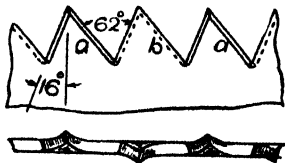


FIG. 34. CROSS-CUT SAW TEETH

Sharpening. The cross-cut and panel saws have their teeth sharpened in the same way, as shown in Fig. 34. The triangular file is held higher at the back, and also sloping towards the handle at the back. This brings the teeth to a *pin* point. The rip saw teeth are more like chisels at the point, as shown in Fig. 35.

In this case the file is held nearly level, and nearly square to the saw, but it has a little inclination towards the handle at the back. The difference in the angles is shown in the illustration. The alternate teeth *a* are sharpened from

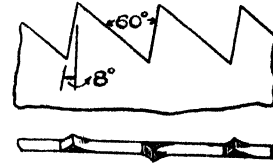


FIG. 35. RIP SAW TEETH

one side; the saw is then turned round and the intermediate teeth *b* are sharpened.

Before sharpening, the teeth are levelled, or *breasted*, then set, and finally sharpened. Fig. 36 shows the usual device for levelling the saw teeth. A flat file is let into a piece of wood and

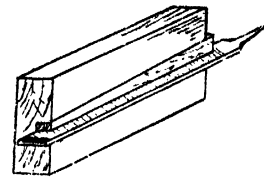


FIG. 36. LEVELLING SAW TEETH

held secure by a wedge. The file is then run along the teeth of the saw.

Setting. A convenient type of *saw-set* is shown in Fig. 37. The saw is placed between the set screw *a* and the pad *b*, both of which are adjusted to give the required set. By squeezing together the handles, the plunger *p* is pressed forward to force over each alternate tooth in

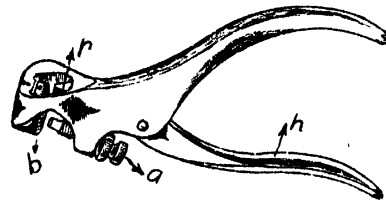


FIG. 37. SAW SET

turn. The saw is then turned round and the intermediate teeth are pressed over in the opposite direction. An expert saw sharpener uses a hammer and *set*; and sometimes the joiner uses a hammer and nail punch, with the saw resting on a hardwood block. Both of these methods require skill to keep the set

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equal throughout the two sides. If the set is greater on one side than the other, the saw will *run* when being used, that is, there will be a difficulty in cutting to the lines. The rip saw does not require so much set as the cross-cut.

When the saw is set it is placed in a pair of *saw chops* to be sharpened. Fig. 38 illustrates the usual type of hand-made saw chops, this being convenient for outside workers; a similar device is made to fit in the vice for shop use. A metal vice, very easy to manipulate, is shown in Fig. 39.

There are various methods of sharpening cross-cuts other than the one shown in Fig. 34, though that gives the best results for general work. For quick cutting in soft woods the *peg-tooth* and *flame, or flerne, tooth* are very good, but they are of very little use for hardwoods, and they are easily damaged.

Handling. The method of using the rip saw is shown in Fig. 33. The teeth edge is held nearly vertical; the usual angle is about 80 degrees with the stuff. For cross-cutting, however, the teeth edge is held at an angle of about 45 degrees with the stuff, as shown in Fig. 40. When cross-cutting heavy or long stuff, the sawyer generally holds the piece *a*, and piece *b* is balanced on the saw block. If it weighs down at the back it is liable to split away before the cut is completed. The saw should be pulled upwards once or twice to start the cut; otherwise the saw will *jump* and probably cut the operator's thumb, which is used to guide the saw as shown in Fig. 33.

TENON SAW. The tenon saw, Fig. 41, is used for finer work than the cross-cut or panel saw, but the teeth are sharpened in the same way, except that they are a little more vertical. It is usually about 14 in. long, with 10 or 12 points to the inch. As the blade is very thin it is strengthened by a *back*, which may be of brass or steel, the better qualities being of brass.

DOVETAIL SAW, Fig. 42. This is for still finer work and has an open handle. It is about 10 in. long, with about 14 points per inch. If either the tenon or dovetail saw is buckled, it may be straightened by tapping the top edge of the back with the hammer.

MISCELLANEOUS. Curved work requires a different type of saw, and Fig. 43 shows a *bow saw*, or *turning saw*, which is specially adapted for cutting open curves. The frame, which is usually beechwood, consists of three parts. The bar *a* is stub-tenoned into the sides *d*. The saw *s* is fixed in the handles by a small pin *p* at

each end, and is then tightened by means of the lever *b*. By turning the lever the double string *c* is twisted and so shortened. This pulls the ends of the sides together at the top, thus stretching the saw on the other side of the fulcrum bar *a*. The usual length of the saw is about 12 in.

For closed curves it is necessary to use a fine saw as shown in Fig. 44 or Fig. 45. The former is called a *keyhole, or pad, saw*. In the illustration the saw, *s*, is inside the handle to protect it whilst not in use. When it is required the screws are slackened and the saw is pulled out to the required distance and then fixed by the screws *a*.

Fig. 45 shows a *compass saw*, which is used for bigger work than the pad saw. Sometimes the blade is slotted to push into the handle, and is then fixed by the screws. There are usually three blades, of different sizes, to this type of saw.

A very useful saw for fine curves, scribings, etc., is the American *coping* saw. It is similar to a small fret saw; the blades are easily inserted and the tension is taken up by turning the handle. The blades are very cheap and should be discarded when dull.

CHISELS

FIRMER CHISEL. The ordinary type of chisel used by the joiner is the firmer chisel shown in Fig. 46. The steel blade *b* has a tang *t* (Fig. 47), to fix into the handle, and a shoulder *s* to withstand the use of the mallet. A brass ferrule *f* prevents the tang from splitting the handle. If the blade is loose in the handle, it should be packed with a shaving and put in with damp salt; this corrodes the tang sufficiently to fix the blade securely. The blade is ground and sharpened in the same way as the plane irons (see Workshop Practice).

BEVELLED-EDGE CHISEL as shown in Fig. 47. This is used for more delicate work than the firmer chisel; the blade is not so strong and is generally confined to hand work, without the mallet. Both the firmer and bevelled-edge chisels may be obtained from $\frac{1}{16}$ in. to 2 in. wide, the smaller sizes rising in $\frac{1}{16}$ in. and the larger sizes rising in $\frac{1}{8}$ in. Chisel handles are made of ash, beech, or box.

PARING CHISELS are about twice the length of those just described and may have either bevelled or square edges. They are useful for deep mortises.

SOCKET CHISELS, Fig. 49, are used for heavy

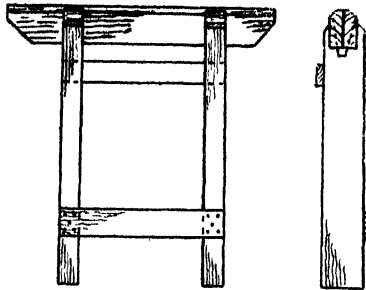


FIG. 38. SAW CHOPS

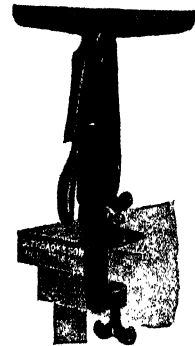


FIG. 39. SAW VICE

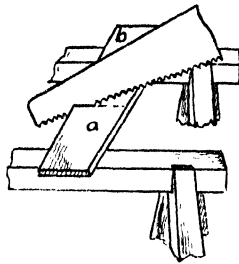


FIG. 40. USING CROSS-CUT SAW

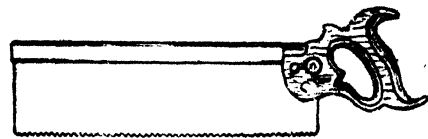


FIG. 41. TENON SAW

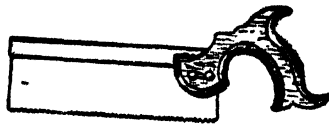


FIG. 42. DOVETAIL SAW

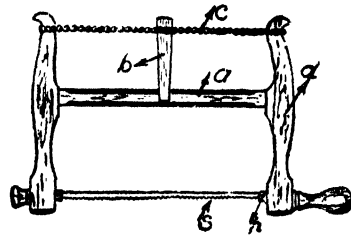


FIG. 43. BOW SAW



FIG. 44. KEYHOLE SAW

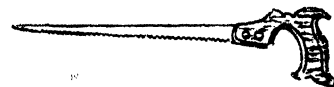


FIG. 45. COMPASS SAW



FIG. 46. FIRMER CHISEL

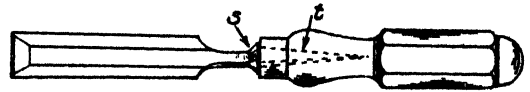


FIG. 47. BEVELLED-EDGE CHISEL

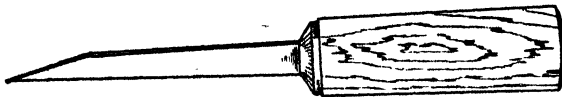


FIG. 48. MORTISE CHISEL



FIG. 50. POCKET CHISEL

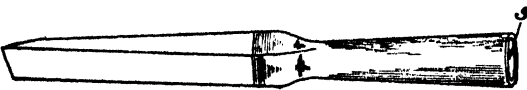


FIG. 49. SOCKET CHISEL

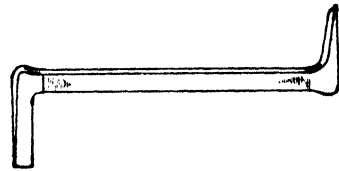


FIG. 51. DRAWER-LOCK CHISEL

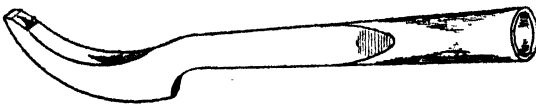


FIG. 52. MORTISE-LOCK CHISEL



FIG. 53. GOUGE

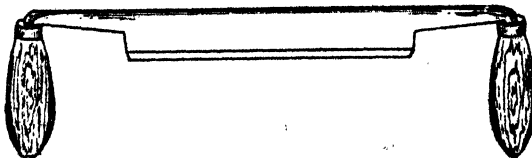


FIG. 54. DRAW-KNIFE

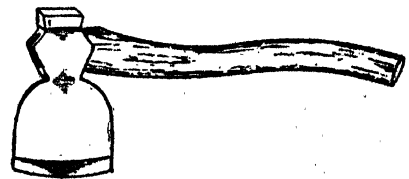


FIG. 55. JOINER'S AXE

work. They are made of cast-steel, and the wooden handle is fitted into the socket s. They may be obtained in sizes from $\frac{1}{4}$ in. to 2 in. wide.

MORTISE CHISELS, as the name suggests, are used for mortising. Fig. 48 shows the usual type. The blade is very strong, and thicker than it is wide, so that it will stand the leverage when mortising. It is generally made of soft steel faced with tool steel so that it is easy to grind.

MISCELLANEOUS. *Pocket, or sash, chisels*, Fig. 50, have a wide and very thin blade. The blade is sharpened on both sides, and is used for cutting the pockets in pulley stiles for sash frames.

A *drawer-lock* chisel is shown in Fig. 51. It is used for the mortise in the rail which receives the *bol* of the drawer lock.

The *swan-neck, or mortise-lock, chisel*, Fig. 52, is used for mortising the door stile and rail to receive the mortise lock. The mortise should be first bored with a brace and bit, sufficiently large to take the barrel of the lock. The swan-neck is then used to lever out the core, especially in the end of the rail. Like the socket chisel, a wooden handle is fitted into the socket.

GOUGES. Gouges are really curved chisels and may be obtained from $\frac{1}{8}$ in. upwards, similarly to chisels. Fig. 53 shows an *outside ground* gouge, and is the usual type for heavy work. For paring and scribing, an *inside ground* gouge is generally used. These require more careful handling than the outside ground type because they *snip* very easily.

There are many other forms of chisels and gouges, but they are generally considered as carving or turning tools. The bent gouges, however, are useful to the joiner for curved work, such as the inside of a wreathed handrail. A V-shaped tool is useful for similar purposes.

MISCELLANEOUS CUTTING TOOLS. The *draw-knife*, Fig. 54, is useful for reducing the width of boards where the waste wood is of no value. It is also useful for chamfering. The bevel is held downwards to prevent the wood from splitting along the grain or the knife going too deep. The stuff is held in the vice when using the draw-knife.

Fig. 55 shows the usual pattern of joiner's *axe*. This is useful either as a cutting tool, or as a percussion tool. It is used mostly for making wedges and driving them home; or for the same purposes as the draw-knife where no vice is available. It is very useful for chopping the

under edge of skirting boards when scribing to the floor. The carpenter looks upon it as the most serviceable tool in his kit, both as a cutting tool and for heavy driving.

BORING TOOLS

BRADAWLS. The bradawl, or *sprig-bit*, Fig. 56, is the simplest form of boring tool. The steel blade may be obtained in many sizes; it is fixed



FIG. 56. BRADAWL

in the handle by a tang. In the better varieties a pin passes through the ferrule and tang to prevent the blade from pulling out when in use. The blade should cut across the grain when being used, with a half-turn to-and-fro motion. This

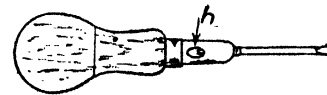


FIG. 57. BRADAWL WITH REMOVABLE BLADES

applies specially to boring near the end of the stuff—otherwise the bradawl will split the wood. The blade is shaped like a chisel but is sharpened on both sides. Fig. 57 shows a useful type in which the blade can be removed. The blade

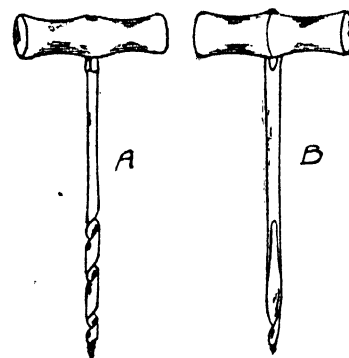


FIG. 58. GIMLETS

is held in position by friction only and can be levered out at the hole *h*. Several sizes of blades are provided with the one handle.

GIMLETS. Two different types of gimlet are shown in Fig. 58, a twist gimlet at *A* and a

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Swiss gimlet at *B*. The blade is fixed in the head by a tapered square, riveted at the top. The gimlet is useful for boring in corners, or where it is not convenient for the brace and bit.

There are many forms of combinations of bradawls and gimlets usually called *toolpads*. The principle is the same in all of them, a number of interchangeable blades being provided to one handle. In some types the blades fit in the hollow handle when not in use. Some varieties contain bradawls, gimlets, screwdriver, countersinks, saw and chisel. Generally they are more favoured by the amateur than the joiner.

BRACE AND BITS. The most useful brace for the joiner is the *ratchet brace* as shown in Fig. 59. The ratchet enables the brace to be turned

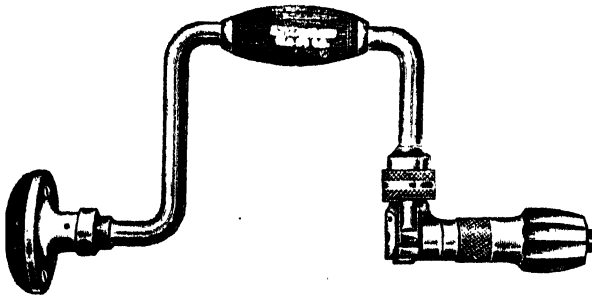


FIG. 59. BRACE

through a small arc instead of through a complete circle, that is, the brace only turns the bit in a clockwise motion. When the brace is turned backwards the bit remains stationary. This enables the joiner to bore holes in corners or near the wall whilst keeping the brace bit upright. The brace is also useful for driving in screws with the screwdriver bit, because there is a greater *purchase* on the brace, especially on the downward stroke when used horizontally. The jaws of the brace are serrated to grip the bit. The main parts of the brace are of hardened steel, nickel plated, with ball bearings; the wooden parts are usually of rose-wood.

TWIST BITS. These are the most satisfactory bits for easy and clean boring, but they are easily damaged. There are many varieties. Fig. 60 shows a "Russell Jennings," Fig. 61 an "Irwin," and Fig. 62 a "Gedge" pattern; the "Jennings" bit is very similar to the "Russell Jennings." All these makes, except the "Gedge," bore a very clean hole across the grain, but are not very good for boring with the grain, i.e. in the end of the stuff. The "Gedge,"

bit is specially adapted for boring with the grain. It also bores very quickly across the grain, but it is not so clean cutting because of the difficulty in keeping it sharp. All these bits may be bought separately, or a full set may be had, as shown in Fig. 63, which ranges from $\frac{1}{4}$ in. to 1 in. diameter, rising in $\frac{1}{16}$ in. The action is very similar in all the twist bits except the "Gedge." The bit, Fig. 61, is drawn into the wood by the screw point *b*, the cutters *a* strike out the circumference of the hole, and *c* removes the waste wood. It is very important that the cutters *a* are only sharpened on the inside.

A *depth gauge* is shown in Fig. 60. The thumb screw *n* fixes the gauge to the stem of the bit. The revolving steel ball *f* prevents any marking of the stuff when the required depth has been reached.

CENTRE BITS. These are the most serviceable bits; they are cheap, easily sharpened, bore a very clean hole, and can be obtained from $\frac{1}{4}$ in. to 2 in. diameter. The centre point *a*, Fig. 64, fixes the position, and *b* cuts out the circumference of the hole, whilst the lip *c* removes the waste wood. The diameter of the hole is twice the distance from *a* to *b*. The cutter *b* must stand prominent from the lip *c*, and must be sharpened on the inside only. The lip *c* is also sharpened on the inside only, so that it acts like a chisel. An improved type has a screw point.

SMALL BITS. Three very useful bits are shown in Fig. 65. A *shell* bit is shown at *A*, a *nose* bit at *B* and a *twist* bit at *C*. These bits are only used for small holes, such as screw and bolt holes, and for *pinning*. They can only be obtained up to $\frac{1}{2}$ in. diameter. The shell bit is a favourite bit because it is easily sharpened and not easily damaged. The nose bit is specially useful for boring in end grain.

COUNTERSINKS. These are not boring tools, but are used in conjunction with boring tools to prepare the holes to receive screw heads, etc. Fig. 66 shows three different varieties; *A* is used for timber, *B* for metal, and *C* for brass or hard wood.

REAMERS. This type of bit is used for increasing the size of holes, or for preparing conical shaped holes. Fig. 67 illustrates three different kinds; *A* is used for wood and is useful for preparing the tapered holes in ladder sides to receive the rungs. For metal a similar shape is used, but it is solid in section as shown at *B*. Another type, for metal, is square in section as shown at *C*. They are also called *rimers*.

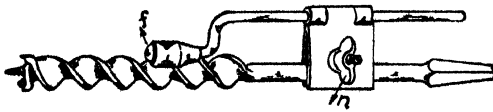


FIG. 60. BRACE BIT WITH DEPTH GAUGE

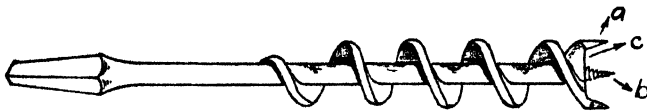


FIG. 61. TWIST BIT

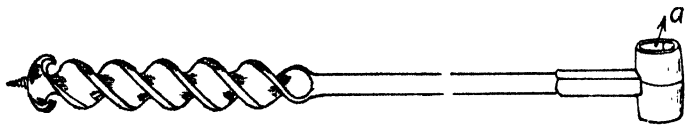


FIG. 62. AUGER

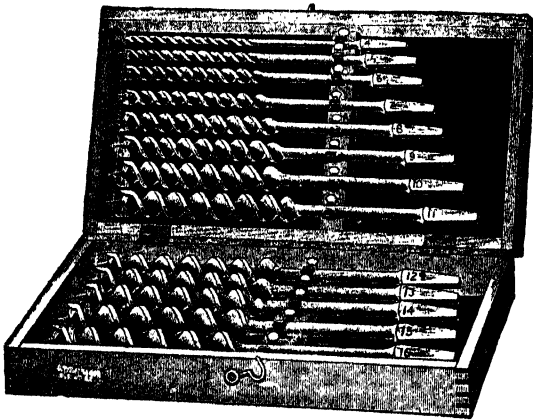


FIG. 63. SET OF TWIST BITS

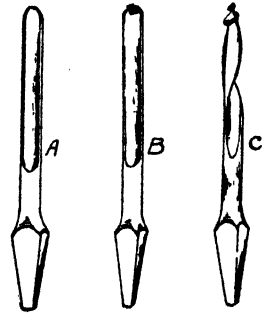


FIG. 65. SMALL BITS

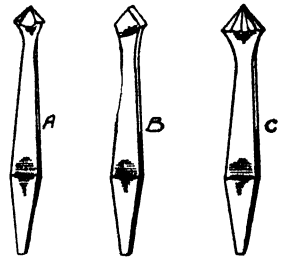


FIG. 66. COUNTERSINKS

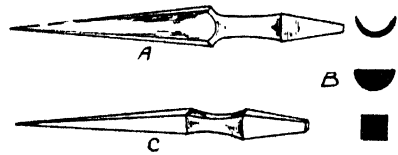


FIG. 67. REAMERS

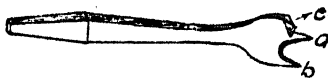


FIG. 64. CENTRE BIT

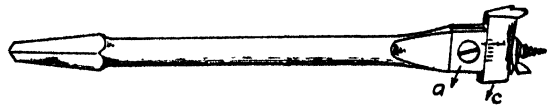


FIG. 68. EXPANSION BIT

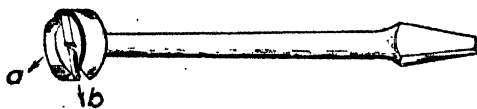


FIG. 69. FORSTNER BIT



FIG. 70. SCREWDRIVER BIT

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EXPANSION BITS. Fig. 68, are very convenient because they can be adjusted to small variations. The screw *a* is loosened to adjust the cutter *c*, which can be fixed to the required size at once by reason of the graduations on the cutter. Various sizes of cutters may be obtained, and the largest size of bit will bore from $\frac{7}{8}$ in. to 5 in. diameter. There are several variations of the expansion bits; the illustration shows a Clark's bit. Another good make is the Steer's bit; Anderson's bit however, is a cheaper production.

FORSTNER BIT. This bit has no centre point to fix the position, but the whole circumference *a*, Fig. 69, is sharpened to fix itself immediately in the required position. The cutter *b* removes the waste wood. It is a very useful bit

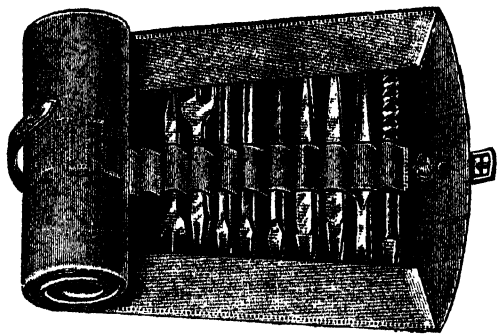


FIG. 71. BIT ROLL

for sinking holes, panels, etc., which are seen and do not go through the stuff; it is also useful for parts of holes on the edge of the material.

AUGERS. For heavy work and deep borings it is necessary to lengthen the stem of the twist bit as shown in Fig. 62. This illustration shows a *Gedge Auger*. A wooden handle is placed through *a* to give the required leverage. Augers are usually about 2 ft. long, but the stem may be made longer for special jobs. Extension rods for brace bits may be obtained.

SCREWDRIVER BITS. These are extremely useful for driving in screws quickly. Fig. 70 shows the usual type. Another type has a slot in the end to use on the screw rivets in saw handles. The chief advantage of the screwdriver bit is the increased leverage afforded by the brace.

There are many other forms of bits, but they are not often possessed by the joiner. Amongst them may be mentioned the *dowel pointer*, the *spoke trimmer*, the *screw and plug bit* which prepares the screw hole for plugging to cover up the screw head, and the *adjustable countersink*.

Care of Bits. It is usual to keep the bits in good condition by carrying them in a *roll*, or *case*. Fig. 71 shows the usual type; the material may be leather, green baize, or moleskin. The last named is the most satisfactory, considering the cost and wear. The bits must be kept sharp, or the strain on the bit will be increased so that it will probably break. It cannot be emphasized too strongly that all the bits

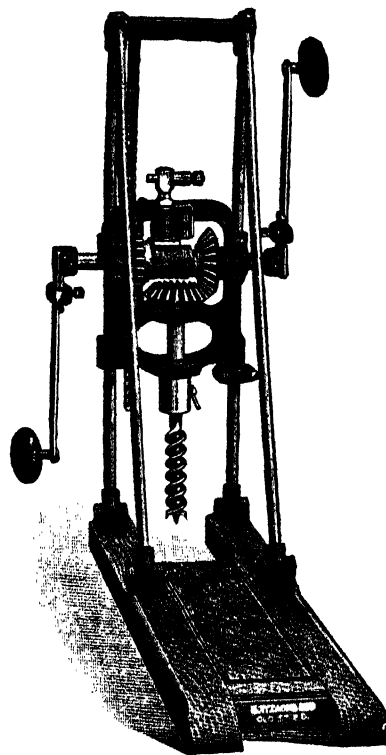


FIG. 72. BORING MACHINE

which have outer cutters, for describing the circumference of the hole, must be sharpened on the inside. If not, the bit will not clear itself, and will require a much greater effort to turn, besides making a ragged hole; this applies especially to the twist bits.

Boring. The beginner often finds difficulty in boring vertically or horizontally, as the case may be. Sometimes an assistant advises him with regard to the position of the head of the brace. The best method is to square the centre line over the face of the stuff, and to fix a thin straight edge in the vice with the stuff, so that the straight edge coincides with the squared line, and projects about 6 in. above the stuff. The

operator then watches the stem of the twist bit to see that it is parallel with the edge of the straight-edge in both directions. For horizontal end boring, the stuff is laid on the bench with the straight-edge resting on the top, and the stem of the bit resting on a small block. The stuff should be fixed to the bench by a bench cramp. If the holes are not at right angles to the edge of the stuff, the straight-edge is arranged to suit the direction of the boring.

BORING MACHINES. For heavy work on roof trusses, floors, etc., a hand boring machine is often used. This consists of a base, upon which the operator sits to steady the frame, a vertical frame which holds the bit, and two handles, so that the operator uses both hands for turning the bit. The vertical frame is adjustable for boring to different angles, and for closing the machine for compactness when not in use. Fig. 72 shows an improved type of boring machine, the usual wooden fittings being replaced by steel rods.

MEASURING AND SETTING-OUT TOOLS

No matter how carefully the joiner may finish a job, it is useless unless it is accurate with regard to size and shape. To this end it is necessary to have accurate tools for setting-out. A square which is not true will upset the most careful calculations, and a "blind" or inferior rule will get the owner into trouble sooner or later.

RULES. A *four-fold* rule is shown in Fig. 73. The advantage of this type of rule is that it is

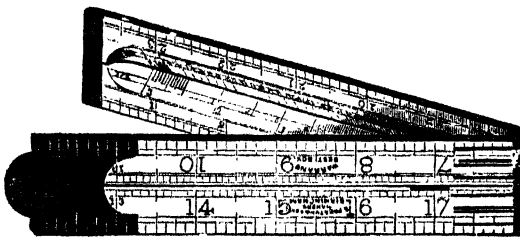


FIG. 73. RULE

convenient for the pocket, and is not so liable to be broken as the *two-fold*. The latter is only jointed once, hence it is 12 in. long, which makes it inconvenient for the pocket. The bench joiner generally prefers a two-fold because it is better for using, and usually more accurate for measuring distances about 6 in. long. The usual length is 2 ft., but many joiners, especially outside hands and foremen, prefer a 3 ft. rule,

which is always a four-fold. It is very convenient for door openings, etc.

All joiner's rules are subdivided into $\frac{1}{8}$ th and $\frac{1}{16}$ th inches, on the outer edges. The better type of rules have the inner edges graduated, as in Fig. 73, for the scales common to the building trades. The knuckle, or middle joint, is marked for setting the legs of the rule to various angles. Many rules have brass lined edges; this

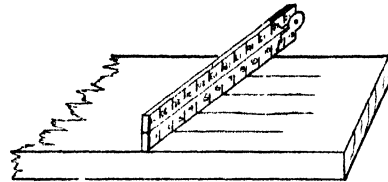


FIG. 74. USE OF RULE

strengthens the rule and prevents it from going "blind," or difficult to read, so quickly.

Subdivisions less than $\frac{1}{16}$ in. are not used by the joiner. He usually refers to a measurement which varies from $\frac{1}{16}$ in., as *bare* or *full*. If the measurement were not quite $3\frac{5}{16}$ in. he would say $3\frac{5}{16}$ in. full, or bare, as the case may be; or *three and five and a half sixteenths* if it were $3\frac{11}{16}$ in.

The Use of the Rule. For accurate measuring the rule should be applied on its edge, to avoid *parallax*, as shown in Fig. 74. This illustration also shows the method of dividing a board into several equal parts. If the board has to be divided into five equal parts, and it is less than 10 in. wide, the 10 in. mark on the rule is placed to one edge of the board, and the end of the rule to the other edge. The board is then marked every two inches of the rule to divide it into five equal strips. If the board is more than 10 in. wide the rule is opened and the 15 in. mark placed on the board edge, then 3 in. divisions are pricked off. The method can be applied to any width of board and any number of divisions. When the divisions have been found the rule is used as a gauge, by applying a pencil to the end of the rule, and using the fingers as the head of the "gauge."

TRY-SQUARE. Fig. 75 shows the usual type of joiner's *try-square*. It consists of a steel blade *b* securely riveted in an ebony stock *s*, which has a brass face to prevent wear. A brass plate *r* on each side of the stock receives the rivet ends. It is essential that the square be perfectly accurate, and it should be tested occasionally. The best way of testing the square is by

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applying it to a board with a straight edge, and squaring lines with both the inner and outer edges of the blade; then by turning the square over, the accuracy is proved if the two edges of the square coincide with the lines. If the square is not quite *true*, it is better to file the edges square to the stock, rather than to attempt to force the blade into accuracy.

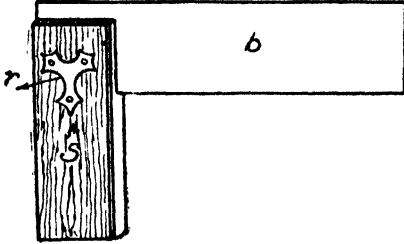


FIG. 75. TRY-SQUARE

The usual sizes of squares are 4 in., 6 in., 9 in., and 12 in. The joiner, however, very often requires a larger size, and usually makes a mahogany one with a blade about 2 ft. by 3 in. by $\frac{1}{8}$ in. and a stock about 1 ft. 6 in. by $2\frac{1}{2}$ in. by $\frac{3}{4}$ in. Fig. 76 shows the usual method of making a wooden square; the blade is glued in the stock and fixed square by the wedges *w*. Any variation afterwards should be corrected by planing the edges of the blade.

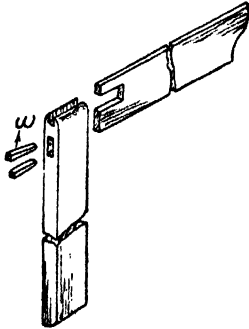


FIG. 76. WOODEN SQUARE

There are several variations from Fig. 75. The *mitre square* has the end of the stock cut to an angle of 45° so that the blade will register either 90° or 45° . The *adjustable square* has a sliding blade, and some squares have their blades graduated as rules. None of these squares, however, are popular with the joiner, who usually prefers the type shown in Fig. 75.

BEVELS. These are used for setting out angles other than right angles. Fig. 77 shows the

usual type, which consists of a sliding blade *b*, a stock *s*, and a screw *a*. The screw is to fix the blade after adjusting it to the required angle. The materials are the same as those used in the try-square.

GAUGES. The most common form of gauge is the *marking gauge* shown in Fig. 78. It consists of a stem *a*, a head *b*, a marking point, or

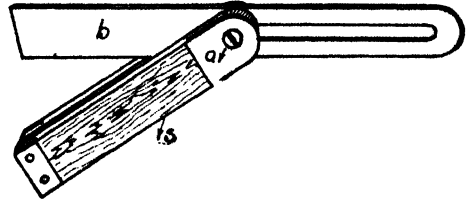


FIG. 77. BEVEL

spur, *s*, and a thumbscrew *t*. The stem and head are usually made of beech, and the screw of boxwood. The spur is filed to a pin point and projects out of the stem about a full $\frac{1}{8}$ in. The head is adjusted to the required position and then fixed securely by the screw.

To make a good line with the gauge, it is necessary to press the head firmly to the edge of the stuff, and to let the corner of the stem, as well as the marking point, rest on the stuff. The gauge is then pushed away from the operator to make the gauge line. Unless the gauge is used in this way, the point is apt to follow the grain instead of keeping parallel to the edge of the stuff. It is advisable to make a light mark on

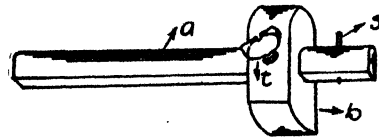


FIG. 78. MARKING GAUGE

the first stroke and to repeat the operation if a heavy gauge mark is required. The gauge mark can be made more visible by running a pencil along it. To *set* the gauge to the centre of the stuff, first loosen the screw and set the head approximately to the correct position, then loosely tighten the screw. The point is lightly pricked into the stuff from one side, and then the gauge is applied to the other side. If the point coincides with the first mark it is in the centre, and the stuff can be gauged. If there is a variation, the stem is tapped on the bench to adjust for the variation and then the screw is tightened up.

MORTISE GAUGE. There are many varieties of mortise gauges, but the essentials are the same in all of them. Fig. 79 shows a common type; the chief variation from the marking gauge is the double spurs *c*. The outer spur is fixed, but the inner one can be adjusted by the screw *a* in the end of the stem. Very often this is a small thumb screw projecting from the end of the stem. The spurs are set to the thickness of the mortise. The head *d* is then adjusted in the same way as for the marking gauge, for the

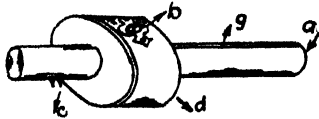


FIG. 79. MORTISE GAUGE

position of the spurs on the stuff. The screw *b* fixes the head to the stem. A projection on the head runs in the groove *g* to prevent the head from turning round. To set the points to the centre of the stuff, proceed as described for the marking gauge. In this case the two points have to coincide. The illustration shows a gauge in which the stem is cased in brass, and the ebony head is faced with brass.

CUTTING GAUGE. The cutting gauge, Fig. 80, is very similar to the marking gauge, except that the spur is replaced by a cutter. An enlarged view of the cutter *c* is shown separately. It consists of a piece of steel about $1\frac{1}{8}$ in. by $\frac{3}{16}$ in.

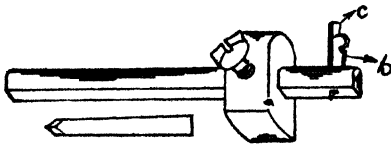


FIG. 80. CUTTING GAUGE

by $\frac{1}{16}$ in., sharpened on both sides to a point, and fixed in the stem by a wedge *b*. The cutting gauge is very useful for cutting through thin stuff, and for making small rebates. It requires careful handling to prevent the cutter from running with the grain.

OTHER GAUGES. In many cases, such as chamfers, the sunk marks made by the spur of the marking gauge are not permissible; so the joiner usually bores a hole in the stem, at the opposite end to the spur, to receive a pencil. An alternative method is to cut a rebate in the end of a small piece of wood, to the required size, for a pencil gauge. This is not convenient except for small widths; and it also requires both

hands, one to run the piece of wood and one to use the pencil. It is very convenient to round one face of the head of the marking gauge for gauging concave circular work. When this is done the head is taken off and reversed, to suit whichever side is required. There are many combinations and variations of the gauges described above, but they are not favoured by the joiner. A *grasshopper gauge* has a long fence and is used with a pencil for gauging in hollows for circular work. It is mostly used in hand-railing.

MARKING KNIFE. This is a very useful tool for accurate setting-out. The pointed end, Fig. 81, is used for pricking off distances and is more accurate than a pencil. The knife end is sharpened on both sides to a cutting edge, and is used for *cutting in* the shoulders of rails for framing, and for stair treads, etc., for accurate sawing. The use of the cutting edge is one of the points of controversy amongst joiners. It certainly assists in accuracy, but it can be very destructive in the hands of a careless setter-out.

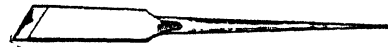


FIG. 81. MARKING KNIFE

Once the mark is made it is very difficult to remove, except by planing a large amount of stuff away; hence the joiner must be sure of the position before using the knife.

MISCELLANEOUS TOOLS

SCREWDRIVERS. The usual pattern of joiner's screwdriver is shown in Fig. 82, although many prefer the *cabinet*, or spindle, screwdriver. Neither has any advantage over the other for utility, except that the one shown in the illustration is stronger than the spindle type. To prevent the blade turning in the handle, the shoulders *g* are let into the ferrule, and the tang is wider than for the chisel.

The American *spiral* screwdriver is now very popular in this country. The blade *b*, Fig. 83, is made to revolve in either direction by simply pushing down the handle. It is removable, three different sizes of bits being supplied with the tool. The slide *s* is adjusted so that the blade may turn right or left handed, or remain rigid as an ordinary screwdriver. It is extremely useful for driving in a quantity of light screws; but it is hardly suitable for heavy work.

The *ratchet* screwdriver shown in Fig. 84 can

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be made to turn right or left hand or remain rigid, by adjusting the slide *s*.

HAMMERS. The *Warrington* pattern, Fig. 85, is most common amongst joiners, but the *claw* hammer shown in Fig. 86 is a favourite with the carpenters. The *cross pane*, or peen, *p* in Fig. 85, is useful for working in corners and for using as a lever, especially for levering back a nail which has bent over. The claw *c* in Fig. 86 is useful for withdrawing nails, and as a lever.

Fig. 87 shows the type used for heavy work, such as flooring, driving up framing, etc. They

piece of waste wood between the framing and the hammer to avoid bruising the stuff.

PINCERS. The *Lancashire* pattern, Fig. 88, is the usual type. A convenient size is 8 in. or 9 in. long, because the easy withdrawal of a nail depends upon the length of the pincers. The action, when being used, is that of a lever, with the rounded part *f* acting as the fulcrum. If *pf* is eight times *nf* then the pull on the nail is eight times the power exerted on the handle. The surface of the stuff should be protected by a try-square blade or a waste piece of wood, to prevent the fulcrum from damaging the stuff.

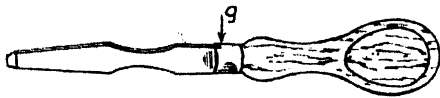


FIG. 82. SCREWDRIVER



FIG. 85. WARRINGTON HAMMER

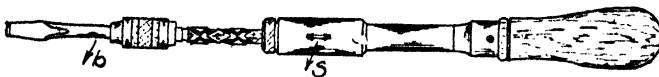


FIG. 83. SPIRAL SCREWDRIVER

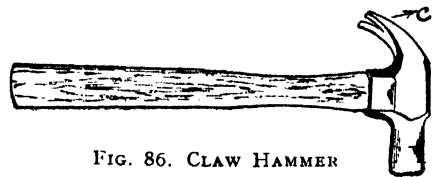


FIG. 86. CLAW HAMMER

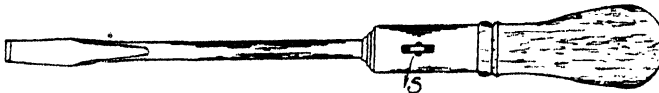


FIG. 84. RATCHET SCREWDRIVER

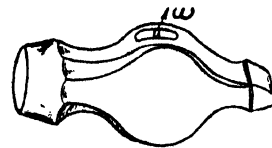


FIG. 87. HEAVY HAMMER

are sold by weight and may be obtained up to 3 lb. The shafts are made of ash or hickory, and are wedged as shown at *w* in Fig. 87. The shaft hole in the head is larger on the outside, so that when the head is wedged it will not fly off.

Using the Hammer. The shaft is about 10 in. to 12 in. long and it should be held as near to the end as possible to get the greatest effect from the blows. When using the hammer near glass or mouldings it is usual to slide the head along a try-square blade to prevent breaking the glass or bruising the moulding. This applies specially to nailing in panel mouldings, or glass beads to rough glass. If the glass is smooth the head can be slid along the glass. When driving up framing with the hammer, it is usual to place a

MALLETS. These are usually made of beech, Fig. 89, and are chiefly used for striking chisels and for knocking framing together. The head is mortised to receive the shaft, the mortise being bigger on the outside so that the shaft is passed through the head from the top. This prevents the head from flying off when being used. The striking faces taper a little towards the handle; theoretically they should taper to the axis of rotation when being used. The head is usually about 6 in. by 4½ in. by 3 in. thick. Many joiners prefer the metal head; this is a cast-steel head made to receive hardwood blocks for the striking faces, which can easily be replaced. The chief advantage of this kind is that it is less bulky, and at the same time it is heavier.

COMPASSES. Fig. 90 shows a pair of wing compasses generally used by the carpenter. They are chiefly intended for heavy work such as scribing mouldings to walls, and skirtings to floors. The wing *w* is riveted to the leg *a* and

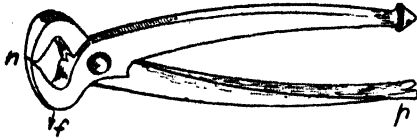


FIG. 88. PINCERS

gives rigidity to the movable leg *b*, which is mortised to slide on the wing. It is then fixed in position by the screw *s*. This type is not suitable for bench work, where they are required more as dividers than as compasses. A more

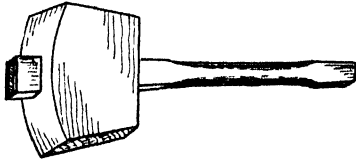


FIG. 89. MALLET

useful type for the joiner has a sensitive spring adjuster, so that the "fixed" leg can be adjusted (within small limits) after fixing the movable leg with the thumb screw.

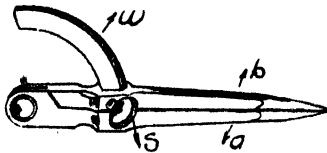


FIG. 90. COMPASSES

TRAMMEL. When it is required to draw circular arcs, or to set out divisions, greater than the compass will allow, it is usual to employ the *trammel heads* shown in Fig. 91. The rod *c* may be any length, and it is usually made of hardwood. The *heads* are fixed on the rod at the required radius by the milled screws *a*. A piece of brass *b* prevents the screws from *biting* into the rod. One head is provided with a socket *p* to receive a pencil for describing arcs, etc. The heads may be obtained in a large range of sizes. They are usually about 6 in. long for joiner's work. A good substitute for the trammel is a wooden lath fixed at one end

by a bradawl, or nail, with a pencil applied at the free end for describing circular arcs.

PUNCHES. A *handrail punch* is shown in Fig.

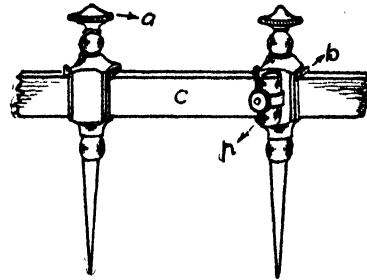


FIG. 91. TRAMMEL

92, *A*; this is used for turning the round nut of a handrail bolt, when it is in position for joining together two pieces of wood. Fig. 92, *B*,

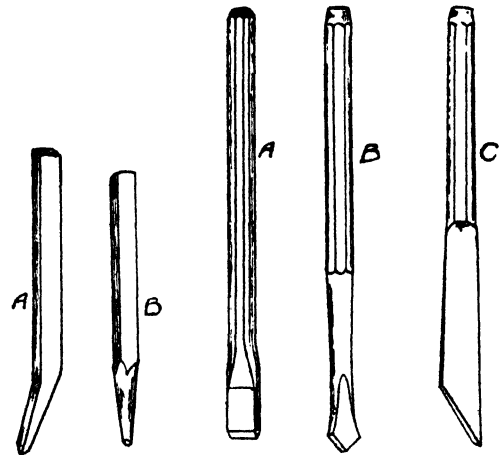


FIG. 92. PUNCHES

FIG. 93. CHISELS AND DRILL

shows a *nail punch* which is used for driving nails below the surface of the wood preparatory to *stopping* the holes. They may be obtained in various sizes, and may be square, octagonal, or circular. The latter variety is knurled so that it may be held securely.

IRON CHISELS. Fig. 93, *A*, shows the usual type of *cold chisel*; it is made of octagonal steel and is used for cutting bricks, stone, concrete, iron, etc. A *plugging chisel* is shown at *C*; this is used for raking out the mortar from the joints of brickwork, preparatory to driving in plugs.

DRILLS. The usual form of drill for making

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circular holes in brickwork, stonework, etc., to receive wooden plugs, is shown in Fig. 93, *B*. There are many other types, one of which is shown in Fig. 94. This is a *pipe drill* and is hollow for part of its length. The serrated, or jagged, cutting point enables it to cut rapidly into brickwork, if it is sharp. The slot *a* is to allow the dust to escape as it works up the hollow tube. The method of using the drill is to give

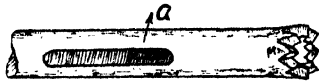


FIG. 94. PIPE DRILL

it a circular motion whilst driving it with the hammer. For small plugs, patent outfits are preferred, such as the Rawplug; and drill bits may be obtained for use with the brace or with hand or breast drills. These are specially useful for drilling in brittle materials such as tiles.

SPIRIT LEVEL. Fig. 95 shows the usual type of carpenter's level. It is generally about 9 in. or 10 in. long for convenient carrying, but the longer it is the better it is for levelling. It is usually made of ebony, and well protected with

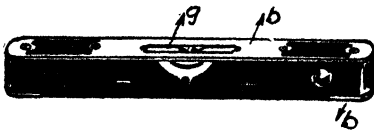


FIG. 95. SPIRIT LEVEL

brass, *b*. The glass tube *g* is *nearly* full of spirits so that a small air bubble shows through the glass. This air bubble rises to the highest point; and because the glass tube is slightly convex it shows in the middle of the tube when the tube is perfectly level. The purchaser should see that the bubble has a quick movement, is easy to see, and is not too big to register clearly.

When using the level, it is advisable to turn it *end for end* after taking one reading, and see if it registers the same. The level shown in the illustration has a small secondary tube at one end, at right angles to the levelling tube. This small tube enables the level to be used as a plumb rule. An ordinary level may be used as a plumb rule by resting it on the stock of a foot

square, whilst the blade edge acts as the rule. Levels may be obtained from waistcoat pocket size to nearly 6 ft. long, and up to 2 ft. long they may be of either wood or metal. Attachment levels are sold for fixing to the steel square, and another type is arranged for screwing to an ordinary straightedge.

PLUMB RULE. This is a straight and parallel piece of yellow pine, with a gauged line down the centre as shown in Fig. 96. The line is terminated by a hole sufficiently large to allow a *plumb-bob* to swing freely without touching the sides of the hole. The string which carries the bob is fixed at the top of the rule. Fig. 96, *B*, shows a brass plumb-bob; the top *a* is threaded

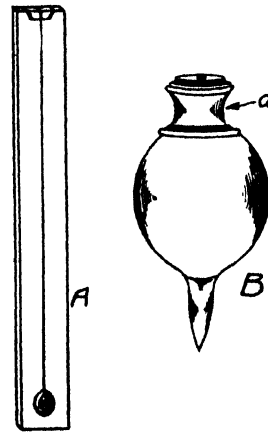


FIG. 96. PLUMB RULE AND BOB

so that it may be removed to pass the string through. The carpenter, however, generally makes his own. He makes a plaster mould round an existing bob and saws the mould in half. He then makes a pouring hole and an air vent hole, puts the two halves together, and pours molten lead in the mould. A piece of wire should be passed through the mould first, to leave a hole in the bob for the string.

Conclusion. The examples described in this article cover all the tools necessary for normal woodworking, but manufacturers are constantly introducing improvements and new types to meet the demands of new materials. The large range of "improved" woods and plastics requires tools more suitable for metalworking than woodworking, and it is necessary to obtain special tools as occasion demands to compete with modern conditions.

Chapter II—TIMBER

Growth. The trees from which we derive timber are called *exogens* or "outward growers." The growth takes place on the outside of the existing wood fibre and under the bark. Each year, in temperate zones, a new ring is added to the tree (except under very special circumstances); hence the term annual rings. In the tropics the growth may be continuous and it is more correct to call them growth rings.

Fig. 97 illustrates the various parts of a tree trunk; *A* shows the sapwood, or *alburnum*, portion of the growth rings, *B* the bark, and *C* the *cambium layer*. The heartwood, or *duramen*, portion of the annual rings is shown at *D*. The *medullary rays* are shown at *M* in the cross section, and at *E* in the longitudinal section. The centre round which the growth takes place is called the *heart*, *pith*, or *medulla*.

Each annual ring consists of two parts; the inner or softer part, and the outer or harder part. The difference is due to the change of the sap during the season. The formation of the new timber takes place in the cambium layer during the ascent and descent of the sap in spring and autumn respectively. The ascending, or spring, sap is immature and forms a soft spongy wood; but after the sun has perfected the sap during the summer, the woody cell formation during the autumn descent is thicker, darker, and more compact. This difference of structure is much more clear in some timbers than in others. It is very evident in redwood and pitch pine; hence the difficulty in trimming up the end grain of these timbers.

The annual rings are divided into *heartwood* and *sapwood*. The heartwood is the inner portion of the tree and is more compact than the outer part of the tree, which is the sapwood. The cell walls of the woody fibre continually thicken year by year, and this, together with the pressure from the outer rings, gradually builds up the heartwood. In most timbers the heartwood is more durable and better in every respect than the sapwood. If the tree is past maturity, however, there is a danger of the heartwood deteriorating by incipient decay. The sapwood should be avoided for good work, but it must be understood that much of the sapwood in the growing tree becomes good

timber after conversion and seasoning. In soft woods the sapwood is usually of a bluey tint; in hard, dark coloured woods, it is of a whitish grey colour.

The *medullary rays* are vertical layers of cells, radiating to the centre of the tree, binding together the annual rings, and distributing the sap throughout the tree. In some trees the medullary rays are very evident, as in the oak, and the timber is cut purposely to expose the

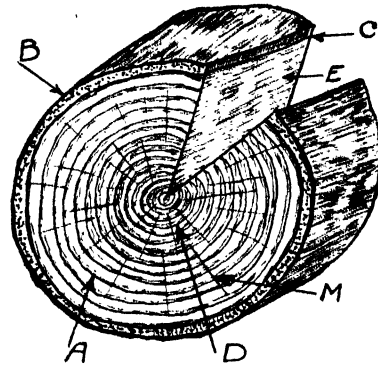


FIG. 97. PARTS OF TREE TRUNK

rays on the surface of the boards to give what is known as *silver grain*, or ray figure.

Timber trees are broadly divided into two classes, *conifers* and *broad leaf* trees. The conifers are cone bearing and have needle shaped leaves, and are evergreens; the timber is classified as softwood. The broad leaf trees are deciduous, that is, they shed all their leaves annually; the timber is classified as hardwood. There are several exceptions to both classifications.

SEASONING

To secure the utmost value from the tree, it is necessary to understand the best methods of seasoning and conversion. Unseasoned timber is a source of trouble, both from the constructive aspect and for durability. Seasoning means reducing the moisture content of the wood to suitable proportions. The best period for felling the tree is when the sap is at rest, either in winter or in summer, preferably in

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winter. The strength and durability of many timbers are nearly doubled by good seasoning.

There are many methods of seasoning, and different woods require different methods. *Natural* seasoning is the best, because the final strength, durability and colour of the timber are not impaired. The log should be cut to the smallest required dimensions and then stacked for seasoning. The timber should be well ventilated but protected both from the sun and rain. This method dries out the moisture and hardens the natural juices. The disadvantage of this method is the amount of time required, which varies from two to five years. Fig. 98 shows a method of stacking deals and planks. The balks *B* should be about four or five feet apart. The outer timbers *a* are closed in a little when

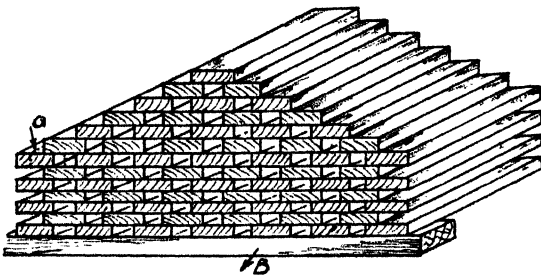


FIG. 98. STACK OF DEALS

the width of the stack is known. Fig. 99 shows the usual method of stacking boards after cutting up the log. The packing pieces, or *skids*, *S* must be placed one above the other, and from three to four feet apart. They must be of the same thickness between any two boards, otherwise they may be of any size. The ends of the boards are often painted or they have strips of hoop iron, called *cleats*, nailed across them, as shown at *a* in Fig. 99; this is to prevent the ends from splitting. Placing the skids level with the ends of the boards also tends to prevent splitting. The skids should be of spruce or pine, to prevent staining the boards as far as possible.

Wet Seasoning. The log is placed in running water, with the butt end facing the stream, for two or three weeks. This method washes out the sap and is not so good as natural seasoning, as it tends to destroy the elasticity and durability of the timber.

Kiln Seasoning. This is now recognized as the most economical and efficient method, but it requires expensive equipment. Expert supervision is necessary to avoid case-hardening,

warp, checks, etc. The timber is loaded on car-bunks, or trolleys, and passed through chambers in which the humidity and temperature are scientifically controlled. There are other methods of seasoning which also combine preservation, as explained later. The latest methods are chemical seasoning by the application of urea.

The newly felled tree contains numerous mineral and chemical constituent, resins, gums, acids, sugar, tannin, etc., in an emulsified condition, and these must be inert before the wood is satisfactory for most purposes. This takes considerable time, even after the moisture is evaporated. It is yet uncertain whether this maturing should take place before or after kiln seasoning.

Second Seasoning. All framing, such as doors, panelling, etc., should be loosely knocked

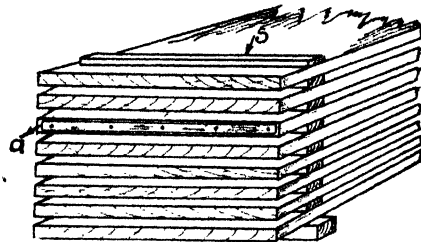


FIG. 99. SEASONING BOARDS

together and then placed in a warm dry room for some time before gluing up. Match boarding, floor boards, etc., should also be stacked as shown in Fig. 98. This is for the purpose of "second seasoning," before fixing the boards in position, otherwise shrinkage will cause open joints. Second seasoning is for the purpose of drying the stuff, rather than for removing or hardening the sap and is only necessary for inside work.

MOISTURE CONTENT. The moisture in wood may be (1) free in the cell spaces, (2) in the cell walls, and (3) in the protoplasm. It is only in the first two conditions in the heartwood, but it may be in all three in the sapwood. Wood is hygroscopic and the moisture content should be appropriate to the relative humidity of the atmosphere, that is, *in equilibrium*. If not, it will either swell or shrink. The percentage m.c. is obtained from the formula

$$\% \text{ m.c.} = \frac{\text{orig. weight} - \text{oven dry wt.}}{\text{oven dry wt.}} \times 100.$$

The following values are important: green timber (heartwood) approx. 40 per cent, limit

or fungoidal growth 20 per cent, air dried 14 per cent, roof timbers 14 per cent., exterior work 16 per cent, interior woodwork 12-14 per cent (ordinary heating) and 8-10 per cent (central heating).

PRESERVATION

Many woods are naturally durable, but most woods require treatment to resist fungi and insect attack. Chemical or mineral solutions, or oils, are forced into the cells as preservatives. These are broadly divided into two groups: tar oil and salts. The latter may be salts of arsenic, copper chromate or sulphate, naphthenates, mercuric chloride, tannin, zinc chloride or sulphate, sodium fluoride, zinc meta-arsenite, or sugar. Mercuric and arsenic derivatives are poisonous. Many of the salts can be painted over, which is an advantage. The ideal antiseptic should be permanent, cheap, colourless, easily applied, odourless, non-poisonous to animals, non-corrosive to metals, and should be toxic to both fungi and insects. At the same time it must have no ill effects on the wood. No antiseptic satisfies all these conditions, but there are many excellent registered preservatives on the market.

CREOSOTE OIL is one of the best preservatives if applied under pressure. The timber is stacked on carbunks and run into the chamber. The air is extracted and then oil is forced into the timber with a pressure of about 200 lb. per sq. in. If the oil is left in the cells it is called the *full-cell* process. This is expensive, and it is usual to specify the amount of oil per cub. ft. There are several registered processes for controlling the amount of oil retained in the wood.

Capillarity. Open tanks are used for this method. The wood is steeped until the required amount of oil has been absorbed. The preservative is steadily heated to about 180° F. This expels the air and the preservative is drawn into the wood on cooling. This method is cheaper but not so good.

The following are well-known proprietary preservatives: Boracure, Carbolineum, Celcure, Cuprinol, Hope's, Jodelite, Microleum, Permolute, Pilcher's, Presotim, Solignum, Wolman salts, etc.

Tar, either coal tar or Stockholm tar, is an excellent preservative, but it is unsightly, and again, the smell is objectionable.

Paint is a good preservative if applied properly; it has no objectionable features and is one of the best means of decorating.

Charring is also good, especially for timber about ground level, such as the foot of posts, etc. The coating of charcoal prevents decay.

CONVERSION

The conversion or "breaking down" of the log into marketable forms of timber is usually performed in the lumber yard, which is either

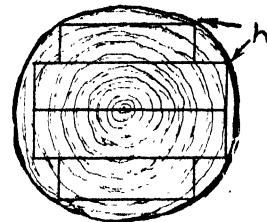


FIG. 100. CONVERTING SOFTWOOD LOG

near to the growing trees or at the nearest port of shipment. Different kinds and sizes require different methods. Fig. 100 shows the conversion of a log into deals and planks. Fig. 101 shows four methods of converting oak. The value of oak usually depends upon the presence of silver grain, hence for the better

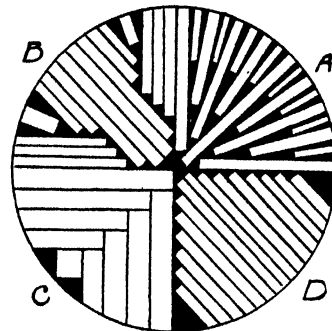


FIG. 101. CONVERTING OAK LOG

class timber the log is *quartered* and then cut radially, or *rift sawn*, as shown at A. This method produces wainscot oak, but is very wasteful. The other three methods, B, C, and D, are more economical, but not so effective for figure.

Pitch pine depends upon the annual rings for the figure in the grain, hence the cuts are made tangential to the rings, or *flat sawn*, as shown in Fig. 102.

The methods adopted for veneers are chiefly *peeling* and *slicing*.

Shrinkage. The effect of shrinkage during

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seasoning must be considered when converting for special purposes. The shrinkage is due to

trated in Fig. 107, which shows the section for a beam; *A* will give a much stronger beam than

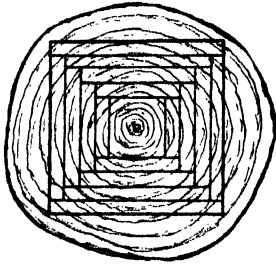


FIG. 102. CONVERTING PITCH PINE

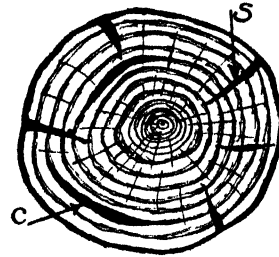


FIG. 103. RADIAL AND CUP SHAKES

the collapse or contraction of the cells after the evaporation of the moisture. The medullary rays restrict radial contraction, and the shrinkage is much greater circumferentially, hence the log is apt to split, as shown in Fig. 103, with faulty

B. Fig. 108 shows the correct and incorrect methods of cutting floor boards; *B* is bad because the heart, *s*, will shell out. If the board has been cut as at *B* the heart should be placed downwards.

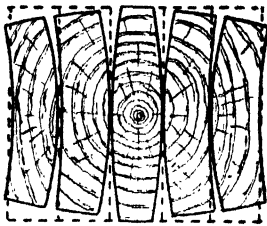


FIG. 104. EFFECT OF SHRINKAGE

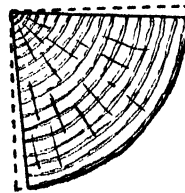


FIG. 105. EFFECT OF SHRINKAGE

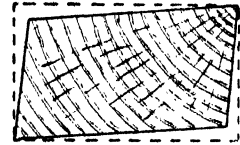


FIG. 106. EFFECT OF SHRINKAGE

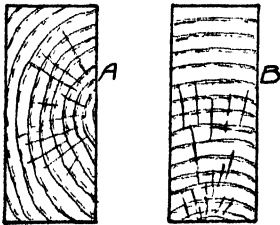


FIG. 107. CONVERTING JOISTS

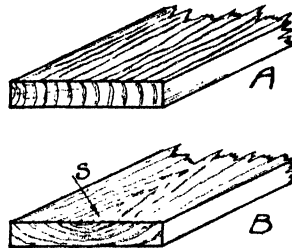


FIG. 108. CONVERTING FLOOR BOARDS

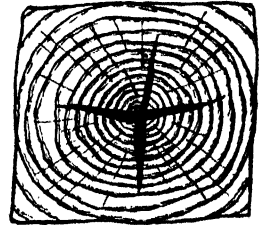


FIG. 109. HEART SHAKE

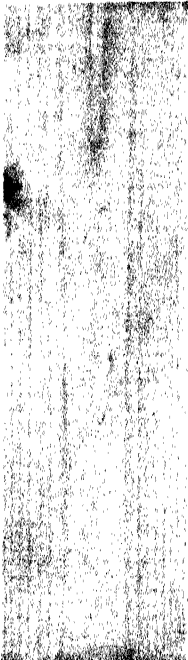
seasoning. The approximate variations in directional shrinkage are: tangential 6-15 per cent, radial 2-7 per cent, longitudinal 1 per cent or less. There is great variation in different species but the radial shrinkage is usually about half that of the tangential shrinkage. The effect on deals and battens is shown exaggerated in Fig. 104. The effect on a quartered log and on a rectangular section is shown in Figs. 105 and 106. Conversion for special purposes is illus-

DEFECTS AND DISEASES

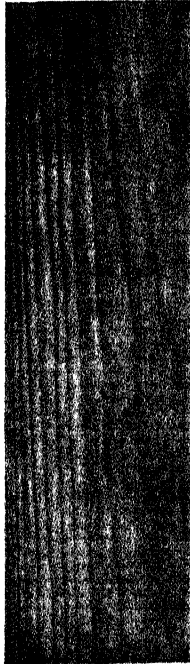
Defects are distinct from diseases. The former usually means that some of the timber is wasted and also that there is a reduction in strength, but the latter implies decay and should be avoided.

Heartshake and *star-shakes*, Fig. 109, are due to shrinkage through age or lack of nutriment, or they may be due to the log lying for a considerable time without having the bark removed.

COMMON TIMBERS IN USE IN BUILDING



SPRUCE (WHITE DEAL)



REDWOOD (YELLOW DEAL)



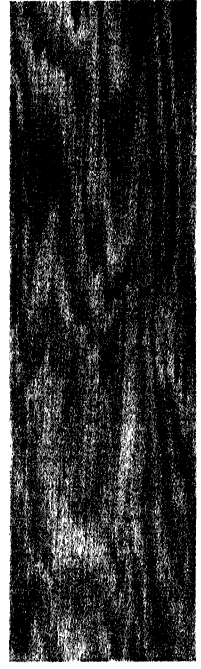
PITCH PINE



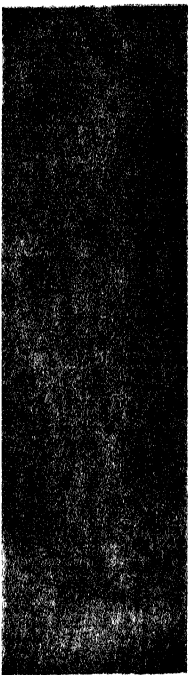
ASH



WESTERN RED CEDAR



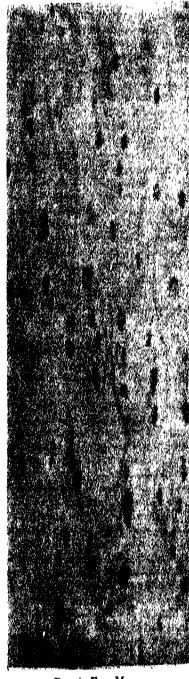
DOUGLAS FIR



BIRCH



HONDURAS MAHOGANY



BIRD'S EYE MAPLE



OAK



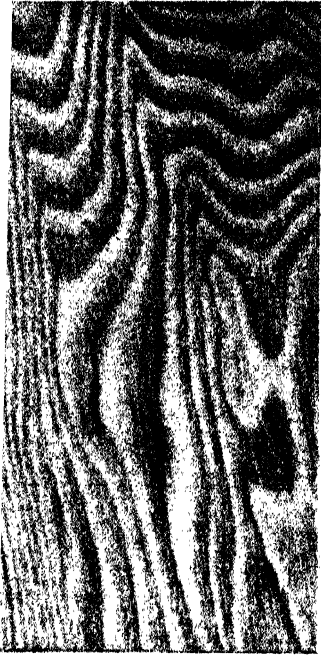
TEAK



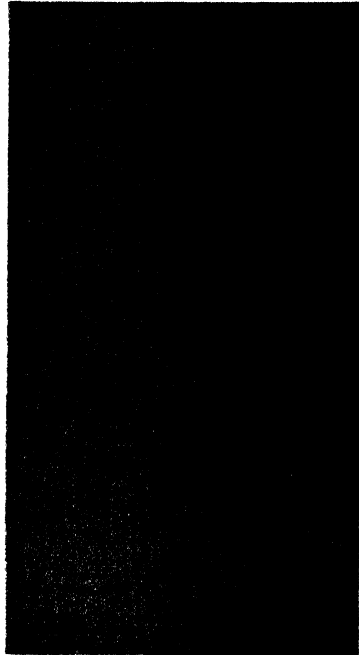
WALNUT

Specimens have been reproduced approximately two-thirds actual size

SE IN BUILDING



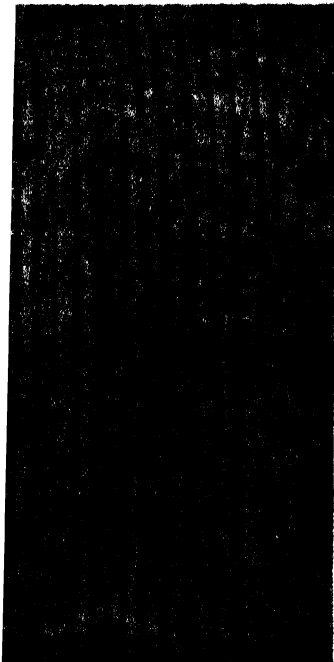
ASH



WESTERN RED CEDAR



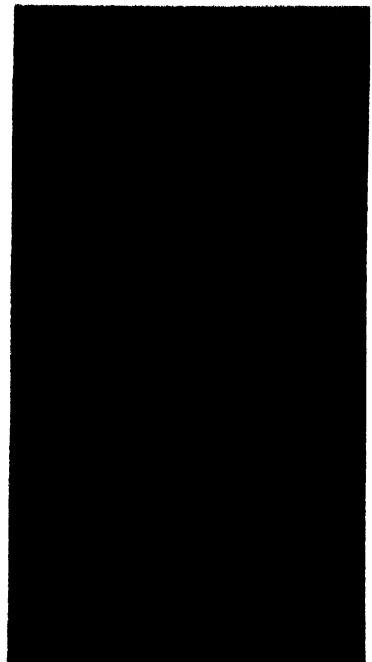
DOUGLAS FIR



OAK



TEAK



WALNUT

approximately two-thirds actual size

Radial shakes, Fig. 103, *s*, are often due to too rapid seasoning, but they may be caused by severe frost bursting the tissue. The sun may cause them if the bark has been damaged. Exposing a felled trunk to the sun for any length of time will also cause them. The cleavage follows the line of the medullary rays.

Cupshakes, Fig. 103, *c*, are caused by unequal growth, probably due to a wet season following a very dry season, or to lack of nutriment during a season. Another cause is the twisting of the tree by the wind, in exposed positions.

Kindgalls are due to broken branches which are afterwards covered with timber which is not uniform with the tree. Any wound in the cambium layer prevents growth for a temporary period, then subsequent growth covers the weak place in the timber.

Upsetts, Fig. 110, are usually the result of bad felling, or *jamming* during the passage of the timber down the rivers. The defect is very prevalent in mahogany. The fibres are usually broken all across the log, hence that portion of the log is useless. Very often it cannot be detected until after cleaning up (planing). Any form of shock will break the pieces apart at the upsett.

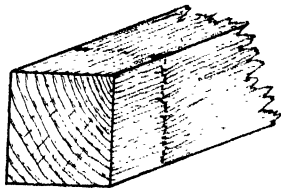


FIG. 110. UPSETTS

Wandering heart is found only in crooked trees. The converted timber is liable to twist badly, and is generally cross-grained. It is bad for structural work.

Twisted grain is due to exposure to wind and gives short grain. It is bad for structural work, mortises and tenons, etc.

Waney edge is caused by too economical conversion, as shown in Fig. 100 *w*. It is accompanied by sapwood. Other defects are bark pockets, burrs, callus, gum veins, resin pockets, stain, warp, and worm-holes. Most defects decrease the strength of the wood, but some of them, such as burrs, increase the decorative value.

Diseases. Ordinary decay commences at the heart in the living tree and is due to old age, but with cut timber it starts with the sapwood.

Over maturity is really old age; the tree has begun to decay, usually at the heart, before fell-

ing. The ages of trees vary, but maturity for pines is about 80 years, and for oak and most hardwoods about 150 years.

Druxiness is decomposition due to a broken branch holding water. The result is light coloured spots or streaks.

Foxiness is a reddish brown stain in hard woods.

Doatiness is incipient decay, causing a greyish stain with black speckles. It is easily attacked by dry rot.

Decay is the disintegration of the wood tissue due to attack by fungi. Many woods are very resistant to attack, but the only safeguard is efficient treatment. Durability probably varies with density in any particular species, but impregnation with preservative varies inversely with density. Mineral and chemical contents affect the resistance. In a few cases fungi attack increases the decorative value, but affected wood should be discarded for all constructional work and carefully considered for any kind of wood-work.

Dry rot. This is the most serious of diseases in timber. It is usually due to the fungus *Merulius lachrymans*. The timber is often infected soon after felling. The disease may be distinguished by the peculiar pungent odour, accompanied by red and brown stripes, when converting. The disease spreads rapidly when in a damp humid atmosphere, and forms a blanket-like covering over large areas. The best preventives are ventilation and well seasoned timber. The cure of dry rot is a difficult procedure. All the infected timber must be removed and destroyed. The brickwork should be subjected to great heat from a blow lamp; and the remaining timbers should be treated with creosote or sulphate of copper, or coated with hot lime. The cause, which is generally lack of ventilation, must be removed. There are other forms of dry rot and each variation requires expert advice for treatment.

Good timber is an excellent conductor of sound. An experienced person can tell, by listening at one end of a log, whilst someone taps lightly at the other end, whether the log is sound or not. In fact, an expert can often tell the nature of the defects if any exist.

MARKET FORMS OF TIMBER

Log, the trunk felled and lopped.

Balk, a squared log.

Plank. Over 2 in. by 10 in. for softwoods, and over 1½ in. by 9 in. for hardwoods.

Deals. From 2 in. to 4 in. thick and from

MODERN BUILDING CONSTRUCTION

9 in. to 11 in. wide for European softwoods, and from 2 in. to 5 in. thick and over 6 in. wide for U.S.A. softwoods.

Boards. Under 2 in. thick and over 5 in. wide for softwoods, and up to 1½ in. thick and of any width for hardwoods.

Battens. Softwoods from 2 in. to 4 in. thick and from 5 in. to 8 in. wide. Also small stuff for special purposes, as tile battens, etc.

Scantlings. European softwoods over 8 ft. long, over 2 in. thick, and under 6 in. wide. U.S.A. softwoods from 2 in. to 5 in. thick and less than 6 in. wide.

Die Square Stuff, large stuff, square in section.

Quartering, small square stuff from 3 in. × 3 in. to 4 in. × 4½ in.

Flitch, a balk cut up the middle.

Load (American), 50 cub. ft.

Float, 18 loads.

A Hundred Deals, 120.

A Square, 100 superficial feet.

A Standard (Petrograd), 165 cub. ft. (London), 270 cub. ft.

Some hardwoods are sold by weight.

Other market forms are: planchettes, plank-ing, ends, thick stuff, masts, poles, casewood, and pitwood.

TIMBERS COMMON TO THE BUILDING TRADES

It is impossible to give in detail the characteristics of the many timbers used by the carpenter and joiner. Every kind of timber has many botanical variations, and each definite species varies greatly according to its source of origin. The following examples are selected, because every joiner should be familiar with them. The coloured plate shows five of the coniferous or softwoods, and seven of the broad leaved or hardwoods, reduced to about half the actual size. The specimens for the plate were provided by The Timber Development Association.

SOFTWOODS

SPRUCE, FIR, WHITEWOOD, OR WHITE DEAL. (See coloured plate.) There are many variations of this timber, some inferior wood (fir) with few good qualities. Other varieties (silver spruce, Sitka, etc.) produce excellent timber; tough, elastic, clean, and easy to work. Hence we find that spruce is used for every kind of work from wood pulp to musical instruments. Good spruce is used for kitchen furniture because it is clean and white, with very little odour. There is little variation in colour between the spring and

autumn wood. Other uses are: floor joists, floor boards, inferior joinery, and constructional work generally. The timber is subject to small hard knots, very often loose, and to resin pockets. It is not suitable for outside work because it weathers badly.

REDWOOD, RED DEAL, SCOTCH FIR, NORTHERN PINE, OR YELLOW DEAL. (See coloured plate.) These names are all applied to the same timber, which is the most used of any timber for constructional and outside work. It is heavier, stronger, and more resinous than spruce; and it is not so easily attacked by decay. The colour is reddish, or brownish yellow. The annual rings are very distinct, owing to the autumn wood being much harder and darker coloured than the spring wood. It is used to a great extent for roof and floor timbers, and all external joinery. It is easy to work, and the knots, though prevalent, are usually sound and firm. The table on page 376 gives further details.

PITCH PINE. (See coloured plate.) This is the strongest and heaviest of the pines, and also the hardest. It is very resinous, and the annual rings are very distinct. For heavy constructional work it has few superiors, because it can be obtained in large sizes and is usually sound inside, though subject to cup shakes. If it is cut tangentially the grain is very pronounced and ornamental, and the curly grain is valuable for panels, etc. Pitch pine is used largely for ornamental work, especially for church work, and is usually finished by varnishing. It shrinks greatly and slowly, so that only well seasoned timber should be selected. The colour is a golden yellow, with strong reddish grain. Much of it is too resinous for painting, because the resinous parts soon show through the paint. Tools require liberal oiling for the resinous timber.

DOUGLAS FIR, COLUMBIAN, OR OREGON PINE (see coloured plate) is somewhat like redwood, but it is more dependable, and may be obtained in much larger sizes, without defects. Balks 70 ft. long and 4 ft. square are obtainable. It has a very pronounced figure owing to the difference between spring and summer wood, and is very strong, fairly durable, and is easily wrought. Although sometimes difficult to paint, it stains and varnishes well. It is used for all purposes, especially for construction, joinery, and plywood.

YELLOW PINE, WHITE PINE, OR WEYMOUTH PINE is the softest and lightest of the pines. It is easy to work and does not shrink or warp

after seasoning. The timber can be obtained in large sizes, free from knots or other defects. For all inside joinery it is in great demand, also for pattern making, cabinet making, etc. It is expensive because of the demand, but the expense is compensated for by the easy working. The timber is straw coloured, with not much variation between autumn and spring wood. A characteristic is the very fine or hairlike resin ducts. It is not suitable for outside work, but excellent for taking glue and paint. Supplies are now scarce, but several N. American pines are very similar: Ponderosa pine, Sugar pine, Lodgepole pine, and Jack pine. Canadian Red pine is also a good substitute, but this is more like redwood.

SEQUOIA, CALIFORNIAN, OR RED PINE, is the largest of the pines. The timber is shortgrained and brittle. It is easy to plane up, but very difficult for end grain working, because of its raggy texture. The colour is dull brown with reddish brown markings. It takes stain and varnish well, and is used for panels, shelving, etc., or for heavy structural work because of its great size.

KAURI PINE is a New Zealand timber, light brown in colour. It can be obtained in very large sizes without knots or defects. The grain is fine and straight, and the timber is lustrous, easy working, and polishes well. Owing to its tendency to warp it should only be used for fixed framing. It is one of the few timbers that shrink lengthwise. Supplies are now scarce.

There are numerous other softwoods, including Chil, Cedar (Western Red), Larch, Hemlock, Cypress, Yellowwood, Yew, etc. Western red cedar is excellent wood and used for joinery, shingles, etc. (See coloured plate.)

HARDWOODS

AMERICAN WHITEWOOD comprises several different timbers, Basswood (*Tilia americana*) and Canary wood (*Liriodendron tulipifera*). Magnolia and Cottonwood are also included. The timbers have the same characteristics: large sizes, easy working, staining and polishing well. They are used as substitutes for more valuable hardwoods. The texture of the timber is similar to that of the yellow pine, although they are broad-leaved trees. One piece of the timber will range through a great variety of colours, from greyish white to yellow and nearly every shade of green. The timber is light in weight, and is not suitable for outside work; it also warps freely.

ASH. (See coloured plate.) Tough and flexible; used for wheelwright's work, tool handles, agricultural implements; ornamental varieties for cabinet making. Liable to insect attack, and weathers badly. Easy to bend. Greyish white in colour.

BEECH. Hard, heavy, even and close texture; medullary rays show as wavy markings; reddish yellow or light brown in colour. Figured timber valuable for cabinet work. Used for planes (because it wears evenly), mallets, chisel handles, bleacher's beetles, furniture, etc. Weathers badly.

BIRCH. (See coloured plate.) Fairly hard and tough, but straight grained. A cheap hardwood, it is used as a substitute for other hardwoods; it stains and polishes well. Works up to a smooth finish with sharp arrises. Light brown in colour; weathers badly.

CHESTNUT. Hard, elastic, durable, especially under the ground. Resembles oak, but coarser in grain, softer, and without silver grain. Often used as a substitute for oak. Used for cabinet making, coffins, and for timber foundations.

EBONY. Very hard, tough, and one of the heaviest of timbers. It sinks in water, weighing about 68 lbs. per cubic foot. The timber is black, but often there are streaks of green and brown. It works to a glossy finish, but with difficulty. *Macassar ebony* is in great demand for ornamental joinery and cabinet work.

ELM. Tough, flexible, rather coarse texture, with large knots; shrinks and warps badly. Very durable under water, hence used for piles; also used for wheelwright's work, turnery and inferior furniture.

EUCALYPTUS. There are over 300 species of these Australian trees, varying from the largest known hardwood trees to shrubs. The commercial woods are jarrah, karri, gums, mountain ash, coolibah, blackbutt, box, gimlet, messmate, red mahogany, peppermint, stringybark, Tasmanian oak, yate, and tallow wood.

GREENHEART. Very hard, strong and durable, Difficult to work. The end grain appears very porous, like cane. Resists insects by reason of a bitter secretion. Dark yellowish green in colour. Used for heavy structural work, piers, jetties, etc., also for outside work or positions where great resistance and durability are required regardless of cost.

LAUAN. There are many species of these woods from the Philippines. They are marketed

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as red or white lauans, and used as a substitute for mahogany, but they are not so good or stable.

LIGNUM VITAE. Similar to Ebony, but not so black or flexible; used for similar purposes.

MAHOGANY (CUBAN). Very dense and heavy, but not difficult to work, except for the figured

varieties, which are among the most beautiful of timbers. It is a rich red brown in colour, with a chalk-like substance in the pores. The timber polishes well and is in great demand for high-class joinery and cabinet work. It is used for pattern making because it does not warp and varies very little after seasoning.

STRENGTH AND CHARACTERISTICS OF TIMBER

TIMBER.	WHERE FOUND	CHIEF CHARACTERISTICS.	CHIEF USES.	Sp. G.	Approx. Wt. per cub. ft.	Elasticity (million lb.)	Ult. Crushing Strength (lb.)	Ult. Tensile Strength (lb.)
Ash. (<i>Fraxinus excelsior</i>)	N. Hemisphere Widely distribtd.	Whitish grey, yellow markings. Hard, elastic, tough. Weathers badly. Liable to insect attack. About 1' 6" diameter	Wheelwrights' work. Cabinet making. Agricultural implements	.8	50	1.65	9,000	15,000
Beech. (<i>Fagus sylvatica</i>)	N. Hemisphere Widely distribtd. N. Zealand	Light to dark brown. Hard, heavy, close texture, wears evenly. Few knots but large. Liable to insect attack. About 3' 6" diameter	Cabinet making. Tools. Musical instruments. Beetles for bleachworks	.8	50	1.35	9,000	14,000
Birch. (<i>Betula alba</i>) (<i>Betula nigra</i>)	N. Hemisphere Widely distribtd.	Pinkish brown. Fairly hard, tough when dry. Good finish for stain and polish. Sharp arrises	Cabinet making. Substitute for superior hardwoods. Kitchen furniture. Plywood	.7	45	1.5	7,000	14,000
Chestnut. (<i>Castanea vesca</i>) (<i>Castanea vulgaris</i>) (<i>Asculus hipp.</i>)	Europe U.S.A.	Brown. Similar to oak except for med. rays. Hard, elastic, durable, especially underground. 4' diameter	Cabinet making. Substitute for oak. Foundation work	.66	42	1.1	7,000	12,000
Elm. (<i>Ulmus campestris</i>)	Britain Central Europe C. America W Asia Guiana	Reddish brown. Tough, flexible, Shrinks and warps badly. Large knots. Durable under water. Fairly even texture. Twisted grain. 4' dia.	Piles and foundations Turnery. Wheelwright's work. Inferior furniture	.55	35	1.1	10,000	13,000
Greenheart. (<i>Nectandra rodioei</i>)	Guiana	Dark yellowish green. Very hard, strong, and durable. Resists insects. End of grain appears very porous	Structural work. Jetties. Outside work	1	62	1.7	13,000	9,000
Kauri. (<i>Dammara Australis</i>)	N. Zealand	Light yellowish brown. Close and even grain. Warps. Shrinks endways. Works easily. Very large sizes	Fixed joinery. Turnery	.55	34	2.0	6,000	7,000
Mahogany (C.) (<i>Swietenia mahogani</i>)	Cuba (W. Indian Islands)	Rich brown red. Chalky pores. Beautiful grain (feathers). Does not warp or shrink much. Hard, heavy, durable. Large sizes	High class joinery and cabinet making. Pattern making	.8	50	2.0	7,000	14,000
Mahogany. (<i>S. macrophylla</i>)	Honduras (Mainland)	Golden red. Softer, lighter, and less durable than Cuban. Splits easily. Large sizes. Varies greatly for working	High class joinery and cabinet making	.6	38	1.5	6,000	15,000
Oak. (<i>Quercus pedunculata</i>) (<i>Quercus robur</i>) (<i>Quercus sessiliflora</i> and other species)	Europe America Widely distribtd.	English. Rich light brown. Strong, durable. Silver grain. Hard to work. Fumes and polishes well. Knotty. Darkens with age. Many species. Large sizes. Corrodes iron	Superior joinery and outside work. Structural work. Shipbuilding	.9	56	1.5	8,500	15,000
		Danitic, not so good or durable as English, easier to work		.8	50	1.2	7,500	12,000
		Austrian, as Danitic. Cut for wainscot		50	1.8	7,000	10,000	
		Canadian, inferior to European in every respect		.8	50	2.0	7,000	9,000
Pitch Pine. (<i>Pinus palustris</i>) (<i>Pinus regida</i>) (<i>Pinus echinata</i>), etc.	U.S.A. (Southern States)	Golden yellow, deep red markings. Strong, stiff, durable. Resinous. Shrinks slowly and greatly. Some specimens very curly. Uneven grain. 2' 6" diameter	Structural work, outside and ornamental joinery	.8	50	2.0	7,000	9,000
Spruce. (<i>Picea excelsa</i>) (<i>Picea nigra</i>) (<i>Picea alba</i>), (<i>Picea rubra</i>)	N. Europe (Baltic) N. America	White, yellow markings. Clean, silvery appearance. Even texture. Small, hard knots. Elastic. Not durable outside. 2' diameter	Kitchen joinery. Inferior carpentry and joinery. Scaffold poles	.35 to .66	22 to 40	1.2 to 1.8	To 7,000	To 10,000
Teak. (<i>Tectona grandis</i>)	India, Burmah, E. Indies	Light to dark greenish brown. Strong and very durable. Resists insects. Easy to work when green, difficult when seasoned. Gritty when dry. Polishes badly but oils well	Structural work. Ornamental and outside joinery. Shipbuilding	.7	46	2.3	12,000	12,000
Redwood. (<i>Pinus sylvestris</i>)	N. Europe N. America	Yellow, reddish markings. Strong, stiff, durable. Resinous. Easy to work. Sound knots 2' 6" diameter	Constructional work. Outside joinery	.65	40	1.5	7,000	10,000
Yellow Pine. (<i>Pinus strobus</i> and other species)	Canada, U.S.A., Japan and Manchuria	Pale yellow. Soft, light, even grain and texture. Easy to work. Very free from knots. Very fine resin ducts. 3' diameter	Good joinery. Pattern making. Cabinet making. Cores for veneering	.45	28	1.8	4,500	6,000

HONDURAS MAHOGANY, OR BAYWOOD. (See coloured plate.) This is lighter in weight and inferior to Cuban, but used generally for the same purposes. Many specimens have a beautiful "rowey grain" with a golden red colour, which shows up well after polishing. It is easier to work than Cuban; but both varieties very often have grain which plucks up with the plane and which is difficult to finish for a polished surface.

WEST AFRICAN MAHOGANY (KHAYA SPECIES). Most of the mahogany now used in this country is from W. Africa. It is very variable but the best qualities compare favourably with Honduras. They are distinguished by the port of shipment. There are many other woods marketed as mahogany but they usually have an alternative name or are distinguished by the source of origin: Seraya, Sapele, Gaboon, Toon, Espave, Coromandel, Meranti, Makore, Thitka, etc.

MAPLE. (See coloured plate.) Hard close grain, not liable to splinter. Resembles beech, but softer. Tangential cuts sometimes produce "bird's-eye" maple, which is in great demand for veneers. Used for superior floor boards for hard wear, furniture, and turnery.

OAK. (See coloured plate.) Tough, hard, and very durable, with a beautiful silver grain if cut radially. It is a widely distributed tree, there being about three hundred varieties. English oak is the best but the most difficult to work. To obtain the silver grain the timber is cut as explained in "Conversion," which is wasteful, hence it is expensive. It is a rich light brown in colour, polishes well, and looks well when fumed with ammonia fumes. The timber goes nearly black with age. *Austrian* oak is easier to work than English; and as only the best qualities are exported, it is in great demand, under the name of *wainscot oak*, which simply implies "radial cut" oak. *Dantric* oak approaches nearest to English. *American* oak, exported to this country, is usually inferior to the above, but is the easiest to work; it is also lighter in weight and coarser. Oak is the most valuable hardwood grown in the temperate zones, being useful for so many purposes. It contains an acid which corrodes iron, leaving a dark stain on the wood.

ROSE-WOOD. Hard, even texture, with beautiful grain; it is a rich dark red, polishes well; used for superior joinery and cabinet work.

SYCAMORE. Hard, tough, even grain, but brittle. Very similar to maple, but whiter and cleaner in appearance. Used for superior

kitchen furniture, turnery, butcher's fittings. The timber polishes well, and sometimes the radial cuts produce a beautiful mottle which is in great demand for furniture.

SATIN WALNUT. Fine close grain, fairly easy to work. Polishes well and is used largely for bedroom furniture. It is a light yellowish brown in colour, with a lustrous finish when planed.

TEAK. (See coloured plate.) Very heavy, strong and durable. The timber may be obtained in very large sizes without any defects. It is straight grained and easy to work when *green*. It contains an aromatic secretion, which hardens with seasoning, and then the timber becomes one of the worst for working, as it is very difficult to keep an edge on the tools. The timber does not take polish, but looks very well when oiled. It offers great resistance to insects and also to fire. When fresh cut the timber is a yellowish green, but on hardening becomes dark brown. It is not suitable for fine arrises, because it splinters easily; the splinters are liable to cause blood poisoning. The timber does not warp or shrink after seasoning. It is used for high class joinery, cabinet making, ship-building, and for good constructional work.

WALNUT. (See coloured plate.) Hard, close grain, beautiful figure. The timber, which is a rich dark brown in colour, is not difficult to work, and polishes well. It is used for high class joinery and cabinet making. There are several varieties; the Italian and Black Sea varieties are often artificially burred to produce a beautiful figured timber known as Circassian Walnut, used for veneers. The American black walnut is the most valuable straight grained walnut. It is used for better class work, and may be obtained in very large sizes. This timber is stronger and more durable than the European variety. American white walnut is a hard dense timber of a pinkish yellow colour. It works up well for polish.

There are many other hardwoods used in this country, including bagac, black bean, blackwood, camphorwood, cedars, chuglum, crabwood, eng, gurjun, haldu, hickory, iroko, kokko, laurel, lunumidella, mora, myrtle, obeche, padauk, poplar, purpleheart, pyinkado, pyinma, Rhodesian teak and mahogany, satinwood, silver greywood, white bombway, white dhup, etc.

PLYWOOD

Plywood consists of veneers, or plies, glued together with alternating grain. This counteracts shrinkage and gives strength. The best

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qualities are resin bonded and are resistant to fire, moisture, peeling, splitting, and bubbling. Casein glues are also extensively used. The number of plies varies according to quality and thickness, from 3-ply to 36 alternating laminations, from $\frac{3}{8}$ in. to over 1 in. thick. Standard sizes are up to 120 in. long and up to 60 in. wide, but special sizes are up to 192 in. and 96 in. respectively, or it may be made to suit special

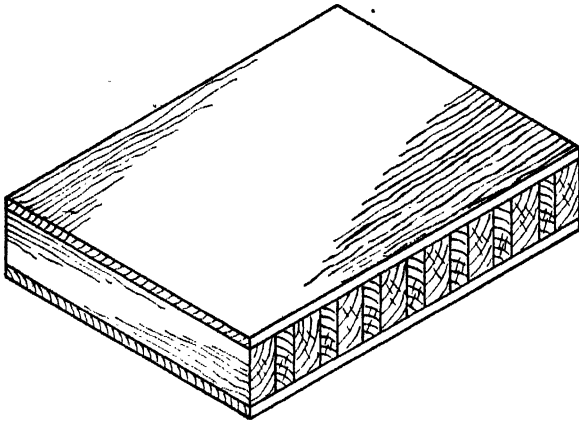


FIG. III. LAMINWOOD

requirements. The first dimension denotes the direction of the grain on the face. The thickness is stated in millimetres, and 3-ply is usually from 3 mm. to 6 mm.; 5-ply from 6 mm. to 12 mm. Sheets over 9 mm. thick may have any number of plies up to 36. Ordinary plywood is built up of rotary cut veneers, but superior plywood may be faced with sawn or sliced veneers, and is called *built-up stock*. If the figured veneers are added to ordinary plywood it is called *veneered stock*. American plywood is usually of Douglas fir, maple, gum, alder, birch, ash, oak, or red gum. European is similar, excluding Douglas fir and gum, but large quantities of gaboon are used. Other woods are used according to local supplies. Hollock and hollong are used in India; and hoop pine, silky oak, maple, and walnut in Australia.

Plywood is graded according to the knots and other defects in the faces, as AA, A, AA/BB, B, BB. Gaboon plywood is graded as Crown, 1, 2, or 3 star. Special qualities may be faced in manufacture with almost any kind of figured veneer, on a core of poplar, aspen, basswood, spruce, or pine. Plywood may be faced with one of the plastic compounds (Bakelite), or it may be metal faced with aluminium, galvanized

iron, copper and its alloys, or stainless steel, and panels may be obtained up to 40 ft. long.

Laminwood. This is a development of plywood. The core consists of thin strips of Douglas fir or redwood, 28 in. thick, glued together, and faced with a thick veneer, up to $\frac{1}{4}$ in., of gaboon. The core is obtained by gluing together a number of thin boards, up to 24, into a square balk, or sandwich, and then sawing across the strips, in slices, to the required thickness. It forms a very stiff, strong, and stable board, and may be obtained up to 20 ft. long, up to 8 ft. wide, and up to 2 in. thick. *Blockboard* is a variation of laminwood having a core of square strips, while *Battenboard* has wider pieces to form the core. These boards may be used as substitutes for panelled framing, doors, counter tops, etc.

POLYCHROMATIC WORK

The following timbers are used for coloured decorative work, because they are uniform in texture, polish well, and suitable for turnery—

BROWN. *Angico wood* (Brazil), yellow brown, black markings. *Calamander* (Ceylon), warm brown, black markings. *Prince-wood*, or *Cyp* (Jamaica), yellowish brown, veined. *Cocus wood* (Burma), yellowish brown, darker markings. *Snake-wood* (Guiana), warm hazel, black spots. *Amboyna* (Singapore), orange brown, small curls and burrs. *Bullet wood* (British Guiana), hazel brown. *Zebra wood* (Brazil) orange brown, darker markings.

RED. *Ruby wood* (India), the colour varies. *Brazilian rose-wood*, dark red, darkens with exposure. *Padouk* (India), rich red. *Tulip wood* (widely distributed), bright red, varies, darker markings, loses lustre on exposure. *Bar-wood* (Africa), dark red. *Beef-wood* (New South Wales), rich red. *Rata* (New Zealand), dark red.

PURPLE. *Amaranthus* (Brazil), from grey to deep purple with seasoning, test before use. *King-wood* (Brazil), varies, deep markings. *Rose-wood* (India), heartwood only.

GREEN. *Green sandal wood* (East Indies), olive green. *Green ebony* (West Indies), dull green. *Laburnum* (Europe), greenish brown.

YELLOW. *Box-wood* (Europe). *Fustic* (West Indies), yellow to green. *Satin wood* (St. Domingo), lustrous yellow. *Degame* (West Indies), pale yellow. *Sandal wood* (East Indies), yellow to tawny brown.

The most satisfactory timbers for black and white are ebony and holly.

Chapter III—WORKSHOP EQUIPMENT AND PRACTICE

THE equipment required for a joiner's shop, outside the tools and machines, is neither elaborate nor expensive. There are several things that are necessary, and many things

there is no confusion with the tools, or with the work when the men are on different jobs. Where the floor space is inadequate, the double bench is an advantage. For large framing

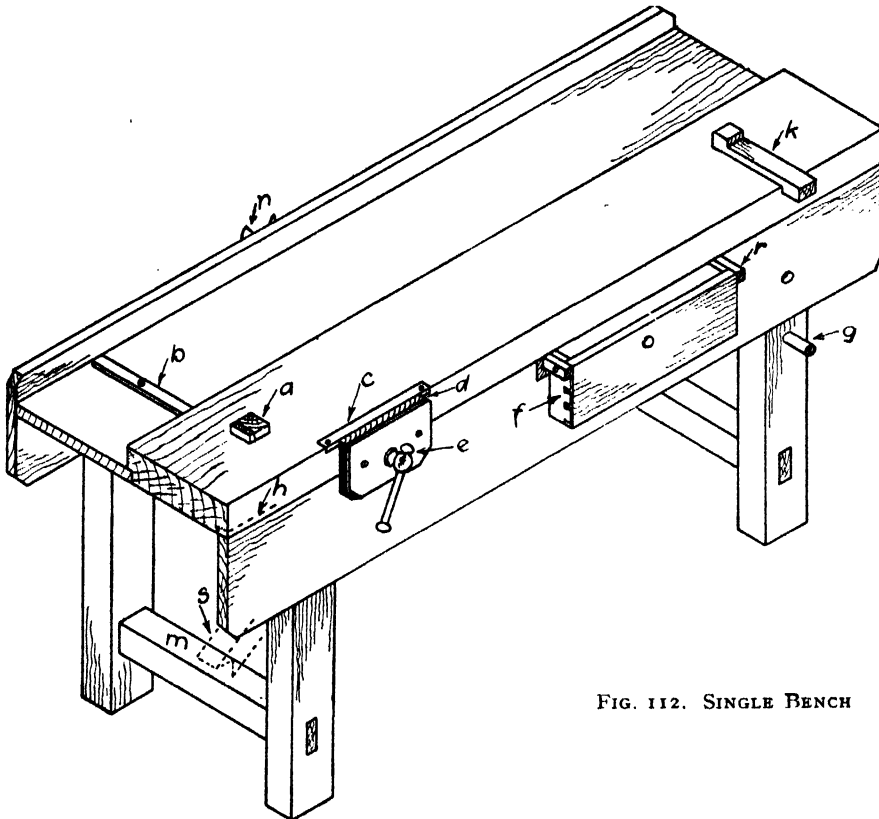


FIG. 112. SINGLE BENCH

that are optional, but of great advantage when they are required. The latter are generally added to the stock as the occasion requires them; hence the equipment is a gradually increasing one. The former includes benches, cramps and cleats, shooting boards, mitre boxes, sawing stools, grindstones, glue kettles, and saw sharpening equipment.

Benches. These may be either single or double. The joiner prefers the single bench because he is independent of his neighbour, and

they are nearly essential, hence it is usual to have both kinds in the workshop.

A single bench is illustrated in Fig. 112. The usual sizes are about 10 ft. long by 2 ft. 9 in. high and 1 ft. 10 in. wide. The top should be about 11 in. by 3 in., and the legs from 4½ in. to 6 in. by 3 in. framed up with 3 in. by 3 in. rails *m*; all the rest of the stuff is 11 in. by 1 in. Very often the bench is made more rigid by using 3 in. by 3 in. braces *s*, with a rail under the middle of the top, to prevent sagging. The top

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is often rebated on both edges as shown at *h*. A drawer *f* is provided for the joiner's tools, and a

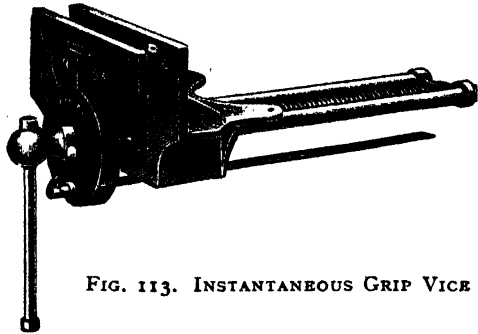


FIG. 113. INSTANTANEOUS GRIP VICE

rack *n* for the saws. To keep the plane irons off the bench, a strip *b* is screwed to the well. It

shown in Fig. 113, is the most useful vice. The *bench stop* may be of metal, Fig. 114, or of hardwood as shown in Fig. 112 *a*. The metal stop can be adjusted by the screw *s*, but it is not

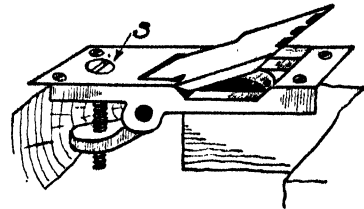


FIG. 114. METAL STOP

favoured by the joiner owing to the danger of damaging the tools. In fact all metal should be avoided on the bench top. The usual form of stop is a pair of hardwood folding wedges. Two *sprigs* are driven in the front and filed to

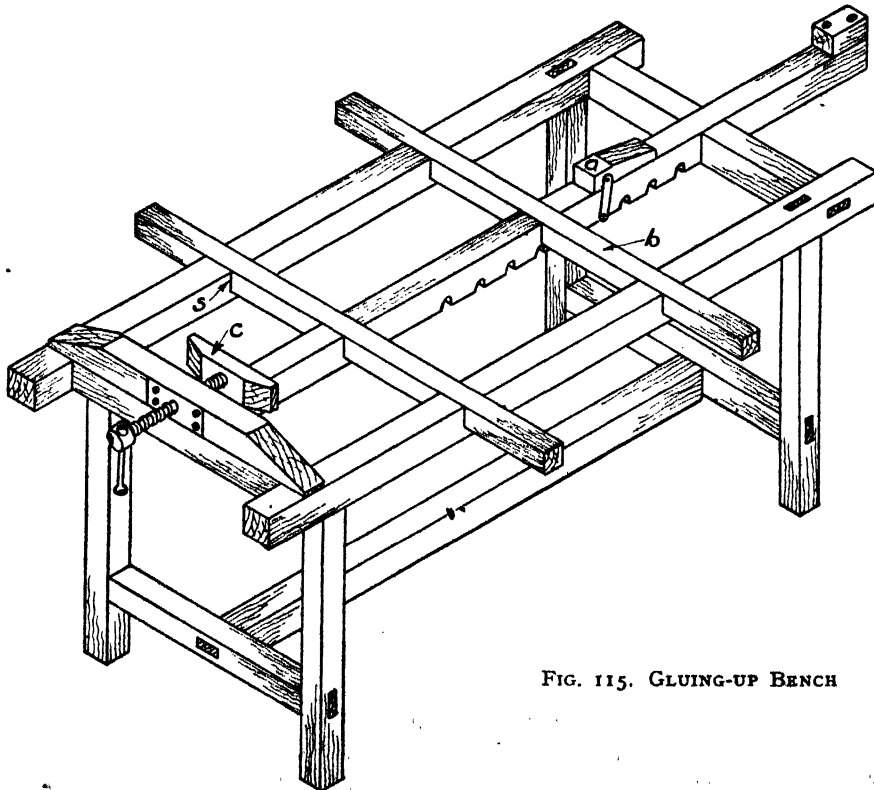


FIG. 115. GLUING-UP BENCH

is fixed with one screw only, so that it may be swivelled round for brushing down the *well*.

The two most important features are the stop *a* and the vice *e*. In both cases there are many variations, but an *instantaneous grip vice*, as

a chisel point, to grip the stuff. This form of stop is easily adjusted with the hammer. The vice jaws should be kept below the bench top, and faced with hardwood *c* and *d*, to protect the tools and timber. When long stuff is in the

vice, the other end rests on the drawer, or on pegs *g* which fit into holes bored in the bench front and leg. The drawer *f* is suspended from the bench top by hardwood runners *r* which slide in rebated pieces screwed to the bench top.

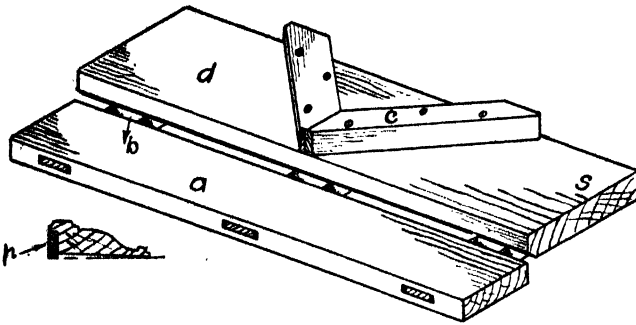


FIG. 116. SHOOTING BOARD

The bench hook *k* shown on the bench is used for shouldering and sawing short lengths on the bench. It may be from 2 in. to 6 in. wide, and may be cut from the solid. The projecting pieces may be glued and nailed on for the wider hooks.

Gluing-up Benches. In large shops a skeleton bench, as shown in Fig. 115, is often

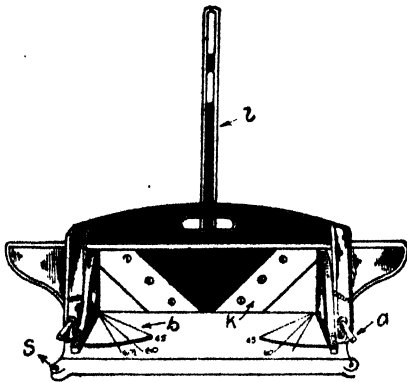


FIG. 117. TRIMMER

used for cramping up framing. The stop, or shoe, *a*, is adjusted to the required distance, and then the screw *c* cramps up the framing. The rails *b* are loose and may be replaced by longer ones if required.

The *door cramping machine* is a metal bench which cramps up a door with one action of a foot lever. Two joiners can glue and cramp up 25 to 30 doors per hour with this machine.

Shooting Boards. There are two forms of shooting boards, one for shooting mitres, Fig.

116, known as a *mitre shoot*, and one for jointing. The construction of the board is the same in both cases. The piece *a* is mortised for the battens *b*, then the piece *d* is screwed from the underside of the battens. The usual size of *d* is about 3 ft. by 10 in. by 1½ in.; and *a* is about 4 in. by 1½ in. The fences form an angle of 45° with the edge of *d*. The stuff is held firmly against the fences whilst the mitres are planed by the try plane running sideways on *a*, which is about ¼ in. below *d*.

Jointing Boards are made and used in the same way as shooting boards, but the fences *c* are omitted and a hardwood stop is fixed at *s*. They are used for making butt joints for short stuff; the piece rests on *d* with the edge pressed up to the try plane running on *a*. This method is quicker and easier than straightening the edges in the vice, and more certain of producing a square edge. A space should be left between *a* and *d* to allow the shavings to fall through.

Panel Boards are usually one piece of well seasoned pine, about 3 ft. by 12 in. by 2 in., with a hardwood stop. They are used for planing up thin stuff such as panels. Sometimes they are framed up to prevent warping; and instead of the hardwood stop two or three screws may be used for the stop. A *sticking board* is also useful for sticking mouldings by hand, but they are very varied in sizes and details, and seldom required. The ingenuity of the joiner will quickly devise a convenient type when it is required.

Mitres. The *trimmer*, or mitreing machine, shown in Fig. 117, is a useful machine for the

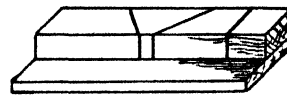


FIG. 118. MITRE BLOCK

joiner's shop. The fences can be adjusted for different angles and fixed to the required position by the lever handles *a*. The table is graduated and marked as shown at *b*. The knives *k*, actuated by the lever *l*, make a clean cut because of the shearing action; and the machine if kept in condition usually dispenses with the mitre shoot. The screw-holes *s* are to fix the trimmer to the bench.

Mitre Blocks. The mitre block, Fig. 118, is a simple and efficient device for sawing mitres

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on small stuff. Although it is usually made for angles of 45° , the saw cuts may be made for any desired angle. There is usually a right angle cut as shown in the illustration. The size depends upon the work it has to do, but usually the bottom piece is about 6 in. by 1 in.,

small sketch in Fig. 116. The packing p is also used whilst shooting the mitre.

There are many forms of metal adjustable mitre boxes, but the joiner usually prefers the home-made box. Fig. 120 shows a Stanley adjustable mitre box. The saw is held above

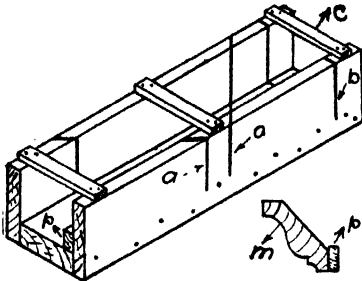


FIG. 119. MITRE BOX

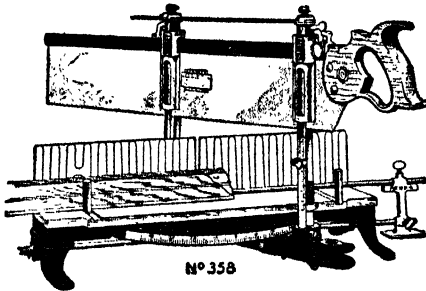


FIG. 120. STANLEY MITRE BOX

and the fence which is nailed to the base board is about 3 in. by $1\frac{1}{2}$ in.

The *Mitre Box* is an extension of the mitre block for bigger stuff. The cuts are the same,

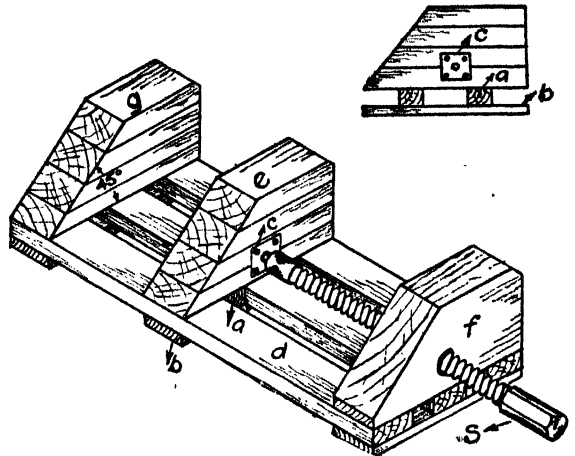


FIG. 121. SCREW MITRE SHOOT

the box, as shown, when not in use, and the angle can easily be adjusted and locked for any angle between 30° and 90° .

Screw Mitre Shoot. This is a device for shooting the mitres of small stuff (see Fig. 121). A block plane is used, running on the bevels e and g , but care must be exercised so as not to damage those faces. The blocks f and g are fixed; f carries the handscrew s , which actuates the movable block e , to fix the stuff between g

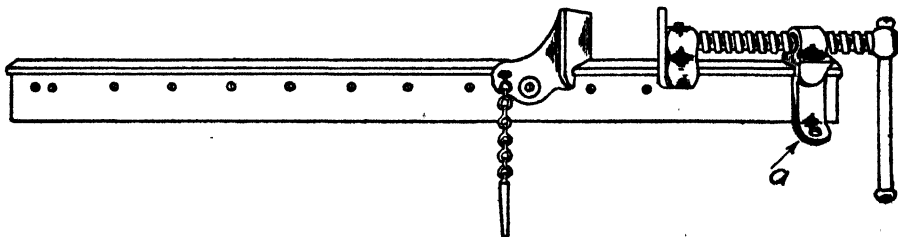


FIG. 122. CRAMP

as shown in Fig. 119, and the sides are strengthened by the pieces c . A 45° cut is shown at a and a 90° cut at b . When cornice or bed mouldings m are being cut, it is necessary to pack the moulding as shown in the small sketch. This also applies to bolection mouldings, when the back is kept clear of the panels, as shown by the

and e . Blocks a are fixed under e to run in the spaces between the base board d , which is built up on the battens b . An end view of the movable block e is shown in the small sketch. The fixed block f can be any shape, so that it is sufficiently rigid to carry the handscrew.

Cramps. A good variety of cramps is a

time-saver to the joiners. There should be several sizes from 2 ft. 6 in. to 6 ft., and also extension pieces for the latter. It is an advantage to have the cramps in pairs, because two cramps are usually required for cramping up. Fig. 122 illustrates the heavy type of cramp, which is usually 4 ft. to 6 ft. in length. The lug *a* is useful for screwing to the bench. If two similar cramps are fixed to the bench in this way, they are very convenient for cramping up sashes, etc., as the work is clear for squaring, pinning and wedging. Sometimes wooden cramps are used for this purpose and hardwood wedges take the place of the screws.

Bench Clamps. The bench clamp, or hold-fast, shown in Fig. 123, fixes the work to the bench whilst the joiner performs the various tool operations. A hole is bored in the bench

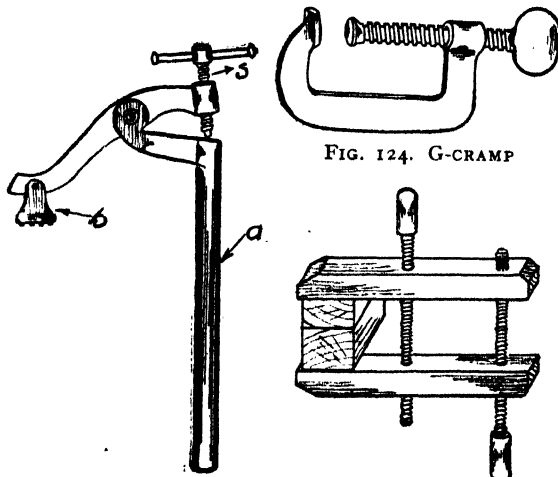


FIG. 123
BENCH HOLDFAST

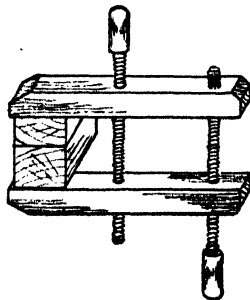


FIG. 125
HANDSCREWS

top or well, to receive the bar *a*, and the stuff is gripped by the shoe *b*. When the screw *s* is tightened, the bar cants over and grips on the sides of the hole, and then the shoe begins to press down on to the stuff.

G-Cramps are useful for small work, repairing fractures, etc. Fig. 124 shows a small type, but larger ones may be obtained with lever handles. *Handscrews* as shown in Fig. 125 are also used for light work, and for holding together several pieces of stuff whilst they are being worked, or after they have been glued. The various parts are of beech.

Cleats. These are used for holding the work after jointing until the glue sets. They may be

of wood or iron. The wooden type shown in Fig. 126 consists of two pieces *c* about 3 in. by $\frac{1}{2}$ in., and long enough to take the work for which they are required. Holes are bored to

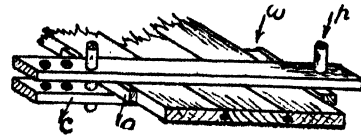


FIG. 126. CLEATS

receive the pins *p*. On one edge of the stuff a protecting piece *a* is placed, whilst at the other edge fox wedges *w* are used to cramp up the joints. The cleats are left on the stuff until the glue sets. The advantage of this type is that the stuff is kept straight whilst drying.

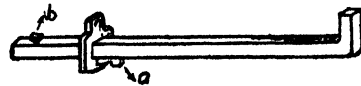


FIG. 127. IRON CLEAT

Fig. 127 shows a metal cleat, which is very useful because it is easily applied whilst the stuff is in the vice. The wedge *a* fixes the shoe in position. A small set screw *b* is put in the end of the bar to prevent the shoe from falling off when the wedge is slackened and for

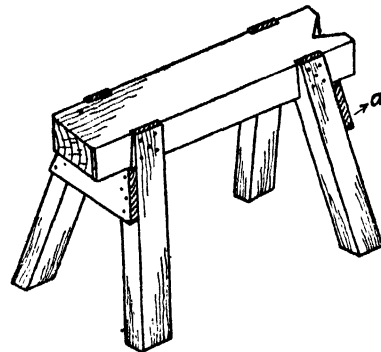


FIG. 128. SAWING STOOL

fixing an extension piece to the bar, if required. The size is usually about 3 ft. long and $\frac{3}{4}$ in. square.

Sawing Stools, as shown in Fig. 128 are necessary both in the shop and on the job. The *vee* cut in the end of the top is for gripping the work, such as doors, whilst the edges are being planed or worked. The top is usually $4\frac{1}{2}$ in. by 3 in. The legs, which are splayed outwards in both

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directions, are 3 in. by 2½ in. and are strengthened by the pieces *a*.

Tool Chests. Many joiners are not satisfied with the tool accommodation and security provided by the bench drawer, and have their own tool chest. Fig. 129 illustrates the usual type,

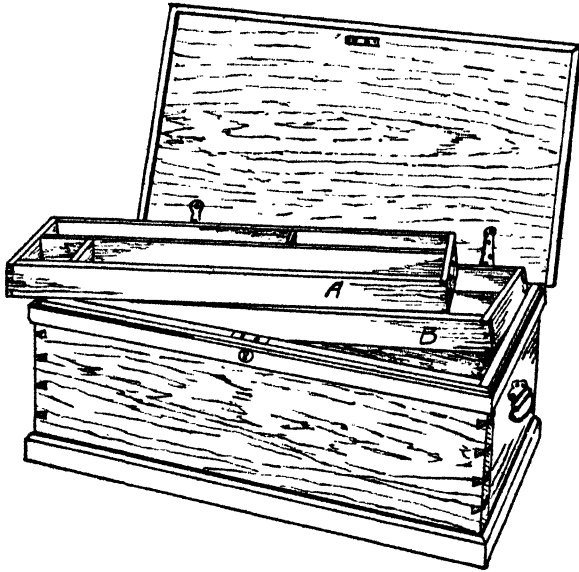


FIG. 129. TOOL CHEST

which has two sliding trays *A* and *B* for the lighter tools. The planes and heavy tools are placed on the bottom of the chest, and the saws are fixed to the inside of the lid by buttons. A common size is about 2 ft. 6 in. by 1 ft. 6 in. by 1 ft. 6 in., and they are made from 1 in. stuff. For outside work, a small portable tool box is often used instead of the *bass*, because it keeps the tools in better condition and more secure.

GLUES

When the usual form of cake glue is used, whether Scotch, English, or French, it is necessary to have some form of heating arrangement. The glue kettle consists of an inner and an outer pot, so that the glue in the inner pot is heated by the water in the outer pot. If the outer pot is allowed to boil dry the glue is quickly burnt and made useless. It is usual, in joiners' shops, to have a *heater* containing several pots, the frame containing water and heated by gas or steam. Fig. 130 shows a gas heater containing three pots, but the same form may be obtained with one or two pots. The

cake glue is broken into small pieces and covered with water; then it is allowed to steep for a night before being heated. The glue should be very hot when being used, and just thick enough to drip off the brush. It should be used in a warm dry atmosphere for good results, and the stuff must be dry and preferably warm. The glued joint should harden in a warm and dry room.

Animal glues may also be obtained in powder or liquid form. The former requires soaking for about one hour before heating. The latter is ready for use in temperatures over 60° F.

Casein glues are from dextrines or caseins, and are in powder form. They are mixed with cold water and set like cement, but they must be used on the day they are mixed. The advantages of these glues are their resistance to water, fire, mould, and bacteria.

Synthetic resins or *plastic glues* are superceding all other adhesives for mass produced work, plywood, aircraft, etc. There are many kinds but they can be divided into four groups. (a) *Thermo-hardening*, which includes phenol-, urea-, and soya-formaldehydes, and melanine resins. (b) *Thermo-plastic*, which includes acryl- and vinyl-polymers, and cellulose derivatives. (c) Casein plastics. (d) Natural resin glues.

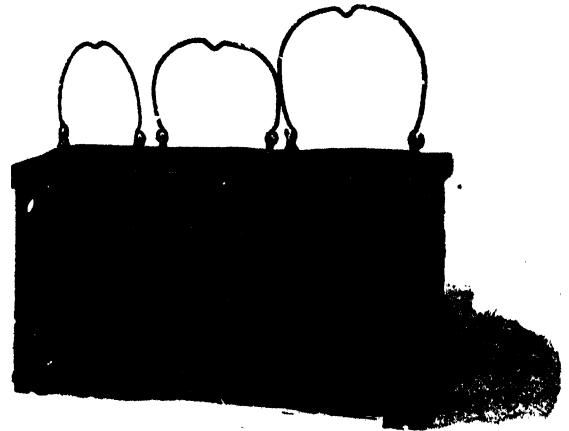


FIG. 130. GLUE HEATER

Group (b) can be made plastic again by re-heating but group (a) are permanent once they are cured, or set. The phenol- and urea-formaldehydes are extensively used, either in liquid or powder form, and for hot-press or cold-press bonding. They require expensive equipment, and expert control in mixing, application by machine spreaders, and moulding. The adhesive

consists of two constituents, or plaskons, one of which is the hardener. The latter determines the setting time. The glue should be applied within four hours of mixing in the hot-press method, and it remains inert for two or more days until it is moulded, or cooked, in an autoclave. The work is clamped and enclosed in a rubber bag before running into the autoclave, and then hot water and compressed air are admitted. This presses the bag round the work and provides the pressure and heat to set the resin. Cold-press resin, used for assembly work, must be freshly mixed about every 2½ hours, unless the glue is kept on ice. Cold water is added to the powered glue to form the adhesive, which must be in the press within 15 minutes of application. New developments are taking place continuously, and intensive research is being applied to the use of electric currents to supply the required heat to avoid the use of autoclaves. This applies specially to dry resins, which may be applied in powder form or as cellophane-like sheets placed between the laminations. The resin is fused to make a permanent joint by placing the prepared work in a heated press.

WORKSHOP PRACTICE

Grinding and Sharpening. The grinding and sharpening angles of chisels and plane irons vary with the work they have to do. Fig. 14 shows the usual angles, but they may vary considerably. The action of a blade when cutting is similar to that of a wedge. Hence the thinner the edge of the chisel the easier it will cut. It is necessary, however, to support the cutting edge to withstand the shock when cutting knots or anything that offers much resistance. It has been found by experience that the given angles are satisfactory for average work. Paring chisels may be ground much thinner because they are only used for light work, and are not driven by the mallet. Some of the irons for metal planes are also ground very thin, when they are only used for light work. A thin grinding angle makes the tool easy to sharpen, but after a few sharpenings the cutting angle becomes stumpy and it is then necessary to regrind. The shop joiner has always the grindstone at hand, which gives him a great advantage over the outside worker for producing good work.

Fig. 131 shows the method of holding the plane iron when it is being sharpened. After rubbing firmly to and fro, and keeping the hands steady to avoid a rocking motion, the

iron is turned over and the back rubbed gently on the stone to remove the burr, or wire edge. For this operation the back of the tool must be perfectly flat on the stone. The best way to test for sharpness is to hold the edge against the light, and if a white edge can be seen it is not sharp.

Oilstones. There are many variations of oilstones, and a good stone pays for itself in a very short time. Some stones are much *quicker*, or *keener*, in their action than others, and the joiner requires a fairly keen stone. The most useful kind, considering the cost, is a *Washita* stone. They are so varied in quality, however, being a natural stone, that it requires an experienced man to select a good one. The stone

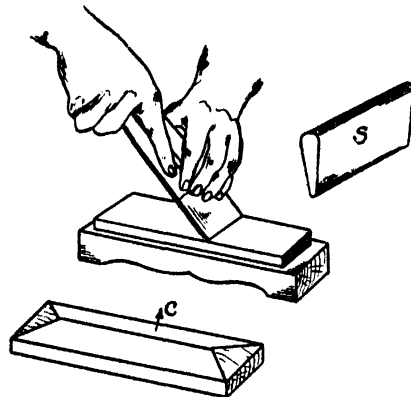


FIG. 131. SHARPENING PLANE IRON

should be tested by drawing the thumb nail along it. If there is a keen, dragging feeling, it is a good stone, unless there are flaws such as cracks, etc. The size should be about 9 in. by 1½ in. by 1½ in., so that it can be turned over in the box to use any edge in turn. If the stone is too wide it is soon worn hollow, and then it is difficult to keep the cutting edge straight. The carpenter requires a keener stone than the bench hand, because he has not the same facilities for grinding. The stone should be mounted in a box and bedded in white lead. It should be covered when not in use by the cover *c*, Fig. 131, otherwise the oil is inclined to harden and spoil the surface of the stone. After a time the stone requires straightening, which may be done by holding it to the side of the grindstone, or by rubbing on a straight stone surface with a mixture of sand and water.

A good oil is necessary to keep the stone in

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condition, and a mixture of neatsfoot oil and sweet oil is satisfactory. Poor oils form a skin on the surface of the stone, and although the oil may be burned out it is better to avoid burning if possible. Washing with paraffin is generally satisfactory for removing the poor oil, or the stone may be rubbed with an emery cloth.

The Turkey stone is a very good stone, but the cost makes it prohibitive to many joiners; also the quality varies considerably. The same

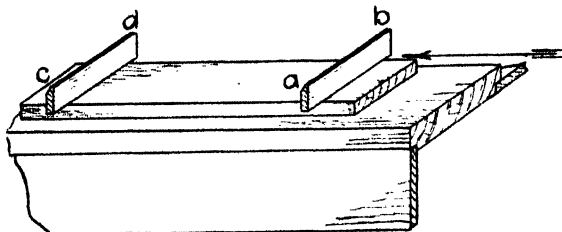


FIG. 132. USE OF WINDING STRIPS

remarks apply to the Arkansas stones. Artificial oilstones, such as the Indian and the Carborundum, are made in various grades, and are generally uniform in quality. They are very keen and have a quicker action than other stones, but they do not produce quite so good an edge. They are the most useful for machine irons and are usually "two-faced" with two different grades.

Sharpening Gouges. The *finger slip*, Fig. 131 s, is necessary for curved edges. It is made from

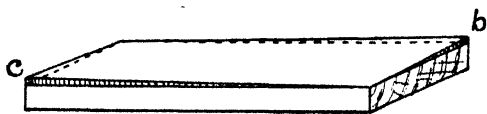


FIG. 133. TWISTED SURFACE

the same materials as the oilstones just described. The inside ground gouge is sharpened on the inside with the slip; and the wire edge on the outside is removed by a gentle rocking motion on the oilstone. The outside gouge is sharpened by a rotary motion on the oilstone, and the wire edge on the inside is removed by the slip.

Sharpening sticks are about 4 in. to 6 in. long and are of different sections, such as circular, square, triangular, etc. They are made from the same materials as the other stones.

Planing by Hand. The first step in the preparation of stuff, by hand, is to straighten the better side. Very often the stuff will warp,

after sawing, and for most jobs it will have to be straightened. Fig. 132 shows the method of testing the stuff to see whether the face is twisted or not. Two short straight-edges, or *winding strips*, *ab* and *cd*, are placed on the stuff and sighted by the eye, as shown by the arrow.

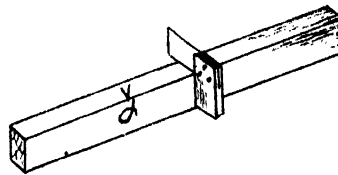


FIG. 134. TESTING FACE EDGE

The eye is brought on to the same level as the edges of the strips. If the edge *ab* coincides with the edge *cd*, then there is no twist in the board. It is then necessary to see if the board is straight, both across and lengthwise. The strips will test the board for across; but it will have to be tested lengthwise either by sighting with the eye, or by using a long straight-edge. Fig. 133 shows a board which the strips have shown to be twisted so that the corners *b* and *c* are raised. The next step is to plane off these *hard corners* with the jack plane.

When the board has been straightened by the jack plane and try plane, it is marked as the *face side*. The method of marking the board is shown in Fig. 134, the mark being placed against the *better edge*. The next step

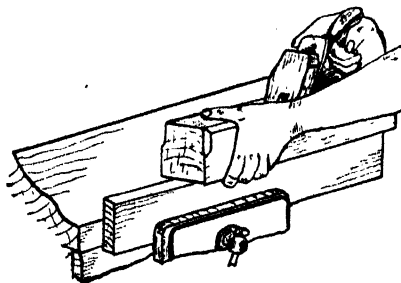


FIG. 135. STRAIGHTENING FACE EDGE

is to straighten and square this edge. Fig. 135 shows the method of straightening the edge with the try plane, the stuff being fixed in the vice. The stuff is tested with the try square as shown in Fig. 134, which also shows the method of marking the face side and front edge. The board is then *gauged* to width and the other edge planed down to the gauge mark and square to the face side. The board is then gauged for

thickness and planed down to the gauge marks.

It is necessary to plane *with the grain*, and the stuff should be examined for the grain, *before planing*, otherwise the plane may pluck up the grain and cause a lot of trouble to remedy. Hardwoods require special care with regard to the grain, and the plane irons should have less *set* than for softwoods. The sole and cutting

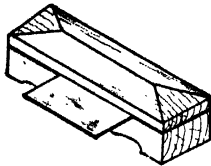


FIG. 136. PREPARING SCRAPER

edge should be oiled occasionally when planing resinous pitch pine. The smoothing plane is used to finish off the surface preparatory to scraping or sand papering.

Scrapers. The scraper is a piece of steel about 5 in. by 3 in. by $\frac{1}{16}$ in. It very often proves a difficult tool to the beginner, especially the sharpening. To sharpen the scraper, the edge is first filed straight and then rubbed on the oilstone to remove the file marks, as shown in

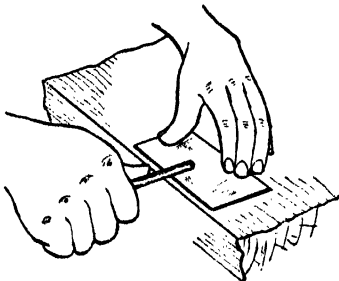


FIG. 137. SHARPENING SCRAPER

Fig. 136. It is then wetted, placed flat on the bench, and rubbed as shown in Fig. 137. The sharpening tool is a cylindrical piece of steel or a gouge, and it is kept nearly on the same level as the scraper. The scraper is then placed on end (Fig. 138) and the sharpener is pulled up the edge sharply and firmly several times, at an angle of about 80° with the face of the scraper. It is then turned upside down and the process repeated for the other corner of the edge. This turns up the corners as shown by the end view of the scraper in Fig. 139, which also illustrates the method of using the scraper. The scraper

should be kept wet, usually by the mouth, whilst sharpening. For curved work, scrapers may be obtained as shown in Fig. 140; but the joiner generally rounds off two corners of the rectangular scraper to different radii.

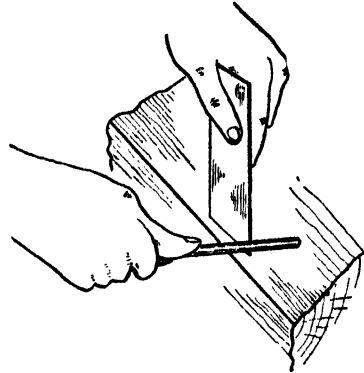


FIG. 138. SHARPENING SCRAPER

Sand-papering. Planed surfaces are always sand-papered for good work, to remove the plane marks and to make the surface more regular. The sand-paper, which is really *glass-paper*, may be obtained in a number of different strengths, or grades. The finer grades are used to finish off the surface. The glass-paper is wrapped

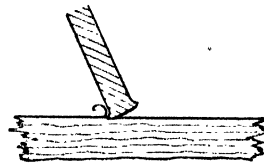


FIG. 139. ACTION OF SCRAPER



FIG. 140 CURVED SCRAPER

round a *rubber*, which for straight work is a rectangular block of cork, or a piece of wood faced with cork linoleum. To sand-paper mouldings, it is necessary to make a rubber (preferably of yellow pine) to the reverse shape of the moulding. The glass-paper should be bent round the rubber and held very tightly, otherwise it will rub off the sharp arrises of the moulding. For varnished or polished work the glass-paper should be used with the grain, as the scratches across the grain are very difficult to remove. In some cases a circular motion may be used with the finer grades of paper, before

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the final rub-down. For painted work the paper is usually used across the grain at an angle of about 45° and then *finished off* with the grain. Sand-paper must be dry when being used, because of the glue which fixes the particles of glass to the paper. Woolly grain, as in Honduras mahogany, is pressed down by the sand-papering, and is apt to rise again when it is being polished. To avoid this it is usual to

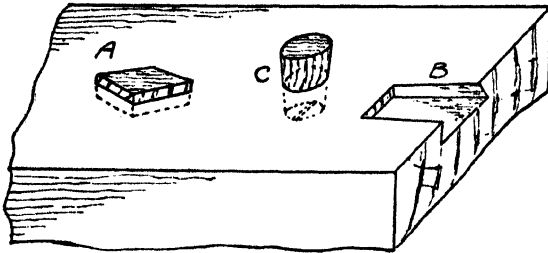


FIG. 141. "LITTLE JOINERS"

damp the surface a little with hot water, to *raise the grain*, before the final rub.

The name sandpaper is applied to all types of abrasive papers, except emery cloth, whether used by hand or on the machines. The abrasive material may be glass, flint, garnet, aluminous oxide, etc. The material is crushed and sifted to the required grade and fixed to the paper by glue. It may be mounted on paper or cloth in sheets or rolls for the different types of machines, or sanders, or for use by hand. For outside work special waterproof paper may be obtained.

The process consists of spreading, beating, and re-heating, so that the abrasive sinks into the glue to make contact with the paper or cloth. Aluminous oxide, garnet, and flint are used for machine papers. Kraft paper is generally used for hand work; manilla paper and white duck cloth for machine work. The grades for ordinary glass-paper are numbers 0, 1, 1½, fine 2, middle 2, strong 2, 2½, and 3. For special work, garnet finishing paper is made in grades from 7/0 to 1/0. Flint paper for machines is graded from 3/0 up to number 4, and special quality garnet paper for sanders is made in grades from 4/0 to number 3. The grades for machines rise by ½ after number 1. All sandpapers are more efficient when they are warm and dry. Also see page 417 for information on sanders.

To Remedy Defects. It is an important part of the joiner's work to remedy defects so often

found in timber. Fig. 141 shows three different forms of "little joiners." In every case the grain of the timber should be *matched* as near as possible, especially for varnished and polished work. The usual method for filling in for loose or dead knots, etc., is shown at A; which is a diamond-shaped piece glued and driven in tightly. A very slight bevel on the edges will ensure a tight fit on the surface. A good method when the defect is at the shoulder of a rail is shown at B. In this case the "little joiner" is driven in from the end and is dovetailed to prevent it lifting afterwards. For covering up screw heads, or filling in for loose knots a pellet C is very convenient.

For small defects it is more usual to use some form of filler, or stopping. The stopping may be plastic wood, putty, or whiting and glue for painted work; litharge and glue for varnished pitch pine; and, for polished hardwoods, beeswax, which is mixed with a colouring pigment, such as yellow ochre, burnt umber, etc., to suit the particular wood. Beeswax fillers may be obtained in stick form, already coloured and ready for use. The end of the stick is heated and applied in the same way as sealing wax. Many fillers contract with drying and evaporation, hence they must be used with caution for large defects. The filler should be left prominent until it has set hard and then cleaned off.

Straightening Boards. Hollow boards should be planed up on the round side, and then wetted on the hollow side and placed with the wet side downwards in a warm room. This swells the fibres on the hollow side, and dries them on the round side, thus pulling the board straight. The planing may then be completed.

For thin wide panels it is better to place a few soft shavings on the panel board along the middle of the panel, and to plane the panel on the hollow side while an assistant presses down on the edges of the panel.

Bruises, such as the dents made by the hammer, may be raised by wetting the damaged fibres. This will raise them so that they may be sand-papered level again when they are dry.

Many other hints on workshop practice and processes are given in succeeding pages as the difficulties arise in the examples of joinery. Experience and ingenuity can always overcome the problems that occur, whether with the materials or the processes, often by the designing of new equipment, which then becomes part of the stock for the benefit of less experienced craftsmen.

Chapter IV—JOINTS AND FASTENINGS

THIS chapter will deal with the joints required for joinery. It is a difficult matter, however, to draw a hard and fast line between joinery and carpentry joints, so that examples will be given which apply equally to both. The joints which

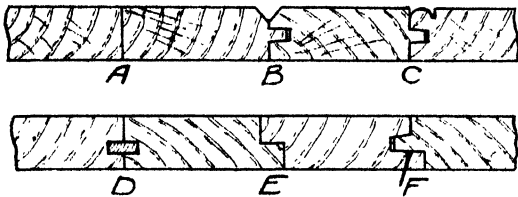


FIG. 142. VARIOUS JOINTS

are definitely carpentry will be dealt with in that section. Variations of the joints will be shown in the constructional details as they arise, because special circumstances often require special methods and ingenuity.

General Principles. The general principles governing the construction of joints may be summarized as follows: (a) Accuracy and simplicity, that is, the joint should be as simple as possible for efficiency. (b) The joint should be arranged and cut so as to take as little from the strength as possible. (c) The abutting surfaces must be sufficiently large to resist the thrust and prevent the crushing of the surface which receives the thrust. (d) The resisting surfaces should be at right angles to the line of pressure. (e) The resistance of the various members, whether wood or metal, should be equal. (f) The shrinkage of the timber must be taken into account.

Classification. The various types of joints may be divided into the following groups: (a) Lengthening of timbers, such as lapped, halving, and scarfed joints. (b) Jointing of timbers not in the same straight line, or angle joints. This class covers the whole range of joints: mortise and tenon, lap, housed, bridled, coggled, mitred, keyed, dovetailed, etc. (c) Joints for increasing the width, or surface; that is, timbers in the same plane, such as panels,

counter tops, floor boards, match boarding, etc. These joints include the butt, tongued and grooved, rebated, dowelled, slot screwed, etc. (d) Hinging and shutting joints, as used for doors, casements, etc.

Joints for Increasing the Width. The *glued butt* joint is the most common and simplest form of joiner's joint, as shown at A in Fig. 142. The joint is not so easy to make as it appears to be, because the edges must be perfectly straight and square. Short lengths are usually *shot*, by means of the try plane, on the *shooting board*, but generally the edges are prepared in the vice. It is an advantage, for thin stuff, to *shoot* the two pieces together, face to face, in the vice as shown in Fig. 143. The *vee* marks on the edges point to the face sides. By this method, if the edges are a little out of square, one

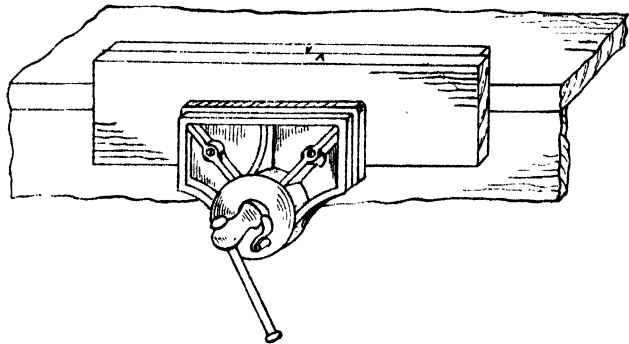


FIG. 143. MAKING BUTT JOINT

compensates for the other. The joint must fit perfectly. There must be no *riding*, or rocking, when the edges are placed together, otherwise the joint will break after it is glued up. The beginner will find that he tends to plane the edges round, but if he tries to plane the edges hollow the try plane will usually do the rest. When the joint is prepared, one piece is fixed in the vice; then both edges are glued and quickly placed together, and the top piece firmly *rubbed* to and fro until it becomes difficult to move.

The rubbing is intended to squeeze out the surplus glue and air bubbles. The "joint"

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should be put carefully on edge until the glue is set. Sometimes dogs (Fig. 144) are driven in each end, but a well made joint with seasoned stuff does not require them.

Long boards are prepared separately, and after gluing the edges they are put in cramps or cleats, Fig. 126, and also dogged at the ends.

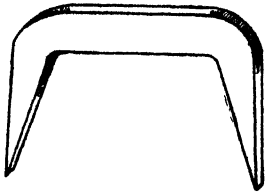


FIG. 144. DOG

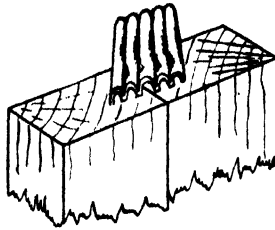


FIG. 145. JOINT FASTENER

This applies also to tongued joints as shown at *D* in Fig. 142, because they are difficult to rub together. If the boards are first cut to the required length, the *corrugated joint fasteners*, Fig. 145, are very good for driving in the ends, instead of dogs. For cheap work, especially shelving, they are often driven in the face of the joints instead of in the ends, and punched below the surface. They are so shaped that they pull the joint up.

Dowelled Joints. Sometimes the butt joint is strengthened by dowels, as shown in Fig. 146.

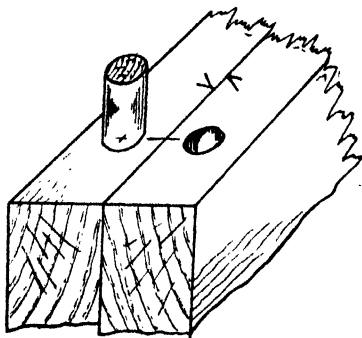


FIG. 146. DOWELLED JOINT

It is then necessary to use cleats or else cramps. When making the joint, it is essential to gauge the centre lines for boring from the face side, and to square the positions of the dowels across the two pieces together. The dowels may be bought in long lengths, in varying diameters; or they may be made by hand with the dowel plate, Fig. 147. When made by hand, it is

best to cut a piece about 3 in. long, any width, but to the correct thickness, and then split the dowels into a square shaped section. These *square* dowels are then pointed and driven through the dowel plate. The holes in the plate are sometimes provided with a small triangular projection *a* which makes a small groove along the dowel to allow the air and surplus glue to be driven out, when driving in the dowel.

Secret Screw Joint. For good work the

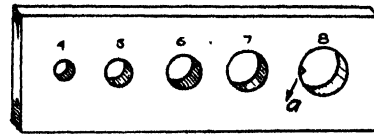


FIG. 147. DOWEL PLATE

secret screw joint is often used; see Fig. 148. This joint requires special care when making. The screws are put firmly into one board *b* and left projecting about $\frac{1}{2}$ in.; corresponding holes are bored in the other board *a*, to receive the

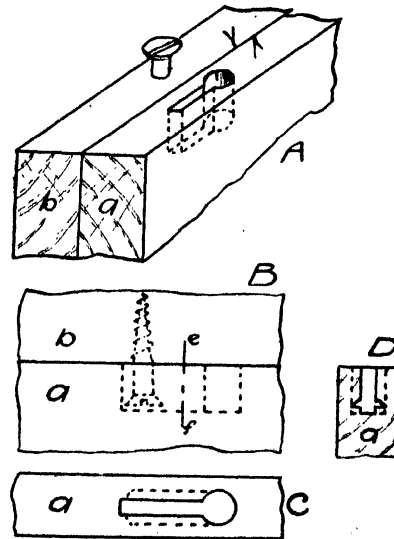


FIG. 148. SECRET SCREW JOINT

projecting heads easily. The positions for both screws and holes are squared across the edges of the two boards, and gauged from the face side as for dowelling, but an allowance is made for the slot. When the holes have been bored (slightly deeper than the projecting screw heads) slots are made the same depth as the holes and a little wider than the screw *shanks*. The slots

should be about $\frac{3}{4}$ in. long. To make the method more clear, a front elevation *B*, a plan *C*, and a section *D* are shown in Fig. 148. When the joint is prepared, the piece *b* is fixed in the vice, and the piece *a* is dropped on to the screws. The two pieces are lightly cramped together and

E is also a common joint. When floor boards have to be secret nailed, a joint similar to *F* is generally used; the projection under the groove is convenient for the nails as shown. For floor boards, the tongue is usually a little below the centre of the thickness to give a thicker wearing surface on the top of the floor.

It is usual to *batten* the backs when the width is built up, to keep the surface flat. Fig. 149 illustrates three different methods

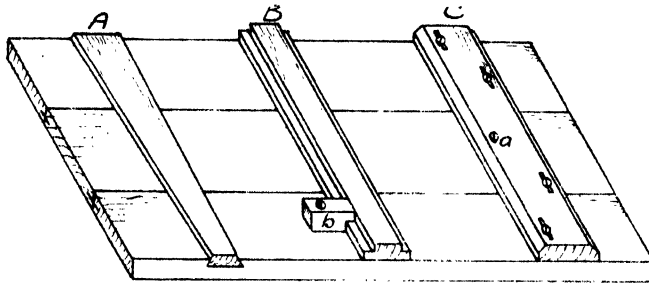


FIG. 149. COUNTER BATTENS

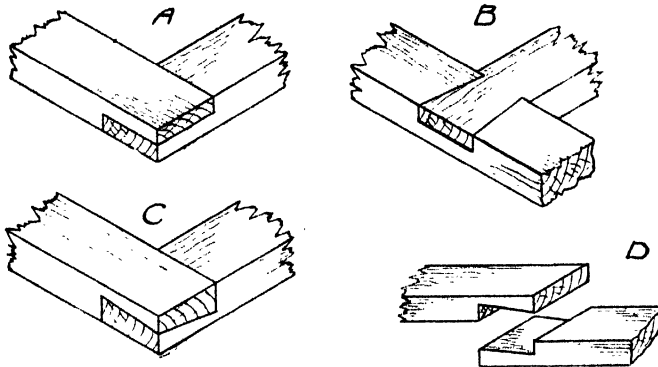


FIG. 150. HALVING JOINTS

piece *a* is tapped at one end to drive the screw heads along the slots. When the joint is satisfactory, piece *a* is knocked back again and the screws are driven half a turn farther in, to pull the joint up. The joint is then ready for gluing and finally knocking together again.

Fig. 142 shows six different ways of building up the width of the boards. The *tongue and groove and vee* joint at *B* is very common for matchboarding, as is the *beaded* joint at *C*. For floor boards the *vee* is omitted in *B*. Either the *vee* or the *bead* may be on both sides of the matchboarding if required. The joint *D* is easier to make by hand than *B*, as the tongue is a loose slip. Hence both boards require ploughing only, and the joint is made true before ploughing. Sometimes hoop iron is used for the slip. Wooden tongues should be made from three-ply wood for strength. The rebated joint-

of preparing the battens so that the stuff is free to expand or contract, without the joints breaking or the boards splitting. The simplest method is shown at *C*; the centre screw is put in without slotting, but all the others are slotted to allow for contraction. Sometimes the fixed screw is at the edge, and then the contraction is all in one direction. A very good method for counter tops is shown at *B*. In this case the batten is usually part of the carcase framing. The *buttons b* are usually fitted so that they can be turned round without unscrewing. This allows everything to be fitted in the shop, and then taken to pieces for conveyance to the job. The *dovetailed key* shown at *A* is not so common, but makes an excellent counter cramp if fitted properly. It should be screwed at one end only, and if shrinkage takes place it should be adjusted and rescrewed.

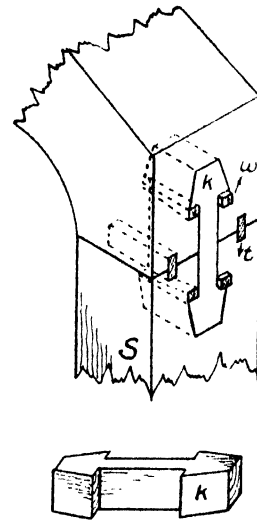


FIG. 151. HAMMER-HEADED KEY JOINT

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Lengthening Joints. The carpenter is more concerned with the lengthening, or scarfing, of timbers than the joiner, hence they will be further considered in CARPENTRY. There are several joints, however, which the joiner is constantly dealing with, one of which is the *lapped halving*. Fig. 150, *A*, shows a *lapped halving* suitable for corner junctions or for lengthening timbers, and *D* shows one specially adapted for the latter purpose. The splay or bevel, is to prevent the two pieces pulling apart after they are fixed together.

A very important method of fixing two pieces together lengthways is shown in Fig. 151; this is the *hammer-headed key joint*. Sometimes the "hammer head" is made part of the stile *S*, but only when the stile is hardwood. The *key K* should be made from hardwood, so that the projecting parts will not split away when the wedges are driven home. In the sketch, two of the wedges *w* are shown projecting, and two driven home. The two tongues *t* are to keep the shoulders from twisting. This joint is generally used between the stile and the head, and at the crown, in circular headed frames.

The *handrail bolt*, shown later, is another method of lengthening timbers. The method of using the bolt will be referred to in HAND-RAILING, for which purpose it is mostly used. A countercramp for pulling together the ends of the stuff, will also be illustrated in STAIRCASING because the most common application is to the strings for a circular well.

ANGLE JOINTS

Mortise and Tenon Joint. This is the most common joint in this classification. Fig. 152 shows the usual form when it is near the end of

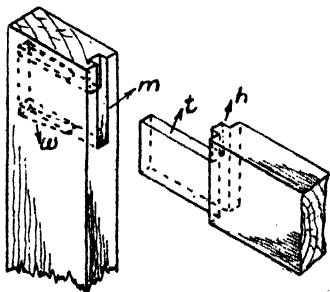


FIG. 152. MORTISE AND TENON JOINT

the stuff. Generally both the mortise *m* and the tenon *t* are made on the machines. If it is

made by hand, the mortise should be bored out as far as possible by brace and bit, and then cleaned out by the chisel, although the mortise chisel is often used for chopping out the mortise. Fig. 153 shows the method of cutting the tenons

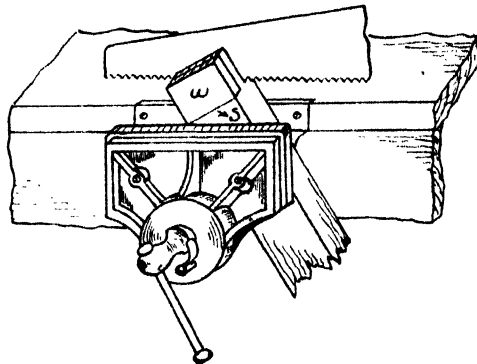


FIG. 153. CUTTING TENONS

by hand. After sawing down the sides of the tenon, in the position shown, the stuff is turned over in the vice, and the vertical cut completed. Then the waste wood *w* is removed by cutting down the shoulders *s*. The shoulders should be cut square, otherwise when the framing is glued up, the joint may look unsightly after cleaning up, although it is a common practice to *undercut* the shoulders a little to ensure a tight joint on the face. For wall framing the back shoulder is sometimes left short for the same reason.

The tenon is secured in the mortise by the wedges *w*, assisted by glue for inside work, and paint for outside work. Very often the wedges are assisted by a pin, or dowel, as shown in Fig. 154, but in this case the pin is often used for pulling up the shoulder tight to the stile. This is known as *draw-boring*, and the stile and rail are bored separately. The thickness of a tenon is usually one-third that of the stuff, and the width is three to five times the thickness of the tenon.

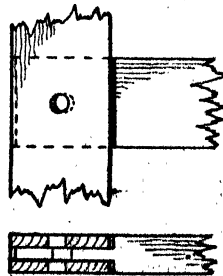


FIG. 154
DRAW-BORING

There are many variations of the mortise and tenon joint. Many of these will be illustrated in the examples of joinery. Fig. 155 shows two examples of *stub tenons*. A *fox-wedged tenon*

is shown at *B*, and the preparation of the tenon is shown at *A*. The size and projection of the wedges *w*, and the depth of the saw cut *c*, must be carefully considered before cramping up the stile to the rail. It is impossible to rectify any mistake after gluing and cramping-up. The saw cut must not be too near the edge of the tenon or the wedge will split the outer portion away. An easier method is shown at *D*, but in this case the wedge *w* can be seen after completion; otherwise it makes a good strong joint. The tenon is shown separately at *C*.

A *chase mortise* is shown in Fig. 156; this is used for placing intermediate rails in position after framing up. The chase *a* must be sufficiently long to slide the rail in position. Hence it follows the circumference of a circle with the rail as radius, and the other end of the rail as

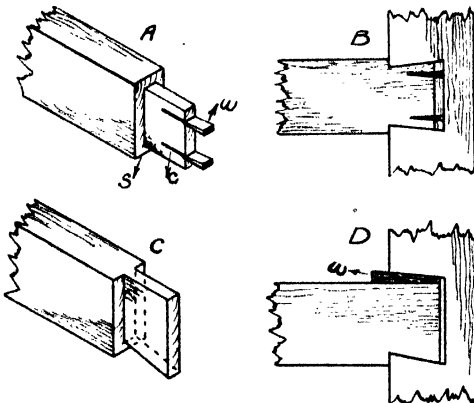


FIG. 155. STUB TENONS WITH SECRET WEDGING

the centre of the circle. The width of the tenon is shown at *b*. The opposite end is usually an ordinary stub tenon.

When the mortise is at the end of the stuff, as in Fig. 152, it is usual to form a *haunch* *h*, so that the tenon can be wedged. The haunch is the same thickness as the tenon, and it goes into the stile about $\frac{3}{8}$ in. to $\frac{1}{2}$ in. If the framing is ploughed, the haunch is usually equal to the depth of the groove, less sufficient clearance to ensure the shoulders coming up to the stile. When the tenon is left the full width of the rail, the mortise is *slotted* from the end of the stile. The joint is then called an *open mortise and tenon* joint, and is generally held together by pins.

Franking is the reverse to haunching and is used on sash stuff, as shown in "Windows." The projection is on the stile and the recess

in the rail to prevent the access of water to the mortise.

Double tenons are often used for heavy work, or for the lock rail of a door which has to receive a mortise lock. Several examples are given in the chapter on doors.

A *tusk tenon* joint, Fig. 157, is used for heavy framing which has to carry a transverse load; it

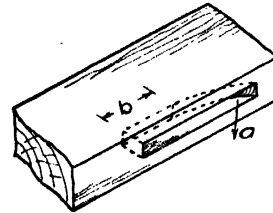


FIG. 156. CHASE MORTISE

is usually employed for trimmer joints. The wedge *w* pulls up the joint, and it is necessary to have a clearance *c*. The proportions are as shown. The bottom of the tenon is on the neutral axis of the section, that is, it should all be in the compression area.

A *housed mortise and tenon* joint is formed when the end of the rail is let into the stile, in addition to the tenon. It is used when the rail is thinner than the stile and has to carry a transverse load.

A *bare faced tenon* has only one shoulder, as shown in the chapter on doors.

Dowel joints are often substituted for the

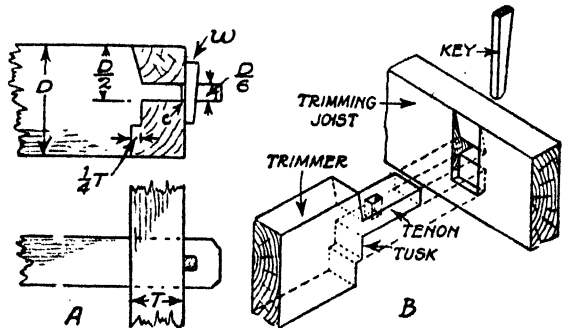


FIG. 157. TUSK TENON

mortise and tenon joint, but they are considered cabinet-making joints rather than joinery joints.

Halving Joints. Amongst the many forms of angled joints the halving joints are very important. A *lapped halving* is shown at Fig. 150, *A*; if the joint is in the middle of one piece it is called a *tee halving*. A good form of *tee halving* is shown at *B*. It is dovetailed so that it cannot

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pull out lengthways. The method *C* is used when it is required that the pieces shall not pull apart laterally; it is, however, not commonly used.

Housing. Fig. 158 shows two methods of housing the ends of shelves, etc., into the uprights.

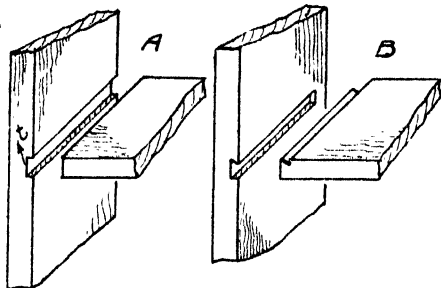


FIG. 158. HOUSING SHELVING

The easier method is shown at *A*. The trench *t* in the upright may be done on the tenoner, or by a trenching plane, or it may be done by saw and chisel. It is usually finished off by an "old woman's tooth," or router, to ensure it being

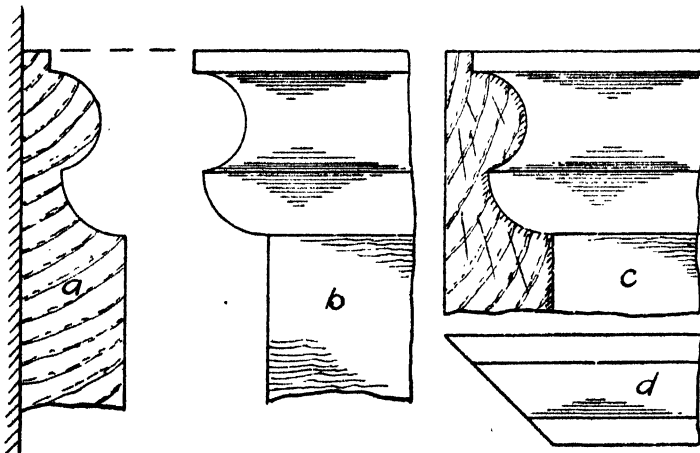


FIG. 160. SCRIBING A SKIRTING BOARD

of equal depth. A more elaborate method is shown at *B*. The dovetail prevents the shelf from pulling out; and by stopping the trench there is nothing shown on the front edge.

Joints with the Grain. Several alternative methods of making angled joints for pilasters, linings, fascias, etc., where the joint is made with the grain, are shown in Fig. 159. Although the examples are shown for right angles they are equally good for oblique or acute angles. *A* is

an ordinary *butt joint* and may be nailed or screwed. *B* is a *tongued joint*; the tongue ensures the edge of the stuff being level with the face of the return piece, besides making the joint dust proof. A *rebated and beaded joint* is shown at *C*, and a *rebated joint with return bead*

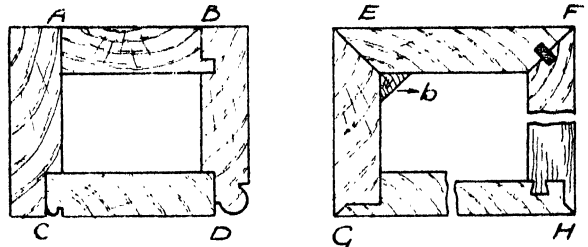


FIG. 159. ANGLED JOINTS

at *D*. The *mitred joint* at *E* may be with the grain or across the grain. It is a common joint for both conditions. The blocks *b* are glued in position to strengthen the joint and to keep it rigid; they may be used with any of the examples. A *mitred joint with tongue* is shown at *F*, and a modification is shown at *G*, which is a *lipped mitre*. This keeps the joint in position better for screwing or nailing. A special combination of a *dovetailed and lipped*

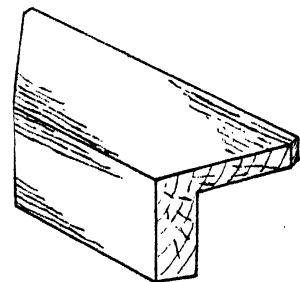


FIG. 161. MITRE TEMPLET

mitre is shown at *H*. This is employed where the grain of the two pieces runs in different directions, as at the junction of the top drawer rail with the side carcase in drawer framing.

Scribed Joints. These are alternative methods to the mitre joints for mouldings, and they are usually applied to the internal angles of wall mouldings and the mouldings on framing. Fig. 160 illustrates the method for a skirting board. The section of the moulding is shown

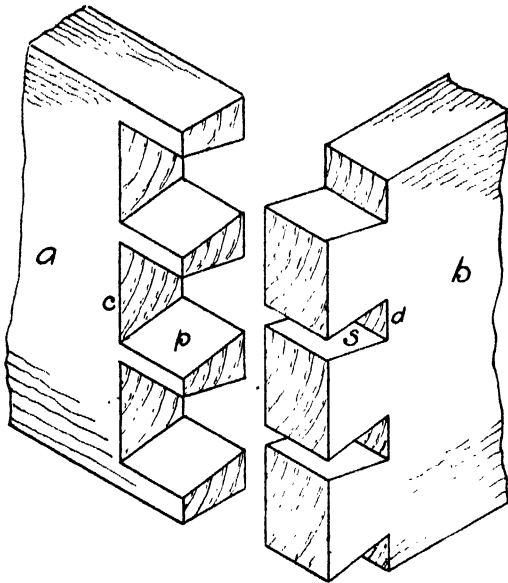


FIG. 162. COMMON DOVETAIL JOINT

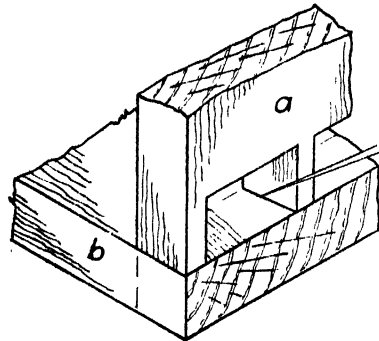


FIG. 165. MARKING SOCKETS

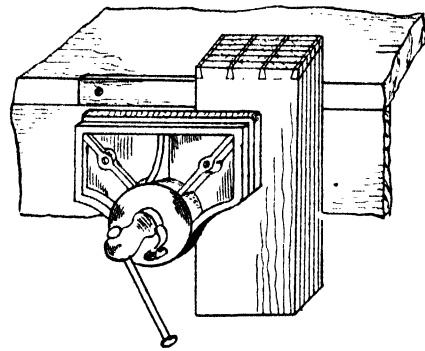


FIG. 166. PREPARING SOCKETS

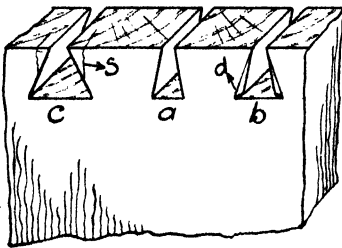


FIG. 163. DOVETAIL SOCKETS

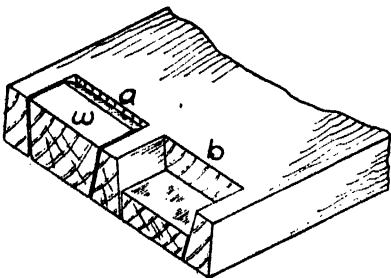


FIG. 164. PREPARING DOVETAIL PINS

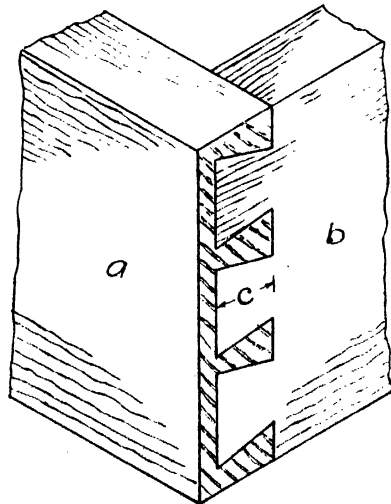


FIG. 167. LAPPED DOVETAIL JOINT

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at *a*; this piece is fixed to the wall as shown. The piece *b* is then *scribed* and pushed up to *a*, and nailed in position. From this example it is seen that a scribing is simply the reverse shape to the moulding. The method of finding the reverse shape is to mitre the moulding, as shown at *c* and *d*, which shows the plan and elevation. After mitring, the scribing is cut to the outline of the moulding on the mitre; this is shown by the hatching. Examples of scribing applied to doors, sashes, etc., will be shown later. The operation of mitring the mouldings

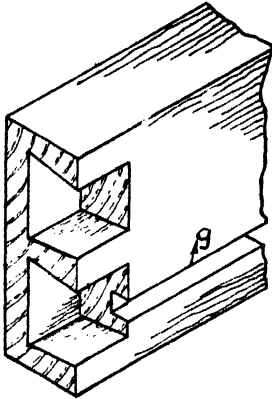


FIG. 168. DRAWER FRONT

on framing preparatory to scribing is performed by means of the *mitre templet* shown in Fig. 161.

Dovetail Joints. Dovetailing is the strongest and most satisfactory method of making angle

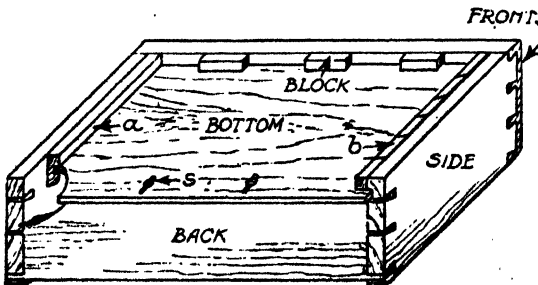


FIG. 169. DRAWER CONSTRUCTION

joints when the ends of the stuff come together. Fig. 162 illustrates a *common dovetail joint*. The number and size of the pins *p* depend upon the required strength and appearance of the joint. The shape of the pins depends to a certain extent upon the taste of the joiner. The usual fault is

to give too much bevel to the dovetails. Fig. 163 shows three different *eyes*, or *sockets*; *c* is bad because it has too much bevel, and the stuff will break away as shown at *S* when the pin is driven into the eye. The correct shape is shown at *a*, and *b* shows the method of preparing the eye before driving in the pin to prevent bruising the fibres. The small bevel *d* is not seen when the joint is assembled. Fig. 162

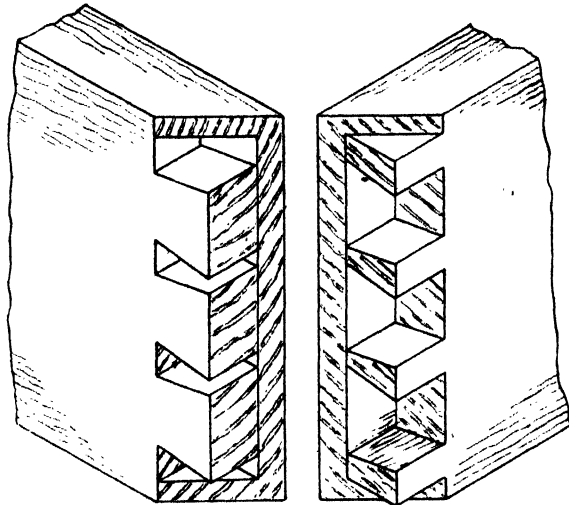


FIG. 170. SECRET DOVETAILED

shows the proportions suitable for stuff about 4 in. by $\frac{3}{4}$ in.

METHOD OF CONSTRUCTION. The common method is to make the pins first. The stuff is planed to width and thickness, then cut to length and the ends trimmed square and true. The thickness of *b*, Fig. 162, is then gauged on both sides of *a*, as shown at *c*, and the thickness of *a* is gauged on *b*, as shown at *d*. The pins are then set out by means of compass, bevel and square for a first attempt, but the experienced joiner usually guesses the size and shape, and very often the spacing. After setting out, the pins are cut down with a dovetail saw, *on the waste side of the lines*, to the line *c*. The waste *w*, Fig. 164, is then cut away with mallet and chisel. Fig. 164, *a*, shows the first step, and *b* shows the stuff cut half-way through. The stuff is then turned over and completed from the other side. It is usual to undercut the shoulder *b* slightly. When the pins are completed, the piece *a* is placed on piece *b*, as shown in Fig. 165, and the pins marked on *b* for the eyes. The eyes are

then cut down, *on the waste side of the line*, and chiselled out, the two end eyes being sawn off. It is often an advantage to bore out the eyes with brace and bit, after sawing, and then pare out the waste wood. When there is a number of similar joints to make, it is common practice to reverse the procedure, and to make the eyes first. The advantage is that a number can be made at once as shown in Fig. 166.

Lapped Dovetail Joint. The common dovetail joint is the strongest but it is not suitable for many cases because the end grain is seen. Fig. 167 shows a *lapped dovetail joint* as used for drawer fronts. This joint is more trouble to make but is only seen on one face. The method of preparing the piece *a* is illustrated in Fig. 168 which shows a narrow drawer front prepared with pins, and plough groove *g* for drawer bottom. When the pins are prepared the procedure is the same as for the common dovetail. Special care is required for gauging the stuff so as not to confuse the thickness of *b*, Fig. 167, with the size of the pins *c*. It is an advantage to have these sizes the same to prevent error; hence, if the drawer sides are $\frac{5}{8}$ in. the drawer front should be about $\frac{7}{8}$ in. thick.

DRAWER CONSTRUCTION. The most important application of the common and lapped dovetail joint is in drawer construction. Fig. 169 illustrates the back, side, and underneath of a drawer. The front and sides are ploughed for the drawer bottom, unless special pieces *a* are planted on the sides to carry the bottom. The back of the drawer is narrower than the sides because the drawer bottom passes over it. Sometimes it is narrower at the top also, as shown in the illustration. After the sides, front, and back are glued together, the bottom is slid into the grooves, and blocked as shown at *b*. The blocks along the sides are usually continuous to form a bigger running surface. If the bottom is not thoroughly seasoned it is apt to split by this method, and it is better to use the planted grooves *a*. The bottom can then be fixed by slot screws into the back, as shown at *S*; this leaves the bottom free to move in the grooves. A small portion of the bottom and back has been removed to show the section of the planted groove. In cheap work the sides run past the back and are trenched to receive the back, instead of dovetailing.

Secret Dovetailing. For good work where no end grain may be shown, the secret, or mitre, dovetail is used. It is not so strong as either of the preceding methods, and rather difficult

to make. Fig. 170 is an isometric view of the two pieces, prepared ready for assembling; after which it appears to be an ordinary mitred joint. Both pieces are first prepared as piece *b* in Fig. 171, then the pins are formed on piece *a*, and the mitre formed. It is then placed in

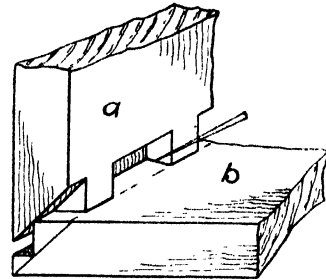


FIG. 171. PREPARING SECRET DOVETAIL

position on piece *b* as in Fig. 171, and the pins are marked for the eyes. Piece *b* is then completed, and the joint glued and assembled. The mitres are usually prepared by a shoulder plane. The secret dovetail is often employed for the external mitres of hardwood plinths and skirtings.

Hinging Joints. Hinging and shutting joints are of many forms, some of which will be

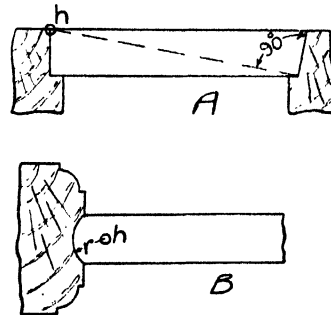


FIG. 172. HINGING AND SHUTTING JOINTS

illustrated as they occur in the examples of joinery. Several examples are given here to show the principle of construction. Every point in plan will move in an arc of a circle, which is struck from the axis of the hinge. Hence the shutting joint will form a tangent to this arc; that is, it will be bevelled, instead of square, the amount of the bevel depending upon the width and thickness of the door or sash. Fig. 172, *A*, shows the plan of a door and frame, the thickness of the door being exaggerated to make the method clear. Draw a line

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from the axis of the hinge to the farthest inside point of the door; then the joint will form a right angle with this line. A pivoted swing door is illustrated at *B*. The centre of the pivot *h* is the centre of curvature *r* for hollowing out the

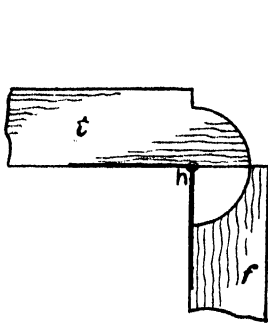


FIG. 173. KNUCKLE JOINT

frame. The edge of the door, however, should not fit the frame, as shown, but should have a little clearance inside, to ensure free working.

Fig. 173 shows a *table, rule, or knuckle joint*. The common application of this joint is for a wall hanging table, where a square joint is not desired. The centre of the hinge *h* should be on the inside edges of the two pieces to give a close joint as shown. When the flap *f* is raised it will form a level surface with the top *t*.

Dwarf Screen Doors, jib doors, etc., sometimes prove difficult to the beginner. Fig. 174 is a dwarf screen door with capping as used in banks, offices, etc., and shows the method of cutting the capping *C*. The plan *B* should be drawn full size (on the capping itself if desired), and the position of the hinge *h* marked on the plan. In this case it is on the joint *j* between door and framing. The next step is to decide upon the amount of the stop *s*, and then describe a circle with radius *r*, from the centre *h*. The capping is then cut, as shown by the double line. The sectional elevation *A* is not required except to project the plan *B*. When the capping has been cut, and fitted, the part *f* is fixed to the framing and the part *p* is fixed to the door. The curved arrow shows the direction in which the door opens. The shutting edge of the door should be rebated and the capping should have a straight splayed cut as described for Fig. 172, *A*. If there are any other projecting members, such as plinth, bed mould, etc., the same method would be applied as to the capping.

FASTENINGS

In addition to the various methods of joining together woodwork, we generally have to reinforce the joints by the use of glue, nails, screws, bolts, coach screws, etc.

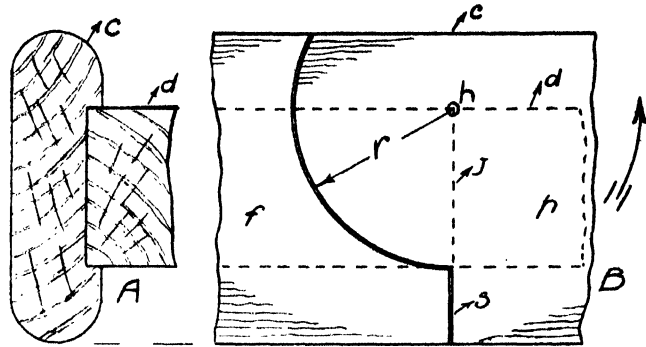


FIG. 174. DWARF SCREEN DOOR

NAILS. A variety of nails is shown in Fig. 175. There are many other forms on the market, but it is seldom that the carpenter or joiner uses any other kind than those illustrated. The *round wire* nail *A* is very good for fixing, because of the round head, but it has a tendency to split the wood and looks unsightly. Hence the *oval*

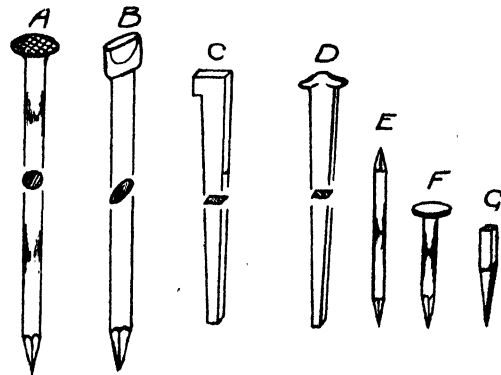


FIG. 175. COMMON TYPES OF NAILS

wire nail *B* is preferred by the joiner. It is the most commonly used for all purposes, and may be obtained from $\frac{1}{4}$ in. to 6 in. long. The head is very small, and besides not tending to split the wood, it may be punched with the nail punch, without leaving an unsightly hole. Both the round and oval wire nails are polished bright, like steel. The small nails are often called *sprigs*.

Wrought and cut nails are blue black in colour and are used only in rough work. A familiar type of wrought nail is shown at *D*; they have been superseded by the wire nails. The *floor brad C*, which is still the favourite nail for flooring, is a cut nail. It is stamped

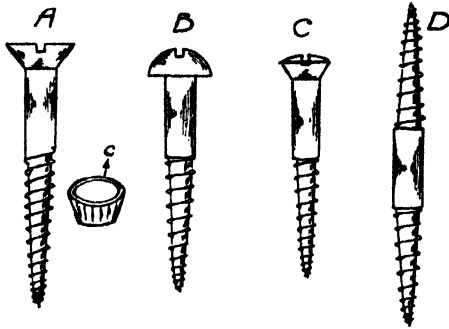


FIG. 176. COMMON TYPES OF SCREWS

from a sheet of metal, hence it is parallel in thickness. As it is generally only used for flooring, the usual sizes are 2½ in. or 3 in. long. The wrought nails *D* may be obtained much longer, like the wire nails. The larger varieties are called *spikes*.

The *clout nail F* is usually about ¾ in. long and has a large flat head. It is used for fixing sash cords to the sashes, and for nailing felting, etc. The *jointing or dowel pin E* is not a nail, but is similar to a round wire nail pointed at both ends. It is used for the same purpose as dowels, for jointing together shelving, box sides, etc. The two pieces forming the joint are marked and gauged as for dowels, and the holes prepared by the bradawl. The pins are driven half-way into one piece, then the edges of the boards are glued and the boards are cramped together. *G* is a special form of cut nail for fixing in panes of glass before puttying. It is a glazier's point and is usually ½ in. to ¾ in. long.

Needle points are needles without eyes. They are very fine, and brittle, so that they are easily broken to the required length.

It is seldom that any preparation is required for nailing. When the nails are near the end and edge of the stuff, however, it is advisable to bore by either the bradawl, or brace and bit, to prevent the wood from splitting. When the nail is driven home, it is usual to punch it below the surface, and then *stop*, or fill, the hole. If the surface has to be painted, putty is the usual stopping. For varnished pitchpine a mixture of litharge and glue is used, which sets very hard.

Whiting and glue make a good hard stopping for white woods. For polished hardwoods, beeswax is generally used. See page 388.

SCREWS. Screws are used where nails do not give sufficient security, or where the fixed piece may have to be removed, or for appearance. They may be obtained in iron, brass, copper, or gunmetal, and they may have a japanned, galvanized, oxidized or nickel plated finish. The sizes vary from ¼ in. to 6 in. long, and they are in various strengths, which are denoted by numbers. Hence a screw is said to be, say, a 1½ in. number 10. The most common form is shown at *A* in Fig. 176. This is known as a *flat headed screw*, and where it is required to be removed occasionally, as in cover boards for pipes, etc., it is often provided with a cup *C*.

Round heads B and *raised heads C* are generally used for fixing metal fittings to woodwork. The *jointing or dowel screw D* is very good for making a light joint, end to end, or for assisting a glued joint in small work. Only one screw can be used in either case, because the screw is fixed firmly into one piece and the other piece is *screwed* on to the projecting half of the screw.

BOLTS. For heavy work we use bolts, as shown in Fig. 177, *B*. The sizes are nearly unlimited, and both the head and nut may be of

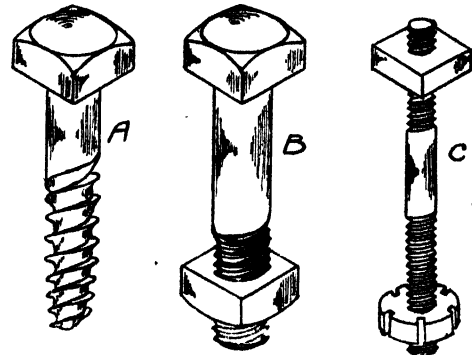


FIG. 177. BOLTS AND COACH SCREW

varied shapes. The *coach screw A* is another excellent fastening for heavy work, and is often used as a decoration for oak doors, etc. For both bolt and coach screw, a spanner is required when fixing in position. The *handrail bolt C* is the best fastening for end to end joints.

WOOD TO BRICK FASTENINGS

In Fig. 178, a pipe nail for fixing down-pipes, etc., is shown at *A*. It is usually 3 in. to 4 in.

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long by $\frac{1}{4}$ in. to $\frac{3}{8}$ in. diam. for driving into the joints of brickwork, or plugged holes. The *holdfast* *B* is used for fixing all kinds of woodwork to brickwork; it is commonly used for

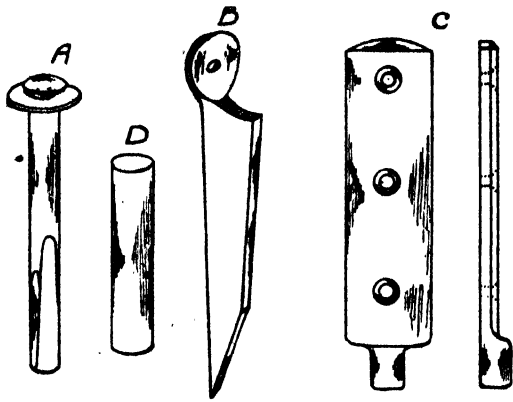


FIG. 178. VARIOUS TYPES OF FASTENINGS

window frames. The feet of door posts are usually held in position on the stone sill by a metal dowel *D*, which is about 2 in. long and $\frac{1}{2}$ in. diameter. The dowel is driven up into the foot of the post and let into a corresponding hole in the sill; it can only be used for new

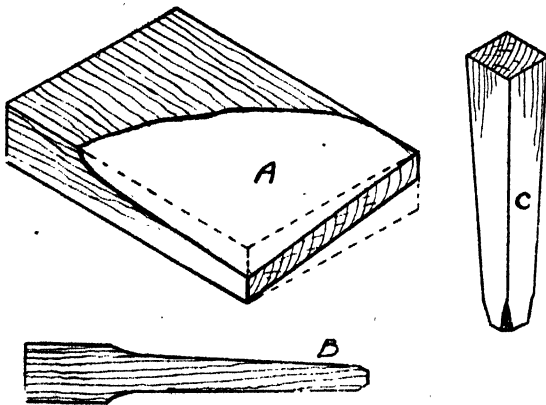


FIG. 179. WOODEN PLUGS

work. For repairs, or when a post has not been securely fixed originally, a *plate dowel* *C* is used; this is about 6 in. long, and the dowel at the end about $\frac{3}{4}$ in. long by $\frac{1}{2}$ in. diameter.

Plugs, Nogs, and Plates. The most common method of fixing woodwork to brickwork is by *plugging*. The mortar joint is cleaned out with a plugging chisel and a wooden plug is driven tightly into the joint. The method of making

the plug is shown at *A* in Fig. 179, and *B* shows a longitudinal section. They are usually made of well seasoned pine or redwood, and about 4 in. by 3 in. by $\frac{1}{2}$ in.; but the size depends upon the brick joint, and upon the work which it has to do. In new work it is a common practice to *build in* pallets *A* or wood nogs *B*, Fig. 180, as the work is being erected. The pallets are 9 in. by 4 $\frac{1}{2}$ in. by about $\frac{3}{8}$ in. and the nogs are the same size as a brick. For small fixings it is usual to drill a circular hole with the *drill* and to drive in a square plug as shown at *C* in Fig. 179.

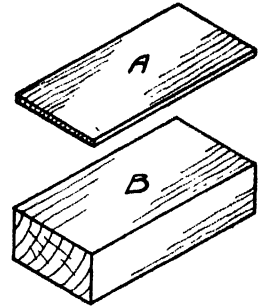


FIG. 180. WOOD NOG AND PALLET

The *Rawlplug* method of fixing is shown in Fig. 181. A hole is drilled and a hollow tube of compressed fibre is inserted. The screw opens out the cylindrical tube, which grips into the brickwork. The *Mellex* is a similar type, but the tube is of soft metal with a lip to prevent it from turning. A convenient method of fixing to concrete is shown in Fig. 182. A hole is chiselled out, larger at the back. The fixing is then inserted and *run in* with any of the quick setting cements that do not contract on

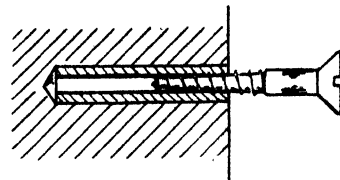


FIG. 181. RAWLPLUG

drying. In stonework it is usual to *run in* with lead. The *glassplate*, Fig. 183, is very convenient for fixing mirrors, etc. to the wall. It is screwed to the back of the frame, and then screwed to the wall.

FIXING SHELVING. Three methods of supporting shelving are shown in Fig. 184. The *shelf nog* *A* is a common method for new work. It is usually 3 in. by 2 in., and long enough to carry the shelf and also go about 4 in. into the brickwork. It is then plugged in position, as shown, before plastering the walls. Two forms of brackets are shown at *B* and *C*; the *wall cleat* is plugged to the wall, and either steel brackets

B or wooden brackets *C* are fixed to the cleats. Other methods of fixing will be described as they arise.

DOOR AND WINDOW FURNITURE

Hinges. The T-hinge, Fig. 185, is the usual form used for batten doors. It is generally

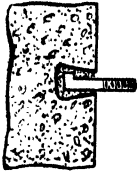


FIG. 182. FIXING IN CONCRETE

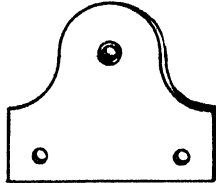


FIG. 183. GLASS PLATE

screwed to the boards, but it may be screwed to the ledge if the frame will allow for it, or is packed out. For heavy doors the *band and gudgeon*, Fig. 186, is generally used. In this case the band *b* is bolted and screwed to the ledge, which is made possible by the projection of the gudgeon *g*. The door can be easily removed.

BUTT HINGES. This type of hinge, shown in Fig. 187, is used for panel doors where there is sufficient thickness of material to take the screws in the edge of the door. When it is required to open the door flat to the wall and it has to clear an architrave or other projection, a *Parliament hinge*, Fig. 188, is used. If the parliament hinge is required for ornamental work, the knuckle *K* is specially shaped and it is called a *pew* or *egg-joint* hinge. This type is used on pew doors. The *rising butt* hinge, Fig. 189, is used where the floor is not level, and it is required to raise the door for clearance as it opens. The hinge has a helical knuckle joint.

FLOOR SPRING. A special form of hinge is required for swing doors which have to open both ways. The usual form is the *floor spring* shown in Fig. 190. The door is fitted and screwed into the shoe *s*, which has a pivot resting in the plate *p*. This pivot is actuated by a spring in the box *b* which always tends to keep the door closed. When the door opens it swings to and fro until the spring brings it to rest. The top of the door has a pivot working in a socket which is fixed to the head of the frame.

HELICAL HINGE. This type of hinge is also used for swing doors. Fig. 191 shows an open helical hinge used for the top hinge. One plate *a* is fixed to the door and the other plate *b* to the

frame. The barrels *d* and *e* contain springs which may be tightened or slackened by turning the collar *c*. A steel pin is provided to insert in the small holes when turning the collars. When the door is swinging it rotates on each barrel in turn. Full instructions for fixing are given with the hinges. The bottom or blank hinge is different and does not contain springs, because the weight of the door presses on to the bottom hinge.

PIN HINGE. When a door with butt hinges has to be removed occasionally, *pin* hinges are used. These are ordinary butts with an ornamental pin *p*, Fig. 187, which can be removed, to avoid unscrewing the hinges.

FASTENINGS. The usual fastenings for a batten door consist of a *thumb latch*, sometimes called a *Suffolk*, or *Norfolk* latch, and one or two barrel or tower bolts. The Suffolk latch is shown in Fig. 192 which shows the appearance on each side of the door. The handle *h* is fixed on the outside of the door and lifts the latch *l* which is on the inside of the door. The latch slides in the *carrier c*, and engages with the *catch a* which is fixed to the frame. The *tower bolt* is shown in Fig. 193. The bolt *b* shoots into a staple which is fixed to the frame. For better

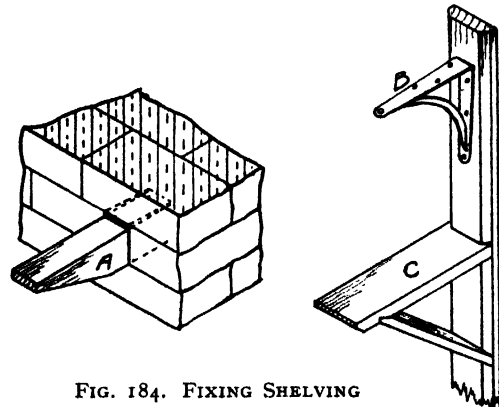


FIG. 184. FIXING SHELVING

class work the bolt is often let into the material and the bolt is behind the face plate, and inside the material.

LOCKS. There is a large variety of locks, both of types and quality. The *rim lock* shown in Fig. 194 serves both as a latch and a lock. The latch *a* is turned by a square spindle passing through the hole *s*, and which carries a pair of *knobs*, or handles. The bolt *b* serves as a lock and is worked by a key. A *receiver*, or *box*, is fixed to the frame to receive the bolt and

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latch. When there is no latch it is termed a *dead lock*.

The *stock lock*, Fig. 195, is a strong type of dead lock. It is made of hardwood, which makes it especially useful for outside work and stable doors, because iron quickly corrodes under these conditions.

MORTISE LOCKS. The mortise lock, Fig. 196, serves the same purpose as the rim lock, both as a latch and a lock. The advantage of this type of lock is that it is buried inside the door. Hence it cannot be removed when it is locked; and also it is not unsightly. The chief disadvantage is the fitting, which is rather troublesome unless special tools are used.

Fixing Mortise Lock. The lock is laid on the face of the door at the required height and with the face plate *f* level with the edge. The key hole and spindle hole are then marked and bored, and also the position is marked of the body *b*. A series of holes are then bored in the centre of the edge of the door, and a little deeper than the length of the lock. The diameter of the brace bit should be a little bigger than the thickness of the body of the lock. The waste wood is then cleaned out with a mortise lock chisel. The lock is pushed into the hole and the face plate marked and fitted into the edge of the door. Before fitting the face plate, the joiner should make sure that the key and spindle holes will coincide with the bored holes through the door. It does not matter how loosely the body of the lock fits into the prepared mortise; but it is important that the face plate *f* should be cleanly fitted into the door edge. The face plate is removed and the back plate *p*, which is part of the body, is securely screwed to the edge of the door. The two screws *s* are set-screws to fix the face plate to the back plate. The striking plate *a* is let into the frame, or casing, to receive the latch and bolt.

Keyhole escutcheons are used to cover up the keyholes. *Roses* are fixed between the handles and the door, to cover the spindle holes, to provide ornamentation, and to steady the spindle.

A useful type of mortise lock has a cylindrical body, or barrel, so that one boring with a brace and bit is sufficient; also it does not disturb the tenons of the lock rail, which is the chief drawback to the ordinary type of mortise lock. In good work, where the doors are sufficiently thick, the lock rail is provided with double twin tenons to prevent the weakening of the joint.

Other common forms of locks are the *night latch*, or *latch lock*, and the *Yale lock*. The former has only a latch which is operated by a key from one side and a sliding knob on the other side. It is a favourite type of lock for entrance doors. The Yale lock is also very common for entrance doors; its chief advantages are its neatness and the peculiar type of corrugated key. The makers claim that the lock cannot be picked, and that every lock has a differently shaped key which is numbered for duplicating if necessary. The lock is very easily fixed.

WINDOW FASTENINGS

Sash Windows. The usual form of *sash fastener* for the ordinary sash and frame is shown in Fig. 197. The plate *a* is fixed to the meeting rail of the top sash and carries the latch *c*. The plate *b*, which carries the catch *d*, is screwed to the meeting rail of the bottom sash.

The *thumb screw*, Fig. 198, is used for fixing the sashes when they are open for ventilation. The screw *s* passes through the inside sash and engages with the plate *b* which is fixed to the back sash. It is also used for fixing the sliding sash in a Yorkshire light.

Casement Windows. Fig. 199 shows a stay for fixing a casement in any position when it is open. The plate *a* is fixed to the sash and the plate *b* to the frame. The screw *c* fixes the stay in the required position. The *quadrant*, or *fanlight opener*, Fig. 200, is used for opening or closing a fanlight which is too high for operating otherwise. An endless cord *c* turns the pulley *w* which moves the sprocketed wheel along the stay. The plate *a* is fixed to the sash and moves with the mechanism. The plate *b* is fixed to the frame.

The usual type of *casement fastener* is shown in Fig. 201. The catch on the plate *b*, which is fixed to the frame, is inverted, as shown, so that the weight of the handle *h* keeps the latch engaged with the catch. The plate *a* which carries the cranked handle is fixed to the casement. When the frame is thicker than the casement the catch is dispensed with and a slot is mortised in the frame to receive the latch. The mortise is covered by a brass slotted plate.

Casements are fixed either by *butt hinges* or by *pivots*. The usual form of pivot is shown in Fig. 202. The pivot *a* is usually fixed to the sash, and the socket *b* to the frame. The method of fixing will be dealt with in the chapter on windows.

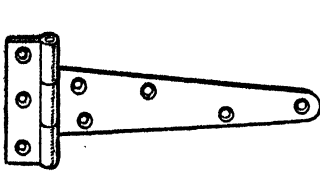


FIG. 185. TEE HINGE

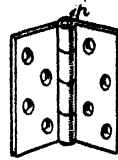


FIG. 187. BUTT HINGE

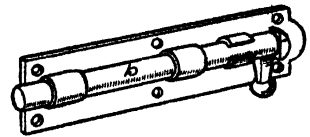


FIG. 193. TOWER BOLT

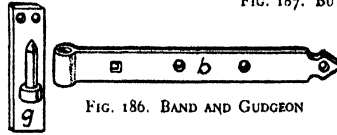


FIG. 186. BAND AND GUDGEON

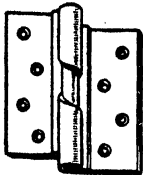


FIG. 189. RISING BUTT HINGE

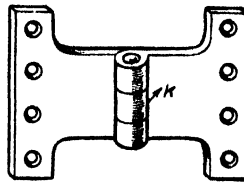


FIG. 188. PARLIAMENT HINGE

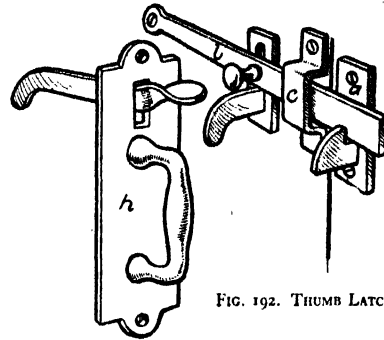


FIG. 192. THUMB LATCH

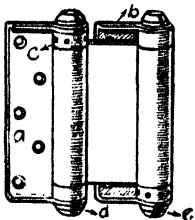


FIG. 191. HELICAL HINGE

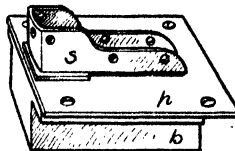


FIG. 190. FLOOR SPRING

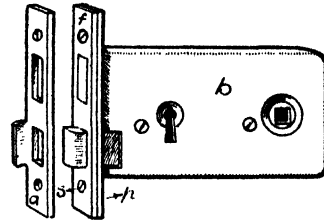


FIG. 196. MORTISE LOCK

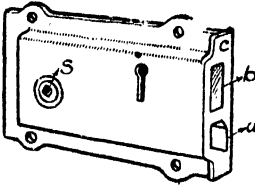


FIG. 194. RIM LOCK

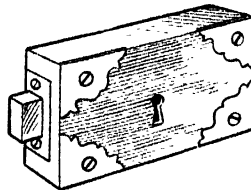


FIG. 195. STOCK LOCK

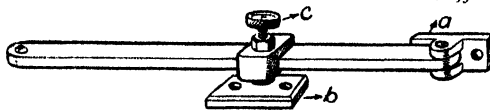


FIG. 199. CASEMENT STAY

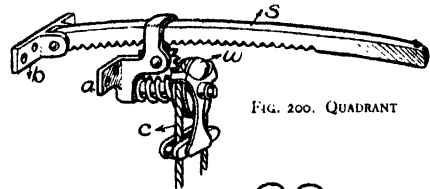


FIG. 200. QUADRANT

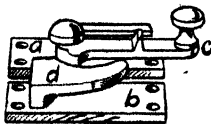


FIG. 197. SASH FASTENER

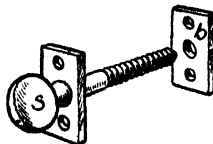


FIG. 198. THUMB SCREW

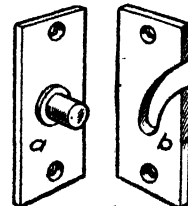


FIG. 202. PIVOT AND SOCKET

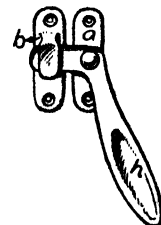


FIG. 201. CASEMENT FASTENER

DOOR AND WINDOW FURNITURE

Chapter V—MACHINE SHOP PRACTICE

MACHINERY is now the most important asset for competitive work. No matter how small the joiner's shop may be, it is essential that there should be machinery of some type if progress is to be made. Every joiner should be able to operate the simpler forms of machines, and to be considered an efficient craftsman, he must be familiar with the capabilities of machinery generally. This chapter will deal, in detail, with the machines suitable for a small shop, and briefly with the equipment necessary for the larger shops.

The blocks and photographs of the machines used to illustrate this chapter have been supplied by Haigh's Ltd., Oldham, and T. Robinson & Son, Rochdale. It must be understood that the illustrations only represent one type out of many. The driving of the machines may be by shafting driven by electricity, gas, or steam, but the most economical for small shops is the direct motor feed. Each machine has a fast and loose pulley supplied ready for driving, but the actual driving depends upon so many factors that it has not been considered here. For foundations, and for laying out the machines to the best advantage in the space available, it is best to seek the advice of the makers, which is always freely given. It is essential, for Board of Trade requirements, that all machinery and belting shall be protected and fenced to prevent accidents so far as possible.

SAWS

Breaking Down, or Log Saws. There are many varieties of this form of saw. The log band saw is a continuous saw which makes a single cut, and is used for heavy work. The saw may run horizontally or vertically. Fig. 203 shows a medium log frame, under driven, with roller feed. This type will make a number of cuts at the same time, with a balk up to 30 ft. long by 3 ft. square. The rate of feed varies considerably according to the number of cuts and the kind of wood, but it is usually up to about 7 ft. per minute. The feed may be by a rack if required.

Circular Saws. This type of saw, with its bench, varies according to the work it is required to do. The heavy types have drag, or roller feeds, so

that there is little pressure required from the operator. Both saw and bench are fixtures, and to vary the depth of the cut it is necessary to change the saw. The lighter type, for hand feed, is shown in Fig. 204. It has either the saw or the bench arranged for raising or lowering, as required. The illustration shows a rising and falling spindle, that is, the saw can be raised or lowered. This type is preferable for the joiner's shop, because usually the bench surface is continued with a wooden bench for the convenience of the long stuff, etc. The groove in the front of the bench is for a sliding table for cross-cutting and mitreing.

The fence may be moved to or fro in both directions, and may be canted down to 45° to cut on the bevel. The large handwheel is to adjust the saw for depth, and the small handwheel is for fine adjustment of the fence to give the required width of stuff when sawing. Fig. 205 illustrates the method of using the saw, *C*. On no account should the operator allow the hand to get close to the saw teeth, because when the cut is near the end, the stuff often goes through quicker than expected due to shakes, etc. in the timber. To avoid danger the sawyer uses a pushing stick, *S*, to feed the stuff through, and steadies the piece with the left hand, about the position *h*. The end of the fence *e* should go past the saw very little, so that the timber will fall away from the saw immediately the cut is completed; if not, there is a danger of the saw throwing the piece back again. It is also dangerous when the *saw cut* closes up at the back of the saw, due to twisted grain. To obviate this danger, which is termed "back lash," a *iving knife* is fixed at the back of the saw, or the *saw guard g*, is continued down the back of the saw and through the wood packing *w*. In addition, for big stuff, there is usually a "backer off" with a mallet and wooden wedge to open the saw cut. The pocket plate *p*, fills the gap in the bench top *b*, and is necessary to remove the saw. The pocket plate is provided with a rebate near the saw, and a corresponding rebate is formed in the bench top at the back of the saw. These rebates are filled with wooden packings *w* which are wound round with hemp and well oiled. The packings prevent the saw

from "running" out of the straight and "wobbling," and also prevent the saw teeth from touching the metal bench.

Fig. 206 shows how the saw *s* is fixed to the

packings. Thick saws are often used for grooves and give better results than the drunken saw. For making rebates on the circular saw, it is usual to make two cuts at right angles to each

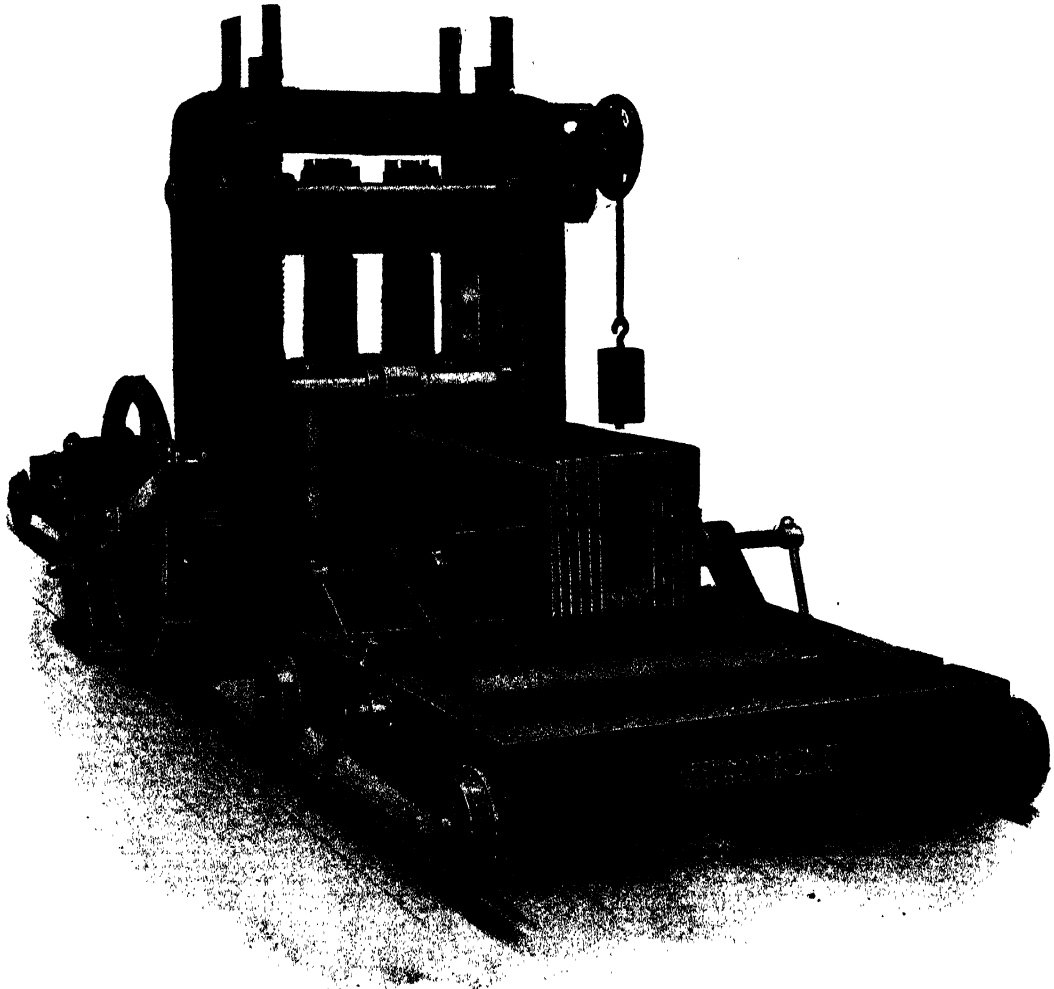


FIG. 203. LOG FRAME SAW

spindle. A pin *p* which is part of the back collar, passes through the saw, and into the front collar *c*; the nut *n* is then screwed up, and it is impossible for the saw to slip when cutting. The packings *w* are used to give eccentricity to the saw when required for grooving, or cutting out the insides for double tenons. These packings make the saw "drunken," but *special collars* are better and more reliable than wooden

other, so that the two cuts just meet each other and the waste wood then falls away.

Fig. 207 illustrates the method of cutting wedges; the small pieces of wood *w*, planed to the required thickness, are cut to length; then a wedge stick *s* is made. The stuff *w* is placed in the wedge-shaped recess in *s* and then run through the saw *c*. The separate sketch *S* illustrates another way of cutting the recess.

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The fence *f* is adjusted to give the required size of wedge, and the piece of wood *p* prevents the wedges from getting to the teeth at the back of the saw, as they accumulate after cutting.

Cross-cut Saws. These saws are used for cutting the stuff to length. The multiple cross-cut benches are fitted with several circular saws.

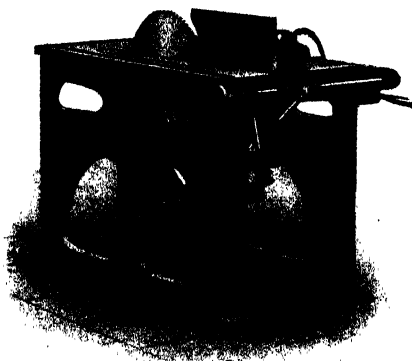


FIG. 204. CIRCULAR SAW BENCH

The common type for joiners' shops is the pendulum cross-cut as shown in Fig. 208. This is a very useful saw for "cutting out" the stuff preparatory to machining. The saw is an ordinary circular saw, but the teeth are cut specially for cross-cutting. The sawyer pulls the saw

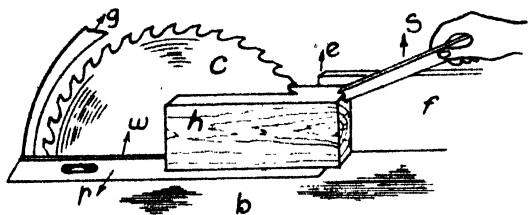


FIG. 205. USING CIRCULAR SAW

towards him when cutting the stuff, hence the guard is in front of the saw.

Bandsaws. These are usually called *ribbon saws* to distinguish them from the log band saws. They may be obtained in many sizes, for light or heavy work. The pulleys *P* vary from 26 in. to 48 in. diameter, and the saws from 14 ft. to 30 ft. long, by $\frac{1}{8}$ in. to 2 in. wide. Fig. 209 shows a useful type for average work, the pulleys being 36 in. diameter. The frame *D* is a one-piece cored casting. For bevel cutting and circle-on-circle work, the table *T* can be tilted down

to 45°. The fence *F* is for straight work, and some bandsaws have a roller feed attachment with the fence. The top pulley may be adjusted by the handwheel *A* for taking up the tension on the saw; this is assisted by the

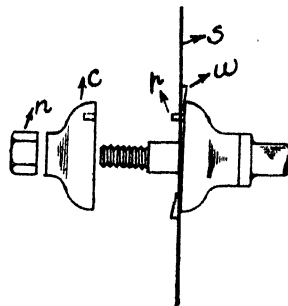


FIG. 206. FIXING CIRCULAR SAW

balanced lever *L*. Small hardwood blocks *B* keep the saw straight to its work; and small revolving wheels *C* prevent the saw from being pushed back when cutting. These guides are placed both above and below the table. The saw is protected by wooden guards *W* and the

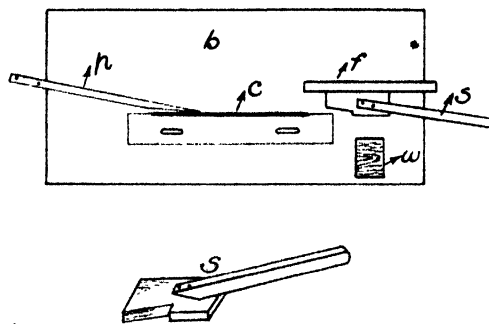


FIG. 207. CUTTING WEDGES

bottom pulley by an iron shield *S*. The starting handle *H* is to put the saw into motion.

PLANING MACHINES

Surfacers. This type of planing machine is intended for planing and straightening surfaces by hand feed, but it may also be used for chamfering, rebating, moulding, etc. The large types are called "trying up" or jointing machines, and some of them will plane up to 30 in. wide, with the tables about 8 ft. long over all.

The cutter block, which must now be of the circular safety type, works below the timber as shown in Fig. 210. These cutter blocks usually have two knives which have a shearing action when cutting, but the heavy types may have up to six knives. Fig. 211 shows the simplest form of this type of cutter block. In most cutter

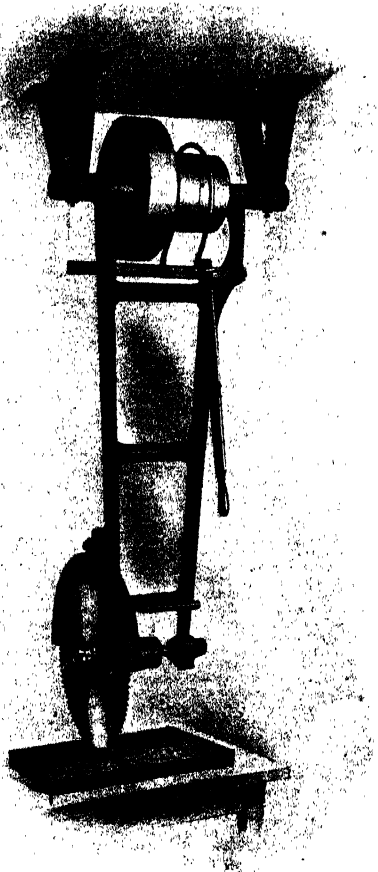


FIG. 208. PENDULUM CROSS-CUT SAW

blocks however, the end is usually arranged for moulding cutters. Fig. 210 is a section through the cutter block, showing the operation of planing. The front table *F* is lowered to the required depth of cut, but the back table *B* is adjusted level with the cutter edge. Hardened steel lips *L* are provided to both tables to prevent wear. The cutter block *C*, which may have a speed of over 6,000 revolutions per minute, is shown fitted with two knives *K*. The knives are fixed by round steel backs *R* which are provided with

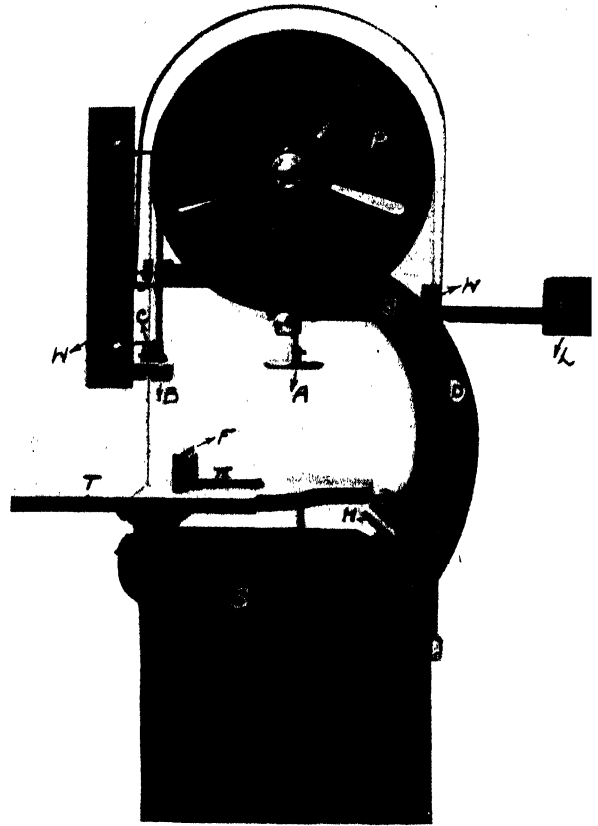


FIG. 209. BANDSAW

clearance. The clearance, besides removing the chippings, provides a partial vacuum which helps to keep the timber down on the table.

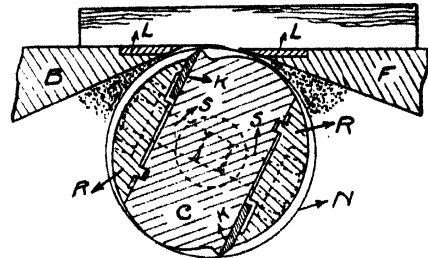


FIG. 210. ACTION OF CUTTER BLOCK

To secure the knives, several studs *S* are used, the nuts of which are sunk in the steel backs (see Fig. 211). The circumference of the cutting edge is shown by the circle *N*.

Panel Planers and Thicknessers. In this

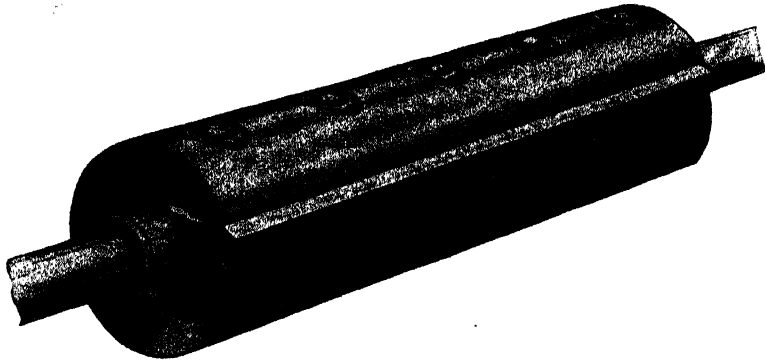


FIG. 211. CIRCULAR CUTTER BLOCK

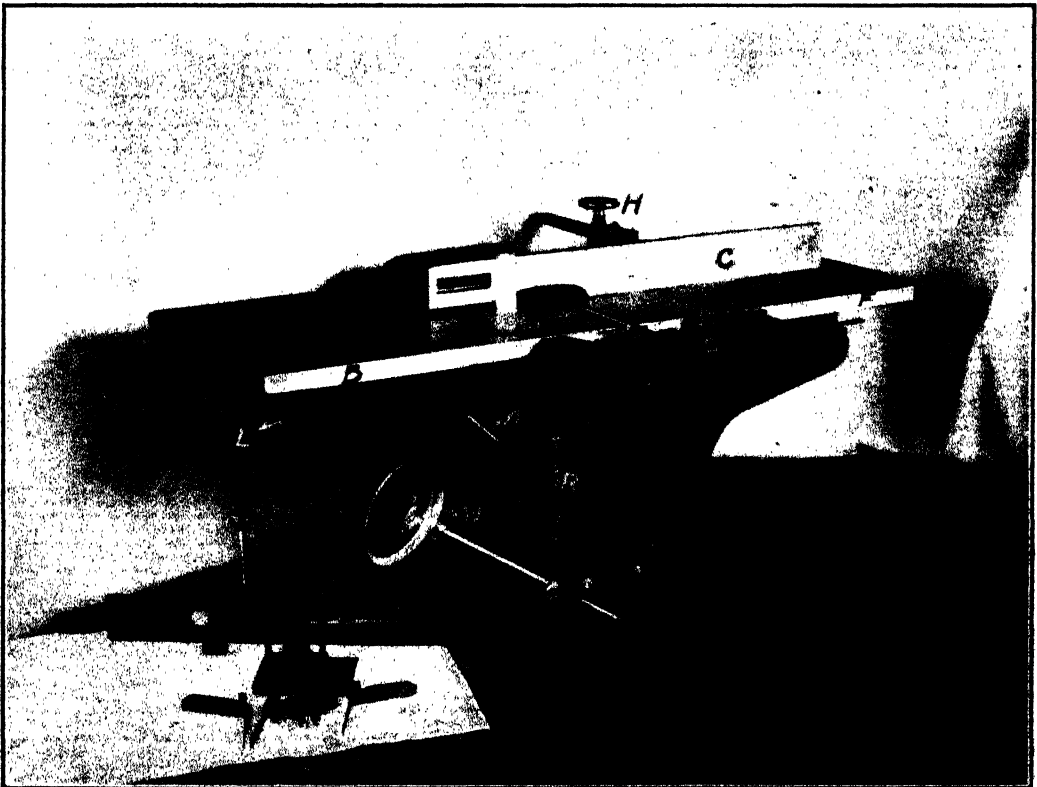


FIG. 212. COMBINED PLANER AND THICKNESSER

type of machine the cutters are above the timber, which is fed by rollers—a fluted roller at the front on the rough stuff, and smooth rollers at the back. The advantage of this type of machine is the parallel thickness of the timber after planing; it is specially suitable for thin stuff such as panels, etc.

Fig. 212 shows a useful combination of surfacer and thicknesser, for small shops. It is

lowered to the required depth. For stop chamfering both tables are lowered. The advantage of this type of machine is that the stuff can be straightened on face and edge on the surfacer, and at once fed through the lower table for width and thickness.

In all planing and moulding machines, it is essential that the knives or cutters should be balanced; that is, the momentum of both

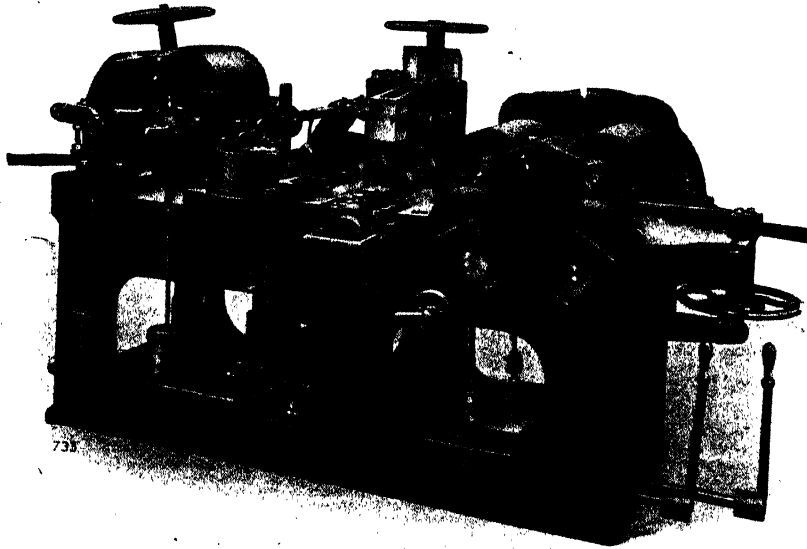


FIG. 213. FOUR-CUTTER

capable also of rebating, chamfering, moulding, etc. The tables *F* and *B* are 6 ft. long overall, by 30 in. wide. The fence *C* is adjusted by handwheel with rack and pinion *H* across the full width of table. This ensures the fence keeping true with the front edge of the table, for rebating, etc. The fence is also fitted with a quick-acting canting arrangement. When thickening, the bottom table *L* is adjusted by the handwheel *W*. An auxiliary fence and side pressure springs may be fitted, enabling mouldings to be fed through by power on the lower table. A guard must be provided to cover the knives when the machine is in operation; it is fixed in the hole *G*. The rule and pointer *R* is to set the lower table to the required depth when thickening. The machine is set in motion by the lever *A*.

For rebating, chamfering and bevelling, the back table is not moved, and the front table is

cutters about the axis of rotation must be the same. It is not necessary for both cutters, when moulding, to project out the same distance, although it is an advantage if they do so. If one is set back it should compensate by being heavier. If they do not balance, the vibration will soon ruin the bearings, besides being a source of danger to the machinist and producing bad work.

MOULDING MACHINES

An essential part of the equipment of large firms, the "four cutter" is a machine for the specialist. There are many types, ranging from three cutters to six or eight cutters, but the term "four cutter" is more general than "moulding machine." The rough stuff is fed into the machine and comes out planed and moulded on all four sides if required. Fig. 213 is an

MODERN BUILDING CONSTRUCTION

illustration of a small machine of this type which will plane and mould timber up to 20 in. by 5 in. The rate of feed can be varied as required,

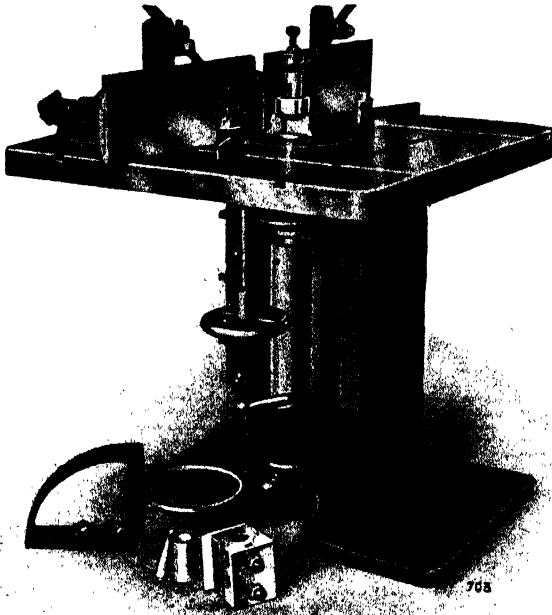


FIG. 214. SPINDLE MOULDER

according to the kind of wood and the amount of cutting which is taking place, but for good class work it should not exceed 60 ft. per min.

Spindle. This machine requires very little driving power, and is quickly set up for operating. It is indispensable even in small shops. Fig. 214 illustrates a common type of single spindle. Moulding may be performed on straight, curved or double curved (circle-on-circle) work. For straight work, the fence shown on the table is used, but it is brought forward in front of the spindle cutters. It is an advantage to face the fence and the table with wood. This enables the machinist to nail strips on the fence to prevent the stuff from canting, when it is being moulded, and for nailing saddles, etc.,

on the table to act as fences. The wood is also a safeguard against the cutters catching the iron fence. For small work, a false fence is sometimes nailed on to the wooden fence, and the cutters allowed to cut their way through the false fence, until they project through as far as required. This is an excellent safeguard against accidents. Top, front and back pressure springs are shown in the illustration; these are to keep the work close up to the fence and table.

MOUNTING THE SPINDLE. There are three methods of mounting the spindle; the illustration shows slotted collars. The cutters are made the correct thickness for the slots, then cylindrical packings are dropped on to the spindle to reach to the locking nut at the top. This type of cutter is used for lighter work and for small curved work. For heavier work the slotted collars are replaced by the square block, shown on the floor. In this case the cutters are fixed to the block by nuts and bolts; the head of the bolt is shaped to fit the dovetail slots in the block. The illustration shows a pair of heavy cutters fixed in the block by two bolts, for planing, but usually the moulding cutters are fixed by one bolt.

A piece of fine sandpaper between the cutter and the block gives greater security.

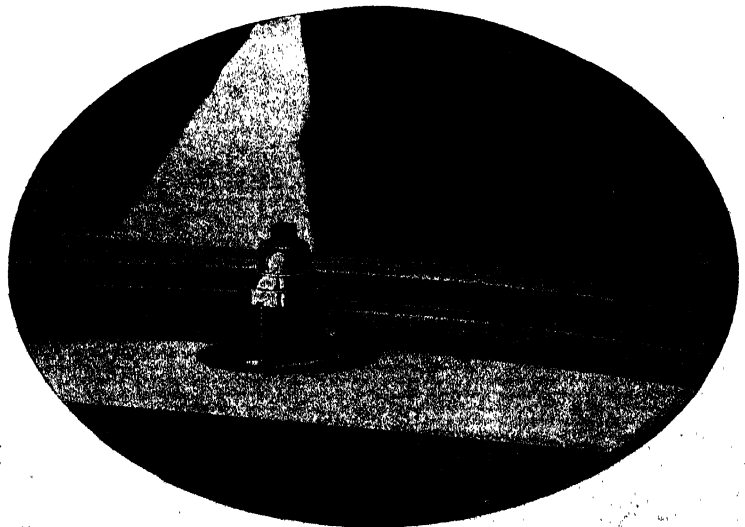


FIG. 215. CIRCULAR MOULDING ON COLLAR

Curved work requires a different fence, but the cutters are fixed up in the same way. The straight fence is replaced by a *ring*, one form of which is shown on the floor in Fig. 214. The work is pressed up to the ring, which may be above or below the cutters. Sometimes wooden curved fences are fixed to the table instead of using the ring. When using the slotted collars it is often convenient to run the work on the collar, as shown in Fig. 215

In this case a *templet* is fixed on the top of the stuff for running on the collar; the "sticking," or moulding, is a rebate and ovolo for sash stuff. The use of this templet or jig, avoids the necessity of cleaning up the stuff to the correct curvature before moulding.

The handwheel below the table, Fig. 214, is to raise or lower the spindle as required, and below the handwheel is a locking lever to prevent the handwheel turning by vibration. Below the table the spindle is increased in diameter to take the driving belt.

French Spindle. The term *French spindle* is applied to spindles which are slotted, as shown in Fig. 214, just above the slotted collar. In this case, a single cutter $\frac{1}{8}$ in. thick is passed through the slot in the spindle, and a long set-screw passes down the centre of the spindle to fix the cutter. The set-screw is shown in the illustration projecting above the spindle. Both ends of the cutter are often cut to the same shape, so that it is perfectly balanced. Usually the stuff runs on the bare spindle.

SHAPE OF CUTTERS. The speed of a spindle may be over 7,500 revolutions per minute, so that the cutters must be carefully balanced and fixed, otherwise the bolts or the cutters may break. An experienced machinist can tell by the sound whether the irons are balanced or not. The shape of the cutters is not quite the reverse of the required moulding, the difference increasing with the distance they project from the axis of the spindle. Hence, when running on the bare spindle there is very little difference, but with the square block the difference between the cutters and the finished moulding may be considerable, each member on the cutter being elongated. The shape can be found by drawing the plan of the cutters, but the machinist can always get the correct shape by applying the cutters to a templet, at the same angle as the cutter strikes the stuff.

Double Spindle. When moulding curved work we have part of the work against the grain. To prevent this, most spindles have a

reversible motion, that is, the cutters revolve in the opposite direction and the stuff is fed left handed. To obviate this reversing, we have the *double spindle*, which is simply two spindles to the one table. The two spindles can then be set up, in pairs, for the same moulding, but revolving in opposite directions. Each piece of stuff can then be finished off at once. Another advantage is that one can be set up to finish off an incomplete moulding on the other. The speed of spindle machines makes the projecting irons difficult to see, hence the machinist should use special care and keep his hands as far from the cutters as possible, as shown in Fig. 215.

HINTS ON USE OF SPINDLE. There are numerous appliances for attaching to the spindle for special work. The *stair-housing* appliance is easily attached and is very useful for all kinds

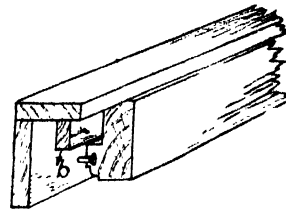


FIG. 216. CRADLE FOR SMALL STUFF

of trenching, such as stair strings, etc. *Wing cutters* are often used for work which is some distance above the table, to avoid the use of the *top steady*. These cutters are *twisted* from a piece of *cutter iron* so that the centre part is horizontal and the ends vertical. The centre part is bored to drop on to the spindle bolt and the vertical ends are shaped to the required outline of the moulding.

Cradles, or saddles, Fig. 216, are used for small stuff, or stuff circular in section. Usually the cradle is nailed to the stuff, especially if it is not rectangular, to prevent it twisting whilst moulding. Packings similar to *b* should be nailed on the back fence to prevent the stuff *canting* as it comes through. Fig. 216 shows a sash bar moulded on one side and ready for moulding on the other side.

"Circle-on-circle," or double-curvature work is moulded by keeping the convex side of one curvature in contact with the table opposite the spindle; the other curvature runs on the ring or spindle collar. If it is required to work with the concave side down, it is necessary to use a *dumpling*, which is a wooden block turned

MODERN BUILDING CONSTRUCTION

to the shape of a large inverted basin and dropped over the spindle. When using the dumpling the spindle has to be raised well above the table, and then a *top steady* is used to prevent the spindle "wobbling." All cross-grained timber should have the sharp arrises of

used for trenching stair strings, recessing panels, etc. For recessing, a compound sliding table is used. The machine is also capable of the following operations: boring, slotting, panel raising, *therming*, dovetailing, tenoning, etc. For *therming*, or square turning, a horizontal

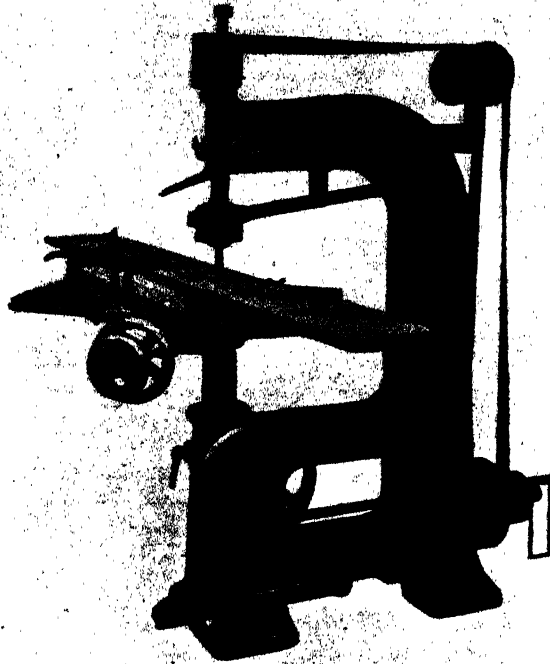


FIG. 216A. RECESSING MACHINE, SHOWING ATTACHMENT FOR CUTTING HOUSINGS IN STAIR STRING BOARDS

The above illustration shows the machine cutting housings in string boards for stairs. A simple attachment for this work enables the operation to be very quickly performed. It consists of a hardwood table with an adjustable ledge to which a pointer is attached. This table is pivoted at a point coinciding with the string nosing and is moved over to an adjustable stop fixed to the main table after each cut, to obtain the taper for the wedges. The stop collars provided on the front of the table are fixed to give the desired length of cut

a moulding cut with a marking gauge to prevent tearing up the fibres; a little care in this respect will save time in cleaning up.

Universal Moulding, or Recessing, Machines. These machines are often called *elephant spindles*. There are two cutter blocks, one below the table, and the other suspended from a projecting arm over the table. The lower spindle is used in the ordinary way as described for the spindle machine. The top spindle is

square cutter block, mounted on a vertical slide for attaching to the overhanging arm, is provided, also a pair of headstocks with dividing apparatus.

MORTISING AND TENONING MACHINES

Mortising Machines. A combined chain-cutter, hollow chisel mortiser, and boring machine is shown in Fig. 217.

The chain cutter, which is on the left of the machine, is a continuous chain mounted on a steel block, with a sprocket wheel at the top.

vary together, a thin cutter making a narrow mortise. This is the easiest and quickest method of mortising.

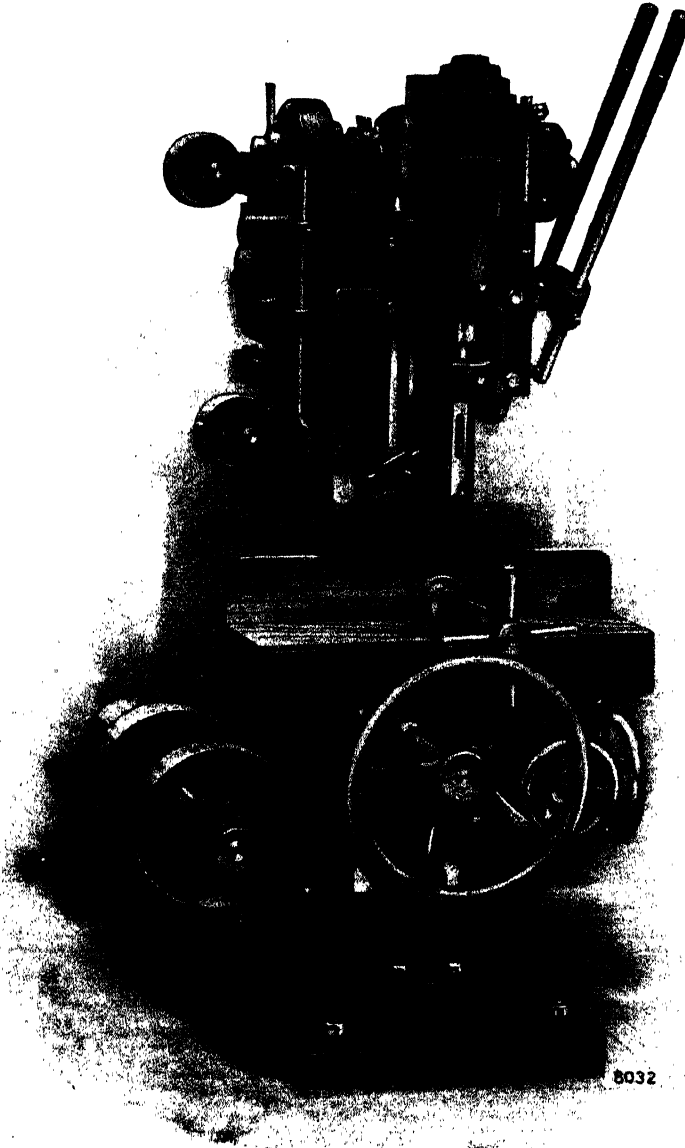


FIG. 217. CHAIN MORTISER

The chain cutter will complete a mortise with one downward stroke, the size of the mortise depending upon the size of the chain. The maximum size is about 3 in. by 1 in., and it will cut about 6 in. deep. The thickness and width

The hollow chisel, Fig. 218 B, consists of two parts; the outer part, which governs the size of the hole, is a hollow square, *sharpened on the inside*; the inner part is a twist bit running down the inside of the hollow square chisel.

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The twist bit works slightly in advance of the square bit and removes the wood; the square bit simply trims the round hole into a square one. These chisels are usually supplied up to

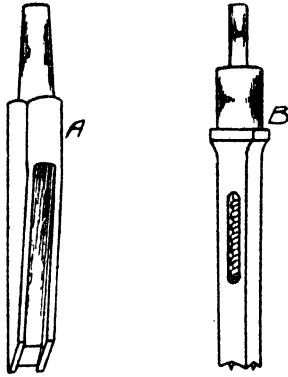


FIG. 218. MORTISE CHISELS

1 in. square for the type of machine shown in Fig. 217.

For ordinary boring, the square chisel is removed and an auger only is used. The chain and the chisel are independent of each other, each being actuated by its own handle. The table is adjustable vertically and horizontally. A special automatic sharpener is supplied for sharpening the chains. Large holes can be bored or sunk, and discs can be made by attaching a *tubular saw* to the boring machine. This "saw" is shaped like the top half of a wine bottle, the bottom edge being cut into saw teeth.

Multiple machines may be obtained to bore a number of holes or mortises in one operation.

LEVER MORTISER. Where no power is available a *hand mortiser*, as shown in Fig. 219, is used. The chisel, which is shown in Fig. 218 A, is driven through the wood by the hand lever. These machines require no explanation, as every joiner has had experience with them. The easiest way to use the chisel is to adopt the same method as when using the mallet and chisel. Start at the middle of the mortise and work up to one end, then reverse the chisel and complete the mortise on one side. The depth should be a little more than half-way through the stuff. The stuff is then turned over, always keeping the face side to the fence, and the mortise is completed from the back. The chippings, or *core*, have to be removed by a *core drift*, which is fixed in the machine in the same way as the

chisel. The chain cutter, however, may work straight through the stuff from the face edge, because it does very little damage to the fibres as it breaks through on the back, especially if the wooden table below the stuff is in good condition. The rough ends of the mortise, on the back, are cleaned up by hand for the wedge room.

Tenoning Machines. This useful machine, shown in Fig. 220, is capable of making single or double tenons (with top and bottom scribings), cross-cutting, haunching, trenching, etc. There are four cutter blocks—top and bottom blocks A and B for the tenons, and top and bottom blocks C and D for the scribings. The machine in the illustration will take timber of any size up to 12 in. by 4 in. and will cut tenons up to 5 in. long. If the tenons are required to be more than 5 in. long the timber has to be passed through the cutters twice. For *double tenons* a drunken saw is fixed to the bottom vertical spindle D. A circular saw S is fixed to an independent spindle; but usually the saw is fixed to the top tenoning spindle A for cross-cutting. The table T runs on dust-proof rollers and is fitted with a quick-acting eccentric lever

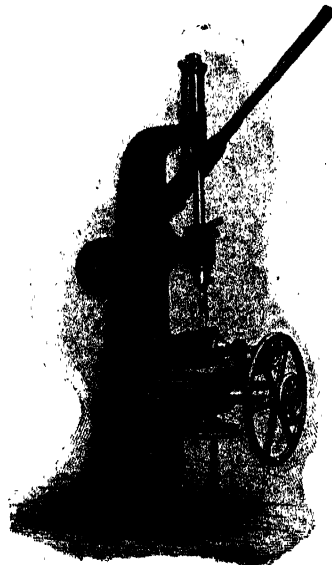


FIG. 219. LEVER MORTISER

clamp, or *clip bar R*, for holding the stuff while tenoning. An ordinary hand clamp may be used instead if desired. The fence is a piece of angle iron bolted to the table, and it can be adjusted for shoulders which are not at right

angles to the stuff. The fence has been omitted in the illustration. All the cutter blocks are adjustable by the various screws *E*, in any direction. Two spring stops *P* are used for fixing the length of the shoulders. The tenoning blocks have two side cutters *a* for forming the shoulders, and two horizontal cutters *b* for forming the tenons. The former cut a little in ad-

Checking requires a special table operated by a rack and pinion and fitted with a *dividing apparatus*.

Larger types of tenoners may be obtained, and also *double ended* tenoners with a chain feed are made, to tenon both ends of the stuff at one operation.

Combination Machine (UNIVERSAL WOOD-

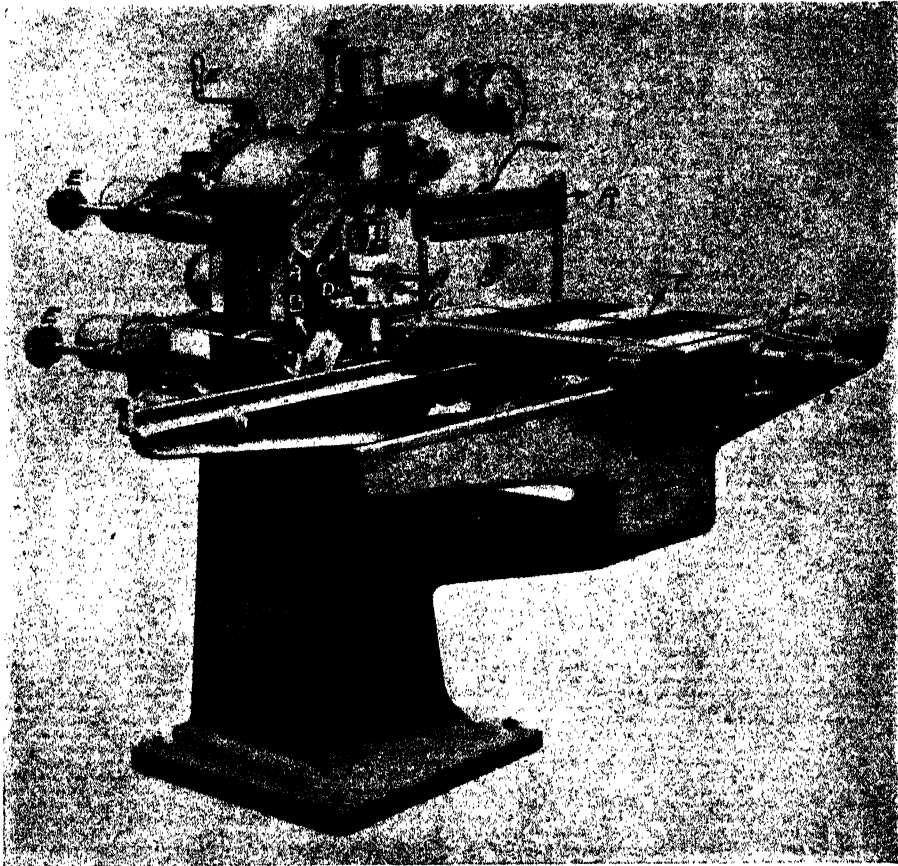


FIG. 220. TENONER

vance of the latter, and the latter are arranged to give a shearing cut; both of these features are intended to prevent the splintering of the wood beyond the shoulders.

The machine is capable of many other operations, such as *trenching*, *checking* for ship's gratings, *square turning*, etc. Trenching is performed by a special saw, or a cutter block fixed to the top spindle *A*. Square turning requires a cutter-block on either top or bottom spindles *A* or *B*.

WORKER). The small builder is usually handicapped by lack of room and money, and finds it impossible to equip himself with the individual machines. To overcome the difficulty there are many combinations of the foregoing machines. These combination machines will perform all the operations previously described, but there is considerable time wasted in changing from one operation to another, and only one part of the machine can be used at the one time, with safety.

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Fig. 221 shows an excellent combination. This machine is capable of sawing, planing, thickening, moulding (circular or straight), mortising, boring, tenoning, recessing, sandpapering, etc. The operations are performed as for the

side down and cut the tenon on the face side, *over the block*; then lower the table and pass the stuff *under the block* to complete the tenons. The capabilities of the machine are too numerous to explain in detail, and full particulars

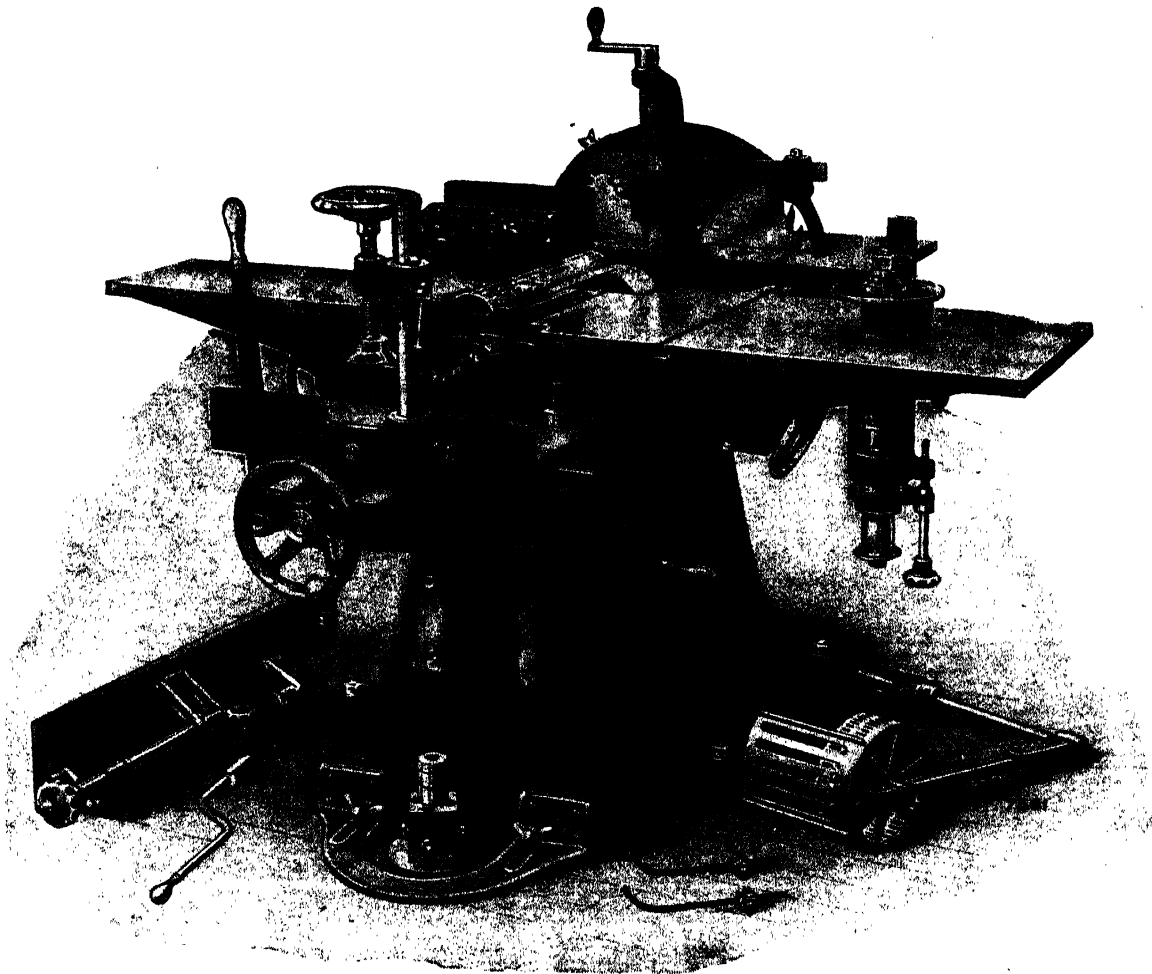


FIG. 221. UNIVERSAL WOODWORKER

individual machines. For thickening, the saw bench table is lowered below the spindle, and a power roller-feed apparatus is attached. A square block is fixed on to the spindle instead of the saw. The block may carry planing irons or moulding cutters. The same arrangement is required for tenoning, but a tenoning block is attached instead of the square block. Tenoning requires a double operation. Place the face

may be obtained from the makers of these machines.

The machine in Fig. 221 is shown ready for sawing, planing, boring, and moulding on the separate spindle, on the right. This separate spindle, however, is only supplied when specially ordered. By the machine, from left to right, are shown the following accessories; straight fence for planer, cranked key, straight fence for

spindle, square block and collars for spindle, pressure springs, spindle guard.

SANDPAPERING MACHINES

Sanders are made for all purposes, from sandpapering small cylindrical work to all kinds of panelled framing, etc. Portable machines are used for sanding floors. The various types are: bobbin, disc, drum, belt (vertical or overhead), dowel, portable, etc. The belt and drum sanders are used for joinery, and the drum sander may have up to eight drums for sanding both sides of the work. Different strengths of paper are used to work up to a finished surface and the cylinders have an oscillating motion to avoid scratching the wood. Also see page 388.

The *endless belt machine* has a system of pulleys to carry the belt of sandpaper. The belt may be 45 ft. long and is usually about 6 in. wide. The belt runs over a pivoted table which carries the work. The machinist presses the paper on to the work with a hand pad and gives it an oscillating movement as the belt revolves. For mouldings the belt has a canvas backing so that it will bend to the *rubber* without breaking. The *rubber* is the reverse shape to the moulding, as for hand sandpapering. An exhaust fan is attached to each machine to carry away the dust.

The endless belts are cut to the required length from a roll, and jointed with a special *jointer* and then backed with gummed paper; a good joint is difficult to distinguish. The abrasive for machines is usually aluminous oxide, flint, or garnet. The backing is manilla paper or white duck cloth. Flint paper is from 3/0 up to 4, and special quality garnet paper is graded from 4/0 to 3. There has been great improvement in these machines within recent years, and they are becoming indispensable in the large shops.

Repairing Equipment. A certain amount of equipment is necessary to keep the saws and machines in order, such as automatic saw sharpeners and knife grinders, emery wheels, grindstones, grinding apparatus for chain cutters, brazing apparatus for band saws, swaging tools, cutter balance, etc. Small shops usually send the saws away to be re-cut, and the large plane irons to be ground

OTHER MACHINES

Improvements and variations are continually taking place, especially in the quality of the materials, bearings, speeds, gearboxes, safety devices, etc., and machines may now be obtained for nearly every kind of specialist work. Large machines may have twenty motors for the different operations. The rate of feed varies with the kind of wood and type of machine, but the rate of feed of a surfacer may be up to 450 ft. per

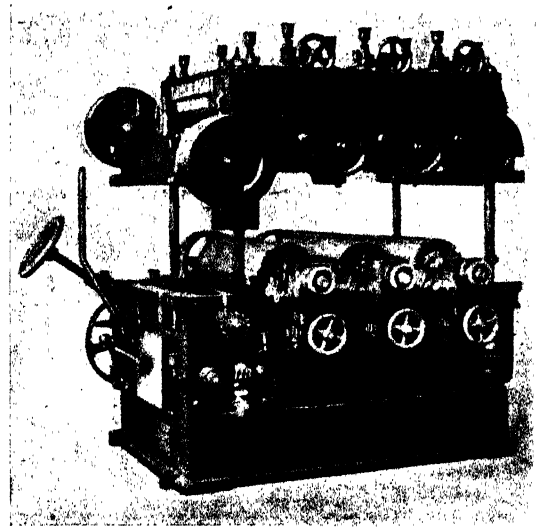


FIG. 221A. ROLLER FEED TRIPLE DRUM SANDER

minute, and some machines may have a speed of 20,000 revs. per minute. The variety of machines used in woodworking and now standardised include: blocking, boring, branding, checking, chucking, combing, copying, corner locking, cramping, dowelling, dovetailing, drilling, edging, elephant, four-cutter, general joiner, glue spreader, grinders, guillotine, handle, jointer, joint gluer, lathe, matcher, mortiser, moulding, nailing, panel shaper, planing, plugging, pointing, recessing, rounding, router, sander, screwing, shive, slicer, slotting, spindle, squaring off, surfacer, taping, tenoner, thicknesser, trenching, turning, universal, veneer cutter and press, etc., together with a great variety of sharpeners, grinders, etc.

Chapter VI—DOORS AND DOOR FRAMES

DOORS are generally classified as *ledged, ledged and braced, framed and ledged, flush, and panelled*. The last named may have any number of panels, and they are named according to the number of panels, or to some special feature, such as *double*

with a bead or *V-joint*. The width is about 6 in., but they are selected from stock so as to build up the width of the door without leaving narrow outer boards. The ledges are usually about 6 in. by 1½ in., and they are bevelled to throw off the water when used outside. The end elevation in Fig. 222 shows three different forms of ledges. The best form for outside work is shown at *C*, because of the throating *t*. The usual method of preparing the edges for inside work is shown at *A*, whilst *B* is suitable for either inside or outside work.

In constructing, select the boards to build up the width, and cramp them together, so that they can be tested. If there is any surplus width, it should be divided between the two outer boards. Sometimes it is necessary to reduce the width of all the boards to make them uniform. The boards then require ploughing again for the grooves. Cut the ledges to the correct length and *return* the ends on the trimmer machine. Mark the position of the ledges on the back of one of the outer battens. Nail or screw the ledges on the batten so that they are square to the edge of the batten. Turn the whole over on the bench so that the ledges lie "out of twist." Place the remainder of the battens in position; cramp up the battens, and nail to the ledges with three or five nails, as shown in Fig. 224. The edges of the battens should be painted, and also between the ledges and battens, before assembling.

Lledged and Braced Doors. Fig. 223 shows a ledged door with the addition of *braces*. The braces, which are the same size as the ledges, make a much stronger door and prevent the door from dropping at the *nose n*. The bottom of the braces must lie on the hinge side, otherwise they would be of little use. The position of the hinges is shown at *h*. Two methods of "letting in" the braces are shown in Fig. 223; either method is good. The usual method is to nail the door together as for Fig. 222, and then fit the braces in and nail the battens to them.

DOOR FRAMES. The usual type of frame for batten doors is known as a *solid frame*. A small portion of the frame is shown in Fig. 222, which also illustrates the method of hanging the door with *bands and gudgeons*. The *garnet hinge* is

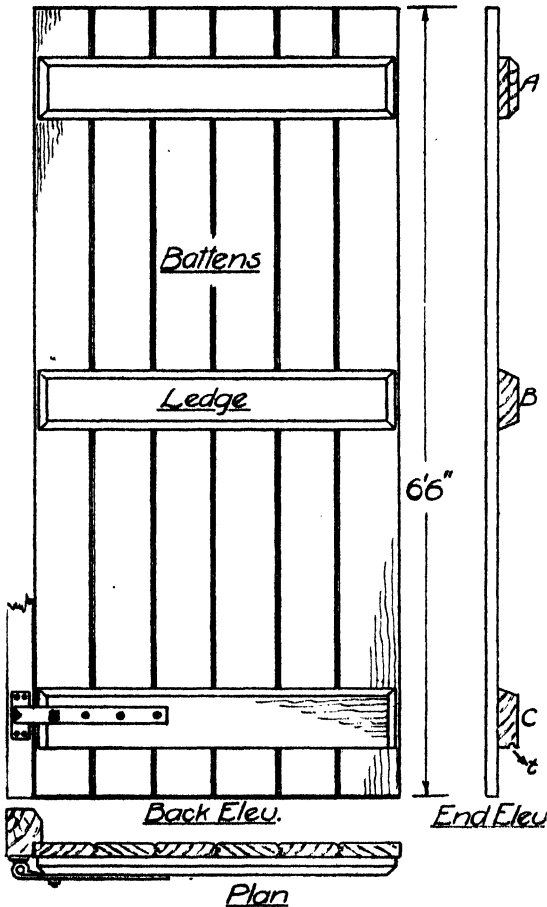
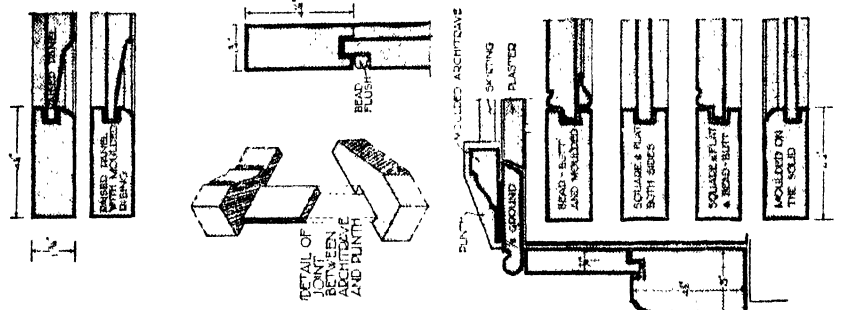
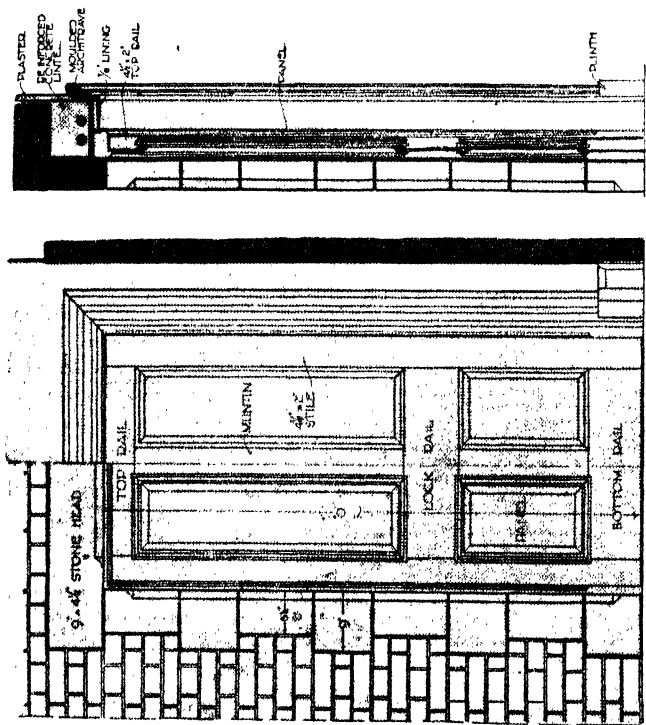


FIG. 222. LEDGED DOOR

margin, sash, Gothic, etc. There are many special types as, *folding, sliding, revolving, dwarf, jib, etc.*

Lledged Door. This is the simplest form of door, as shown in Fig. 222. It is generally used for outbuildings and temporary work. The door consists of a number of *battens*, or boards, and three or four *ledges*. The battens are usually 1 in. thick and they are tongued and grooved,

DETAILS OF EXTERNAL DOOR.



SECTION

OUTSIDE INSIDE ELEVATIONS

PLAN

CONSTRUCTIONAL DETAILS OF FOUR-PANELLED DOOR AND FRAME

very often used instead of bands and gudgeons. Sometimes the rebate in the frame is dispensed with, and the door planted on the face of the frame.

Fig. 224 shows the same type of frame, but rebated for a 2 in. door. The frame stiles, or *jamb*s, are fixed at the feet by iron dowels *d*, as shown also in Fig. 226. The head is generally built into the brickwork. Three different methods of tenoning the stiles to the head are shown in Fig. 225. The usual method is shown at *A*,

top rail, and ledges, makes a strong door very suitable for weathering. The stiles and rail are usually 2 in. thick; that is, they are equal in thickness to the ledges and battens together. Fig. 224 shows half outside elevation and half inside elevation. The battens run from the rail

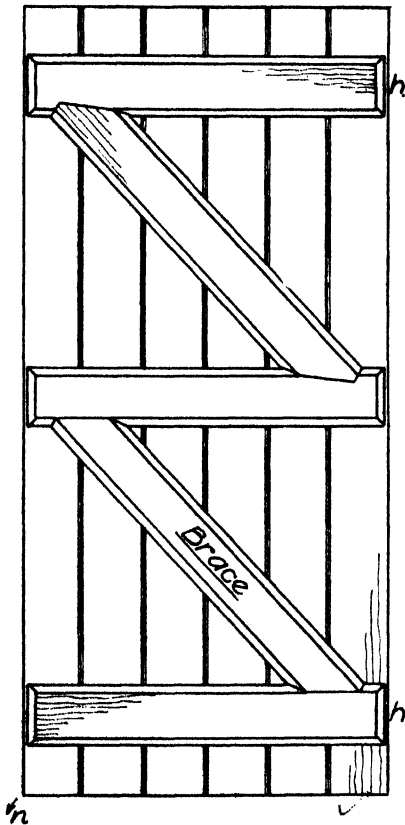


FIG. 223. LEDGED AND BRACED DOOR

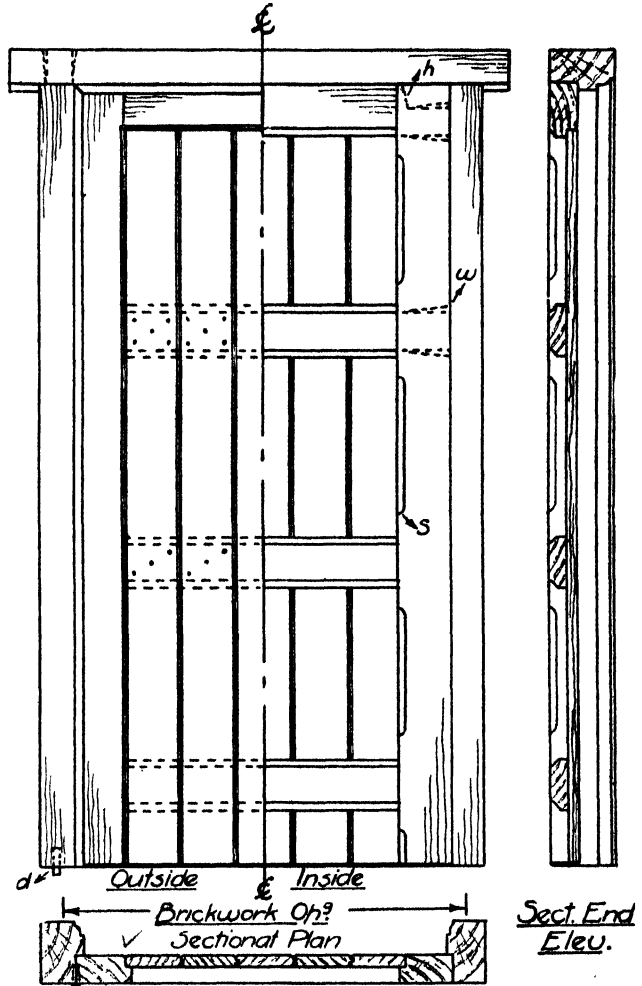


FIG. 224. FRAMED AND LEDGED DOOR

the ovolo moulding being scribed as at *s*. A mitred joint *m* is shown at *B*, where the return bead will not allow for scribing. For wide frames it is common practice to make double tenons as at *C*, which also shows a scribed joint.

Framed and Ledged Doors. Fig. 224 shows a framed and ledged door as used for external positions where appearance is not very important. The framing, which consists of stiles,

to the floor. Sometimes the framing includes a bottom rail, 2 in. thick, which is rebated to receive the battens. The stiles and top rail are rebated for the battens. If the boards are too narrow to build up the width, the stiles may be ploughed instead of rebated. The top rail is tenoned into the stiles as for a panelled door, which will be described later; but the ledges have a bare-faced tenon. See Fig. 230 (B). The ledges are very often wider than shown in

MODERN BUILDING CONSTRUCTION

Fig. 224, and arranged as in a four-panelled door isometric projection. One stile is removed and several parts broken to show the method of

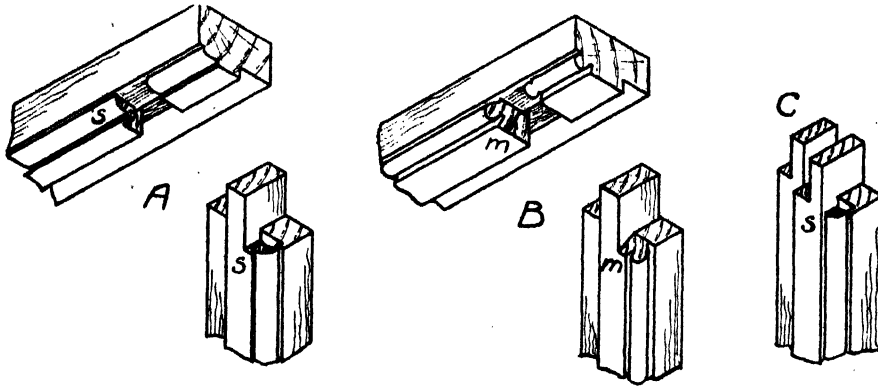


FIG. 225. DETAILS OF SOLID FRAME

stop-chamfered, *s*, but the chamfers on the ledges run through. All the members of the framing are flush on the back. The door is hung with butt hinges, braces being added if required.

FANLIGHTS. The frame for the above type of door generally has a *fanlight* as shown in Fig. 226. This provides both light and ventilation. The stays *s* are intended to keep the frame square until it is fixed. The sectional plans *a* and *l* show the methods of finishing off the frame inside the building. The architrave *a* is used where the frame is flush with the plaster. When the reveal is continued, a lining *l*, or plaster, is necessary. The *transom* *t* receives the head of the door and the hinges at *b* for the fanlight sash. Sometimes a hopper *h* is used to prevent draughts. The method of making the sash will be described in the chapter on "Windows."

Panelled Doors. For better class and inside work the doors are usually panelled. They consist of framing, which is grooved to receive panels of thinner material, the number of panels depending upon the size of the door and the taste of the designer. Fig. 227 shows a six-panelled door in

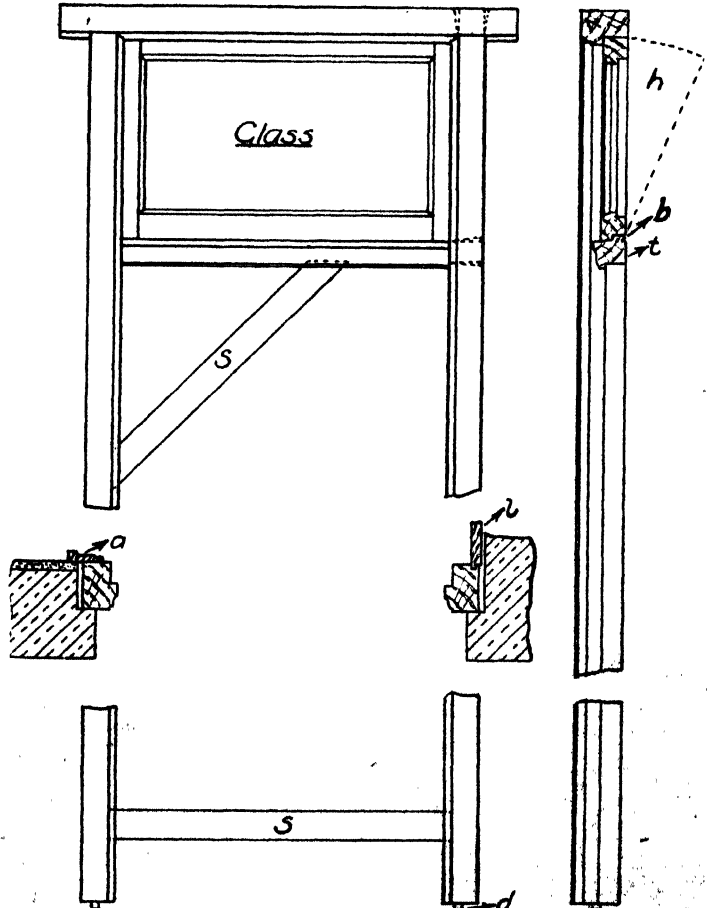


FIG. 226. FRAME WITH FANLIGHT

construction. The names of the various members are given on the drawing. The extra part of the stiles, or *horn c*, is to protect the corners of the door until it is hung.

The common type of panelled door has four panels, that is the *frieze* rail is omitted. The usual sizes are 6 ft. 8 in. by 2 ft. 8 in. and 6 ft. 6 in. by 2 ft. 6 in. The thickness varies from 1½ in. to 2½ in. A 6 ft. 8 in. by 2 ft. 8 in. by 1½ in. door, with a solid frame, has been selected to illustrate the preparation of joinery work.

SETTING-OUT. The first step is to set out the work *full size* on a *rod*. The size of the rod, or board, should be just sufficient to set out the work clearly, so that another person can proceed with the work without difficulty. The drawings on the rod are generally confined to *sections*, except for circular work, and only the essential details are shown. Fig. 228 shows the usual method. The first step is to set out the brickwork opening and then give the correct margin. In addition to showing the work, the rod should give the number of the job and name, the number of doors or other work required, the position on the job, and how finished (painted, polished or varnished). It is convenient to have all the details on one side of the rod, but generally both sides are used as in Fig. 228. The *setter-out* assumes that the joiner has a general knowledge of the work, and usually only shows the same detail once. For instance, in the simple case of the panelled door, the joiner knows that all the panels on one side will have the same kind of panel moulding; hence it is only shown in one place.

CUTTING LIST. The *list of materials* required is taken from the rod. Large firms have their own printed forms, and the form on the next page shows the usual type of cutting list, though it is subject to much variation. The last six columns are for office use only.

Two carbon copies are made out in addition to the original sheet, so

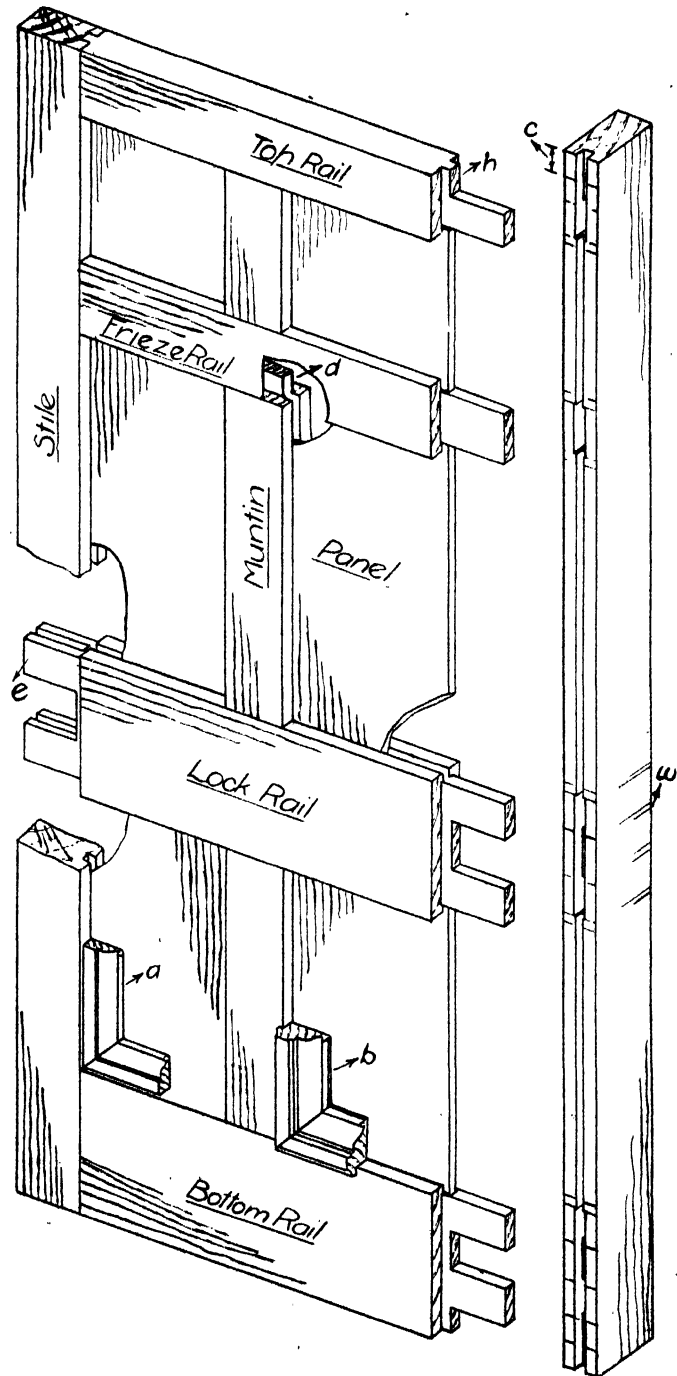


FIG. 227. PANELLLED DOOR

MODERN BUILDING CONSTRUCTION

that the setter-out, machinists, and the office each have a copy. The machinists' copy accompanies the stuff through the various

that the stuff may be selected and used to the best advantage.

After "cutting out," the material is sent to

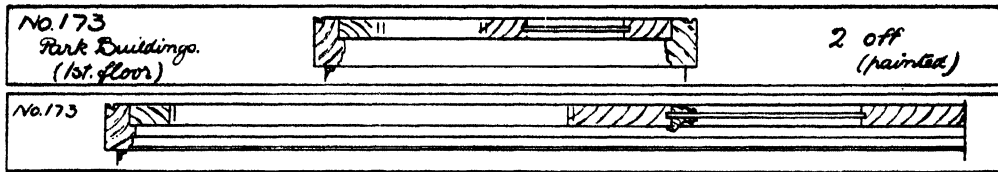


FIG. 228. ROD FOR DOOR AND FRAME

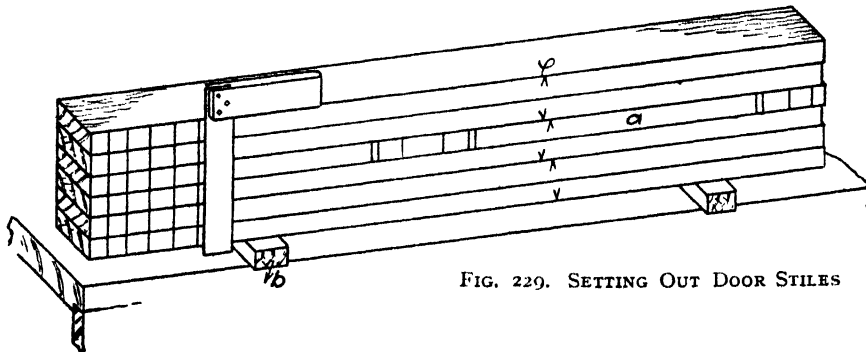


FIG. 229. SETTING OUT DOOR STILES

processes, together with the rod and sometimes detail drawings. The cutter-out (sawyer) and machine shop foreman should know the position of the work and its importance, so

the machines. The machinists complete the various operations from the rod and drawings, and the stuff is received by the joiners ready for assembling.

G. BUILDER & CO., LTD., LONDON

No. of Rod.....173.....

Date8/12/45.....

Name of Job.....Park Buildings.....

Description of Work.....2 Panelled Doors and Frames (1st floor).....

No. of Pieces	Description	Wood	L.	B.	T.	Finished Sizes		Cube	Cut	Rate	£	s.	d.
						B.	T.						
4	Stiles (Fr.)	Redwood	6 11	5	3	4 1/2	2 1/2						
2	T. Rail (Fr.)	Redwood	3 6	5	3	4 1/2	2 1/2						
4	Stiles (Door)	Yellow Pine	6 10	5	1 1/2	4 1/2	1 1/2						
2	Heads	Yellow Pine	2 8 1/2	5	1 1/2	4 1/2	1 1/2						
4	L. and B. Rail	Yellow Pine	2 8 1/2	10	1 1/2	9 1/2	1 1/2						
2	Munt.	Yellow Pine	2 -	5	1 1/2	4 1/2	1 1/2						
2	Munt.	Yellow Pine	3 3	5	1 1/2	4 1/2	1 1/2						
	Bolection Mld.		54 -	2 1/2	1 1/2	From stock							
	Panel Mld.		54 -	2	1 1/2	From stock							
4	Panels	Yellow Pine	3 -	10	1 1/2								
4	Panels	Yellow Pine	1 10	10	1 1/2								

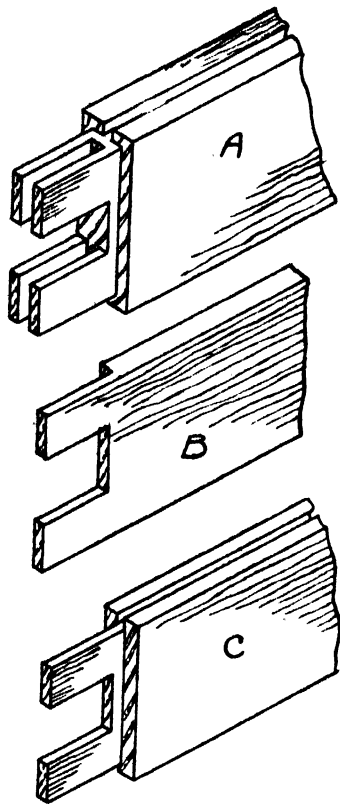


FIG. 230. TENONS FOR LOCK RAILS

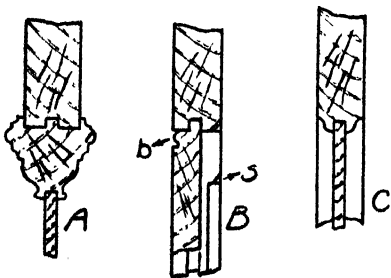


FIG. 231. PREPARING PANELS

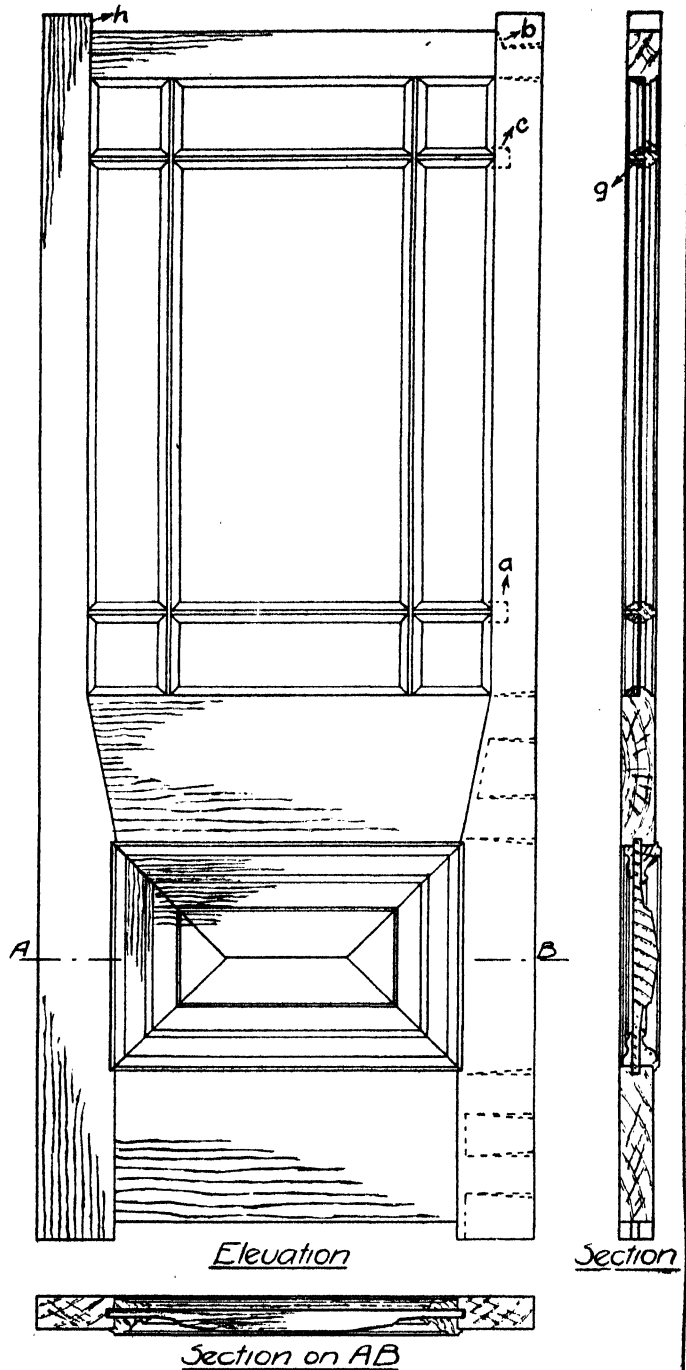


FIG. 232. DOOR WITH DIMINISHED STILES

MODERN BUILDING CONSTRUCTION

In the smaller shops, however, the joiner receives the rod from the foreman, together with the planed-up stuff. He has to see the job through and set out all the stuff for the machines. The following is a description of the procedure under these conditions.

SETTING OUT THE STUFF. Arrange the stuff to the best advantage and mark the face side and

shoulders. The *muntins* may be set out from the stiles, allowance being made in the length of the muntins for shrinkage, or discrepancy in the width of the rails.

Preparation. The mortises and the tenons should be prepared, and then all the stuff ploughed for the panels. A piece of waste stuff is ploughed at the same time to test the panels

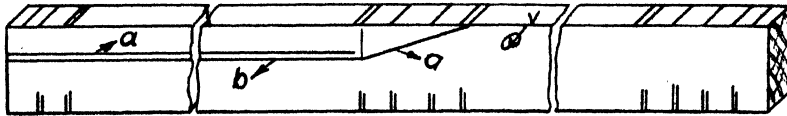


FIG. 233. DIMINISHED STILE

edge of each piece. Set out one stile, marking the position of the rails and mortises on the face edge. Square the mortises over to the back edge and mark the wedge room. The mortises are the depth of the panel groove from the edge of the rails. Next place the stiles together in pairs, as shown in Fig. 229. The stile which was first set out is marked *a*, and shows the position of the top, bottom, and lock rails.

for thickness. This piece is called a *mullet*, and the process of using it on the panels is termed *mulletting*. The method of preparing the tenons is shown in Fig. 227. The top and bottom rails are *haunched* at *h* for wedging, and the muntins are stub-tenoned at *d*.

Fig. 230, C, shows the usual method of preparing the lock rail, and A shows double tenons as used for specially thick doors, to receive

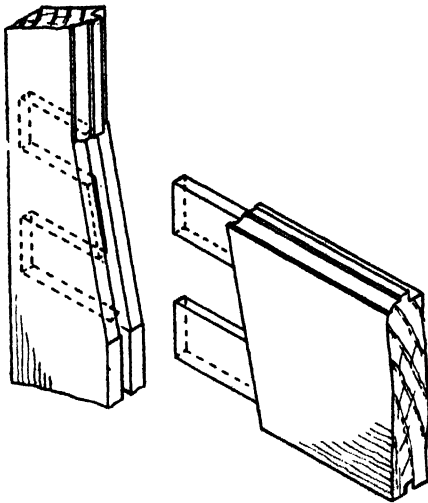


FIG. 234. JOINT OF LOCK RAIL

The V marks point to the face side. Square over the lines on all the edges, back and front.

Set the mortise gauge to a mortise chisel which is approximately one-third of the thickness of the stuff. Then set it to the middle of the stuff and gauge the mortise holes from the face side. Next set out one rail for tenoning, if there is a tenoning machine; if not, all the rails will require to be squared over for the

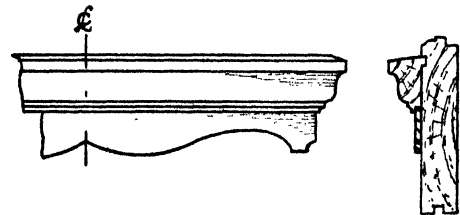


FIG. 235. APRON MOULDING

the mortise lock. The lock rail of a framed and battened door has bare-faced tenons as at B.

SECOND SEASONING. The doors should now be put in a warm, dry room for *second seasoning*. The stiles and rails are knocked loosely together, and the doors are stacked so that they are out of twist. The muntins are generally placed near the doors. The time for seasoning depends upon the kind and condition of the stuff and the urgency of the job, and it may vary from two weeks to six months. The material for the panels should be seasoning at the same time.

PANELS. The panels should be cut to size so that they have a clearance of $\frac{1}{8}$ in. all round. They should be mulleted for easy assembling. Many good doors are spoiled through the panels being too wide; generally, a little expansion takes place when the doors get on the job, and the panels force off the stiles; this, of course, applies to seasoned stuff.

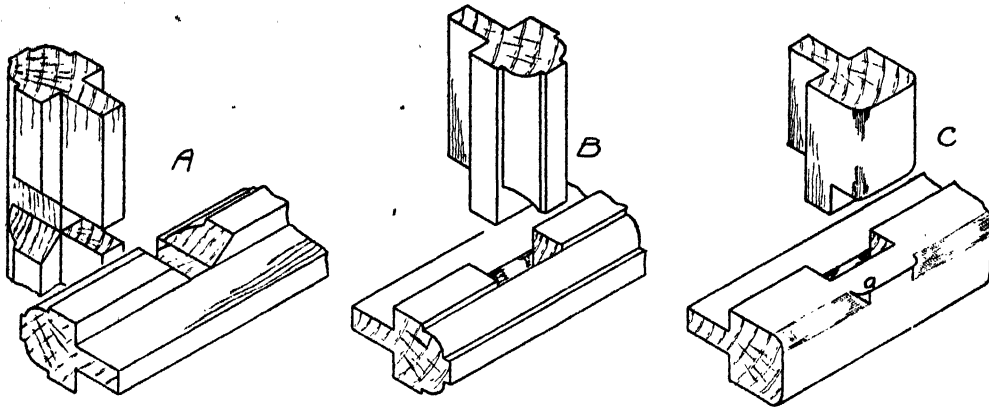


FIG. 236. PREPARING BARS

ASSEMBLING. When all the parts have been fitted, commence assembling in the following order: bottom rail, muntin, panels, lock rail, muntin, panels, head, stiles. Knock everything up to test the joints; then knock asunder for gluing. The tenons and shoulders of the muntins and rails should be glued, but care should be taken not to put any glue on the panels. The ends of the rail tenons should not be glued, so that the joints will hold if the stiles shrink. Cramp up the door on a level surface, dip the wedges in the glue, and wedge up. The top rail should be wedged to drive it down, and the bottom rail to drive it up. This tightens the shoulders of the muntins. The door should now be put on one side for the glue to harden. It is then planed up, sandpapered, and moulded.

MOULDING THE PANELS. Fig. 227 shows a panel moulding at *a* and a bolection moulding at *b*; the latter gives a bolder appearance to the door. Small mouldings are usually cut in the mitre block to the correct length. Large mouldings are generally mitred on the circular saw a little longer than required, and trimmed to length on the trimmer. The panel moulding must be nailed to the framing only; the nails must not fix the panels. To prevent the hammer from bruising the mouldings, place the blade of the try-square under the nail and slide the hammer head along the blade. Bolection mouldings in good class work are often slot-screwed through the panel; this secures the moulding, but leaves the panel free; the slot screws are covered by the panel moulding behind.

A solid bolection moulding, which is framed up and inserted when putting the door together, is shown in section in Fig. 231, *A*. Sometimes the moulding is stuck on the solid as at *C*; the ends of the rails then require scribing. *A*

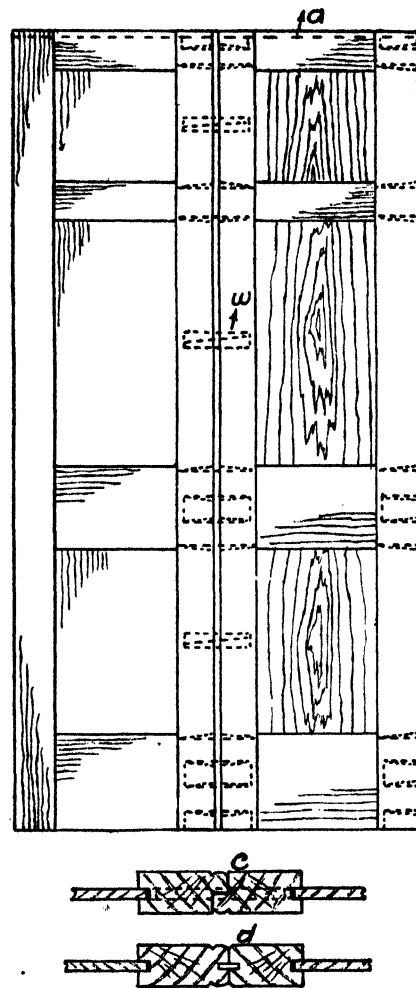


FIG. 237. DOUBLE-MARGIN DOOR

MODERN BUILDING CONSTRUCTION

bead flush panel is shown at *B*; this is used where strength is the chief consideration. The bead *b* may be planted, by mitring it round the rebated panel. The framing is stop-chamfered on the back, as at *s*.

DIMINISHED STILES. Stiles which are diminished above the lock rail, as in Fig. 232, are called *gun-stock* stiles. They are reduced in width to give a bigger lighting area, and for appearance.



(Elliott's, Reading)

FIG. 237A. REVOLVING DOORS

The upper part is of glass, which may be one large square, or ornamented by bars, as in the example. In good class work the face of the bottom panel is raised and belection moulded. All the members above the lock rail are rebated and moulded. The head is the same width as the reduced part of the stile and is haunched, as at *b*, because there is no plough groove. The glass is usually beaded, as at *g*.

The difficulty in this door lies in the preparation for the lock rail. Fig. 233 shows the method of setting out the stile. It is cut to the lines *a* and then moulded and rebated to the line *b*. An isometric view of the joint is shown in Fig. 234.

The moulding may be mitted, but it is better scribed to allow for shrinkage in the lock rail. A common error is to allow the diminishing for the full width of the rail and not to allow for the *sticking* on the rail. Further ornamentation is usually provided by an *apron moulding*, as shown in Fig. 235, which shows half the elevation and a section through the lock rail. An example is shown in Fig. 243.

PREPARING THE BARS. The preparation of the bars is shown in Fig. 236. They may be mortised and tenoned and scribed as at *B*, which is sometimes termed *franking*. They are better halved and mitred, as at *A*, but this method takes much longer, because it is done by hand. It is common practice to round the corners instead of sticking a moulding, as shown in *C*. A *mason's mitre*, *a*, is very often used for the joints in this case. In all cases the horizontal members should run through on the rebate side, otherwise the thin rebated edge is soon broken off. The ends of the bars are stub-tenoned into the door, as shown at *a* and *c* in Fig. 232.

Double-margin Door. For very wide doors it is usual to build them up as shown in Fig. 237. The door consists of two narrow doors securely jointed at the middle. The method of construction is to prepare and fit the two doors separately. The inner stiles are mortised for three pairs of folding wedges *w* and rebated or ploughed for a tongue, as shown in the enlarged details *c* and *d*. The plan of the folding wedges is shown dotted in *c*. The rails are then glued and wedged to the inner stiles and the two stiles fixed together by the folding wedges. The ends of the folding wedges are cleaned off to the bottom of the panel groove. The tenons of the rails should be a little less in length than the width of the inner stiles to allow for the stiles shrinking. The panels are placed in position and the outer stiles glued and wedged up. A metal bar *a* may be let in the top and screwed to assist in fixing the two halves together.

MISCELLANEOUS TYPES

Revolving Doors. Fig. 237A shows a good type of revolving door as used at the entrance to public buildings. It may have two or four wings, or compartments, revolving round a central axis. The wings may be folded to the side or centre to give an uninterrupted passage.

Flush Doors. These are doors with unbroken plane surfaces, and they are very popular for interior doors in all types of buildings. In some cases, as for hospitals, they have a small glazed

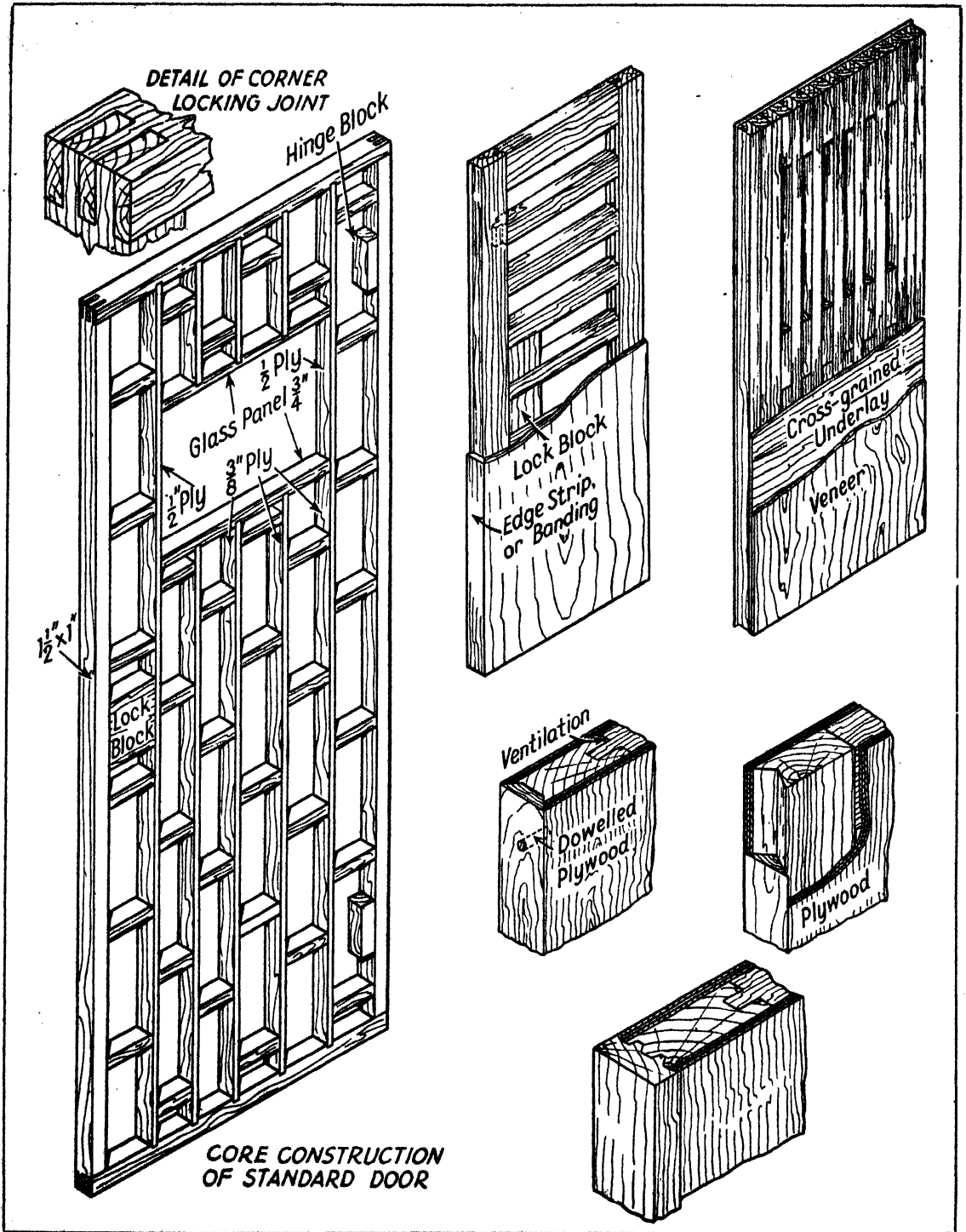


FIG. 237B. CONSTRUCTION OF FLUSH DOOR

MODERN BUILDING CONSTRUCTION

panel at the top. There is great variation in the construction of the cores. They may be framed up in any way, as shown in Fig. 237B, but they are all faced with plywood, at least

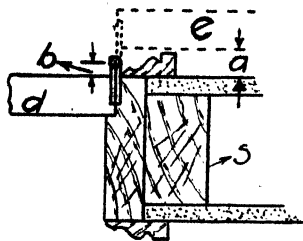


FIG. 238

SECTION OF DOOR LININGS

Superior doors may have the faces veneered with figured wood, as shown in the second example. At the present time, owing to the shortage of timber, the tendency is to have a much lighter core. This is shown in the third example, which is the standard door suggested by the British Standards Institution (War Emergency). The height is standardised at 6 ft. 6 in., but the width rises as usual up to 2 ft. 10 in., with a finished thickness of $1\frac{1}{2}$ in.

It is usual to protect the edges of the plywood with edging strips, and again the details vary according to the manufacturer. Three different types are shown in the illustration, but there are many other variations. The introduction of plastic and casein glues has made these doors reliable for external doors, free from peeling and blistering as they are water- and fire-resisting. They all require expensive equipment, presses, etc., in manufacture and are essentially mass-produced doors. For insulating purposes flush doors may be obtained with fibre cores, and laminwood is also used, but this is a solid door.

Jib Doors. These are doors that are disguised as far as possible to present an unbroken surface with the wall. The panels are flush with the framing on the face unless the wall is panelled, but the back may be of any design to conform with the communicating room.

Dwarf Doors. When doors are less than 5 ft. in height they are called dwarf doors. Hence they are varied in design, but the most common example is where it continues a low screen, in offices and public buildings. It is usually provided with a wide capping as shown in Fig. 174 in "Joints."

Stable Doors. These are *framed, ledged, and braced* doors made in two halves. The bottom half is secured by a bolt inside, and the top half by a stock lock.

Fireproof Doors. These are usually solid doors coated with sheet iron, unless they are entirely

of iron. The door is formed of three thicknesses of boards, or battens, with the middle layer running horizontally. These doors slide on runners, either on the floor or overhead.

DOOR FRAMES AND FINISHINGS

Inside Doors. Inside doors are either flush or panel doors, and the frames are called *casings*, or *linings*. A simple form of lining is shown in Fig. 238. The width depends upon the thickness of the wall. The example shown is for a studded wall *s*. The thickness is usually $1\frac{1}{2}$ in., with a $\frac{1}{2}$ in. rebate for the door. For cheap work the lining is often 1 in. thick, and the rebate is formed by planting a $1\frac{1}{2}$ in. by $\frac{1}{2}$ in. piece round the lining.

PANELLED LININGS. For better class work and thick walls, the linings are panelled as shown in Fig. 239. The linings are fixed on grounds *g* and *f*. The stiles, *b*, and head of the framing are ploughed to receive the rebates *a* and *c*, either

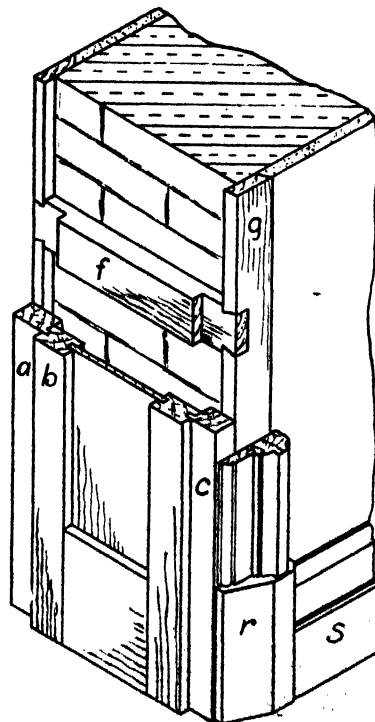


FIG. 239. PANELLED LININGS

of which may receive the door. The soffit, or head, carries out the same design as the jambs, and is trenched to receive the ends of the jambs. The grounds allow for secret fixing throughout, and are suitable for hardwood linings. The

grounds *g* are bevelled to form a key for the plaster.

In superior work the grounds are often framed together before fixing, and the horizontal grounds *f* are dovetailed into the stiles *g*. The grounds may be fixed to plugs, pallets, brick nogs, or breeze bricks. The panels would be moulded either with panel moulding or bolection moulding.

ARCHITRAVES. The architraves provide ornamentation, and cover the joint between the plaster and the woodwork; they are usually nailed to the grounds and linings. In superior work they are often slot-screwed to the grounds, and fixed to the *plinth block* *r* by a dovetailed feather, worked on the end of the architrave. Fig. 240 shows the back of the block prepared to receive the feather, which is also screwed to the block.

SKIRTING BOARDS. The skirting for the above class of linings are usually of the built-up type and fixed on grounds. They may be fixed by slot screws as shown by the oblique view, Fig. 241. The vertical grounds, or *soldiers* *s*, are plugged to the wall about every 3 ft. apart. The plaster should be filled in level with the grounds to avoid runs for vermin. A groove *g* is run round the floor to receive the bottom edge of the skirting; this groove assists the secret fixing and allows for shrinkage. Skirting boards in ordinary work are fixed to plugs only, the grounds being omitted.

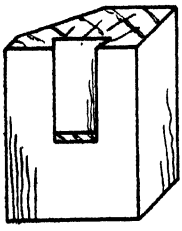


FIG. 240
PLINTH BLOCK

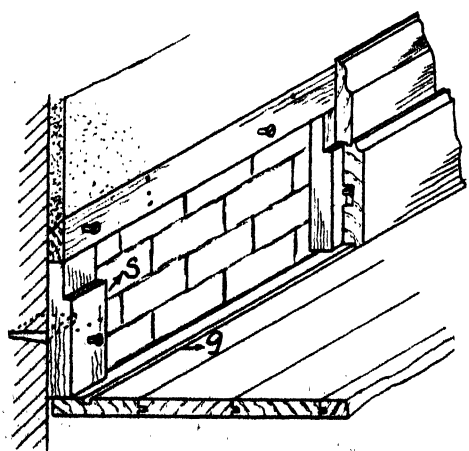


FIG. 241. FIXING SKIRTING BOARDS

DOOR WITH PEDIMENT. Fig. 242 shows a five-panel door and finishings suitable for a dining-room. The construction of the overdoor, or *pediment*, *P*, is shown by the section *A*. The *dentils* *d* may be cut from the solid, or planted. The cornice *c* may be carried round the room in the form of a picture rail *r* and plate shelf *p*, as shown by the section at *B*. Alternative methods are shown of finishing the lower portion. A panelled *dado* is shown at *E*, and a plaster finish at *L*, with a dado rail *a* and skirting *s*. The plaster would probably be finished with *lincrusta* wallpaper. The dado framing would be fixed on grounds in a similar manner to the linings. A section through the dado is given at *D*. The pediment and cornice are built up on blocks *b*. The bolection mouldings have been omitted in the door sections.

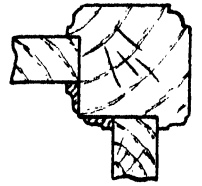


FIG. 244
RETURN STILE

Vestibule Frames. These are usually all of the same type, and consist of stiles, mullions, transom, and head. Fig. 243 shows the application to a bank vestibule, in mahogany. The example is fixed between two walls, but often one stile receives a return panelling to form the vestibule from the main office as shown in Fig. 244. A lining or moulding *l*, Fig. 243, usually breaks the joint between the wall stile and the plaster. Alternative methods of building up the cornice at the ceiling are shown. The cornices should be returns of those round the vestibule and the inner room. The section

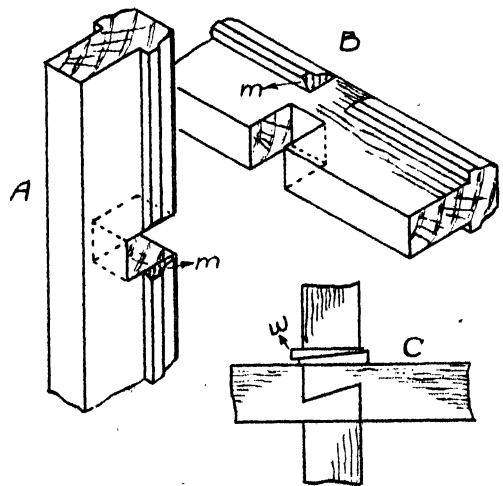


FIG. 245. DETAILS OF VESTIBULE FRAMING

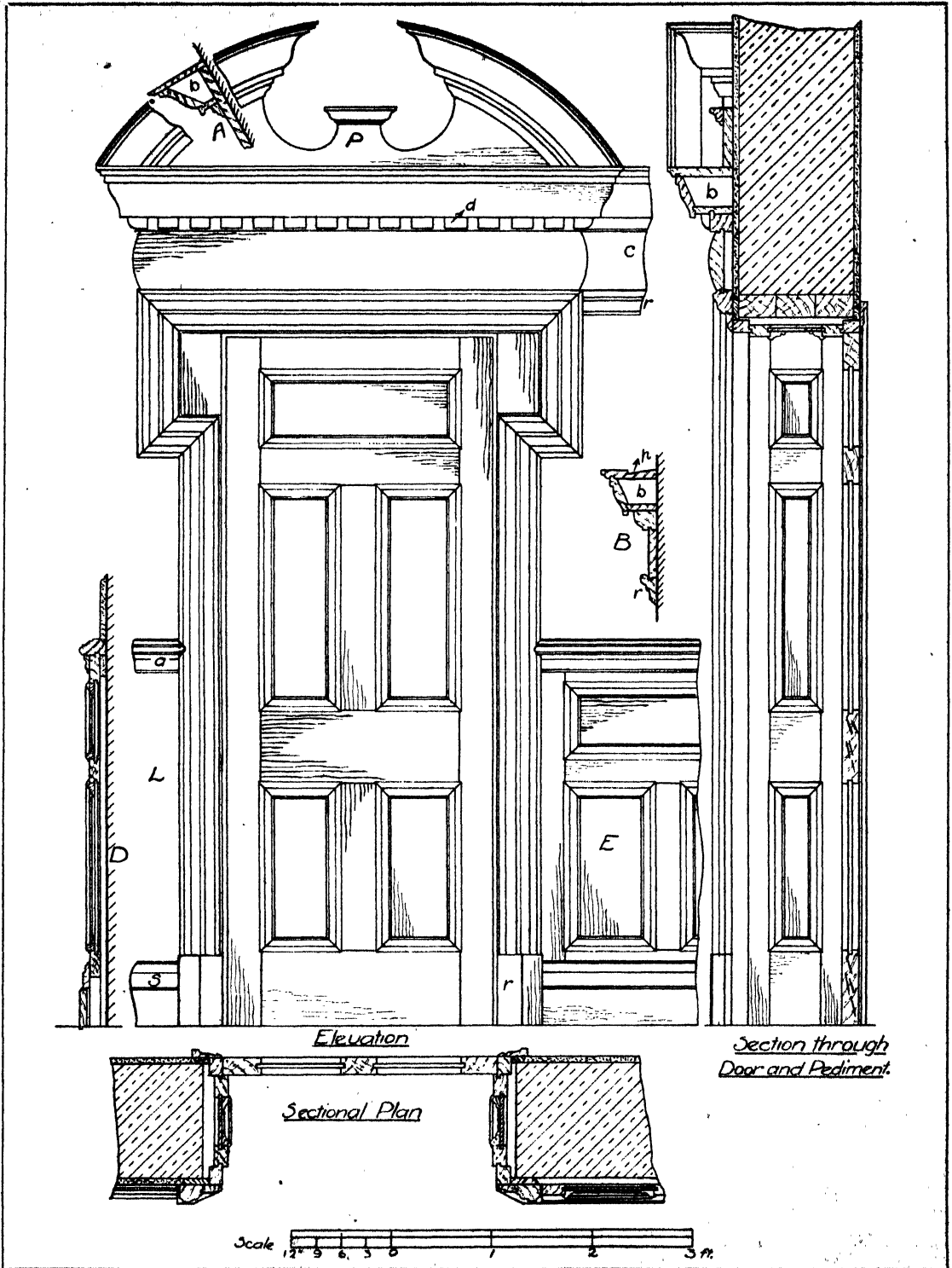


FIG. 242. INSIDE DOOR AND FINISHINGS

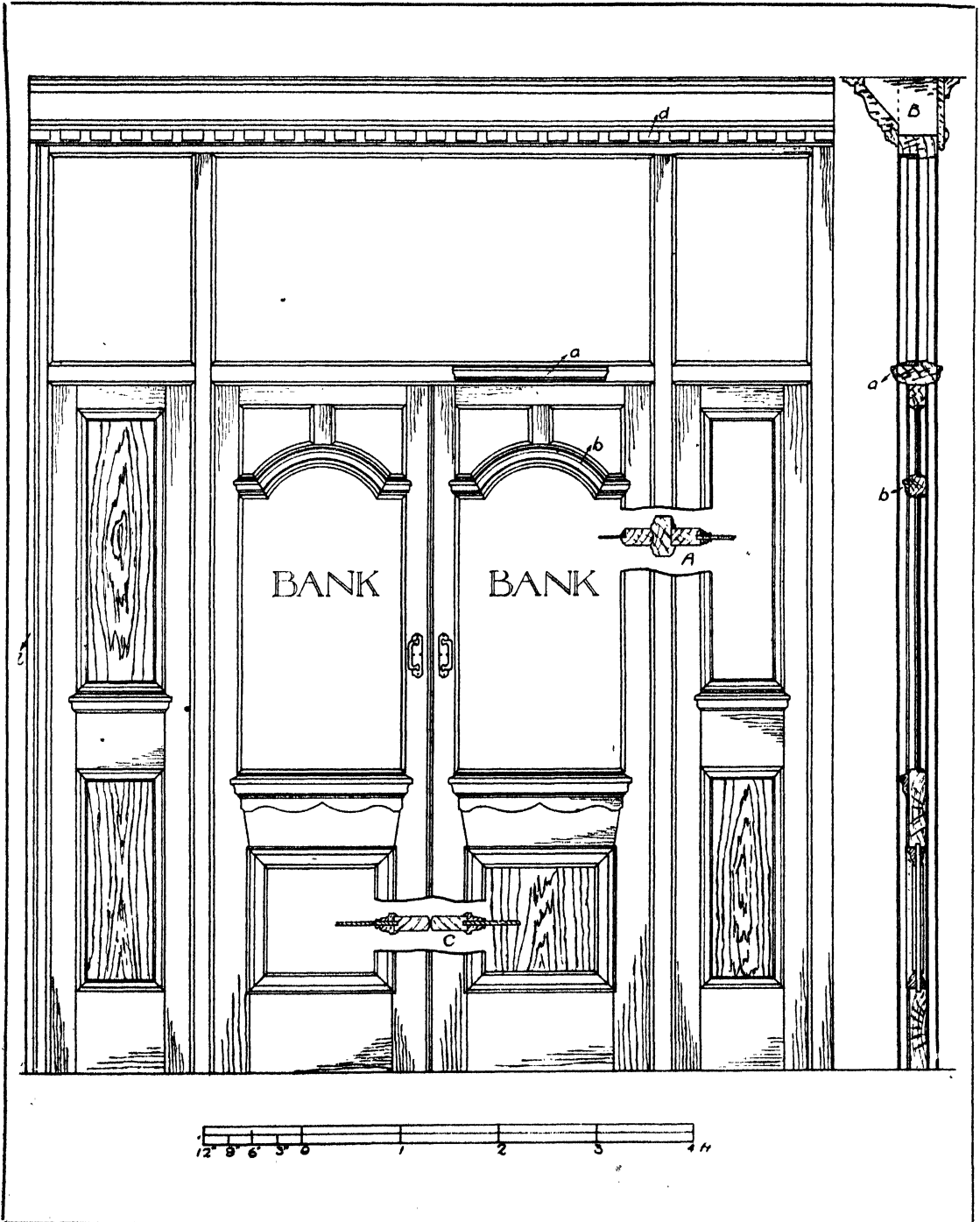


FIG. 243. VESTIBULE DOOR AND FRAMING

MODERN BUILDING CONSTRUCTION

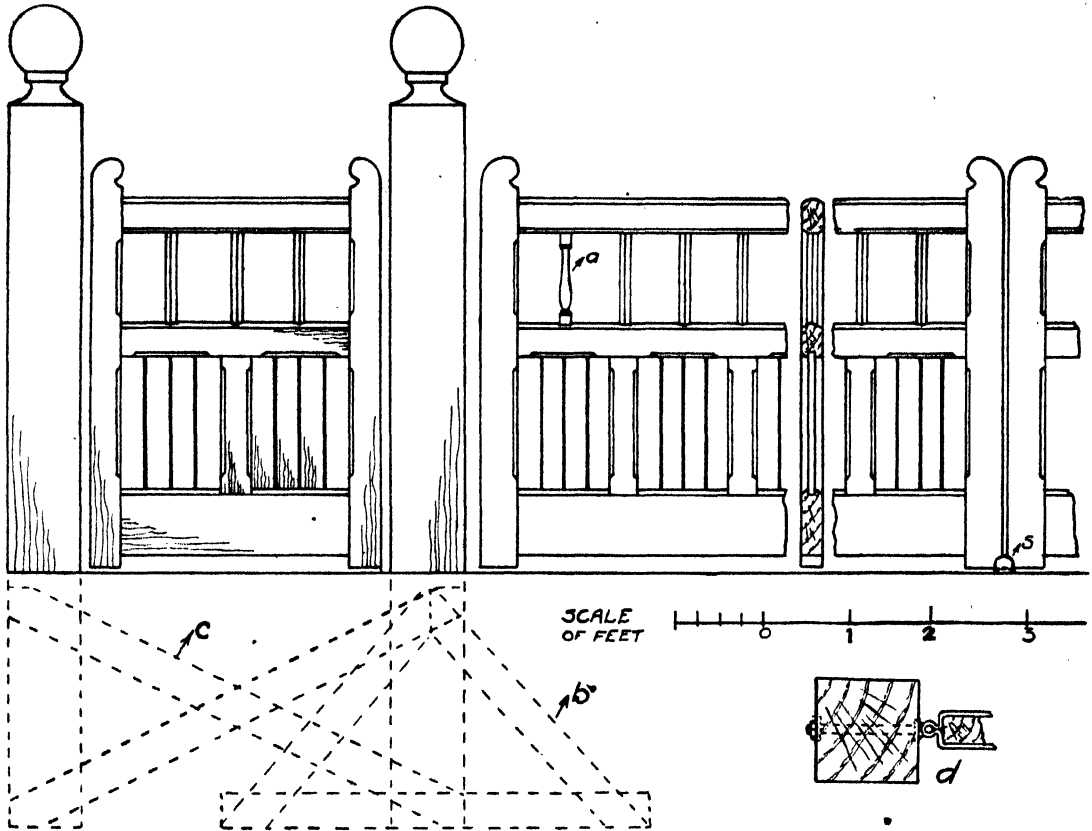


FIG. 246. CARRIAGE GATES

A through the mullion shows the door stile and the method of fixing the side framing. Section C

shows the meeting stiles of the swing doors. A moulding *b* may be planted on the doors and the moulding *a* may be planted on the transom or stuck on the solid. The top lights of the framing would have gilt lettering, giving the name of the firm, address, etc.

Fig. 245 shows alternative details for the joint between the mullion and transom. A halving joint is shown at *A* and *B* with a mitred moulding *m*. This method allows for a continuous transom. The detail *C*, which is a vertical section through the centre, makes a strong mortise and tenon joint. The folding wedges *w* secure the dovetailed tenons. They are trimmed off level with the rebate and are not seen on completion.

Warehouse Doors. Doors for warehouses, stables, etc., are of the "framed, ledged, and braced" type. They usually run on pulleys, either on the ground or on an overhead rail. There are several excellent patent rails for this

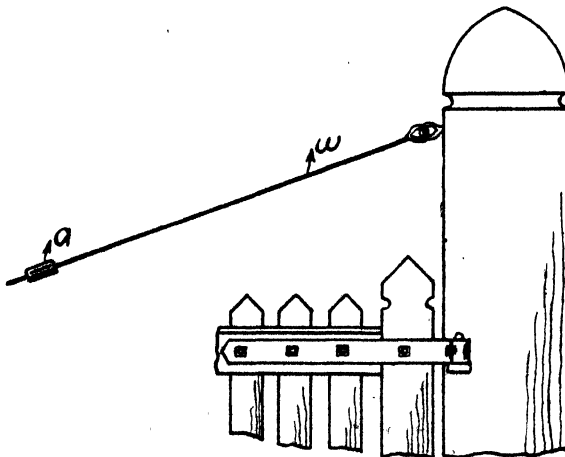


FIG. 247. HANGING GATES

method of hanging. Sometimes a small door, or wicket gate, is framed in the larger door for convenience of entrance.

Gates. There is such a large variety of gates that it is impossible to mention more than one or two. Fig. 246 shows part of a pair of carriage gates, with small side gate. The lower part is panelled, the panels being tongued and grooved boards. The upper part may have the bars square in section and placed diagonally; or they may be square, or circular turned as at *a*. The stop *s* is hinged to fall flat when the gates are opened. It is essential that the gate posts should be fixed securely. They are sometimes bedded in concrete. Two methods are shown, by dotted lines, of fixing them without concrete. Strong rough stuff, about 6 in. by 2 in., and well creosoted, may be fixed diagonally as at *c*. The end view of the posts would then be as at *b*. If each post were fixed independently, the method *b* should be used in both directions. The rough stuff would be fixed by large spikes or coach screws. Sometimes long bolts are used with distance pieces. The gates are hung with bands and gudgeons, as shown in the enlarged detail *d*.

Very wide gates for works, level crossings, etc., have a tendency to drop at the nose, no matter how carefully they are braced. A common method of preventing this is shown in Fig. 247. The post is carried up about 3 ft. or more above the gate, and a strong steel wire *w* is fixed to the top of the post and beyond the middle of the gate; a tension sleeve *a* (a long nut with right- and left-hand threads), adjusts the length of the wire to keep the nose at the correct height.

Gates that open in either direction and have to lift over rising ground should have the bottom band arranged as in Fig. 247*a*. The "gudgeon" consists of two strong dogs, as shown in the plan and elevation. The band is specially formed so that only one side at once

is in action, when the gate is swinging. The top band would be the same as in Fig. 246*d*.

HANGING PANEL DOORS

FITTING DOORS. The door should be laid on two saw blocks, or stools, and the sizes of the rebate opening transferred to the door by means of two laths. If there is any surplus size, it should be sawn off. If the door is too short, a piece should be planted between the horns before they are sawn off. The door should now be tested in the opening and $\frac{1}{8}$ in. allowed at the sides and top, and sufficient at the bottom to clear the floor coverings.

HINGING. For the ordinary four-panel door two 3 in. butt hinges are sufficient. The hinge should be "let in" both door and frame. The marking gauge is set to half the thickness of the butt, less half the clearance of the joint. The door is placed on its edge and the positions marked for the hinges. The amount of width of the hinge to be "let in" depends upon the condition of the floor and wall. To get an idea of what is required, rear the door and place the hanging stile to the frame stile with the door at right angles to the frame. This will show whether the bottom hinge needs to project out farther than the top hinge so that the open door will clear the floor. Fig. 238 shows a door *d* hinged to clear an architrave. The projection of the hinge *b* will give a clearance *a* when the door is opened as at *e*. The distance *a* will be twice *b*.

When the hinges have been screwed on the door, they are opened, and the door is placed in the rebate. It is "packed up" on a chisel to the correct height, and the positions of the hinges marked on the frame. Then the frame is cut out in the same way as the door. The flaps of the hinge should be sunk into the door and frame the full thickness at the inside edge of the flap. Also, the screw heads should be just below or perfectly flush with the surface of the flaps. These two precautions will prevent any *binding* of the hinges when the door is closed. The door is next placed at right angles to the frame, packed on a chisel to the correct height, and screwed to the frame. Further instructions on hinging were given in the chapters on "Joints" and "Door Furniture."

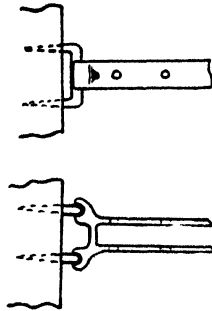


FIG. 247*a*
HANGING GATES

Chapter VII—WINDOWS AND VENTILATORS

THE following classification covers the ordinary types of window, although there are many variations and combinations: fast sheets, sashes and frames, casements, Yorkshire lights, and pivoted sashes.

are as described previously (see Fig. 236). The bars are usually 2 in. by 1½ in. or 1 in., and they are moulded both sides.

Pantry Window. Fig. 249 shows a small window suitable for a larder, etc. It is an

FAST SHEETS

Fast sheets, or *fixed sash* windows as they are sometimes called, consist of two stiles, head and sill, with intermediate bars if required to give a smaller size of glass, or to provide

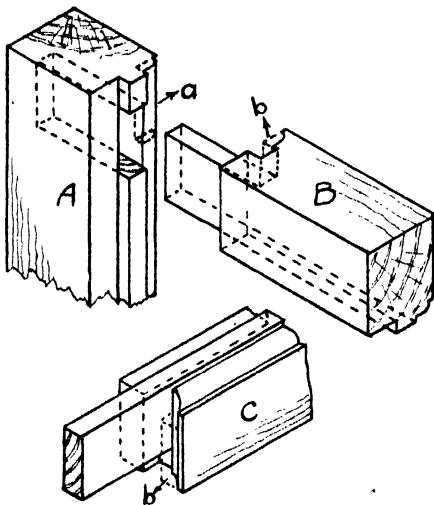
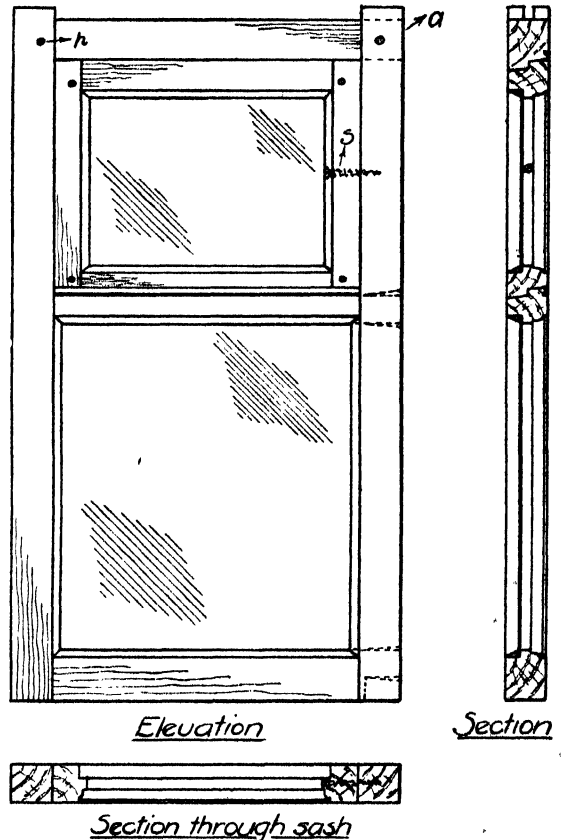


FIG. 248. DETAILS OF SASH JOINT

ornamentation. The stiles, head, and sill are usually 3 in. by 2 in. sash stuff, and may be obtained from stock at most joiners' shops. The method of making the joints is shown in Fig. 248. The stile *A* is mortised to receive the tenons on the top and bottom rails *B* and *C*. It is a *franked* joint, and it differs from the haunched joint on the doors. The square of the moulding is left projecting, and a corresponding recess is mortised out of the rail. When the work is done on the machines, the rail is scribed through for the ovolo as shown on *C*. When it is done by hand, it is usual to remove the moulding on the stile at *a*, and only scribe a small portion, leaving the dotted piece *b*. The joints for the bars



Elevation

Section

Section through sash

FIG. 249. PANTRY WINDOW

extension of the fast sheet by the addition of a pivoted sash to give ventilation. The joint on the sill is the same as described for the fast sheet. The moulding is removed above the transom to receive the pivoted sash, which is rebated on the top and bottom rails only. In good class work the stiles are rebated also. This adds to the difficulty of pivoting, as will be described later. When the stiles are rebated, it

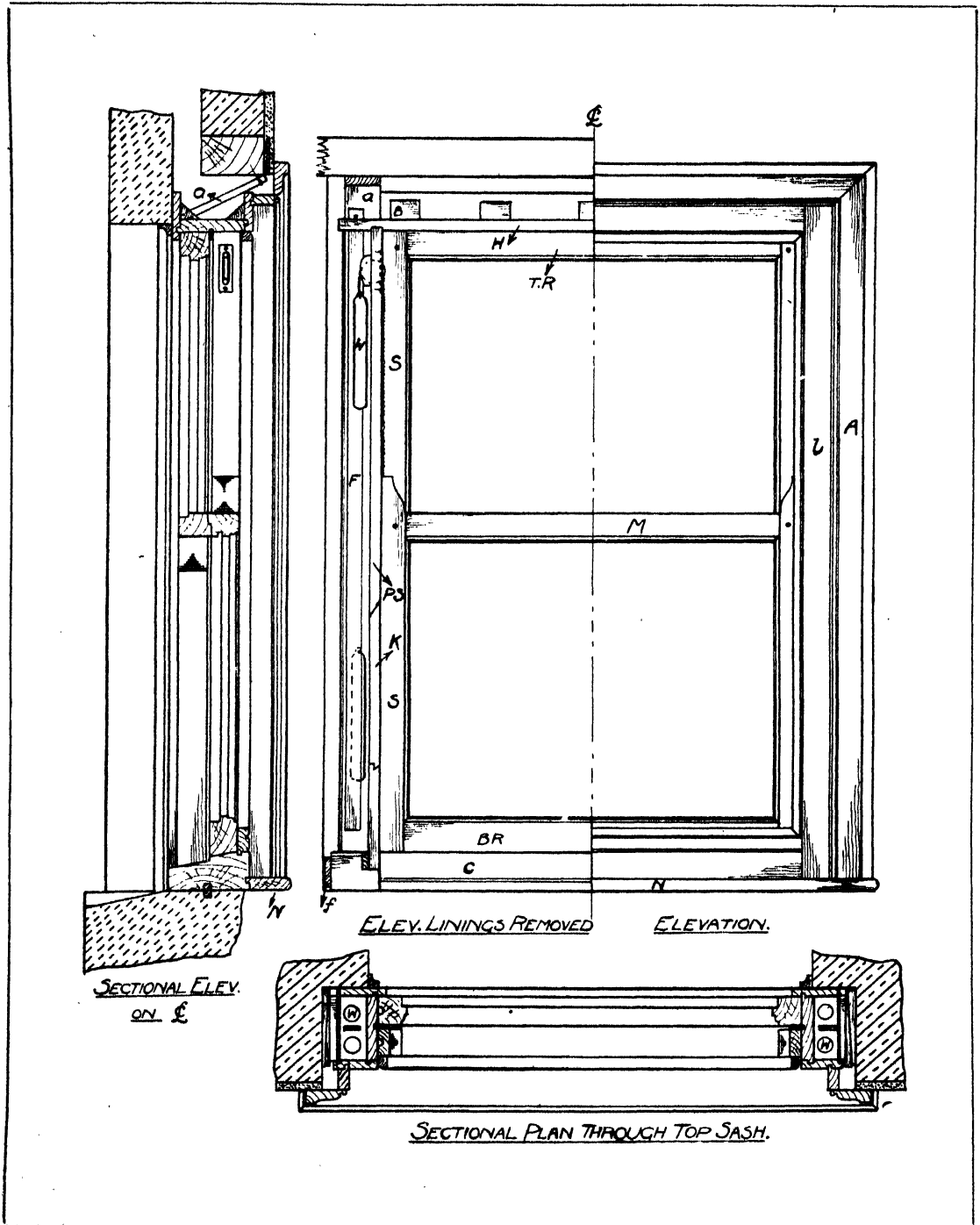


FIG. 250. SASH AND FRAME WINDOW

MODERN BUILDING CONSTRUCTION

is easier to hinge the sash on the bottom rail and use a quadrant for opening. The heads of the stiles are slotted at *a* for the tenons on the

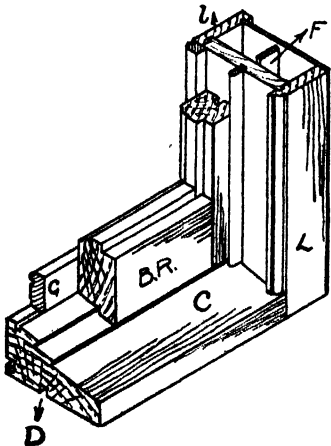
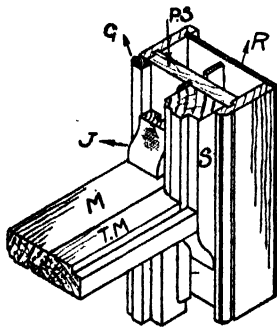
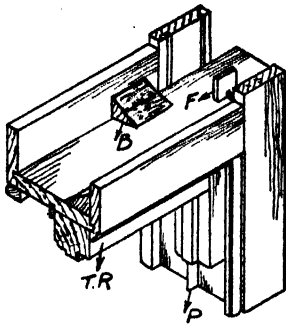


FIG. 251. DETAILS OF SASH AND FRAME

head; after the sash is pivoted the head is pinned in position, this saving the labour of fitting the sash at the top. Strong screws *s* may be used instead of pivots for economy, and they are quite satisfactory. The pivots or screws

should be a little above the centre, so that the sash will keep closed. Two small eyes, with a cord, are sufficient to regulate the opening of the sash.

FIXING. The above types of windows are usually fixed in the recess by wedging at the ends of rails and at the top of the stiles. Large windows, as in factories, have holdfasts to supplement the wedges. A hardwood slip let in the window sill and stone sill, as shown in Fig. 250, keeps out the wet and assists in fixing the frame. The slip and sill should be bedded in white lead and oil.

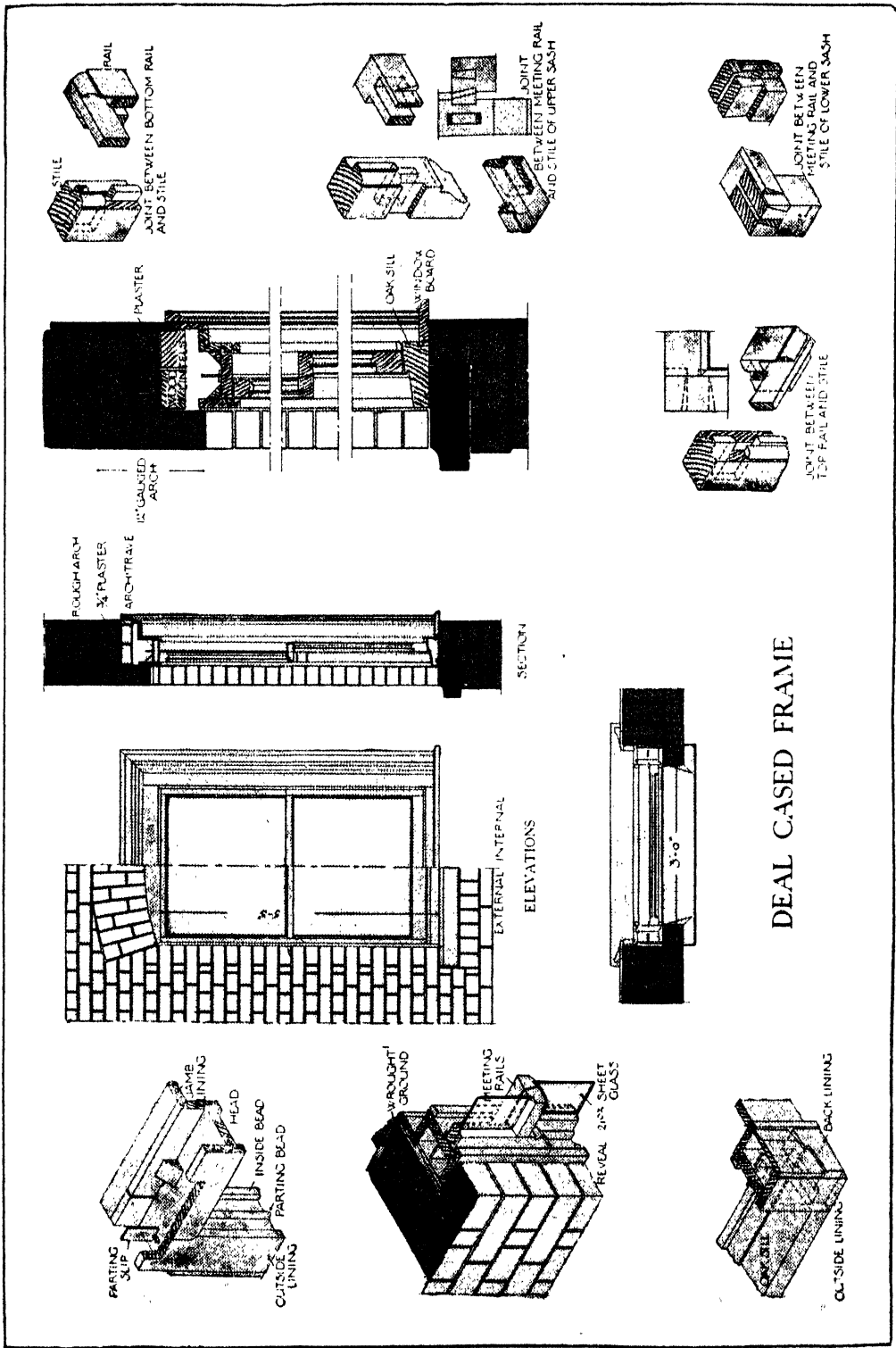
Linings are afterwards fixed round the inside of the frame and scotias on the outside. The window should be bedded against the brickwork with hair mortar.

SASH AND FRAME WINDOWS

Sash and frame windows have two sashes sliding vertically in a cased frame. The sashes are hung by cords and balanced by weights; the cords pass over pulleys. It is perhaps the most common type of window and presents many difficulties to the beginner. Fig. 250 shows three views of the usual type of sash and frame, and Fig. 251 gives isometric views of the details; in several cases alternative details are given. Half-inside elevation and half-inside elevation with the inside *linings l* removed, together with sectional plan and sectional end elevation, are shown in Fig. 250. Sufficient brickwork has been drawn to show the methods of fixing and finishing. The reference letters apply to either Fig. 250 or Fig. 251.

The frame consists of 6 in. by 3 in. sill *C*, 5½ in. by 1 in. pulley stile *PS*, and head *H*, 3 in. by ¾ in. inside linings *l*, and 3½ in. by ¾ in. outside linings *L*. A 1 in. by ¾ in. guard bead *G* and a 1 in. by ¾ in. parting bead *P* are used to control the sliding of the sashes. Parting slips, or feathers, *F*, are used to separate the weights, and rough back linings *R* are nailed to the edges of the linings or as shown in Fig. 251, to keep the box free from mortar, etc. Each sash is balanced by two iron or lead weights, which together approximately equal the weight of the sash. The top sash is slightly less in weight and the bottom sash slightly heavier than their respective balance weights; this is to keep the sashes closed.

The above dimensions vary according to the importance of the work. They are dependent upon the thickness of the sashes, which varies from 1½ in. to 2½ in., the stock sizes usually being



DEAL CASED FRAME

CONSTRUCTIONAL DETAILS OF DOUBLE-HUNG SASHES AND FRAME

2 in. thick. The sashes consist of the following: 2 in. by 2 in. stiles *S*, 3 in. by 2 in. bottom rail *BR*, 2 in. by 2 in. top rail *TR*, 2 $\frac{3}{8}$ in. by 1 $\frac{1}{2}$ in.

the table of the mortising machine. The frame sill is trenched for the stiles by a special saw on the tenoner, and the ends are "tenoned" to

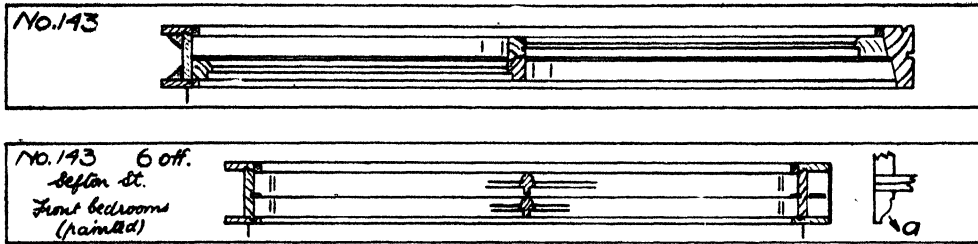


FIG. 252. ROD FOR SASH AND FRAME WINDOW

or 1 $\frac{1}{2}$ in. meeting rails *M* and *TM*. Sometimes bars are included to strengthen the sashes.

CONSTRUCTION. The window should be set out on a rod as shown in Fig. 252. If the material is from stock, it is not necessary to give many

receive the linings (see Fig. 253). It is necessary to run them through twice for the trench, because of the wedge room, unless the cut for the wedge *w* is made by hand. The table fence is canted to give the bevel for the wedge. The sill is ploughed for a nosing *N* and at *D* for a hardwood slip.

PULLEY STILES AND HEAD. The head is tenoned to the same length as the sill to receive the stiles, and is slotted to receive the parting slips. The pulley stiles require considerable preparation. A pocket *K* is cut out for the weights to be removed when required. Two pulleys, over which the cords run, are let in at the top. Fig. 254 shows a pulley stile with pocket removed and prepared for the pulleys. Fig. 253 shows an alternative and better method of cutting the pockets, but different firms have different methods. Sometimes they are cut from the middle of the stile; this method allows the lining to be nailed on the full length of the edge of the stile; the disadvantage is in re-hanging, as the paint is broken outside and looks unsightly. The pockets in Figs. 253 and 254 are cut at *C* by dropping the stiles on to the circular saw along the groove for the parting bead. The bottom is then cut by the pocket knife, or sash chisel, and the top is either cut by the pocket knife, as in Fig. 253, or by the dovetail saw, as in Fig. 254. A screw *S* at the bottom holds the former in position, and a screw at the top fixes the latter.

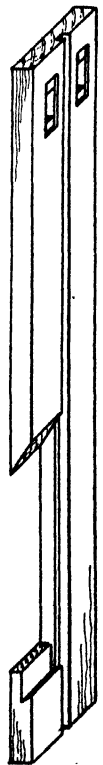


FIG. 254 PULLEY STILE

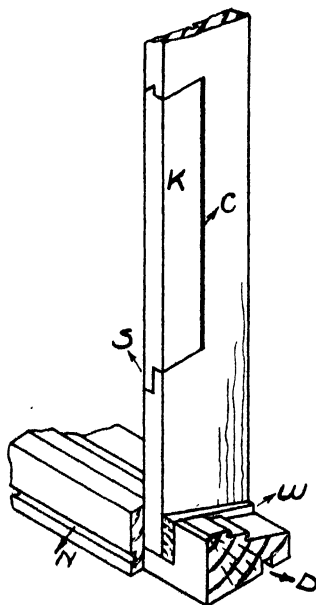


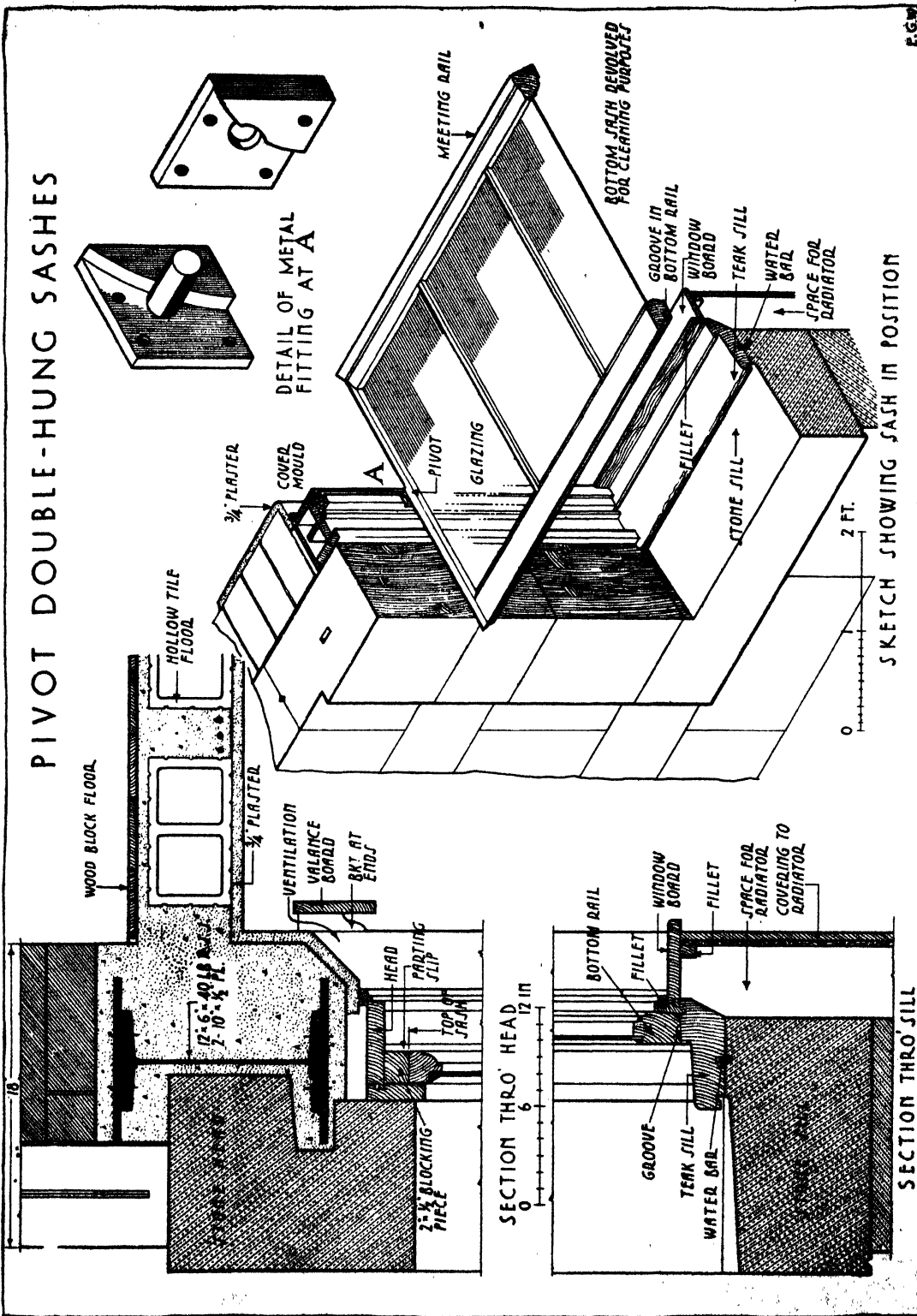
FIG. 253. DETAIL FOR SILL AND STILE

details. The method of "setting out" is as described for doors. A separate detail is given for the joggle *a*. A double line is sufficient to show the sticking on the stuff.

In the smaller shops one of each of the members is set out for the machines, except the sash stiles for the mortising. These are usually all set out as for door stiles, unless there are a large number, when a *stop* can be fixed to

ASSEMBLING. Wedge and nail the stiles to the sill and the head to the stiles. Lay the frame

PIVOT DOUBLE-HUNG SASHES



SKETCH SHOWING SASH IN POSITION

on the bench, outside downwards and "out of twist." Fix the frame temporarily to the bench after it is squared, and nail on the inside linings. Fig. 255 shows a simple arrangement for holding the frame square. A 4 in. by 1½ in. piece *a* is

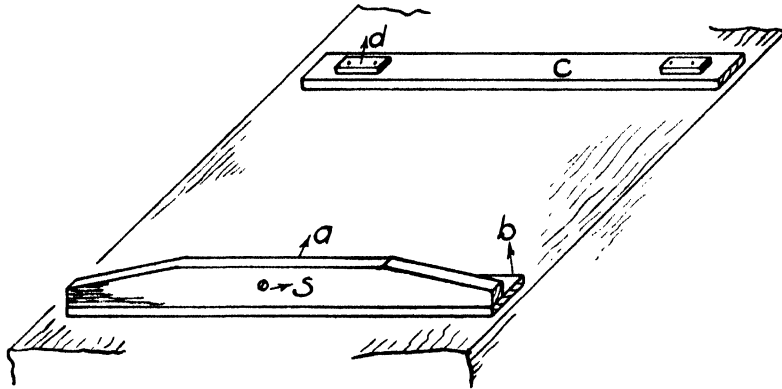


FIG. 255. ASSEMBLING SASH FRAME

fixed firmly to a 4 in. by 1 in. piece *b*. The latter is fixed to the bench. A piece *c*, similar to *b*, is fixed to the bench, at the required distance from *b*. The sill is fixed by a screw *s* passing through *a*. After squaring the frame, small pieces *d* are nailed to *c* in the top corners of the frame. The frame is now held square whilst the linings are nailed in position. Avoid nailing the linings to the pocket. Turn the frame over so that the pieces *d* will again fit in the top corners, test for squareness, and again insert the screw *s*. Now nail on the outside linings. If they are moulded, it is necessary to mitre the corners for the moulding. A ¾ in. piece is used to keep the projection of the lining equal over the pulley stile. Blocks should be glued to head and linings, as shown in Figs. 250 and 251.

THE SASHES. The joints for the sashes have been explained, except for the meeting rails. Fig. 256 shows the stile *s*, with joggle, and the meeting rail *m*. A small trench is made on the side of the stile to receive the projecting part of *m*, so that this part is stronger and has no feather edge. The projection, when rebated as shown, excludes dust and draughts, and prevents interference with the catch from the outside. The joggle strengthens the joint because the rail can be wedged, and it also provides ornamentation. A number of stiles are cramped together to prepare the joggles. The sashes are painted or glued, wedged up, and pinned. They are cleaned off when the glue is hard, and ploughed about two-thirds of their length for the sash cords.

FITTING THE SASHES. The sashes should fit in the frames without any planing of the edges other than the trimming of the wedges. It is an advantage to test the sashes for height before nailing the frame together, because a little adjusting can easily be made on the pulley stiles. When the sashes are ready, the frame is laid on the bench and the top sash fitted in position. The parting bead is put in place and the bottom sash fitted, and, lastly, the guard bead. For superior work, the guard bead on the sill is usually made wider, as shown in Figs. 250 and 251. This wide guard bead acts as a draught preventer when the window is open a little. Usually, the sashes

are removed, and numbered with the frame; then everything is primed before sending to the job. After the sashes are glazed, they are weighed to select suitable balance weights *W*.

FIXING THE FRAME. The frame is fixed as shown in Fig. 250. The sill is bedded in white lead and

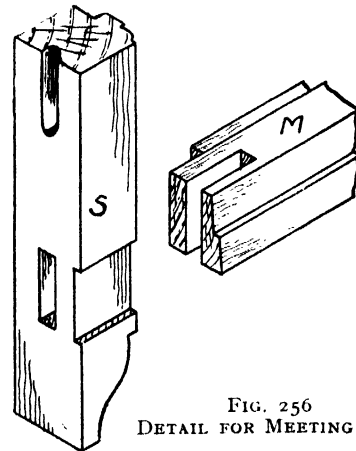


FIG. 256
DETAIL FOR MEETING RAIL

oil, and the frame bedded against the brick-work with hair mortar. Folding wedges *f* are used to fix the sill, and waste pieces of floor board *a* are pressed up to the outside lining and nailed to the lintel. Holdfasts may be used in addition.

HANGING THE SASHES. The sashes are hung after the frame is fixed and the sashes glazed. The beads and pockets are removed and a mouse

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is used to thread the cord over the pulleys. The mouse may be a piece of lead, chain, or even a bent nail; it is attached to a piece of twine for pulling the cords through the pulleys. The mouse is passed over the pulley, down the inside of the box, and out at the pocket, and, of course, the sash cord follows. The weight is

bottom sash, and the guard beads are fixed. The beginner is apt to cut the top cords too long and the bottom cords too short, which prevents

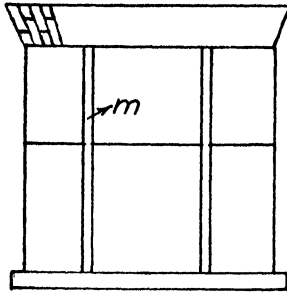


FIG. 257
DIAGRAM OF VENETIAN WINDOW

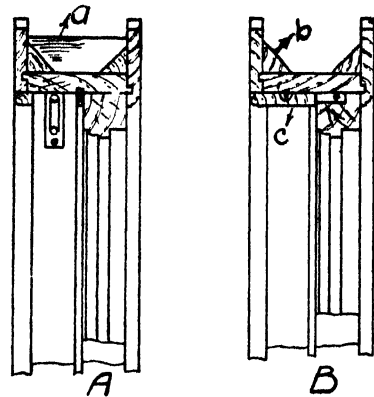


FIG. 259. VERTICAL SECTIONS THROUGH MULLION WINDOW

secured firmly to the cord and then lifted to the top of the box. The cord is then nailed temporarily to the face of the pulley stile with one clout nail, and cut to length. When the four cords are ready, the two outer ones are nailed to the top sash. The latter is placed in position, and the pockets and parting beads replaced. Then the remaining cords are nailed to the

the sashes going into position. It is best to thread the cords through the four pulleys in one operation, to save cord and labour.

Mullion Windows. The usual type of mullion window is shown by a diagram in Fig. 257. This is known as a *Venetian window* and consists of three pairs of sashes. The mullion *m* may be solid as in Fig. 258, *A*, or boxed as at *B*. The

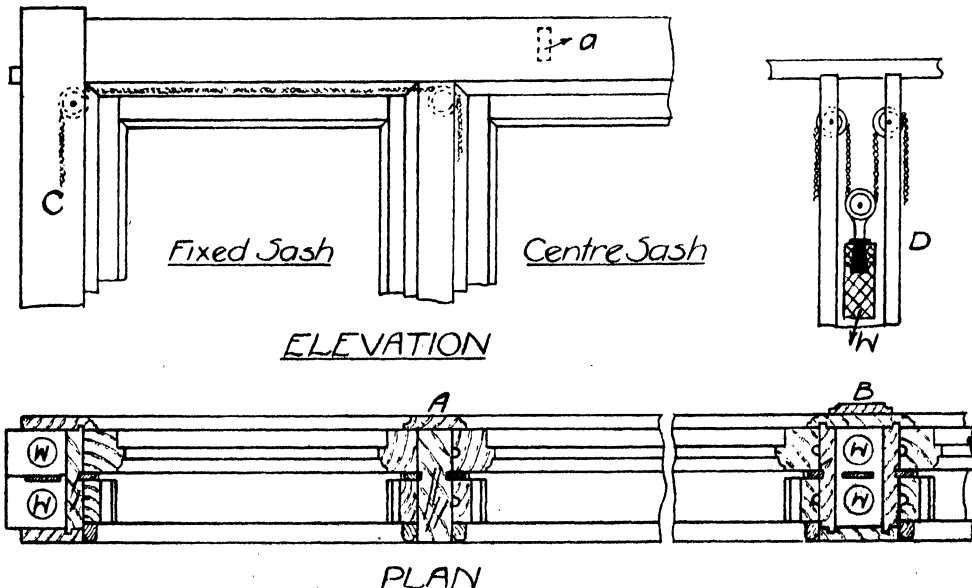


FIG. 258. DETAILS FOR MULLION WINDOW

solid mullions are used because they entail less labour and do not exclude much light. In this case the centre sashes only are hung. The cords *c* pass over the fixed side sashes as shown in the elevation. Hence the pulleys are placed at the top of the stiles. This requires special pulleys, or else the top part of the face plate broken off; the latter is generally adopted for cottage work. *A*, Fig. 259, is a section through the centre sash showing the position of the pulleys, and *B* is a section through the fixed sash showing the cords passing over the top. The method of covering the cords with a wide guard bead is shown at *c*. The top linings are strengthened by pieces *a* and blocks *b*.

at *B*, Fig. 258. The usual method of hanging the sashes is shown at *D*, which is an elevation

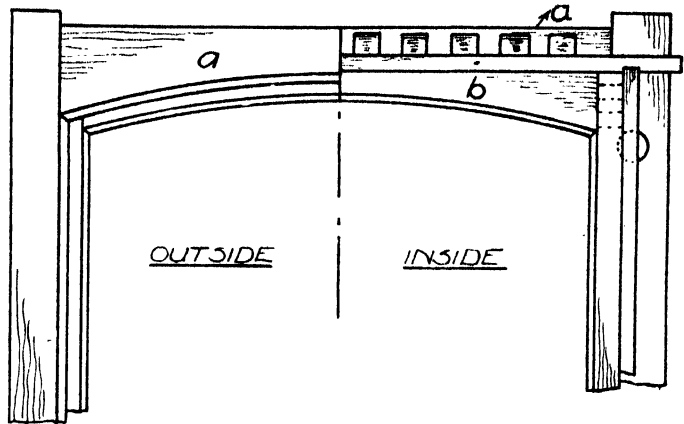


FIG. 260. SEGMENTAL-HEADED SASH AND FRAME

BOXED MULLIONS. When all the sashes are hung or only one mullion is used, it is necessary to have a boxed mullion, as shown

with linings removed. The weight *W* serves the sash on each side of the mullion. It is

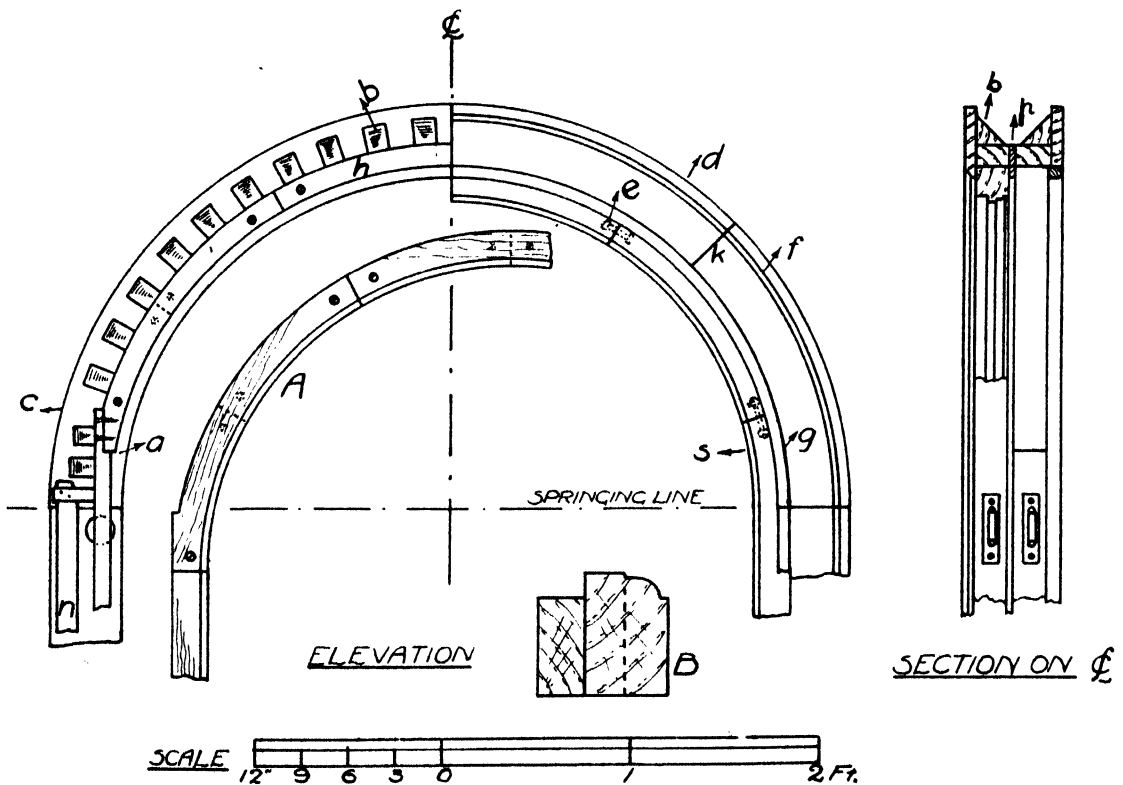


FIG. 261 SEMICIRCULAR-HEADED SASH AND FRAME

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specially prepared of lead, with a pulley at the top, through which the cord is passed. The disadvantage of this arrangement is that the two sashes are affected when the cord breaks. If each sash is hung separately, a wider mullion is required to contain four weights. The constructional details of the sashes and frame are the same as for the ordinary sash and frame.

Segmental-headed Sash and Frame. When the brickwork opening has a flat arch, it is usual to follow the outline of the brickwork with the lower edges of the outside lining *a*, and the sash

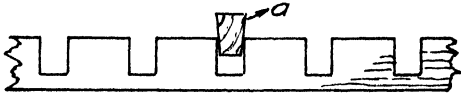


FIG. 262. BENDING CIRCULAR LININGS

top rail *b*, as shown in Fig. 260. All the remaining details are the same as for the ordinary sash and frame. The sash top rail is generally wide enough at the ends to allow for two tenons, as shown by the dotted lines. The inside linings and beads have been removed in the illustration.

Semicircular Heads. The details for a circular-headed sash and frame are shown in Fig. 261. The details below the *springing* are the same as for the ordinary sash and frame, but above the springing there are many difficulties for the beginner. There are two methods available for several of the members, either to cut out of the solid or to bend the stuff. The former method will be described first. The head *h* of the pulley stiles will be *built up* in three parts as shown at *p* in the section, the parting bead forming one part. The joints are broken (that is, not opposite) and the pieces well glued and screwed together; this makes a very strong job. A stop *a* is arranged on the head for a corresponding projection on the sash, otherwise the *crown* of the sash would bang on the frame and break the glass. The tongues are omitted on the head because of the labour entailed; an additional number of blocks *b* make up for the lack of tongues. The pulley stiles are carried up to screw to the head. The inside *d* and outside *c* linings are cut out of a wide board. They are in several pieces to suit the width of stuff; there is less alteration in shape, after shrinking, if the stuff is narrow. The joints *k* are usually tongued to prevent warping. A groove *f* is required for the plaster or linings. The guard beads *g* are cut from the solid or steamed and bent; they do not require to be removed for

rehaning, hence they can be glued and fixed securely.

SASHES. These may be "built up" as described for the head. The elevation of the sash is shown at *A*, the dotted lines showing the method of breaking the joints. The best method of building up the thickness is shown enlarged at *B*. If the thickness is built up as shown by the dotted line, both the moulding and rebate will require sticking; hence it is usual to build up at the rebate line as shown.

When the sash stuff is cut from the solid, the joints are made by handrail bolts *e*, or hardwood keys or dowels; this entails more labour than building up the thickness. It is usual to have a little of the circular part on the straight stile of the sash, as shown at *s*.

BENDING THE HEAD. It is a common method to bend the pulley-stile head to the required shape. If it has a large radius, it may be cut out on the drunken saw as shown in Fig. 262. It is then bent round a *drum*, *saddle*, or *centre*, to the required shape, and pine pieces *a* are glued and driven tightly into the grooves. These pieces are as long as the width of the head. The head is then left on the drum until the glue is hard. The parting bead is "planted on" instead of the head being grooved.

An alternative method is to commence with a piece sufficiently thin to bend round the drum, and then glue blocks on the back, afterwards covering the back with canvas, well glued. This method is usual for expensive hardwoods.

YORKSHIRE LIGHT

These windows have a sash sliding horizontally, as in Fig. 263. The frame consists of two stiles, head and sill, all 5 in. by 2½ in. or 3 in., and an upright bar *b* at the centre, of 2 in. by 2 in. sash stuff. The sash is made in the usual way.

The sill and the head run through, with the stiles tenoned into them. The head is rebated for the sliding sash, and also half-way for glazing. The sill is ploughed for an oak runner *r*. There are several alternatives for running the sash. If the frame is too thin for guard beads *g*, an oak lath may also be used at the top for the sash; this lath would be planted and put in with the sash. Sometimes the sash runs on a metal plate with ball bearing rollers. Metal shoes running on a metal strip may also be obtained. The sash is secured by a thumb-screw *t*. Alternative details of the joint at the centre stiles are shown by horizontal sections in

Fig. 264; in each case, *a* indicates the outer bar and *b* the sash stile.

CASEMENT WINDOWS

Sashes of casement windows are hinged. The usual type is shown in Fig. 265, though there

at the top. An enlarged section of the hanging stile of the lower lights is shown in Fig. 266. The throatings *t* prevent the water getting through by capillary attraction.

When the casements open inwards, as shown in the alternative vertical section in Fig. 265,

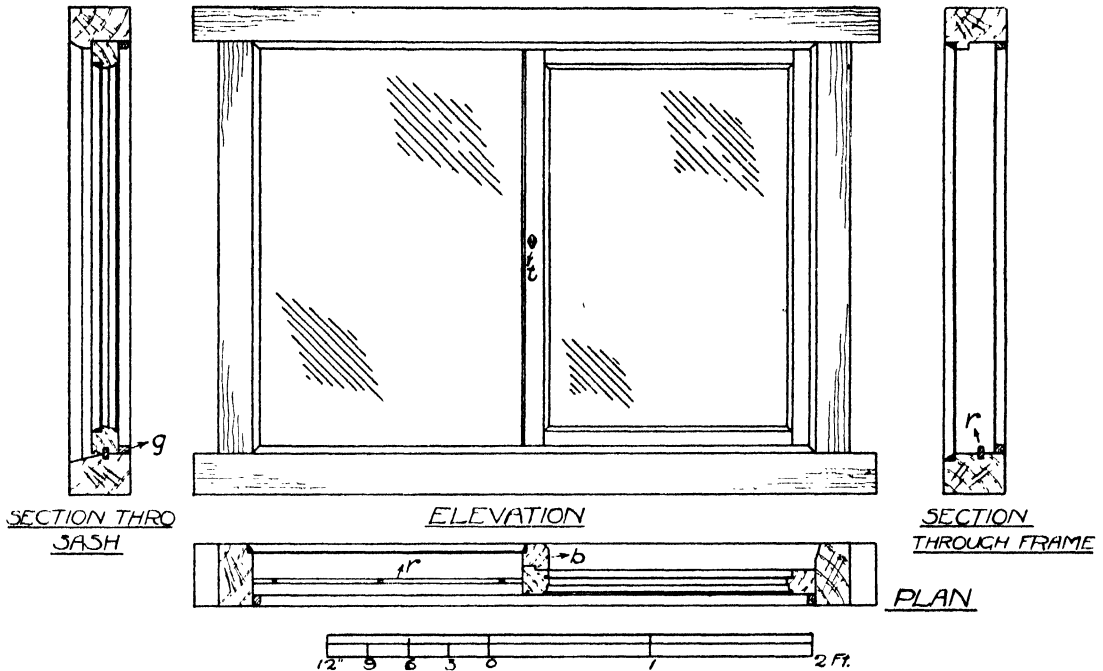


FIG. 263. YORKSHIRE LIGHT

are many variations. The frame consists of two stiles, head, sill, transom, and mullion, all of 5 in. by 3 in. stuff. The casements are similar

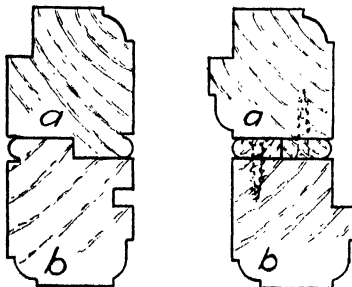


FIG. 264. DETAILS FOR MEETING STILES

to the ordinary sash, all members being of 2 in. by 2 in. sash stuff, except the bottom rails, which are 2½ in. or 3 in. wide. The casements open outwards, hence the top lights are hinged

there is a difficulty in making the sill watertight. The given detail allows the water to get through, but it runs away again through the weep holes *w*. An alternative detail is shown at *C* in Fig. 267. The casements are fixed in position, when open, by a casement stay; and secured, when shut, by a casement fastener. When the top lights open inwards they are hinged at the bottom and controlled by a quadrant. The illustration shows a frame for an opening with wood lintel. It is intended to be fixed on the completion of the brickwork, and the projecting horns are nailed to the lintel. In present day construction it is usual to build in the frame during the erection of the brickwork, and in this case the head and sill run through as shown in later examples.

Bay Windows. Modern bay windows are usually of the casement type. Fig. 267 shows two details, one for a square bay *D* and one for an octagonal bay *A*. The angle posts are heavy

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when the framing is thick, and very often the rebates are "planted" as shown in the details, so as to use smaller stuff and to save labour.

cornice mould *c* is mitred round the window. The top boarding is covered by lead, and a small gutter is formed near the wall in the boards, to

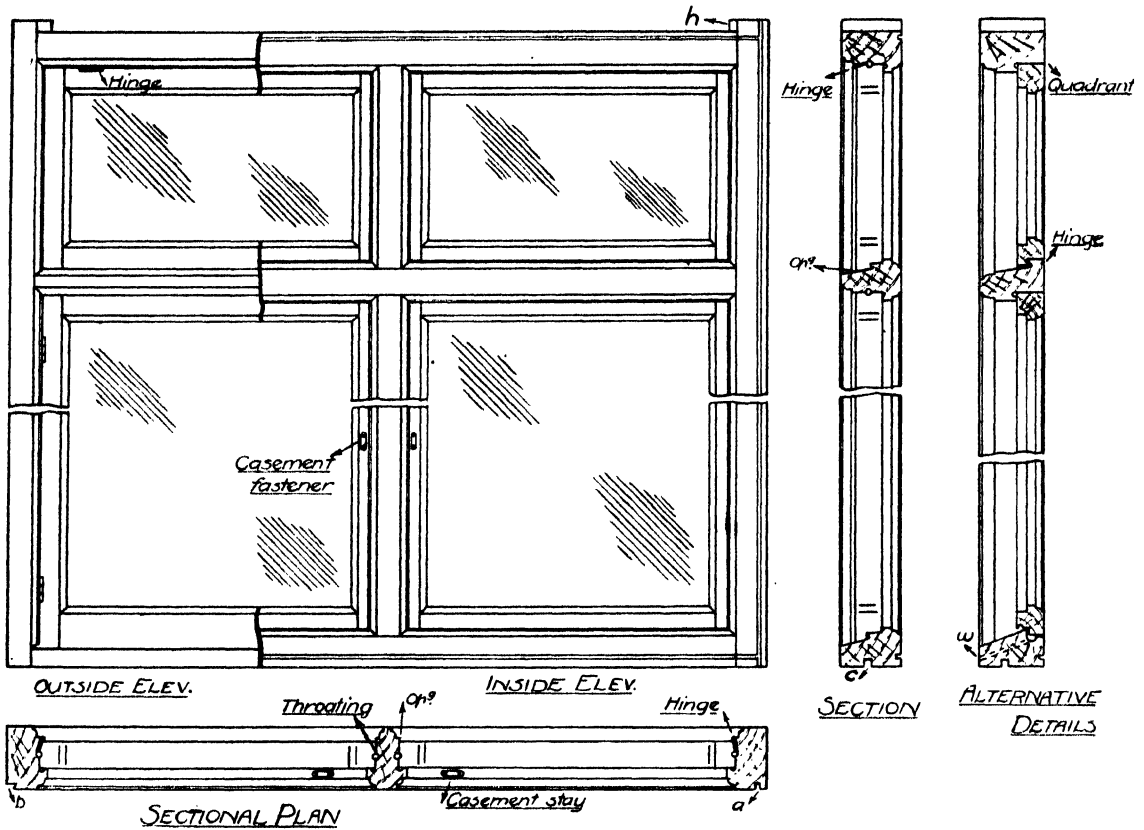


FIG. 265. CASEMENT WINDOWS

Detail *A* shows the stile built up of two 5 in. by 3 in. pieces. This is quite satisfactory and labour-saving, as the sections of the framing can be wedged up and then the angle joint put together. It should be well painted and screwed. Detail *A* shows the sash opening outwards and detail *B* shows the sash opening inwards. Detail *C* is a vertical section through *B*. Fig. 268 shows the simplest way of finishing the head of the bay. The 4 in. by 2 in. pieces *B* are fixed at the wall and rest on the window head. *A*

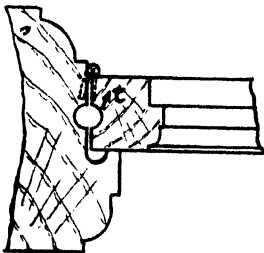


FIG. 266. DETAIL FOR HANGING STILE

carry away the water. Underneath the bearers *B* may be plastered or boarded.

French Windows. This form of window has the lower casements arranged as doors. Fig. 269 shows the type being used extensively in modern house construction. If the doors open outwards, there is no difficulty in making them water-tight. If they open inwards, the sill is often a source of trouble. Fig. 270, *B*, shows one method in which a projecting metal bar forms the rebate. The weep hole and gutter are not necessary, but are an additional precaution. Adam's patent metal water bar, as shown at *A*, is generally used in good work. The metal bar *a* is screwed to the doors and the casting *c* to the sill. A flap *b* is hinged to *c*, and falls flat on to *c* when the door is open. When the door closes a projecting spur *d* engages with *b*, so that it is lifted

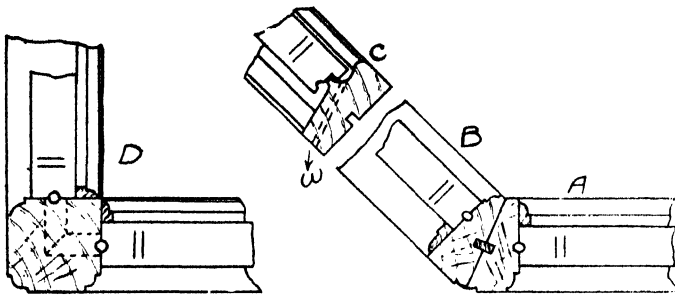


FIG. 267. DETAILS FOR BAY WINDOWS

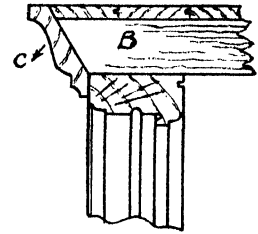
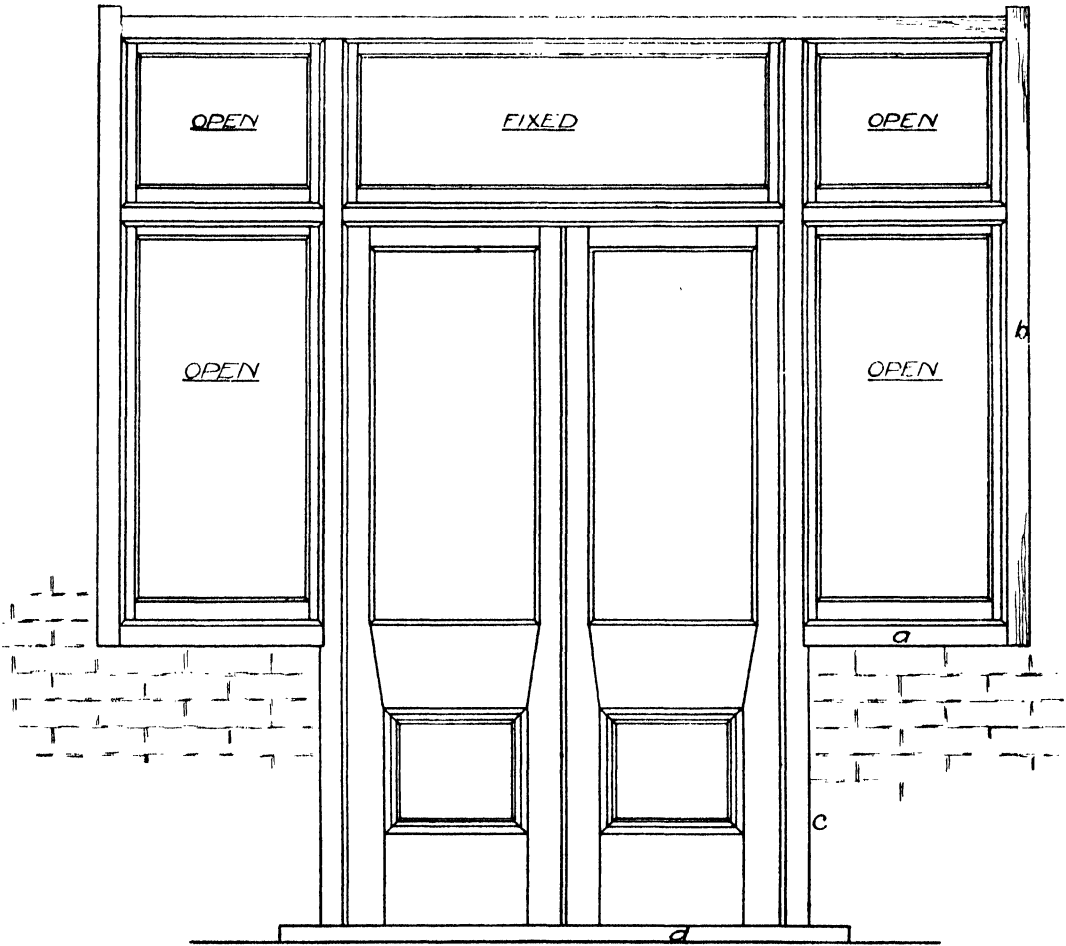


FIG. 268
HEAD OF BAY WINDOW



SCALE OF FEET | | | | 0 | 1 | 2 | 3 | 4

FIG. 269. COMBINED DOORS AND WINDOW

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up and pressed against *a*. Alternative details for the sill are shown in Figs. 265 and 267, but they are not so good.

The sills *d* and *a*, Fig. 269, should be of oak. A nosing is fitted to *a*, and architraves break the joints between the plaster and *b* and *c*. These stiles should be ploughed on the edge to form a key for the plaster. The details for the casements are as previously described.

Stormproof Windows. These are mass-produced casement windows with special features to guard against driving rain. Originally, the

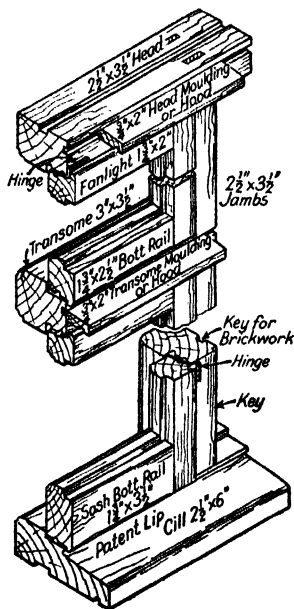


FIG. 269A. DETAIL OF STORMPROOF WINDOW

name implied double windows, but the manufacturers have incorporated the term in the registered name of the type shown in Fig. 269A. In many cases the windows have little claim to be stormproof except for a liberal supply of throatings. The example, however, has the additional lip to the casements, which requires a patent cranked hinge. In addition there are numerous throatings and two hood mouldings, which, together with the freely fitted sashes, prevent capillarity and resist driving rain. The sashes have a corner locking joint, instead of the mortise and tenon, fixed with rust proof pins. These windows are well designed for their purpose and are sufficiently strong to resist rough usage.

Pivoted Windows. When the joint between

the sash stiles and the frame is not rebated, there is no difficulty in pivoting the sash. Pivots may be obtained to screw on the face of the stile, or the pivots shown in Fig. 202 may be let in the edges of the stile and frame.

When the stiles are rebated the fitting of the pivots is a more difficult matter. The rebates

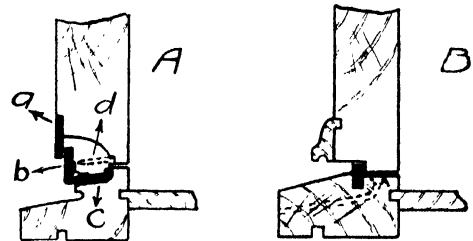


FIG. 270. DETAILS FOR SILL

have to be specially cut, and part fixed to the sash and part to the frame. Fig. 271 shows the method of preparing the beads to form the rebate. The pivots are fixed to the frame and the socket to the sash. The method is also shown in Fig. 272. The outside beads at the top and the inside beads at the bottom *a* are

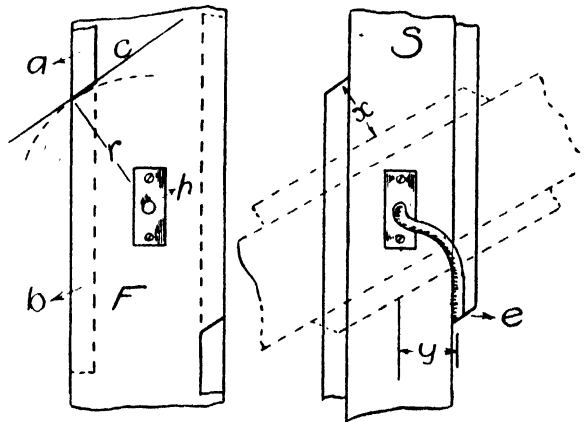


FIG. 271. PREPARING REBATES FOR PIVOTS

fixed to the frame; the remainder *b* are fixed to the sash.

METHOD. Draw the position of the sash full size when it is open at the required maximum position, as shown by the dotted lines in *S* or the parallel line *c* in *F*, Fig. 271. The line *c* is a distance *x* away from the sash. From the centre of the pivot *p* draw a line *r* to the outside of the bead, where it is cut by *c*; a line at right angles to *r* gives the cut for the bead. In Fig. 272 the sash is drawn horizontally, and the line *xx*

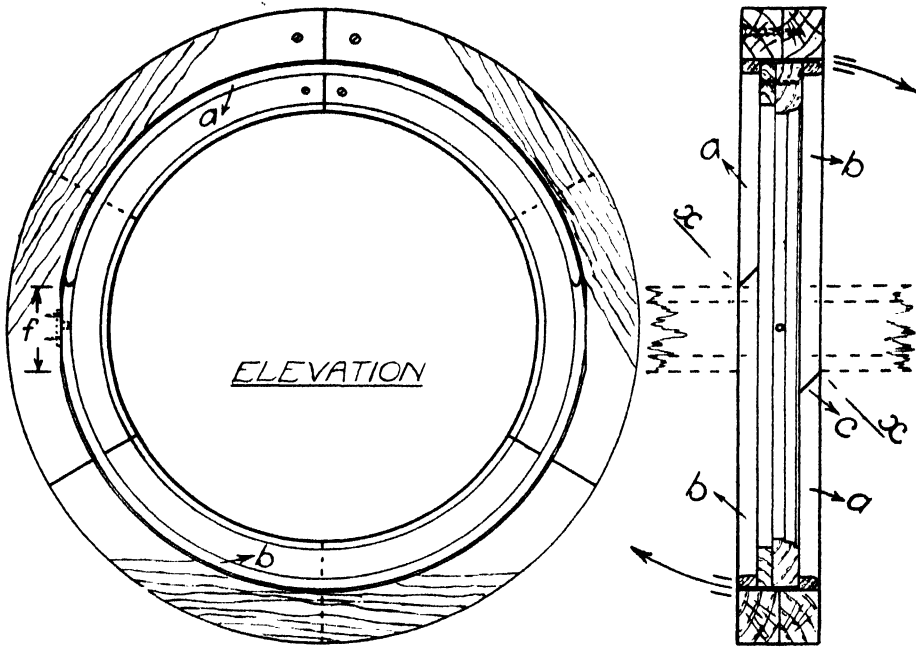


FIG. 272. BULL'S-EYE WINDOW

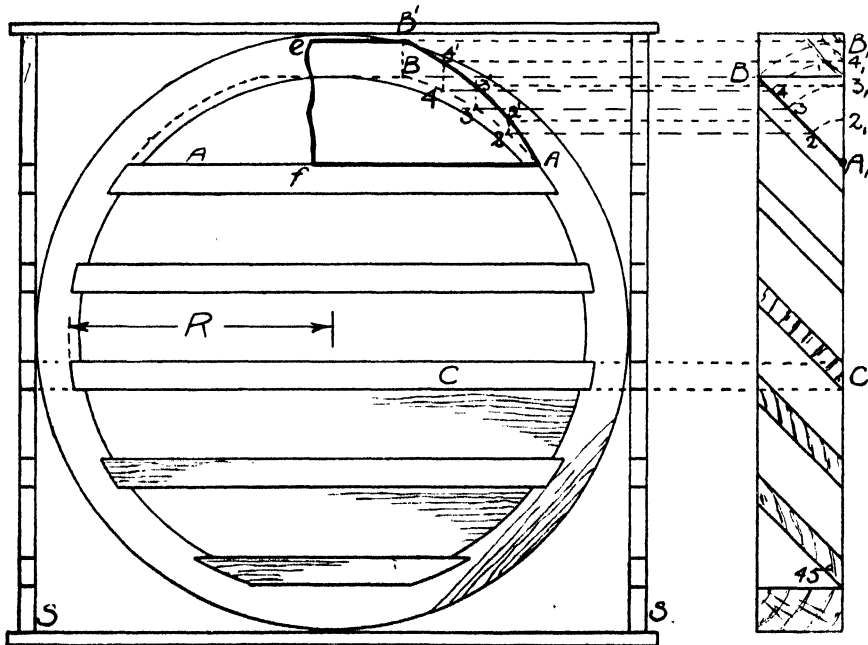


FIG. 273. CIRCULAR VENTILATOR

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passes through the centre of the pivot, hence the cuts c are at right angles to xx .

The next consideration is the placing of the sash in position after the pivots and sockets are

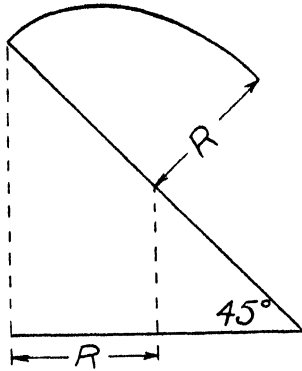


FIG. 274. TEMPLAT FOR LOUVRES

fixed. Room must be allowed to lift the sash to drop it on the pivots as shown at S , Fig. 271. The distance x must be at least equal to y . In the view S the sash only is shown, while at F the frame only is shown. The groove e passes up the sash bead and across the sash as a passage

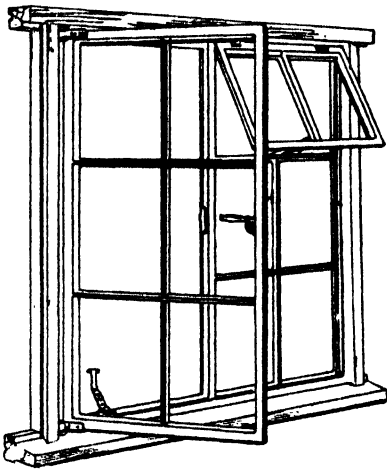


FIG. 275. METAL CASEMENT WITH WOOD SURROUND

for the pivot when the sash is being placed in position.

Fig. 272 shows a *bull's-eye* window with a pivoted sash. The foregoing remarks on pivoting apply to either rectangular or circular sashes, but there is another consideration with the circular sash. It is necessary to have a flat surface on the frame round the pivots, as shown

at f . The depth of this flat surface f must be at least equal to the thickness of the frame. It may be worked on the solid frame as in the illustration; but usually the frame and the sash are prepared circular, and then the necessary amount is cut off the sash and beads and glued to the frame.

VENTILATORS

Circular Louvres. The elevation and section of a circular ventilator is shown in Fig. 273. The frame may be cut from the solid, and jointed

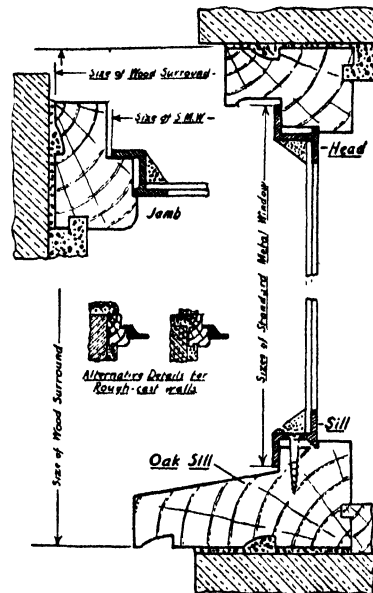


FIG. 276. DETAILS FOR STANDARD SURROUND

by keys or handrail bolts, or built up in two thicknesses with the joints crossed. The difficulty lies in cutting the louvres. The geometrical method is to revolve the surface of each louver into the vertical plane to find the true shape. Consider the top louver and revolve the top surface about the corner AA as the axis or hinge. The end view of the axis is shown at A_1 , and A_1B is the end view of the top surface of the louver. The elevation of the top surface of the louver is $A, 2, 3, 4, B$, and the end view is $A_1, 2, 3, 4, B$. All the points in elevation will move at right angles to the axis AA , and they will be projected from the end elevation. Hence they will take the positions $A, 2^1, 3^1, 4^1, B^1$, and a freehand curve through these points will give the true outline of the louver. Both ends of the louver are the same shape, of course.

PRACTICAL METHOD. Set out the louvres on two boards *S*, Fig. 273. The boards are the same width as the thickness of the frame. Place these on each side of the frame, which has been assembled temporarily. Nail strips to the ends of these boards to keep them in position. With a straight-edge mark the positions of the louvres on the face and back of the frame. Cut a strip of cardboard equal in width to the thickness of the louvres. Set the cardboard to the marks on the front and back of the frame, and mark the positions of the louvres on the inside of the frame. Take the frame asunder and cut out to the marks about $\frac{1}{2}$ in. deep. The frame can now be put together permanently.

CUTTING THE LOUVRES. Set out a quarter of an ellipse as shown in Fig. 274. To draw the ellipse, set out a line *R* equal to *R* in Fig. 273. Draw a line at 45° (because the louvres are at 45° in the frame), and project *R* on to the 45° line. This projection gives half the major axis for the ellipse, and *R* is half the minor axis. Draw the quarter ellipse by any method, and cut it out for a templet. Apply the templet to a groove in the frame until a portion is found to fit the groove. Mark this portion, and apply it to the particular louvre for which it is intended. Repeat for each louvre. The edge cuts may be found by applying the bevel to a straight-edge laid across the frame.

METAL WINDOWS

The various types of windows previously described may be obtained in metal built up of

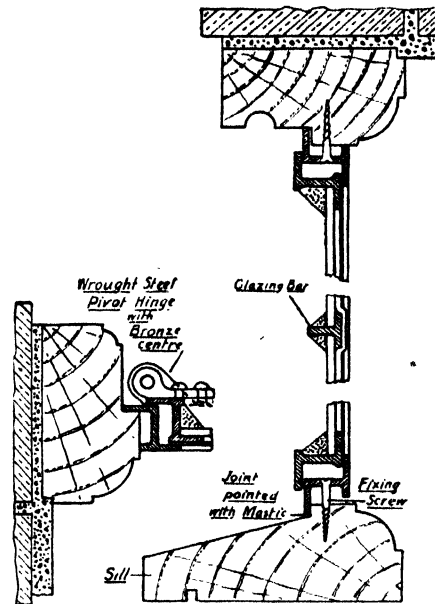


FIG. 277. SECTION THROUGH OPENING CASEMENTS standard steel sections, and the manufacturers claim to have a window for every condition and

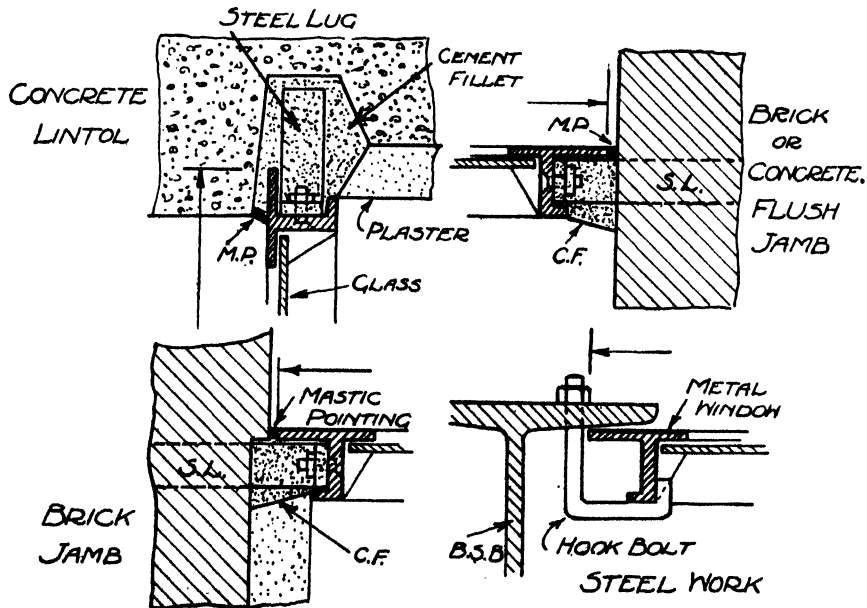


FIG. 278. METHODS OF FIXING

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kind of building. The standard types include casement; sliding, either horizontal or vertical; balanced; or combinations of these; and they may be built up to any required size or shape by means of coupling mullions or transoms. Most of the illustrations are from information supplied by the Crittall Manufacturing Co., Ltd., 210 High Holborn, London.

Casements. The common type is illustrated in Fig. 275, which may be obtained with or without wood surround. The details, with surround, are shown in Figs. 276 and 277 which also show the method of measuring the windows. Any required clearance must be allowed when forming the opening, unless the windows are

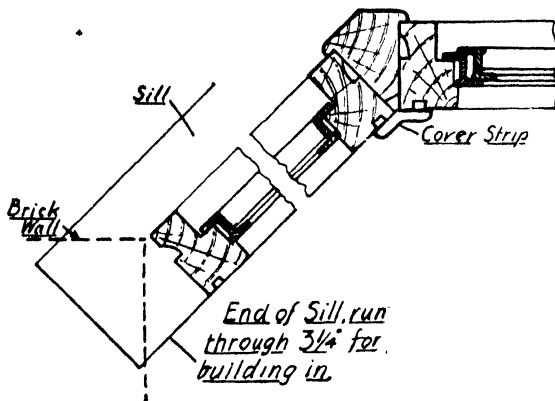


FIG. 279. DETAILS FOR BAY WINDOW WITH METAL CASEMENTS

built-in during erection, which is the better method when convenient. An allowance of $\frac{1}{16}$ in. must be included for each coupling mullion and transom in the over-all sizes. Any form of wood surround may be used to suit the characteristics of the building so long as they are arranged for the standard sizes of the metal windows.

Fixing. The wood surrounds are fixed in the same way as those previously described, but when the metal windows are fixed directly to the brickwork or concrete steel lugs are usually inserted in the wall. Fig. 278 shows different methods of fixing with various materials and conditions.

Glazing. Metal windows may be glazed inside or out. For industrial purposes inside glazing is preferred to allow for easy replacement. In the latter case, it is recommended that wood or metal beads be used instead of putty.

BAY WINDOWS. Fig. 279 shows how the stand-

ard sections are built-up to form bays. The wood surround allows for any form of bay. When the metal frames only are used the standard form of coupling mullion is used.

FRENCH CASEMENTS. Fig. 280 shows one kind of this form of window. More elaborate types may be obtained with espagnolette bolt; and side casements may be fitted, as shown dotted. The latter should be provided for ventilation even if the lighting is not required.

Vertically Sliding Sashes. The metal alternative for the "double hung sash" window is shown in Fig. 281. This type of metal window is being used extensively at the present time and is very efficient in every respect. The illustra-

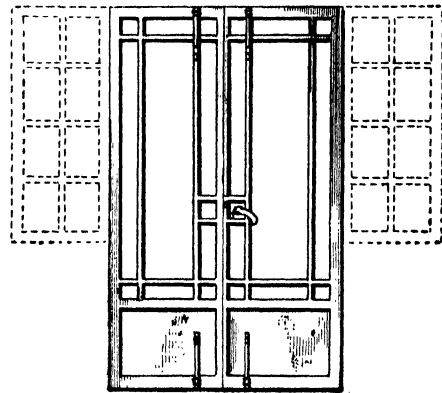


FIG. 280. METAL FRENCH WINDOW

tion, together with the details in Fig. 282, is self explanatory. The balance weights *W* and running gear are accessible by means of pressed steel spring covering-plates *A*; and a baffle *B* is provided for ventilation when the sashes are closed. The sashes may be fitted with mechanical gear for operating the sashes instead of using balance weights.

Sliding Sashes. A useful type of combined sliding and casement window may be obtained that allows for easy cleaning from the inside. Also windows sliding horizontally are made for cavity walls so that the opening sash slides into the cavity, leaving the entire opening for ventilation.

Balanced Windows. There are several forms of balanced windows that eliminate weights and cords. The "Austral" window, made by H. Hope and Sons, Birmingham, and shown in Fig. 283, is a good example of this type. The sashes are balanced on arms, which allows for

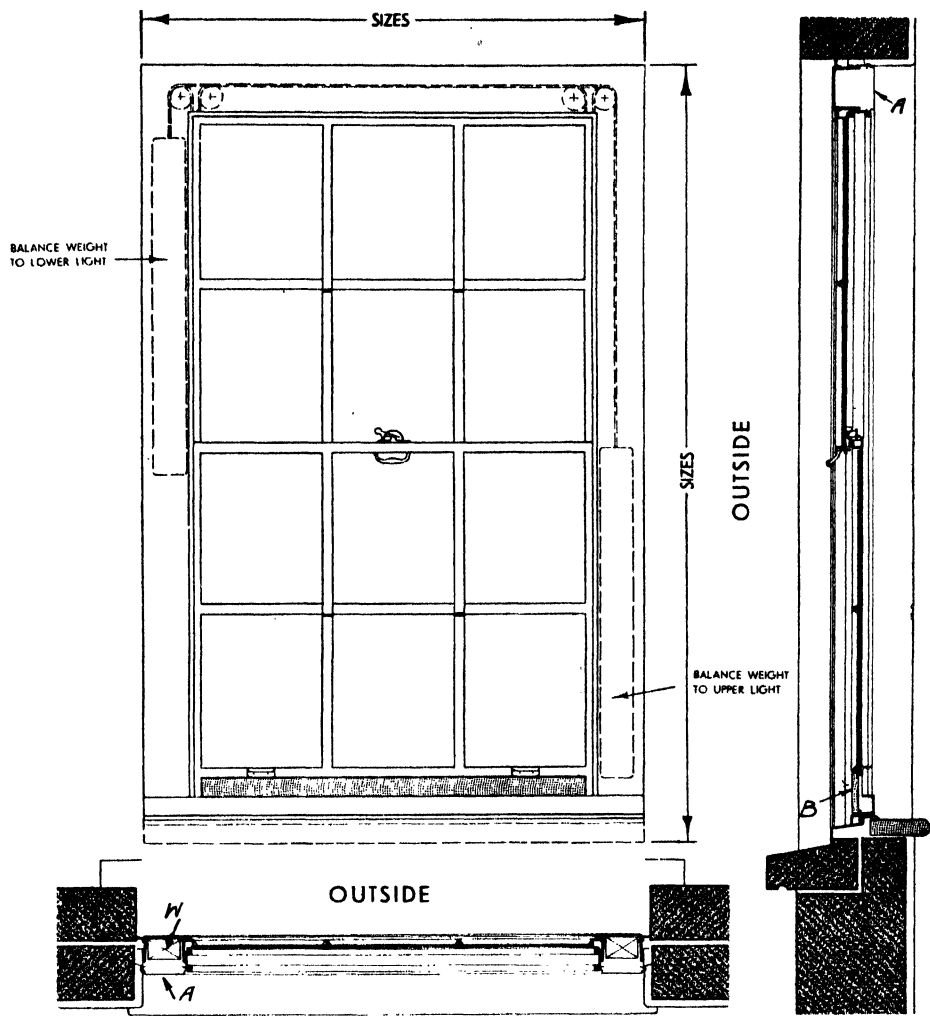


FIG. 281. DOUBLE HUNG SASHES

Crystals

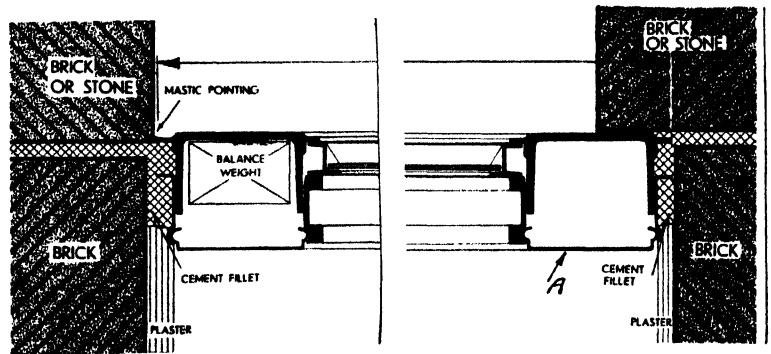


FIG. 282. DOUBLE HUNG SASH DETAILS

Crystals

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easy cleaning as well as good ventilation. Fig. 283 shows the sashes open at the middle only, while Fig. 284 shows the sashes open for maximum ventilation. The arm, which is pivoted to the sashes, revolves through a quarter circle, as shown by the dotted lines. The bottom sash is lifted up to open, and the sashes swing apart without effort owing to the perfect balance, but stay fixed in any required position.

ROOF LIGHTS

Skylights. A section through the usual form of skylight, and an isometric view of the sash, are shown in Fig. 285. The light runs parallel to the roof surface and is lifted above the slates

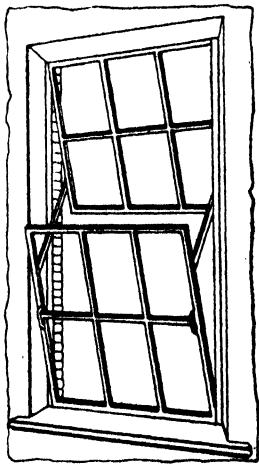


FIG. 283. "AUSTRAL" WINDOW

by a 9 in. \times 1½ in. curb *K*. Three sides of the curb are at right angles to the roof, but generally the front is perpendicular, as in the drawing. A gutter is formed at the back and sides, and the lead *l* is usually carried over the top edge. The rafters *t* are trimmed to receive the curb.

The sash, or light, consists of two stiles and head, 5 in. \times 2 in., with one or more bars, all of the same thickness; the bottom rail is the depth of the rebate thinner. The glass runs over the bottom rail, which is dished out as at *C* to carry away the condensation. A lead apron is sometimes placed under the glass on the bottom rail. This lead requires saw kerfs *b* in the stiles and bars. The stiles and bars are rebated for the glass, but the head is ploughed as shown at *d*. Protecting fillets *a* about 1½ in. \times 1½ in. are mitred round to keep out the driving rain. The light is hinged at the top, and has a skylight opener at the bottom. The method of making

the joints is shown in the isometric view. A bare-faced tenon *e* is used on the bottom rail.

Dormers. These lights are intended for ornamentation, as well as light and ventilation. Fig. 286 shows a dormer with side-lights. Generally, the side-lights are omitted and slates or lead substituted. The framing, or raker, *r*, in the roof is usually between two purlins *p*, and then curbs *k* are used to rise above the slates

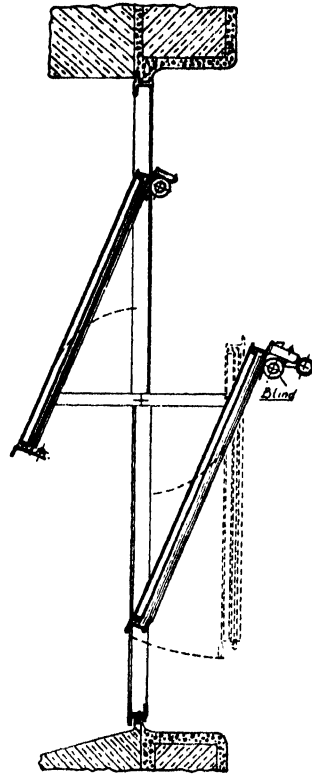


FIG. 284. DETAILS FOR "AUSTRAL" WINDOW

for the lead flashings *n*, or aprons. The front elevation is shown, together with a sectional side elevation on *AB*. The heads *d* run over the stiles to carry the barge boards and projecting roof; and the stiles are tenoned into them. The front head *h* is tenoned into the side heads.

The front sashes open, but the side, or spandril, sashes *f* are fixed. An enlarged horizontal section through the corner stile is shown separately. The rafters, to carry the slates, run over the side heads to form projecting eaves; and the front is finished by barge boards tenoned into a finial *l*. Where the dormer roof dies away on to the main roof, valley boards *v* are nailed on

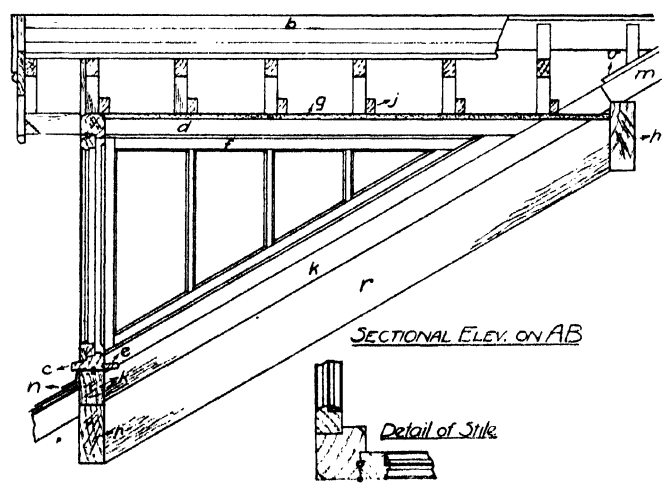
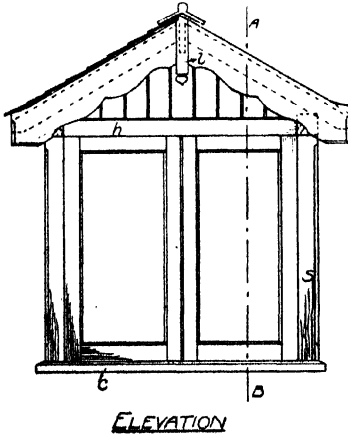
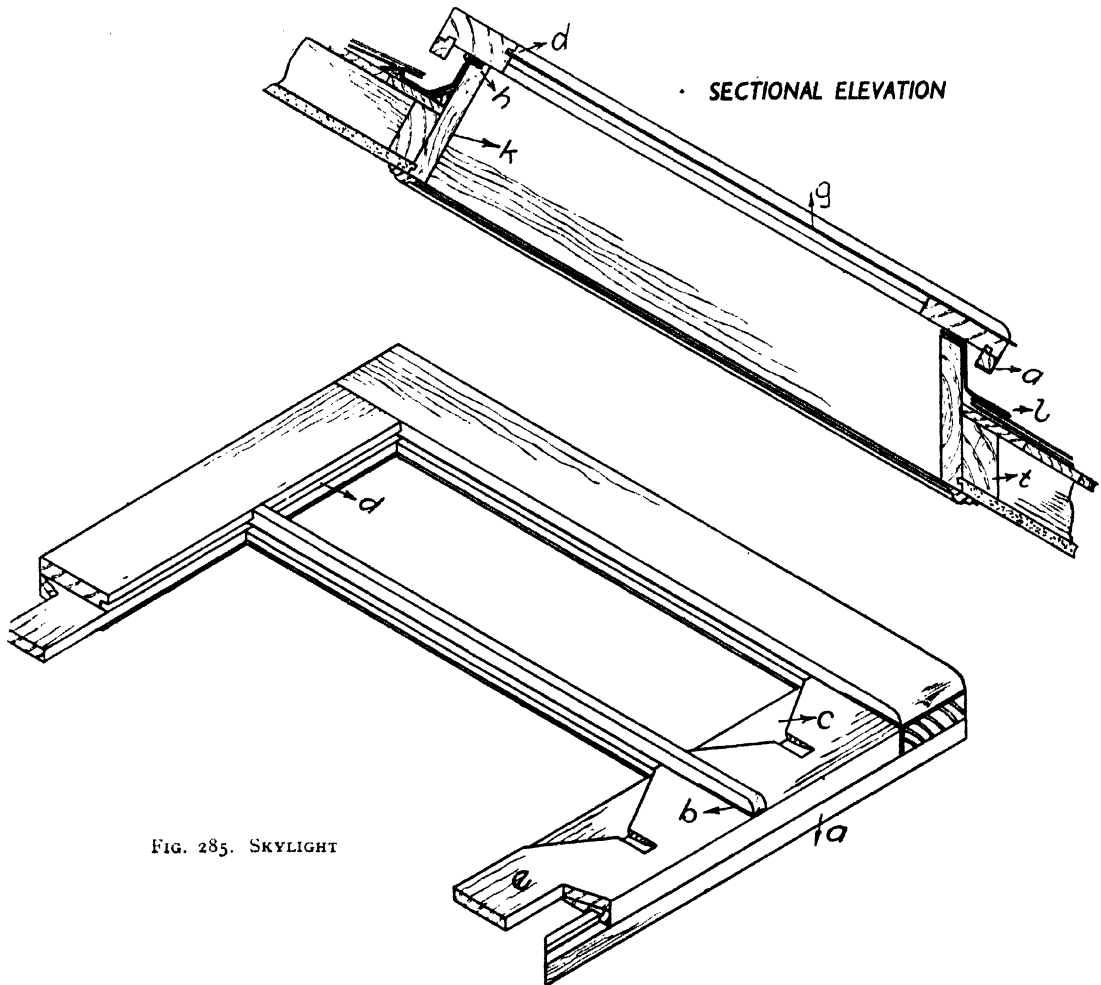


FIG. 286. DORMER LIGHT

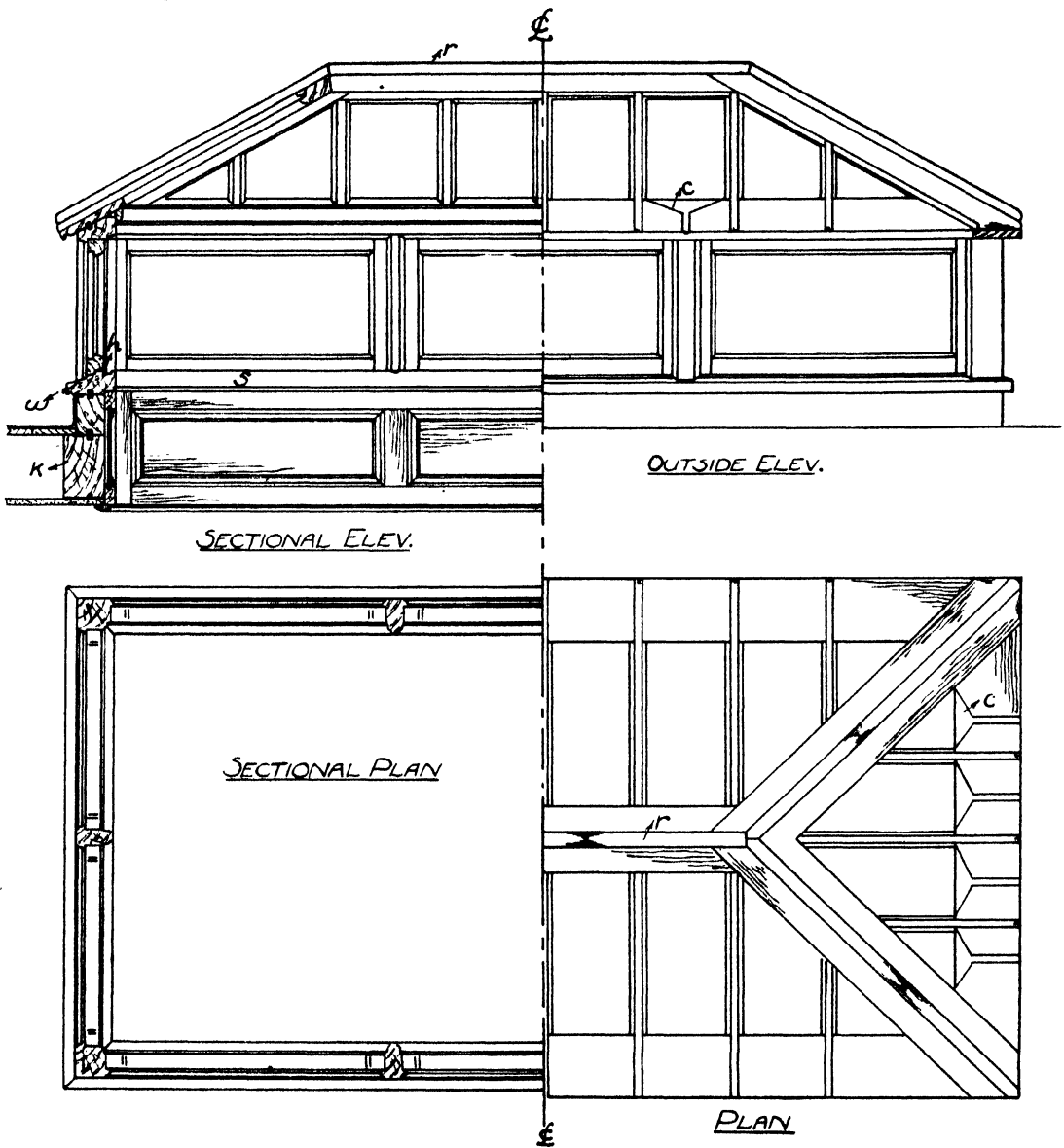


FIG. 287. LANTERN LIGHT

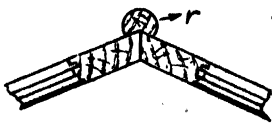


FIG. 288
SECTION THROUGH HIP

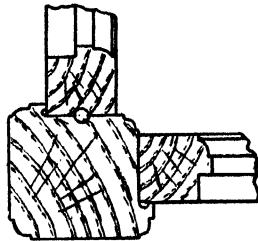


FIG. 289
SECTION THROUGH STILE

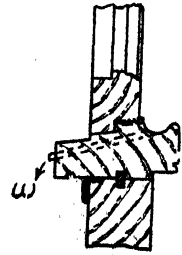


FIG. 290
SECTION THROUGH SILL

to the common rafters *m*. Ceiling joists *j* are thrown across to receive lath and plaster *g*, or boards. A deep lining usually covers the curbs and rakers, and a nosing *e* is tongued into the sill *c*. A flat top is often used instead of the pitched roof.

Lantern Light. Fig. 287 shows the outside and sectional elevations together with plan and sectional plan of the usual form of lantern light. The flat roof may be of steel, reinforced concrete, or wood covered with sheet lead as shown. The curb *K* consists of two pieces, one 9 in. by 5 in. which forms the trimmer for the roof opening, and one about 6 in. by 3½ in. to lift the light above the roof surface. A framed curb is often

roll *r* is fitted well and bedded in thick lead paint. A loose tongue in the joint adds to the strength and assists in the fixing, especially if the stiles are not straight. The method of obtaining the bevel between the hip stiles is shown in "Builder's Geometry"; it is the bisector of the dihedral angle that is required. The bevel at the ridge is obtained direct from a sectional end elevation. The ridge and hips are often covered with sheet lead.

The details for the roof lights are the same as for the skylights. The bottom rail is dished out for the condensation in each square as shown at *C*. Another safeguard against condensation is required on the sill; this may be

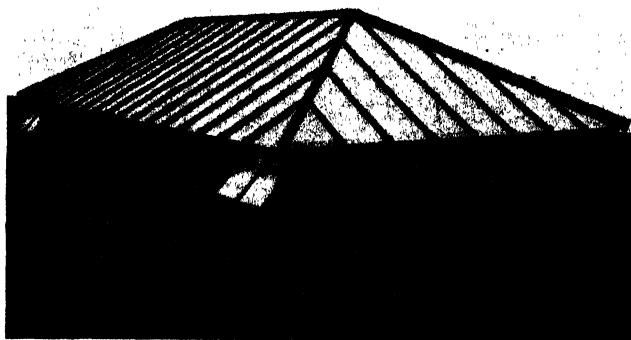


FIG. 291. METAL LANTERN LIGHT

substituted for the latter to give a greater height above the flat roof. The outside of the curb is covered with sheet lead, which is a continuation of the roof lead. If the roof is of concrete, asphalt is used instead of lead.

The details of the vertical framing of the light are very similar to those for a square bay. Usually, however, the sill *S* is mitred at the angles and jointed with handrail bolts. The stiles are then stub-tenoned into the sill, and fixed by bolts or coach screws. When the height is small, the head, stile, and sill are bolted together by a long bolt passing through the length of the stile. Another method is to mortise the stiles for the head and sill. The tenon ends are mitred inside the stile, and the projecting part of the sill passes over the stile and is mitred at the corner.

The roof lights are difficult for the beginner. Sometimes moulded and rebated hips are used; but it is much easier to make the joint as shown in Fig. 288. This method is quite good if the

planted on the face of the sill, or the section may be formed as in Fig. 290. In either case the weep holes *w* are necessary. As indicated, small copper piping is sometimes driven into the weep holes, and this tends to give greater durability.

The sashes in the vertical framing are generally made so that some of them will open, either by hinges or pivots. In the example they open inwards and are hinged at the bottom. If they open outwards they should be hinged at the top. The stiles and head may be rebated instead of square as shown in the example. Quadrants may be used to open the sashes, but the long cords are usually objectionable. A better method is to use tension-rod or rotating shaft gearing which can be operated by a screw on the wall, endless chain, or electric motor.

Lantern lights are usually in exposed positions, and every precaution should be taken to prevent the driving rain finding its way inside. Throatings, as in Fig. 289, should be used as freely

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as possible. The panelled framing used to cover the curb may be substituted by plaster or boarding.

are subject to variation according to the conditions, especially at the seating, and for the ventilation and glazing. Every precaution is

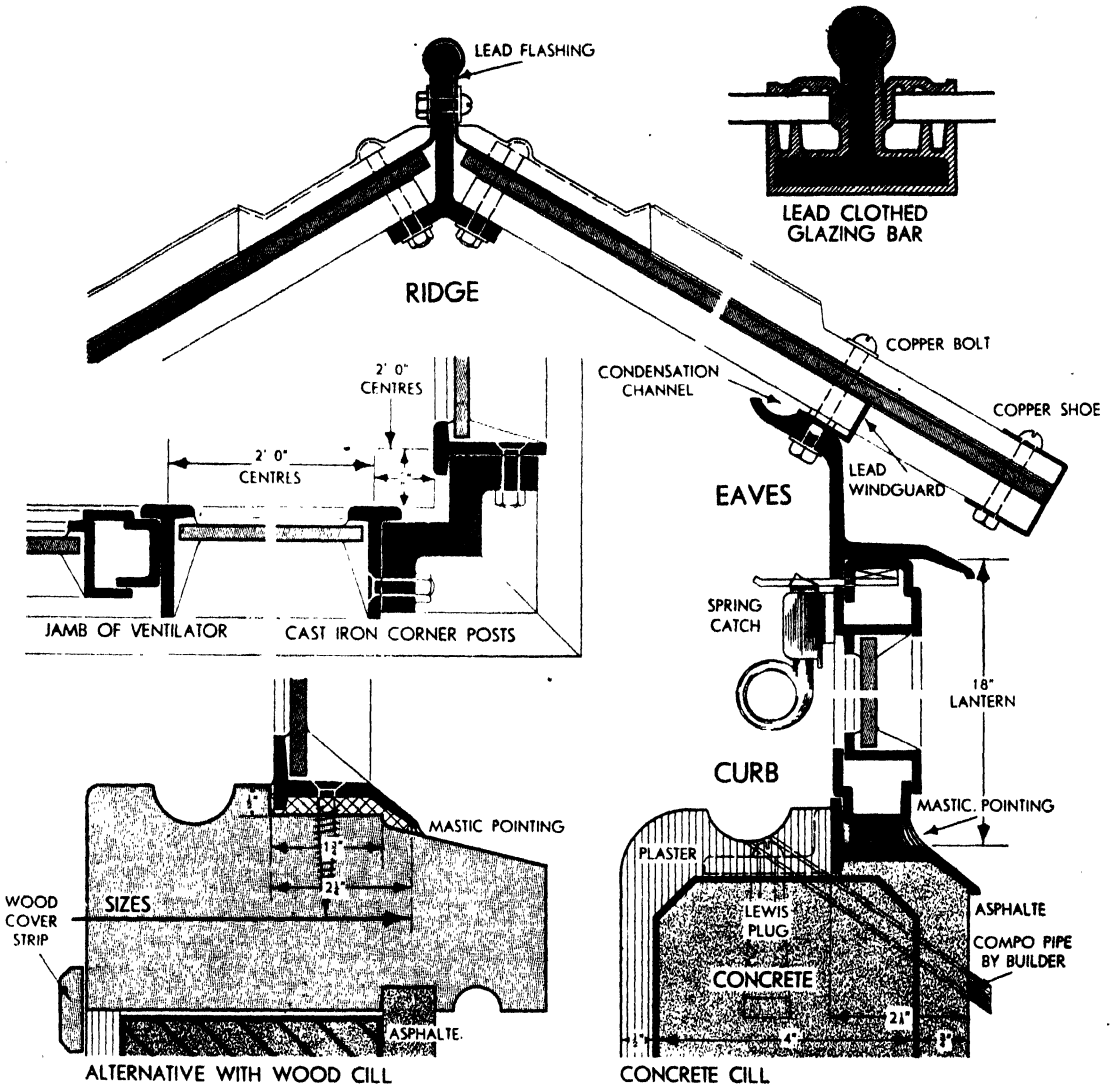


FIG. 292. DETAILS FOR LANTERN LIGHT

Cristalls

Metal Lantern Lights. These may be obtained to suit any conditions and sizes, and they are invariably used on steel or concrete buildings. Fig. 291 illustrates a typical example and Fig. 292 the details for one of this type. The details

taken to carry away the condensation which in some cases is assisted by the patent glazing. The manufacturers are constantly improving the details for metal lights and the treatment against corrosion.

Chapter VIII—CIRCLE-ON-CIRCLE WORK

FRAMING which is circular in both plan and elevation is termed *circle-on-circle*, or *double curvature*, work. The conditions vary considerably, as explained in "Builder's Geometry." The example shown in Fig. 293 is the usual condition, and has *radiating jambs with level soffit*. Two methods of constructing the head are explained. The geometrical method is more accurate, but the approximate method will appeal more to the average joiner.

GEOMETRICAL METHOD

Draw the plan and elevation as shown in Fig. 293. The front inside curve will be a semicircle in elevation; the other curves in elevation are approximately semicircular, but actually they are semi-ellipses. The head is built up of two pieces, with handrail bolts or hardwood keys at the joints. It is usual to place the transome a little below the springing *SG* to give rigidity to the stiles.

THICKNESS OF PLANK. To find the thickness of material required draw the chord *AB* in plan, and draw a line *TN* parallel to *AB* and tangential to the outer curve. The *thickness of the plank* is the perpendicular distance *P* between these two lines.

FACE MOULDS. Divide the outer curve of the elevation into any number of equal parts, as *Sa'b'c'd'D'*. Project these points on to the outer curve of the plan to *Cabc'dD*. Draw radial lines from *O* (which is the centre of curvature for the plan) through these points in plan to intersect the two faces of the plank *AB* and

TN. Where the radial lines intersect *AB* and *TN*, erect perpendiculars from *AB* and *TN* respectively. Make the lengths of these perpendiculars the same as in the elevation; that

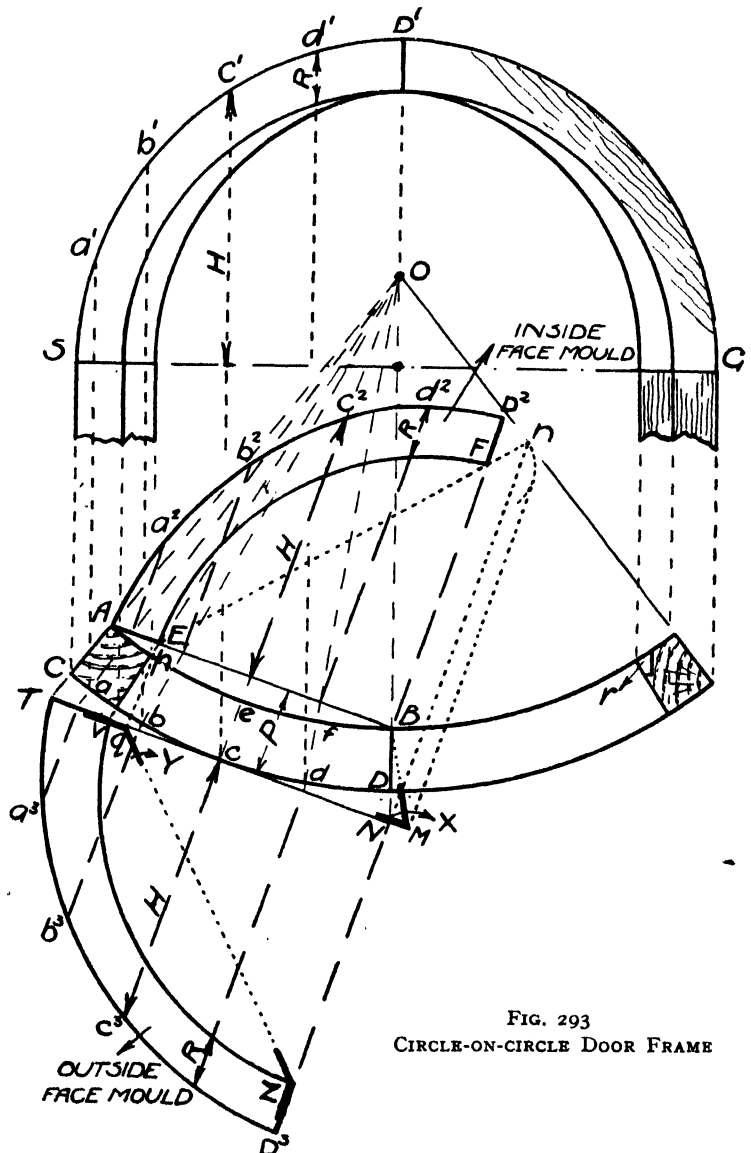


FIG. 293
CIRCLE-ON-CIRCLE DOOR FRAME

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is, the height H is the same in all three positions for c^1 , c^2 , and c^3 . The bottom edge of the mould is best found by marking off the distances R on the perpendiculars equal to R on the elevation. The points are then joined up by freehand curves.

BEVELS. Join the inside corners EF of the inside face mould and produce to meet a perpendicular to TN from N . With radius Fm

the face mould is on the edge of the plank. Mark the bevels as shown, and place the inside face mould to the points E and B on the back of the plank. Cut the plank to the outlines of the face moulds.

The curves for the vertical faces are found by drawing the radial lines ob , oc , od , etc., in Fig. 293, on the plank, and marking the positions of the points for the thickness of the head on the

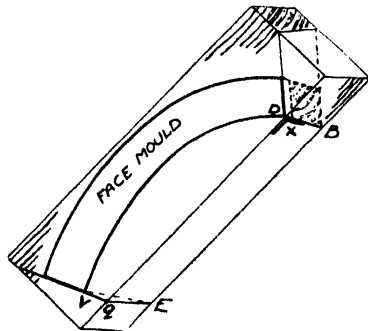


FIG. 294. APPLYING FACE MOULDS

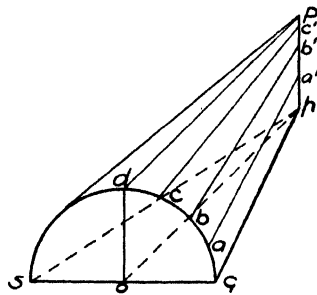


FIG. 295. DIAGRAM OF CUNEOID

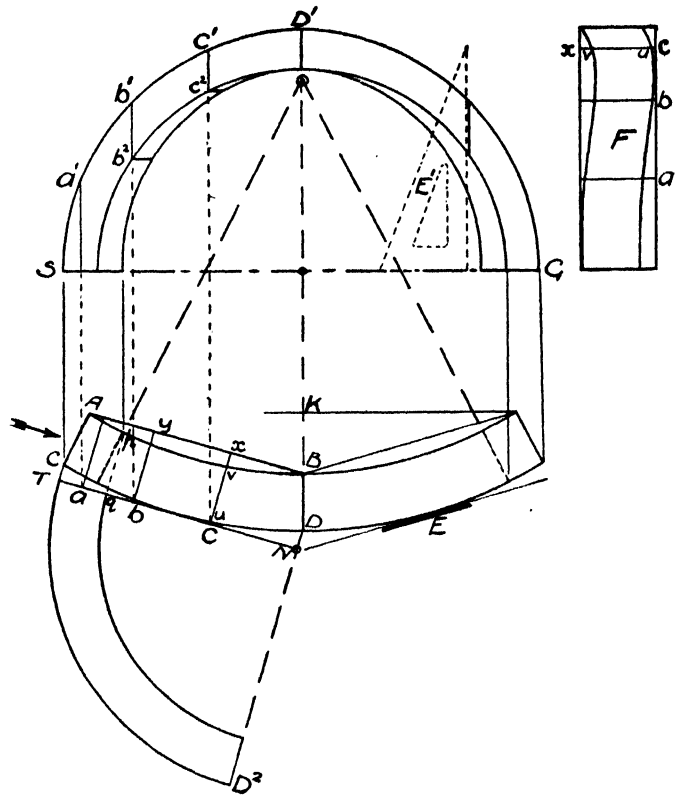


FIG. 296. APPROXIMATE METHOD FOR CIRCLE-ON-CIRCLE HEAD

describe an arc, and draw a line tangential to the arc and parallel to Nn to meet TN produced. Then TMB gives the required bevel X for the plank. The angle Y is the bevel for the face of the plank at the springing; and Z is the bevel on the face at the crown.

PREPARING THE HEAD. Fig. 294 is a sketch showing the application of the outside face mould to the plank, preparatory to cutting the top and bottom curves. The distance vg is the same as in Fig. 293, which is obtained by drawing pq at right angles to TN . The top corner D of

radial lines. The points are obtained from the plan as in ce , df , etc.

To make the method clear, a sketch of a cuneoid, from which the head is cut, is given in Fig. 295. The front of the cuneoid is semi-circular and the back is a perpendicular line Pp . The horizontal radial lines are shown in aa^1 , bb^1 , etc. From the sketch, it will be seen that a convenient method of drawing the radial lines on the plank is to bolt the two pieces together at the crown, and tie the feet together with a stretcher at the springing. Then erect the head

and also a perpendicular rod, as illustrated by the cuneoid, and with a straight-edge mark the radial lines on the head. An alternative method is to make falling moulds.

When the head is finally squared up it should be gauged for the moulding and rebates. If there is a sash opening inwards, the rebate will be as shown at *r*, Fig. 293.

APPROXIMATE METHOD

Usually the greater part of the door frame is buried in the recess, and the following approximate method is quite satisfactory. Set out the plan and elevation as before, and draw *AB* and *TN* as in Fig. 296. The thickness of the plank is found as before; in this case it is *cx*. With centre *N* and radius *NT* describe the circular arc *TD²*, and with *Nq* as radius draw a parallel arc. This will give an approximate face mould. Mark the outline of the face mould on the plank and cut the plank square to the face, leaving the lines full for the final trimming.

Make the joint at the crown the same as the angle *ABD*. The face bevels are given by the face mould. Note that *ND²* is at right angles to *TN*.

Divide the outer edge of the elevation into any number of equal parts, as *Sa'b'c'D'*. Project these points to the plan as shown at *a, b, c*. Draw lines across the plan square to *TN*, as *cx, by*, etc.

Bolt the two pieces together and erect them over the plan. Erect perpendiculars with a large square on both faces of the "head," as *b¹b², c¹c²*, etc., from the points *a, b, c* on *TN*. The method of applying the square is shown at *E* and *E¹*. Draw lines to represent *by, cx*, etc., on the top and bottom edges of the plank, joining up the perpendicular lines on the faces. Mark on these lines the points where the plan curves cut the lines, as *u* and *v* on *cx*. Join the points together by free curves both on top and bottom edges. The result is illustrated at *F*, which is an end view of the plank looking along the arrow in the plan. Next unbolt the head and work off the waste material.

The method of trimming up the top and bottom edges is illustrated by a sketch in Fig. 297. Make two blocks *b* equal in thickness

to *BK* in Fig. 296. Place one block under the head and one on the stretcher as shown in Fig. 297. A radius rod *r* with a falling pencil *p* is used to mark the inner and outer curves. Usually only the soffit curve is required to be accurate. The stuff is finally trimmed up and rebated.

MISCELLANEOUS CIRCULAR WORK

A difficult but uncommon example in double-curvature work is the sash and frame. The good craftsman will readily overcome the difficulties by a careful study of the geometry

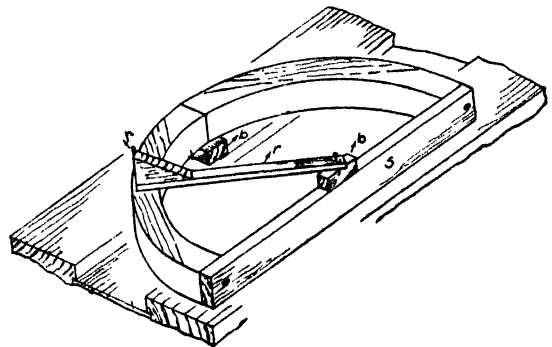


FIG. 297. CIRCLE-ON-CIRCLE HEAD

explained in "Builder's Geometry" and "Stair-casing." Lack of space prevents a detailed explanation in this section. The usual method is to obtain the "moulds" by drawing the "stretch-out" of the various members. The frame, generally, has parallel jambs and level soffit, hence it is a simple matter to build up a temporary drum, or cylinder, upon which the members are "built up" or bent. The head is cut to the mould from a suitable veneer, bent round the drum and stayed, or blocked, on the back.

If the sash is constructed of three pieces, the thickness of the plank for the middle piece is obtained from the plan in the same way as explained for the two-piece head in Fig. 293, and then the "stretch-out" moulds are applied. Circular bars in elevation are called *cot*, or *chord*, bars. They are steamed and bent round a cylinder and then cut to the "mould." A piece of straight stuff is left on below the springing.

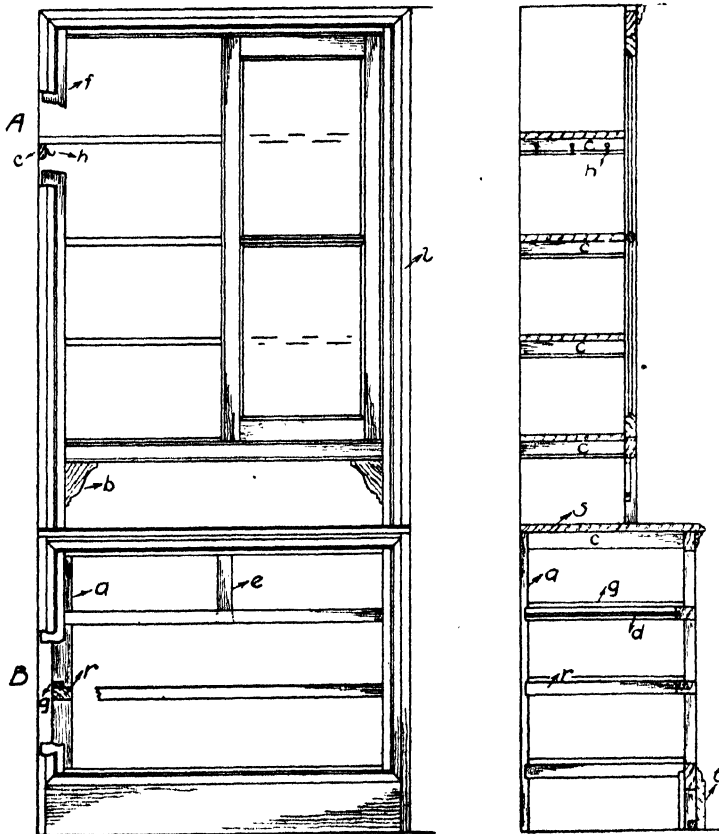
Chapter IX—FIXTURES AND FITTINGS

THE following examples are intended for cottages. Similar fittings are generally included in speculative houses. They are, however, useful in any type of house, and a little more work in the details and construction would make them suitable for better class work.

Kitchen Cupboard. A kitchen cupboard, built in a recess, is shown in Fig. 298 by elevation and sectional end elevation. The lower portion is framed for drawers and is separate from the top portion. The runners *r* for the drawers are tenoned into the front rails of the frame and

housed into a 2 in. by 1 in. piece *a*, which is plugged to the wall. Guides *g* for the drawers are planted on the runners. The runners may be ploughed for division panels, or false bottoms *d*, but they are usually omitted in inferior work. If they are included, they require rails at the back to carry them unless they run into the plaster. The vertical piece *e* is tenoned into the rails, and wedged, to divide the top space for two small drawers. A centre runner is required to carry the drawers; this would be carried at the wall end by a cleat plugged to the wall or to a back rail. The construction of the drawers has been explained in the chapter on joints. A wide shelf *s* is fixed on cleats *c* to cover the drawer framing and to form a dresser.

Above the shelf is an open space, and above that again is the cupboard with four shelves. The doors to the cupboard, one of which has been omitted, have glass panels. The shelves are fixed on cleats *c*, which should



Scale 0 1 2 3 ft.

FIG. 298. KITCHEN DRESSER AND CUPBOARD

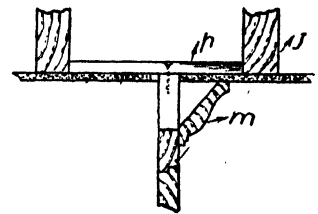


FIG. 299. DETAIL OF CORNICE

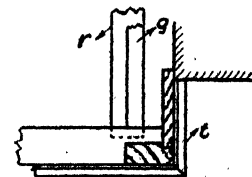
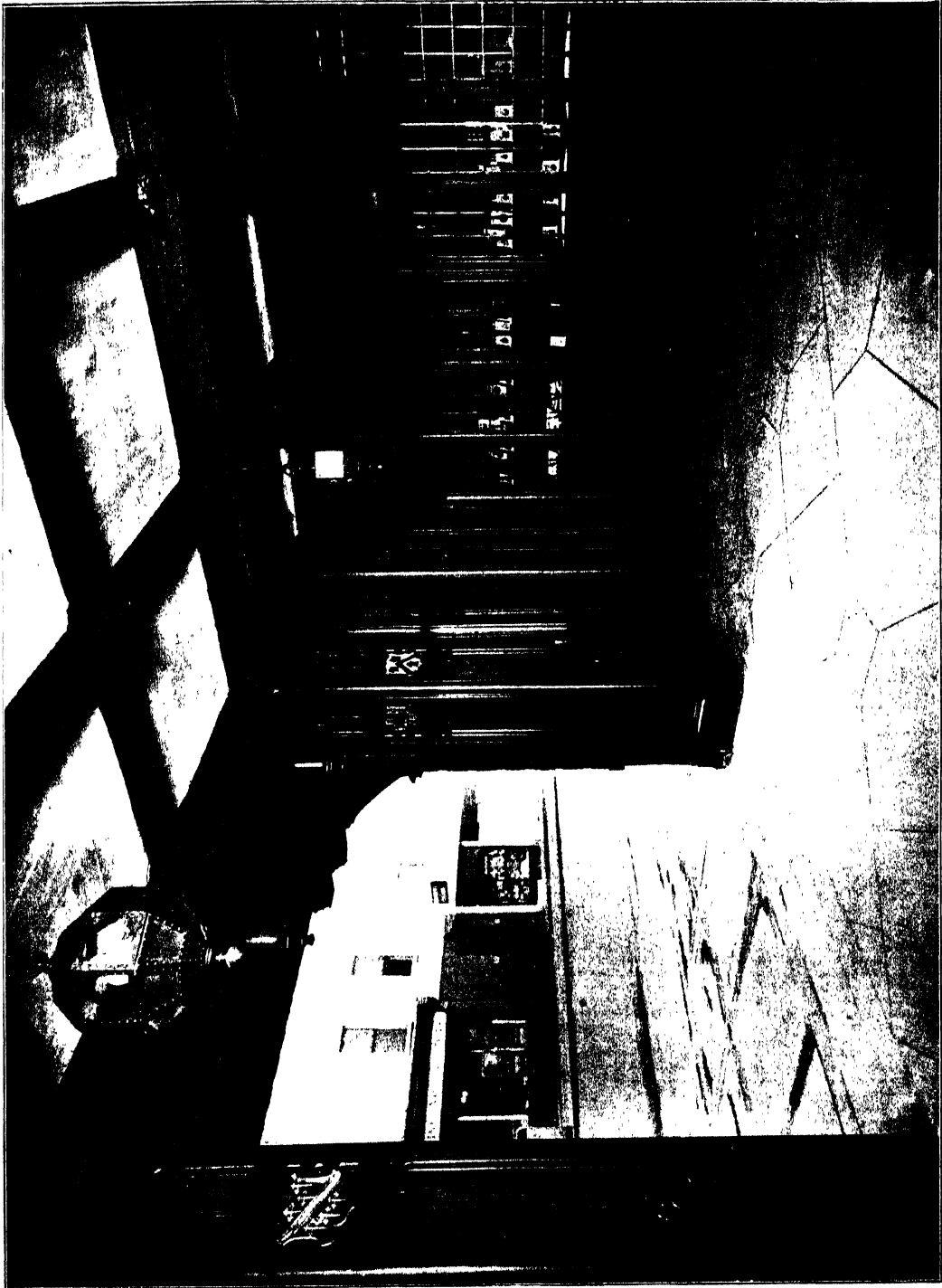


FIG. 300. DETAIL FOR KITCHEN DRESSER



By kind permission of

Messrs Liberty & Co.

VESTIBULE TO MAIN ENTRANCE

A fine example of high-class Joinery in Oak. Showing Entrance Doors, Panelled Ceiling with Carved Bosses, Carved Framing, and Linen-fold Panels

(T.3461)

be wide enough to act as pin rails for the cup hooks *h*. In inferior work, the shelves rest on nails until the walls are plastered, which then fixes the shelves. The front edges should be carefully plumbed, as they act as rebates for the doors. The bottom shelf stands $\frac{1}{2}$ in. above the rail for the same reason. If the frame is rebated all round, the shelves may stand back from the doors. The doors may be ornamented by bars if desired.

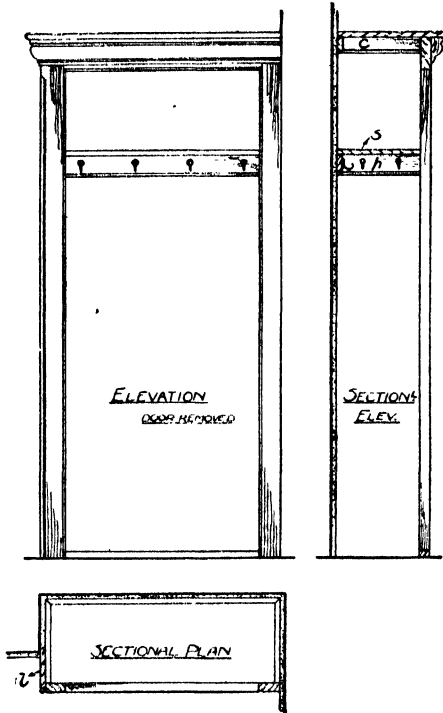


FIG. 301. WARDROBE

The cupboard frame is usually 3 in. by $1\frac{1}{2}$ in. stuff. A cornice mould or bed mould *m* may be fixed at the top, as shown in Fig. 299, by lowering the top rail; this gives a bolder appearance to the cupboard. The frame is fixed to the edge of the shelves, and the top horns to the ceiling joists. If the joists *j* are inconveniently placed, a piece *p* may be fixed between them as shown in Fig. 299, to nail to the frame stiles.

The open space below the cupboard is ornamented by two brackets *b*. The rail and stiles should be rebated for the brackets. An architrave or lining *l* is mitred round the frame. The

left-hand stile has been broken at *A* to show the cleat *c*, and at *B* to show the runner *r*. Sometimes the drawer portion projects outside the recess; the return end may then be prepared as shown by a horizontal section in Fig. 300.

Wardrobe. A useful wardrobe for a small recess is shown in Fig. 301. The frame consists

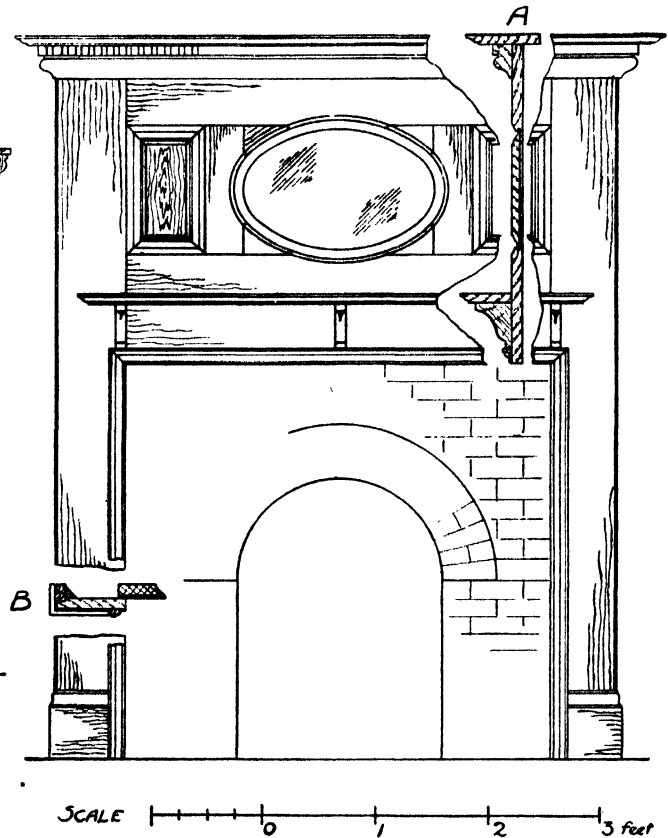


FIG. 302. WOOD MANTEL

of head and stiles only, and it is made to take a 6 ft. 4 in. by 2 ft. 4 in. four-panelled door. The door has been omitted for clearness. The cleats *c* and the pin rails *p* are plugged to the walls, and then the shelf *s* is fixed. Usually, everything is fixed before the plaster receives the finishing coat. The top, which is usually tongued and grooved boarding, is fixed after the frame.

The example shows the recess too small for the wardrobe. Hence a lining *l* is used to make out the width. The lining may be stop-chamfered instead of having the return bead. A strip of wood is nailed on the floor to keep

out the dust, and to raise the door above the floor coverings. Special wardrobe fittings may be used instead of the hooks shown in the example.

Mantel. Fig. 302 shows the finishings for a fireplace as used in speculative houses. The mantel is of pine, painted and enamelled, and looks very effective. The fireplace is formed of tiles to match the hearth. The construction

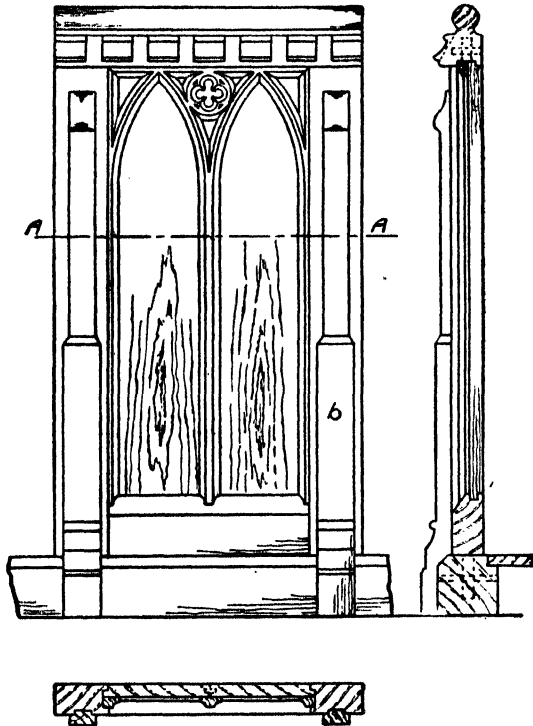


FIG. 303. FRAMED END FOR PEW

of the mantel is very simple except for the mirror. If the mantel has to be made by hand, a rectangular bevelled mirror, instead of the oval one, would eliminate much labour. The mirror fits in a rebate and is covered at the back by a piece of plywood. The panels, which are raised, may also fit in rebates instead of the plough grooves. This would be an advantage if the stuff were only 1 in. thick. The lower shelf is screwed through from the back and is supported on three brackets. The sections at A and B show the method of construction.

CHURCH FITTINGS

The usual type of church work is Gothic in design and rich in ornamentation. It has many

peculiar features for which oak is most suitable. Generally the mouldings are stuck on the solid, and mason's mitres are carved after the framing is glued up. The tenons are secured by pins which show on the face and form a feature of this class of work. The top edges of the horizontal members are bevelled and the mouldings die away on to the bevels. The panels are faced with tracery work, which is fret cut and glued on to the panels. *Dentils* and *crenelles* are freely used for decorative purposes.

Benches and Pews. Fig. 303 shows the elevation, vertical section, and horizontal section on A-A, of a bench or pew end, which illustrates several of the above features. The panel moulding, however, forms part of the tracery work and is housed into the stiles. The stiles are tenoned into the top rail and pinned. The pins do not come through to the face because of the dentils. The feet of the stiles are tenoned into the curb, which runs the full length of the aisle to receive the series of bench ends. The buttresses *b* are for decorative purposes, but they also strengthen the framing.

A simpler form of solid bench end is shown in Fig. 304. The panel is sunk and the tracery work planted. The moulding on the top may be planted as a cap, but the example shows the moulding stuck on the solid. The back to the seating consists of top and bottom rails, with muntins *m* about every 3 ft. apart, but the distance depends upon the length of the benches. The intermediate portion consists of tongued, grooved, and veed boarding, tongued into the rails. The book shelf is screwed to the under edge of the top rail, with occasional brackets as a support. The book rack is screwed under the bottom rail. The seat is tongued into the back and supported by uprights placed under the muntins. Both back and seat are housed into the bench end.

The aisle is usually of concrete with tile, composition, or granolithic finish, but the flooring *f* to the pews is generally of wood, either blocks or boards. The curb *c* is usually about 5 in. by 4 in., and it is held in position by the concrete; it is rebated to receive the floor boards. Fig. 305 gives the details for the back of the seating. A vertical section through the top rail is shown at A, and a horizontal section through the muntin at B. The latter shows alternative methods of tonguing the boards into the muntin. The term *pew* is now generally applied to all fixed seatings; formerly it was

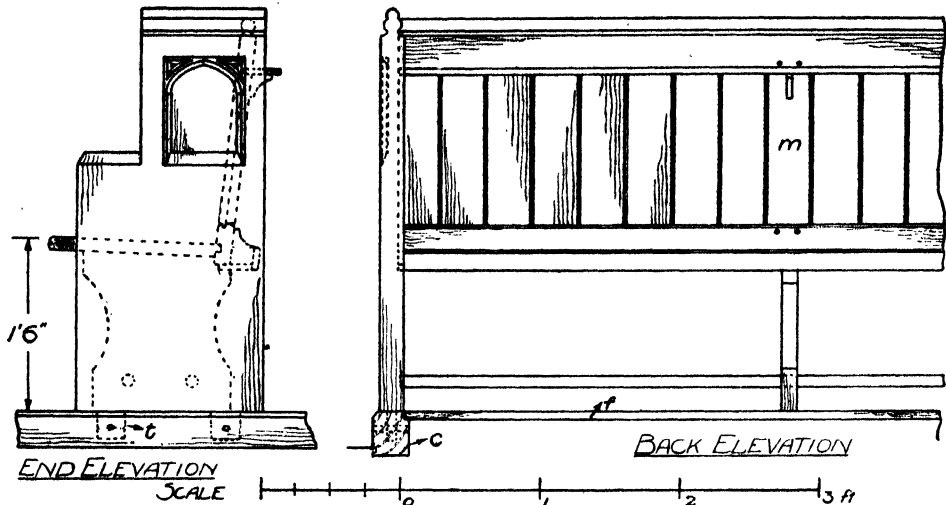


FIG. 304. CHURCH PEW



FIG. 305. DETAILS FOR BACK OF SEAT

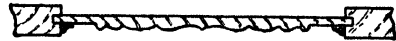
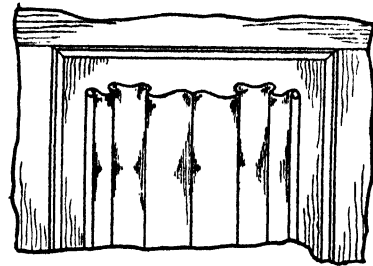


FIG. 307. DRAPED PANEL

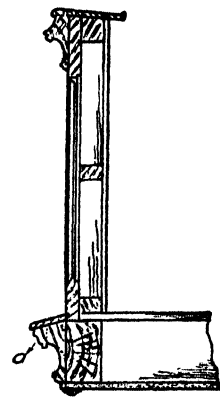
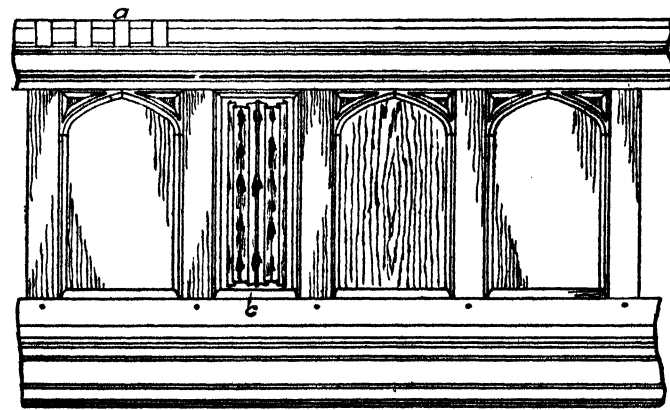


FIG. 306. GALLERY FRONT



FIG. 308. REREDOS FOR CHRIST CHURCH, BRIDLINGTON

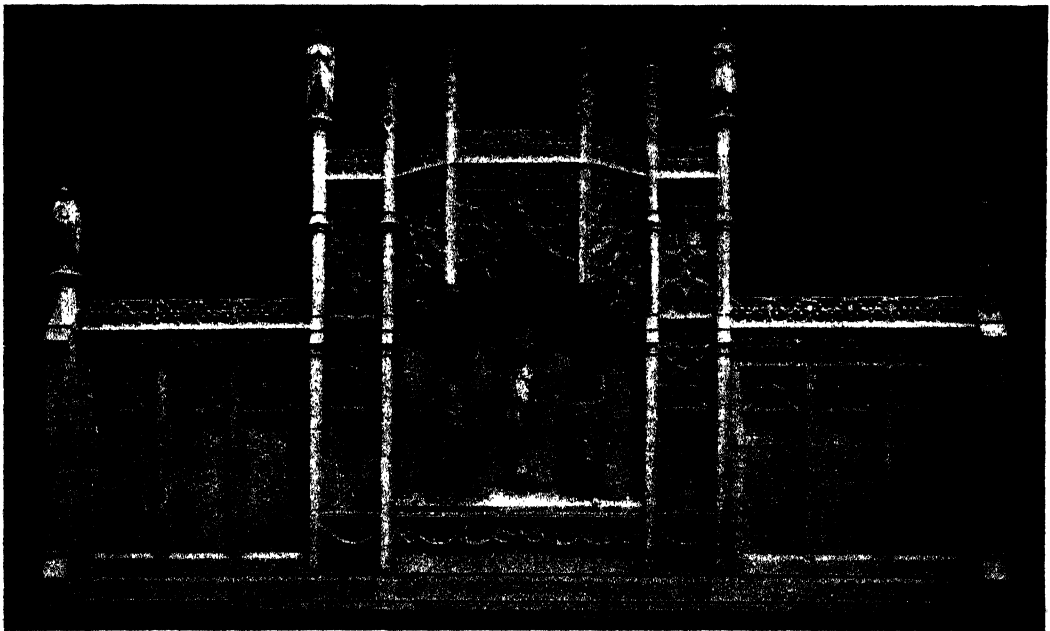


FIG. 309. MEMORIAL REREDOS, CLEVELEY'S PARISH CHURCH
Harry Hems & Sons, Sculptors, Exeter

applied only to the "closed in" variety, the open seats being termed *benches*.

Gallery Front. A panelled front for a small gallery is shown in Fig. 306. The framing for the face is $1\frac{1}{2}$ in. thick, and the back is covered with $\frac{3}{4}$ in. match boarding. The tracery work

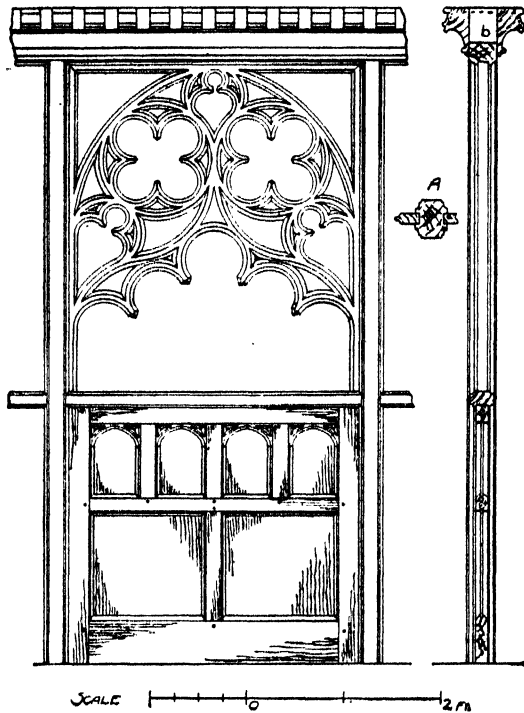


FIG. 310. PARCLOSE SCREEN

and scotias are planted, the scotias being scribed on to the bevel *c* of the bottom rail. To relieve the monotony of the panelling a "linen fold," or "draped," panel may be included about every four or five panels, according to the length of the front. Ornamental bosses would be placed under the draped panels to relieve the moulding *a*, which is built up as shown by the dotted line. The dentils *d* would be continued throughout the front. Fig. 307 is an enlarged detail of a draped panel showing the horizontal section and part elevation.

Screen. A portion of a parclose screen is given in Fig. 310. The cornice may be dentilled as shown, or it may be crenellated. Blocks *b* should be fixed on the head to carry the moulding, which should be rebated for a cover board. The panelled framing at the bottom may have the top and bottom rails running through, to

give an appearance of continuity to the whole screen. A horizontal section through the stile of the screen and the open tracery panel is shown at *A*. The tracery on the bottom panels is planted as for the gallery front. In the vertical section the details for the open tracery panel at the top and the planted tracery at the bottom have been omitted.

Several illustrations of more elaborate church

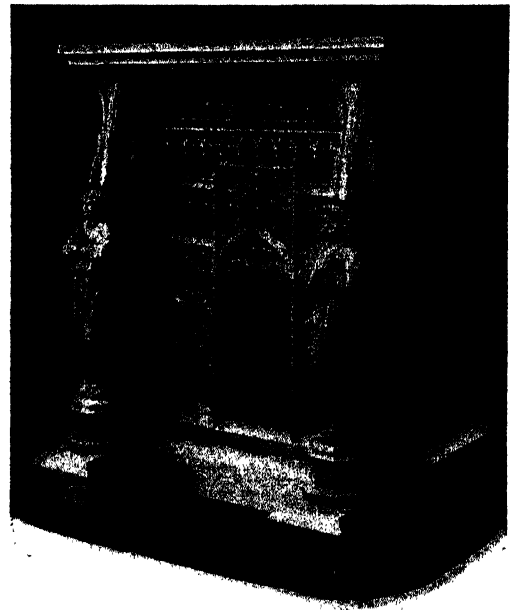


FIG. 311. READING DESK

work have been supplied by H. Hems & Sons, of Exeter. They are included, Figs. 308 and 309, as interesting examples of woodworking, but they are the work of specialists, and it is not probable that the average joiner would ever have to contend with this class of work. Two different styles of reredos are shown and a reading desk (Fig. 311).

Conclusion. For other information on woodworking and allied subjects, the reader is referred to the sections on "Carpentry," "Staircasing and Handrailing," "Shop Fronts and Fittings," and "Preliminary Operations."

The following books can also be recommended for further study: *Joinery and Carpentry* (edited by R. Greenhalgh); *Practical Joinery and Carpentry*, by R. Greenhalgh; *Modern Practical Joinery and Modern Practical Carpentry*, by George Ellis.

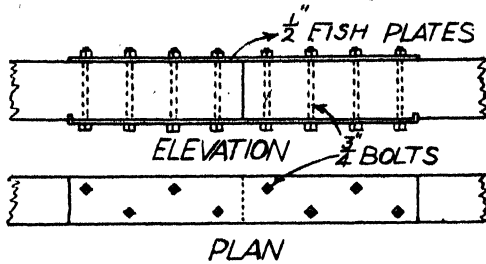


FIG. 1. FISHED JOINT

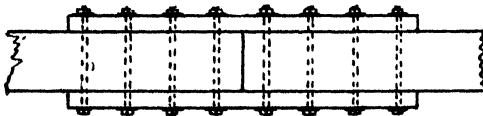


FIG. 2. FISHED JOINT WITH WOOD FLITCH PLATES

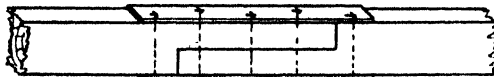


FIG. 3. HALVED JOINT

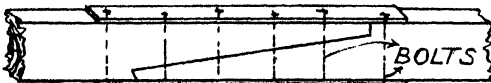


FIG. 4. SPLOY SCARFED JOINT

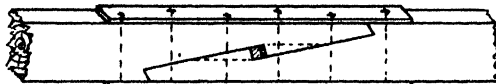


FIG. 5. SPLOY INDENTED SCARFED JOINT

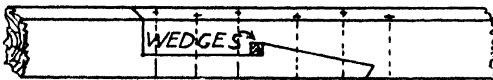


FIG. 6. INDENTED SCARFED JOINT

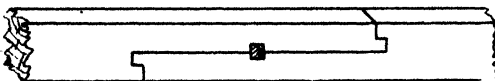


FIG. 7. LIPPED HALVING JOINT

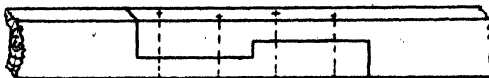


FIG. 8. TABLED JOINT

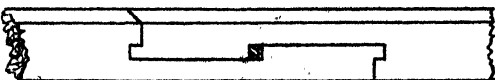


FIG. 9. LIPPED TABLE JOINT

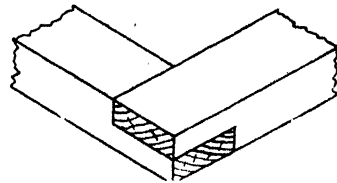


FIG. 10. HALVED JOINT AT ANGLE

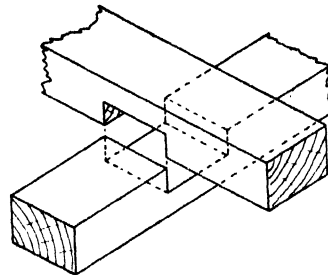


FIG. 11. HALVED JOINT AT RIGHT ANGLES

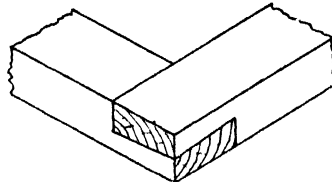


FIG. 12. BEVELLED HALVING AT ANGLE

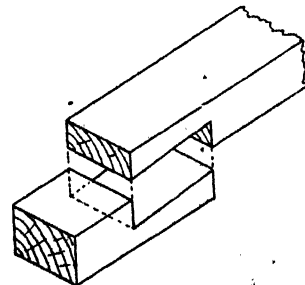


FIG. 13. LONGITUDINAL BEVELLED HALVING JOINT

Carpentry

By C. H. HANCOCK, F.B.I.C.C.

Chapter I—JOINTS

CARPENTRY is the art and practice of cutting, framing, and fixing together of timbers for the constructional part of a building, where strength is required. Generally the timber is covered by other materials. It is distinct from joinery, in which the timber in all cases can be assumed to be wrought.

Carpentry Joints should be designed with a view to resisting the particular stress, or stresses, that they may be required to withstand, and should be made as simple as possible, to ensure the accurate fitting of each part. Owing to the shrinkage that is liable to take place in the material used, the joint must be secured, and in most cases strengthened, by the use of iron straps, bolts, dogs, wooden pins (trenails), wedges, keys, nails, or screws.

In the design and the construction of joints, consideration of the following principles will be helpful—

(a) To cut the joints and arrange the fastenings, so that the pieces of timber connected are as strong as is possible ;

(b) To arrange that each abutting surface in the joint shall be, as nearly as possible, perpendicular to the pressure which it has to transmit ;

(c) To cut and fit each pair of surfaces accurately, in order to distribute the stress uniformly. The area of each surface should be in proportion to the pressure it has to bear ;

(d) The fastenings should be so arranged that they are equal in strength to the pieces which they connect ; and

(e) To place the fastenings so that there shall be sufficient resistance to prevent the joint giving way, by the fastenings crushing or shearing their way through the timber.

Stress and Strain. Where a load, or force, is applied to a member, it causes the fibres to be *stressed*. This stress tends to produce a *strain*—which is an alteration in shape or form of the timber. If the strain be too great the timber will fracture.

The chief stresses found in carpentry are

tension, compression, cross or transverse stress, and shearing.

TENSION is a force that tends to pull the fibres asunder, as in the case of a tie-beam or king-post.

COMPRESSION is a force that tends to crush the fibres, as when a load or force is placed upon a post or strut.

CROSS, OR TRANSVERSE, STRESS is caused when a load or force is placed in such a manner that it tends to bend the timber, as when a load is placed upon a beam.

SHEARING is a force that tends to push or slide one part of the fibres past the other ; when this shearing is longitudinal or parallel to the fibres it is called *detrusion* ; for example, at the end of a tie-beam, the pressure exerted by the principal rafter tends to slide off the portion of the tie-beam left for the abutment of the principal rafter.

Longitudinal Joints. Owing to the introduction of steel joists and girders, the necessity for connecting timbers in the direction of their length has considerably decreased, and therefore only a few of these joints need be considered.

Fished Joints. These joints are made by placing two timbers with their ends abutting, and bolting two, or more, wood or iron fish-plates to them. The length of the fish-plates should be from four to six times the depth of the beam. Fig. 1 shows the plan and elevation of a fished joint, with wrought-iron fish-plates bolted to the timber. When this joint is used in a beam (a use only advised in exceptional circumstances) the plate on the underside should have its ends turned up into the beam, as shown. This will assist the bolts in resisting the tensional stress in the lower part of the beam. Fig. 2 shows a similar joint, but the fish-plates in this case are of wood. When fished joints are used for posts, the plates should be placed on all sides. Although clumsy in appearance the total length of the timber is maintained.

Halved Joint. Fig. 3 shows a simple form of joint, each piece being cut away to half its depth

MODERN BUILDING CONSTRUCTION

and secured by bolts ; if used as a beam, fish-plates should be used, as shown in Fig. 1.

Halved joints besides being used for connecting timbers in the direction of their length may

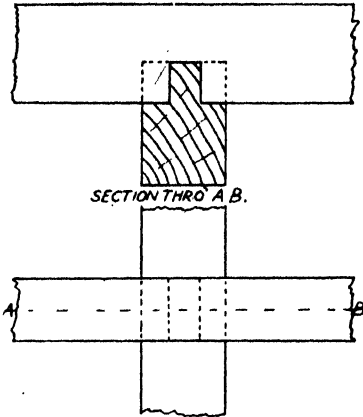


FIG. 14. COGGED JOINT

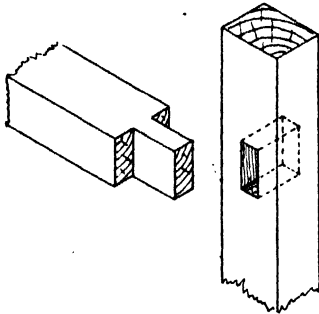


FIG. 15. MORTISE AND TENON JOINT

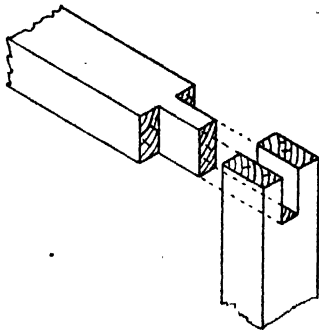


FIG. 16. OPEN MORTISE AND TENON JOINT

also be used when the timbers are at an angle to each other. They may be secured by bolts or nails. Figs. 10 and 11 show two timbers halved together at right angles to each other.

Fig. 12 shows a halved joint bevelled in both directions. A bevelled halving joint for connecting timbers in the direction of their length is shown in Fig. 13. The above joints are

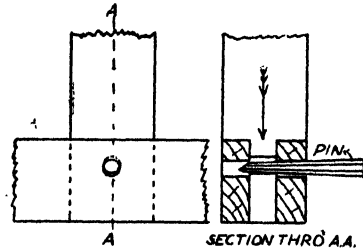


FIG. 17. MORTISE AND TENON JOINT DRAW-BORED AND PINNED

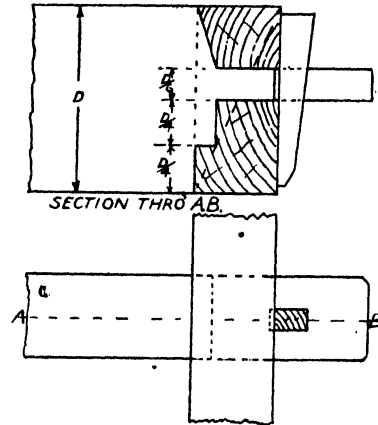


FIG. 18. TUSK TENON JOINT

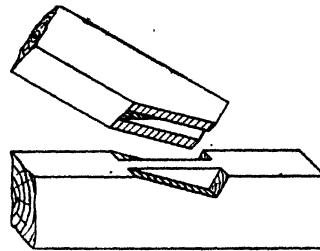


FIG. 19. BRIDLE JOINT

suitable for the joints of wall-plates and other similar construction.

Scarfed Joint. An effective and easily made joint, to resist cross or transverse stress, is shown in Fig. 4 ; the top abutment is square, and the underside slightly bevelled to assist in resisting the stress. The joint is secured by fish-plates and bolts.

Splay Indented Scarf. This joint is shown in Fig. 5, and is suitable for beams when subjected to tension, as in tie-beams. It can be tightened by the hard-wood wedges, but care must be taken when driving the wedges, otherwise the joint will be liable to shear along the dotted lines. To give additional strength, fish-plates and bolts are added. A similar joint is often used for the ridge board in a roof.

Fig. 6 shows a scarfed joint designed to resist tension and transverse stress. A short plate is fixed to the underside, but the strength of the beam would be considerably increased if the plates were as shown in Fig. 5.

A lipped halving joint is shown in Fig. 7; this joint is held together by the hard-wood

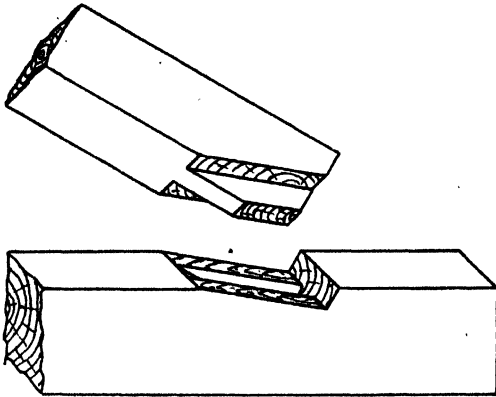


FIG. 20. OBLIQUE MORTISE AND TENON JOINT

wedges; bolts or other fastenings are necessary to prevent it moving sideways.

Tabled Joints. These types of joints are used to connect beams, as they resist both tension and compression.

Fig. 8 illustrates a plain tabled joint held together by bolts. A lipped table joint is shown in Fig. 9. This joint has lips which help to resist cross stress, and an indent so that the joint may be brought up tight by hard-wood wedges.

Other Joints. Fig. 14 shows a *cogged joint* used for connecting two timbers. It will be seen that a notch is cut out of the upper beam to fit over the cog in the lower beam. The strength of the upper beam is maintained, as its full depth rests on the notches cut in the lower beam. Cogged joints are used for the joints between purlins and principal rafters, and between the joists and binders in floor construction.

A *mortise and tenon joint* is shown in Fig. 15.

These joints are used for all kinds of framing, and may be secured by wedges, bolts, nails, and pins. The thickness of the tenon should not exceed one-third the thickness of the material to be mortised. An open or slotted mortise and tenon joint is shown in Fig. 16. Fig. 17

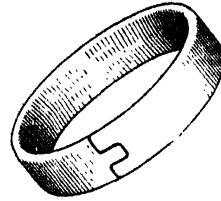


FIG. 20A. SPLIT-RING CONNECTOR

illustrates a mortise and tenon joint with *draw-bore pin*, for bringing the joint up tight at the shoulders. To ensure this, a hole is first bored through the piece containing the mortise, the tenon is then inserted, and the position of the hole marked on it, the bit generally being used to mark the centre of the hole. The tenon is then taken out of the mortise and a hole bored



FIG. 20B. INSTALLATION OF SPLIT-RINGS IN COLUMN

through it, the centre of the hole being brought nearer to the shoulder to leave sufficient draw-bore, so that when the pin is driven in, it will force the tenon down in the direction of the arrow.

Fig. 18 shows a *tusk tenon joint*; it is one of the best and strongest joints used for framing timbers together. The proportion of the tenon and tusk are figured in, and the depth of the

MODERN BUILDING CONSTRUCTION

housing for the tusk should not penetrate the dotted diagonal line. The tenon passes through the timber and projects far enough to enable a

is shown in Fig. 20. It can be used in similar positions to those described for the bridle joint (Fig. 19). As will be seen, a portion of the beam

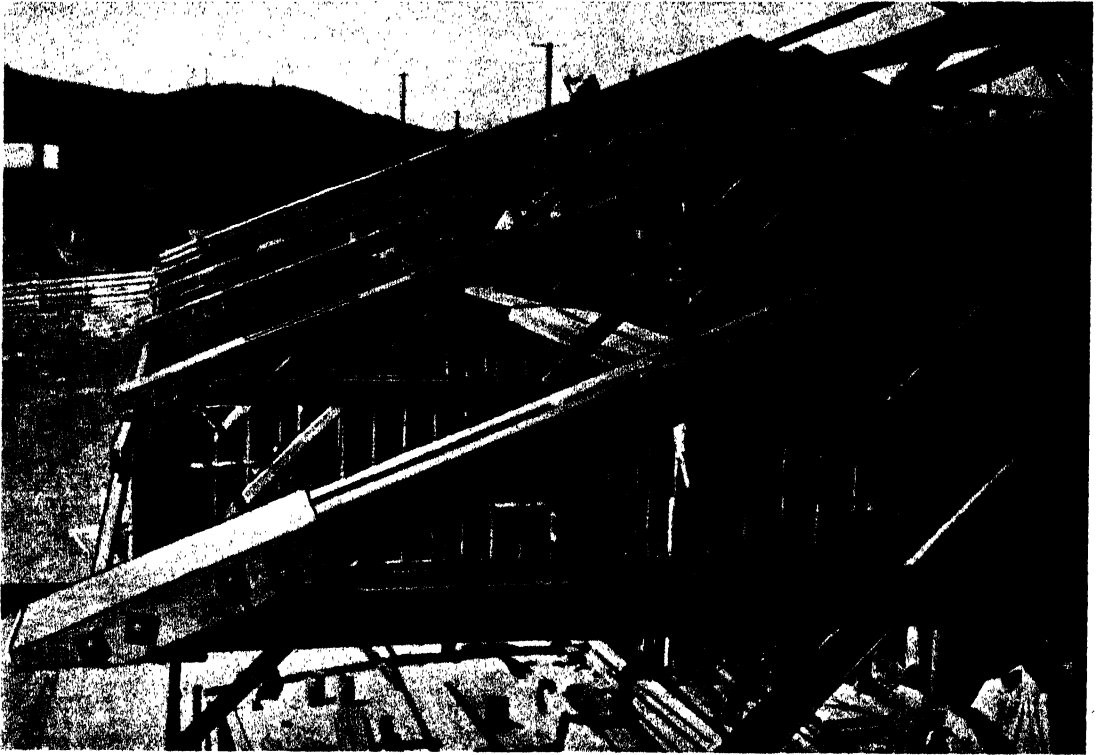


FIG. 20C. ROOF TRUSSES BUILT UP WITH SPLIT-RINGS

wedge to be driven through it, so as to bring the shoulder up tight.

A *bridle joint* is shown in Fig. 19. It is the reverse to a mortise and tenon joint, the middle portion of one member being cut away, so that

it is cut away to form an abutment to resist the thrust of the member to be fitted. This abutment should be cut perpendicular to the direc-



FIG. 20D. CLAW PLATES (MALE AND FEMALE)

it will fork over the cog left on the other member. Bridle joints can be used at the end of struts, braces, and principal rafters, or any other timber member where compression has to be resisted.

Oblique Mortise and Tenon Joint. This joint

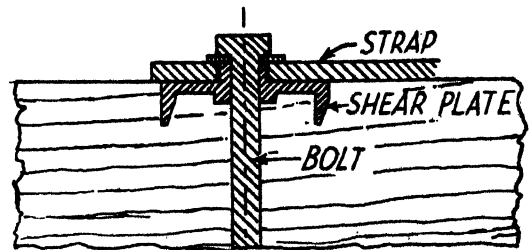


FIG. 20E. CROSS SECTION OF CLAW PLATE ASSEMBLY

tion of the thrust, but should not exceed one-quarter the depth of the beam. To prevent lateral movement, a mortise and tenon is required, but this need not be more than 1 in.

to 2 in. deep, as the joint would be secured by nails, bolts, or straps according to the size of the timber used.

TIMBER CONNECTORS

During recent years the method of joining timbers by means of metal *connectors* and bolts has become widely used in all kinds of structural work. These connectors give greater efficiency

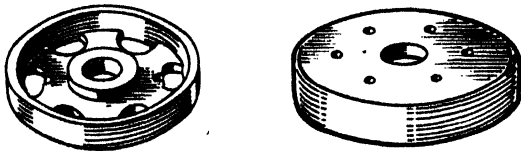


FIG. 20F. SHEAR PLATES

to the joints and make practicable the utilization of a higher proportion of the strength of the timber outside the joint than is possible with most other types of fastenings.

There are a number of connectors of various types and sizes available, and they are suitable for joining most timbers in light or heavy construction. Figs. 20A to N show the various types in more general use.

The **Split Ring** shown in Fig. 20A consists of a steel ring with a tongue and groove break, or "split." The ring is thinner at the edges than

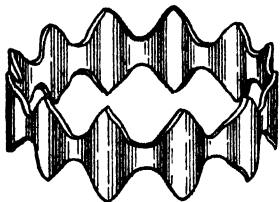


FIG. 20G. TOOTHED RING CONNECTOR

in the centre; thus there is a slight taper on the inside face to facilitate installation, and ensure a good fit when the ring is driven into the circular grooves which are cut in the timber to receive them.

These grooves are illustrated in Fig. 20B, which also shows how the rings are used in building up a spaced timber column.

Fig. 20C shows portions of roof trusses which have all their splices and connections made with split rings. The **Claw Plates** (shear) shown in Fig. 20D are made with, or without an outside hub or boss (male and female). They are used primarily for joining metal to wood, but they may be used in pairs for joining timbers. For fixing metal to timber, the outside hub on the face of the male plate fits into a hole in the metal plate or strap which is to be attached to the timber, as shown in Fig. 20E. Where the device is used for joining timbers together, male and

female plates are used to give rigidity to the joint. The plates are installed by forcing the teeth into the wood beyond the depth of the circular groove and housing cut out to receive the rim and plate portions.

Shear Plates, shown in Fig. 20F, when fitted, lie flush with the surface of the timber. They are used in pairs for timber to timber joints, and singly when fixing metal straps or plates to timber. Shear plates are often employed when the framing has to be taken down and reassembled, and in all cases where wood and steel connections are required.

The **Toothed Ring**, another form of connector, is shown in Fig. 20G. No groove is required for this ring as the teeth are sharp and are embedded in the wood by pressure. Fig. 20H shows a

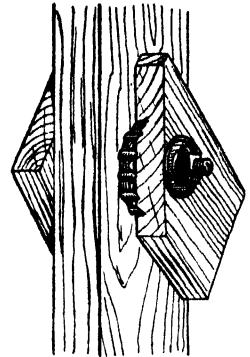


FIG. 20H. TOOTHED RING USED IN JOINT

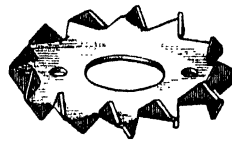


FIG. 20I. DOUBLE-SIDED BULLDOG CONNECTOR

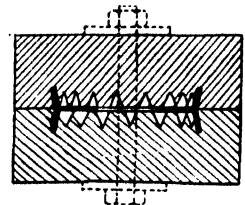


FIG. 20J. ILLUSTRATION OF "BULLDOG" IN USE WITH TIMBER

toothed ring joint between a brace and post; a portion of the brace is cut away to show the ring embedded in the wood. There is, however, a disadvantage in the use of this ring, as it

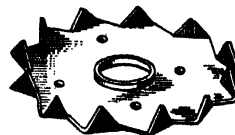


FIG. 20K. SINGLE-SIDED BULLDOG CONNECTOR

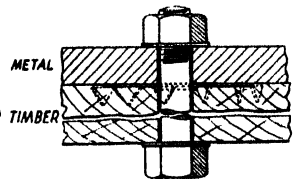


FIG. 20L. BULLDOG CONNECTING TIMBER TO METAL

tends to cant and the teeth to slide if it comes in contact with a knot or hard part of the timber.

The **Bulldog** double-sided connector, shown in

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Fig. 20I, consists of a steel plate with sharp teeth projecting from each side. The teeth are

another must be prevented. A flanged clamping plate in use is illustrated in Fig. 20P.

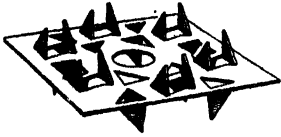


FIG. 20M. FLAT CLAMPING PLATE

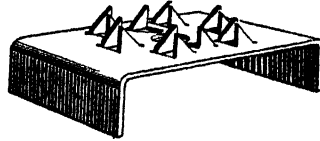


FIG. 20N. FLANGED CLAMPING PLATE

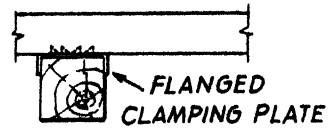


FIG. 20P. FLANGED CLAMPING PLATE IN POSITION

forced into both timbers by the tightening of a bolt (Fig. 20J).

Spiked Grid Connectors, shown in Fig. 20Q, are used for the following types of timber to timber joints: two flat surfaces; one flat and

A single-sided connector, shown in Fig. 20K,

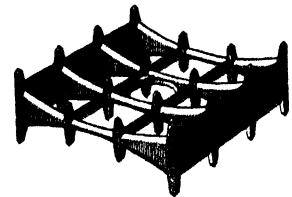
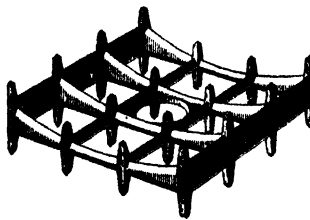
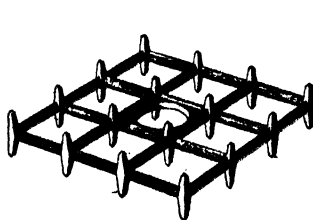


FIG. 20Q. SPIKED GRIDS: FLAT, SINGLE CURVE, DOUBLE CURVE

is used for connecting metal plates to timber (Fig. 20L). These connectors are light and strong, and are used for many types of timber constructional work.

one curved surface; two curved surfaces (such as poles or piles). Fig. 20R shows a method of embedding spiked grids by the use of special bolts and a ratchet wrench.

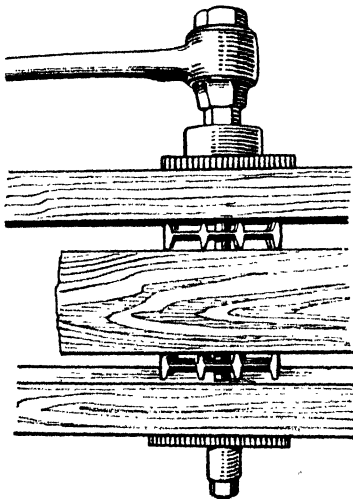


FIG. 20R. METHOD OF EMBEDDING SPIKE GRIDS IN TIMBER.

Fig. 20S illustrates flat grids and a single curve grid used for connecting a brace with piles.

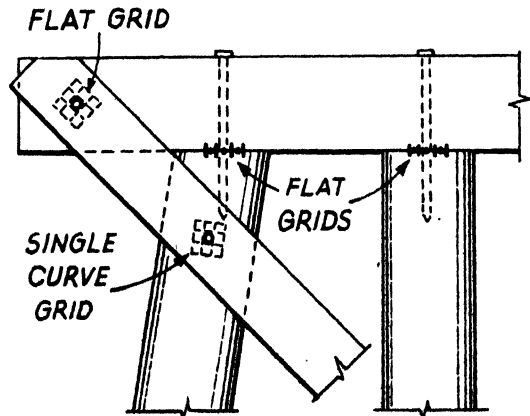


FIG. 20S. SINGLE CURVE AND FLAT GRIDS USED IN PILE BENT

Clamping Plates, shown in Figs. 20M and 20N, are used when two timbers cross each other at right angles, such as a guard or tie timber, where lateral movement of one timber on

(Note, all the above connectors may be obtained from Messrs. MacAndrews & Forbes, Ltd., who are the sole selling representatives for the United Kingdom.)

Chapter II—FLOORS

THE timbers that are arranged to divide a building into stories are termed floors, and may be classified according to their position, type, and span, as follows—

- (a) Ground, or basement, floors ;
- (b) Single floors ;
- (c) Double floors, with wood or rolled steel joist binders and bridging joists ;
- (d) Double floors as (c), but with the addition of ceiling joists ; and
- (e) Concrete floors, with joist or fillet.

Ground Floors. Fig. 21 illustrates a portion of a ground floor. The bridging joists are supported at their ends on *wall-plates*, and intermediately on *sleeper walls*; the latter walls are generally *honeycombed*, as shown, to allow for the free circulation of air, and are placed 4 ft. to 6 ft. apart. The joists are not *trimmed* around the fireplace, but are carried by a wall-plate resting on a fender wall. The floor boards should be tongued and grooved to prevent draughts, in case the joints open through shrinkage.

Single Floors. Single floors are generally used for the first and other floors in dwelling-houses, and are suitable for spans up to about 16 ft. Where possible, the joists should span the shortest distance of the room, and advantage should be taken of any partition, or wall, to shorten the span, and therefore economize in the size of joists. Fig. 21A shows a plan, cross, and longitudinal sections of a single floor, trimmed for the fireplace and around the chimney breasts. The wall-plate is carried on a "set-off" in the brickwork, and the floor is stiffened by two rows of *herring-bone strutting*. Where the joists vary in depth they should be notched down on to the wall-plate, so as to bring their top edges level for the floor boards, any unevenness being made good in the plaster ceiling. The joists should be fixed with their round edges upwards. The *trimming joists* and *trimmer* should be made $\frac{1}{2}$ in. thicker for every joist to be carried, but generally they are made 1 in. thicker than the bridging joists. The ends of the trimming joist should be placed not less than 2 in. from the face of the chimney breast,

if as shown, and not less than 9 in. from the inside of the flue when built in the wall. Fig. 22 shows the tusk tenon joint used for connecting the trimmer to the trimming joist; the tenon is made long enough to pass through the trimming joist and project so that a wedge, or key, can be driven through to bring the shoulders up tight. A similar joint is used between the

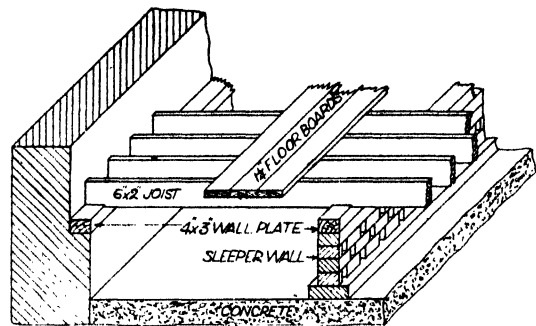


FIG. 21. SKETCH OF PART OF A GROUND FLOOR WITH SLEEPER WALL

trimmed joists and the trimmer, but in this case the tenon does not project, and need not go through the trimmer. Figs. 23 and 24 show alternate methods that are often employed for trimming, but are not to be recommended where strength is required.

An alternate method of trimming for the fireplace and flues, when the bridging joists run parallel to the hearth, is illustrated in Fig. 25. One half shows a trimming joist, with short trimmer supporting the trimmed joists, this trimmer being built in the wall. It could, however, rest on a corbel (if required). A bearer is bedded in the concrete, as a fixing for the floor boards. The other half of the drawing shows the floor boards in position, with a border mitred round the hearth. This border is about $\frac{1}{2}$ in. in thickness and 2 in. to 3 in. wide, and for a good job should be of oak or any other suitable hard wood. In Fig. 26 a section through the floor and hearth of Fig. 25 is shown. A fillet is nailed to the trimming joist to support the concrete, and a bearer is also shown for the fixing of the laths for the plaster.

BUILDING ACTS. The London Building Act,

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1930, requires the following with regard to floors—

Timber or woodwork shall not be placed—

- (a) In any wall or chimney breast nearer than 12 in. to the inside of any flue or chimney opening ;
- (b) Under any chimney opening within 10 in. from the upper surface of the hearth of such chimney opening ;
- (c) Within 2 in. from the face of the brickwork or stonework about any chimney or flue, where the

plugs are to be inserted within 6 in. of any flue.”)

CALCULATIONS. For dwelling-house floors with the joists placed at 14 in. centres and 2 in. thick, the depth of Northern pine joists may be obtained by applying the following rule, which is found to give a satisfactory result—

$$\begin{aligned} \text{Depth in inches} \\ &= \frac{\text{Span in feet}}{2} + 2 \end{aligned}$$

For example, when the span is 14 ft., then

$$\text{Depth} = \frac{14}{2} + 2 = 9 \text{ in.}$$

Detailed calculations for timber beams, joists, etc., will be found in the sections on “Structural Engineering” and “Preliminary Operations.”

STRUTTING. Strutting, as previously mentioned, is used to give additional stiffness to the floor, by distributing the weight and preventing the joists from buckling, or bending sideways. It is fixed at right angles to the joists, and at distances of 4 ft. to 6 ft. apart. The two kinds of strutting generally adopted are *solid strutting* and *herring-bone strutting*. Fig. 27 illustrates solid strutting, which consists of 1 in. or 1½ in. boarding, cut tightly between the joists and nailed to them as shown ; these struts tend to become loose, if any shrinkage in the joists takes place.

Herring-bone strutting is shown in Fig. 21 and is the better method, for if any shrinkage in the joists occurs this strutting has a tendency to become tighter, as the ends are fixed to the edges of the joists. Fig. 28 shows an enlarged detail of the strutting fixed in position, together with method of obtaining the correct length and bevels of each strut ; to obtain these, a line is marked on the joists where the strutting is to be fixed, and parallel to it at a distance rather less than the depth of the joists another line is drawn. The material—about 2 in. by 1½ in.—is then laid on the joists with one edge to the line on one joist, and the other edge to the other

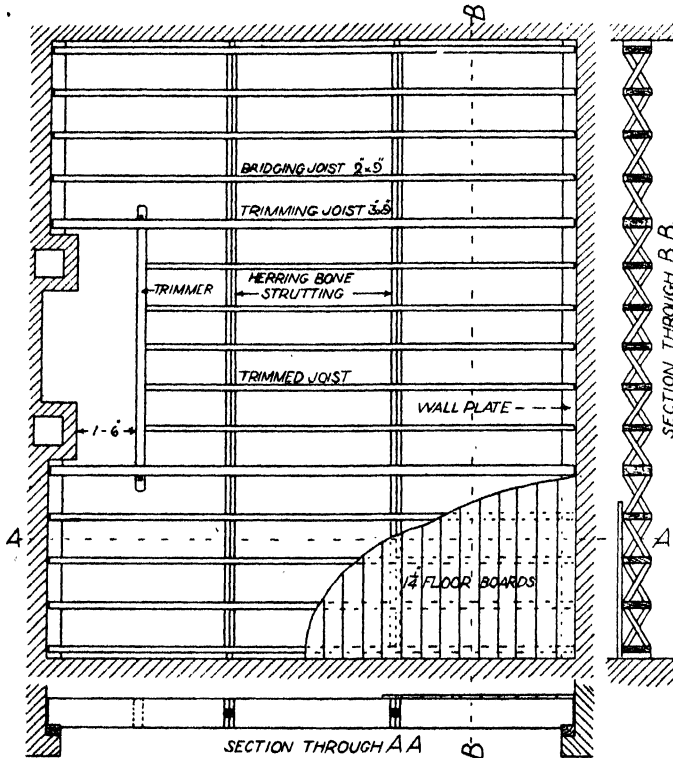


FIG. 21A. PLAN AND CROSS AND LONGITUDINAL SECTIONS OF A SINGLE FLOOR

substance of such brickwork or stonework is less than 8½ in. thick unless the face of such brickwork or stonework is rendered ;

(d) The following loads in addition to the weight of the floor have to be provided for when calculating the sizes of the timbers—

Floors used for domestic purposes	70 lb. per sq. ft.
Office or counting-house floors	100 lb. "
Workshop or retail shop floors	112 lb. "
Warehouse floors	224 lb. "

(The Ministry of Health Standard Specification for cottages requires “No timber or

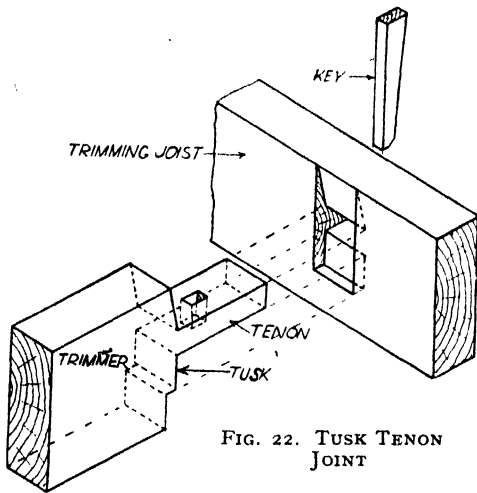


FIG. 22. TUSK TENON JOINT

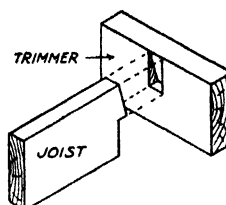


FIG. 23. BEVELLED HOUSED JOINT

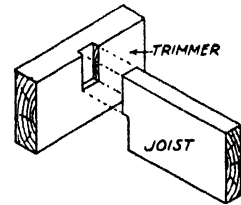


FIG. 24. HOUSED JOINT

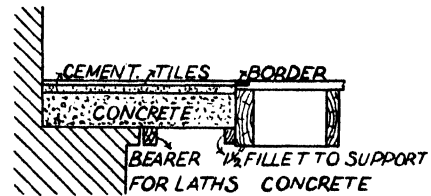


FIG. 26. SECTION THROUGH FLOOR AND HEARTH OF FIG. 25

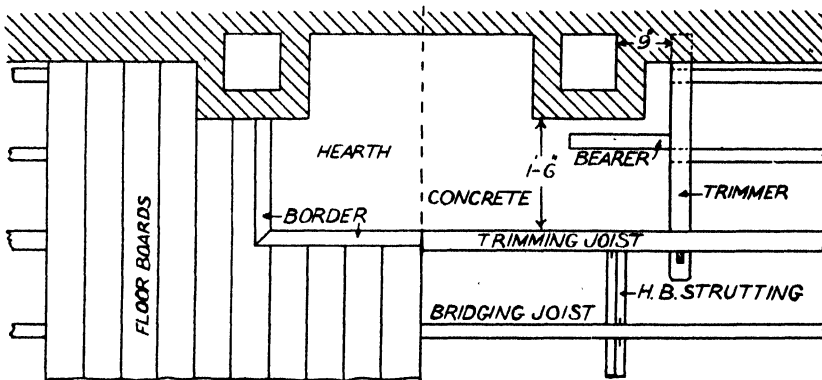


FIG. 25. ALTERNATE METHOD OF TRIMMING FOR HEARTH

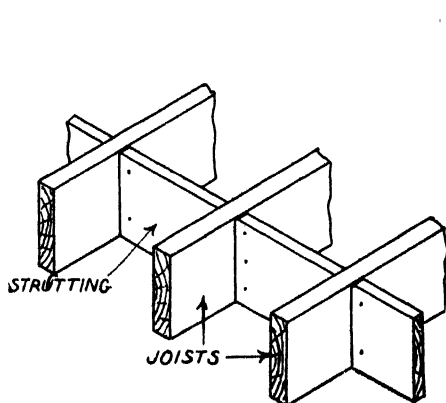


FIG. 27. SOLID STRUTTING

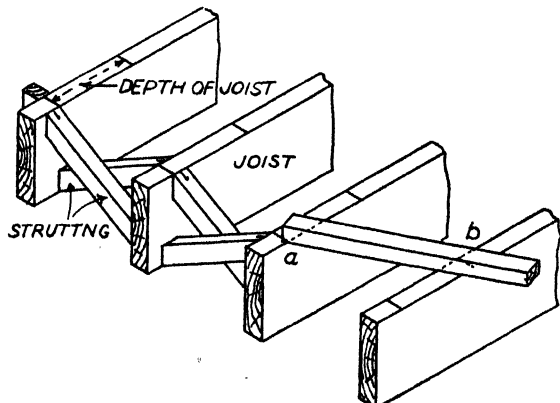


FIG. 28. HERRING-BONE STRUTTING

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line on the next joist, and is marked on the underside as shown by the dotted lines at *a* and *b*. The struts are cut to these lines; and to prevent the end splitting when nailing, a saw kerf is made in the end of the struts as shown.

BEARINGS FOR JOISTS. Joists are often built in the wall and bear directly on the brickwork. In

“off-set,” formed by corbelling the brickwork as seen in Fig. 32.

In both cases the joists are spiked to the plates, and in the case of fire, there would be no danger of the wall overturning if the floor gave way. Fig. 33 shows the wall-plate supported on wrought-iron corbels built in the wall and placed about every 3 ft. This is a good

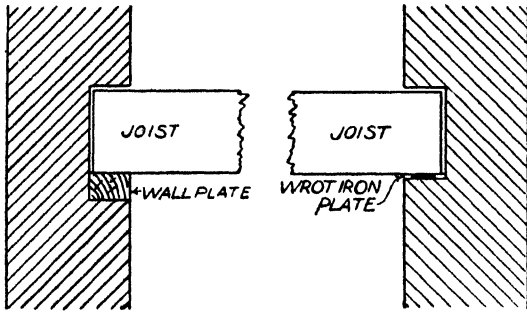


FIG. 29. PLATE AND JOISTS BUILT IN

FIG. 30. JOISTS RESTING ON IRON PLATE

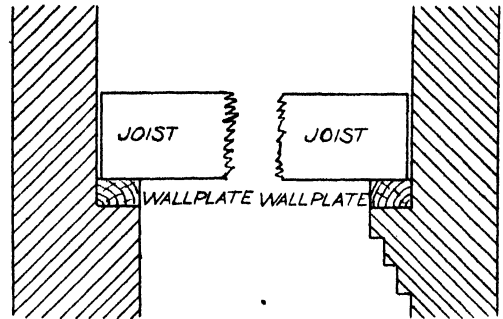


FIG. 31. JOISTS FIXED TO PLATE RESTING ON SET BACK

FIG. 32. PLATE RESTING ON OFFSET

this method the weight is not evenly distributed along the wall, and the ends of the joists are liable to dry rot. (As a precaution against an attack of dry rot, all timbers should be treated with creosote before being built in the brickwork.) Another method of building the joist in the wall is shown in Fig. 29. A wall-plate is bedded in the wall and the ends of the joists

method to adopt for party walls, or when the walls are thin.

PREVENTION OF SOUND. To prevent the passage of sound through single floors, felt or “Cabot’s quilt” is placed on the top edges of the joists before the floor boards are laid.

Another method is that of sound boarding and pugging, as shown in Fig. 34. Fillets are

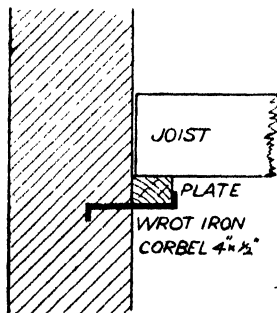


FIG. 33. PLATE RESTING ON IRON CORBELS

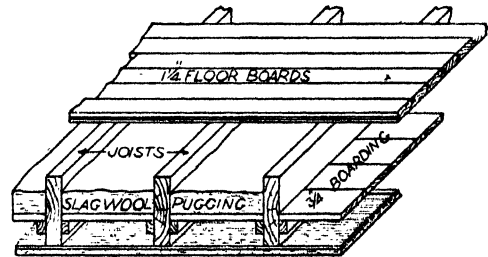


FIG. 34. SKETCH SHOWING SOUND BOARDING AND PUGGING

are nailed to it, or the joists may rest on a wrought-iron bearing plate as shown in Fig. 30. In both cases, space should be left for the air to circulate freely around the ends of the joists. A better method is when the wall-plates rest on a “set-back,” as shown in Fig. 31, or on an

nailed to the sides of the joists, and rough boards are cut in loose between the joists, and laid on the fillets. On these boards slag wool, to a depth of 2 in. to 3 in., is laid. Rough mortar and coke breeze are other forms of pugging used.

JOINTS IN FLOOR BOARDS. Figs. 35 to 42 show the various methods adopted for jointing the

edges of floor boards. When secret fixing is required, as in the case of hardwood, or other floors that are stained and polished, the joint shown in Fig. 41 is used.

Heading Joints. Fig. 43 shows a square butt heading joint, and a splayed heading joint is shown in Fig. 44. This is a better joint, and one

placed between the shoe and the edge of the board. Another form of floor cramp is shown in Fig. 47. This cramp grips the sides of the joists, and the ram is forced forward to the edge of the floor boards by the lever. To release the cramp, the lever is pulled back, the foot pressed on the front pawls, and the ram will be pulled

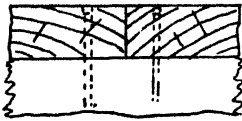


FIG. 35. SQUARE JOINT

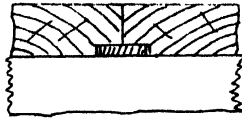


FIG. 36. REBATED, WITH FILLET

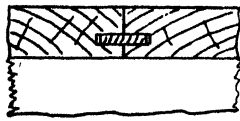


FIG. 37. GROOVED, WITH LOOSE TONGUE

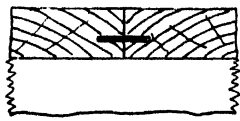


FIG. 38. GROOVED, WITH IRON TONGUE

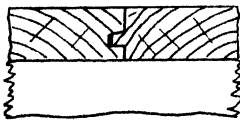


FIG. 39. TONGUED AND GROOVED

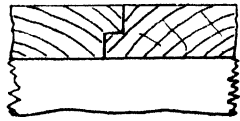


FIG. 40. REBATED DOWELLED

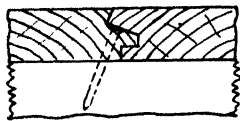


FIG. 41. SPLOY TONGUED, GROOVED AND REBATED

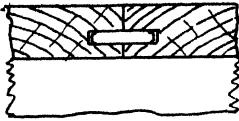


FIG. 42. REBATED DOWELLED

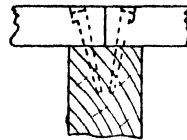


FIG. 43. SQUARE HEADING JOINT

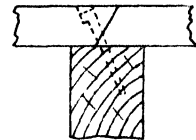


FIG. 44. SPLOYED HEADING JOINT

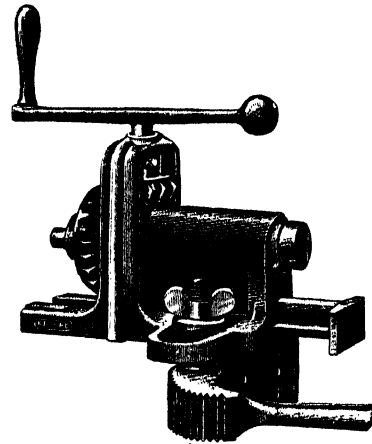


FIG. 45. RECORD FLOORING CRAMP (TOP ACTION)

brad is sufficient to hold both boards down to the joist. The dotted lines show the shape of the floor brad and its position when driven into the joist.

LAYING FLOOR BOARDS. A number of useful cramps are obtainable for cramping the joints between the boards up tight before nailing. A "Record" cramp, with a top action movement, is illustrated in Fig. 45. To prevent the cramp from slipping, the joist is gripped by the lug on one side and the pointed studs on the other side. The shoe which acts on the board moves forward, or backward, along a screw that revolves when the handle is turned.

A similar cramp, but with the action on the side, is shown in Fig. 46. To prevent damage to the edge of the boards, a short piece of floor board, or a piece of thicker timber, should be

back by the spring. Fig. 48 shows how the cramp is used with the aid of a "draw bar" to cramp floors over a flush surface, or floor boards over joists fully bedded in concrete, etc.; this method can be used for cramping the last board.

FOLDING. Where cramps are not available other methods are employed. One of the best to ensure a close joint is that known as "folding the boards into position," and is shown in Fig. 49. To do this, a board is fixed in position near the wall; four or five boards are cut and laid down, and the outer edge of the last board marked on the joists. Then a board is lifted up, and another board fixed to the joists at a distance of $\frac{1}{4}$ in. to $\frac{1}{2}$ in. nearer to the first board than the mark on the joist. The boards are now arranged to form an arch, with two or three pieces of timber placed on the crown across

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the boards; two or three men jump on the cross pieces, and so force the floor boards down in the direction of the arrow.

Another method employed is that of fixing a board down temporarily on the joists, at a

ceiling joists, and are used for spans of 16 ft. and upwards. In this type of floor the binders are placed (where possible) across the shortest span of the room, at distances of about 8 ft. centres, so far as any openings in the wall will

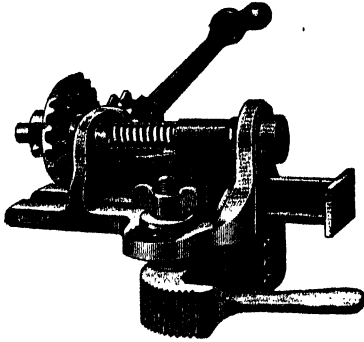


FIG. 46. RECORD FLOORING CRAMP (SIDE ACTION)

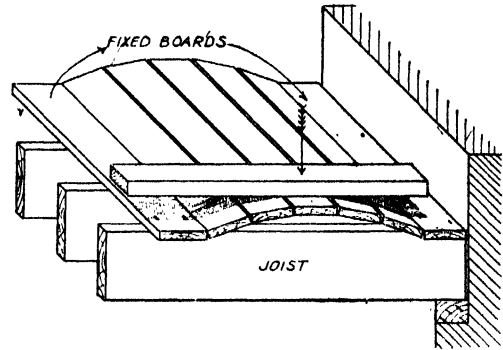


FIG. 49. FOLDING FLOOR BOARDS INTO POSITION

distance from the boards to be fixed so as to enable a pair of folding wedges to be driven in, and so force the joints up tight.

The last board or two could be levered up by a piece of timber similar to that shown in Fig. 50, the lever being kept in position until the board

allow. These binders support the bridging joists, and ceiling joists (if any), and should rest on stone templates, or corbels. Wooden binders are rapidly being displaced by the introduction of rolled steel joists, owing to the sizes and lengths of the latter now obtainable.

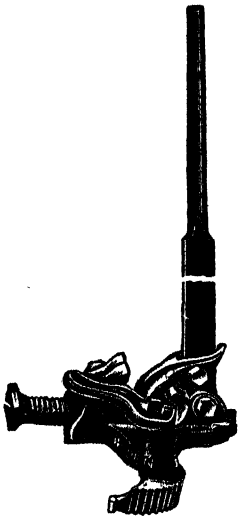


FIG. 47. LEVER FLOOR CRAMP

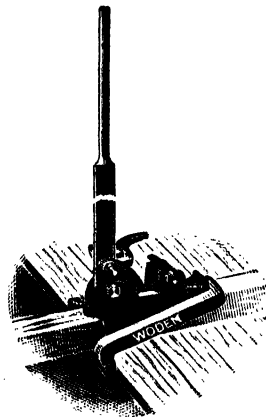


FIG. 48. LEVER FLOOR CRAMP ILLUSTRATING ITS USE ON A CONCRETE FLOOR

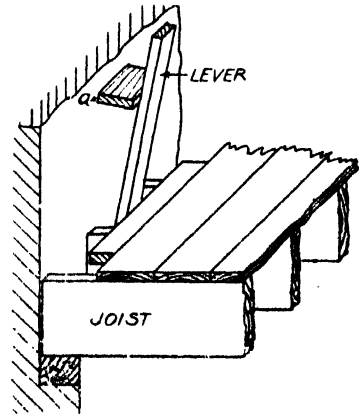


FIG. 50. SKETCH SHOWING HOW FLOOR BOARDS MAY BE LEVERED INTO POSITION

is nailed by a short piece of board *a* used as a strut.

Double Floors. Double floors consist of binders and bridging joists, with or without

Fig. 51 shows the plan and section of a double floor, with binders of timber supported by stone templates. The bridging joists are coggled and nailed to the binders and to the wall-plate at

their ends. They should be long enough to span at least two openings, so as to tie the binders together, as shown by the jointing in the plan. A fire-place is shown trimmed for hearth and chimney breasts, with tusk tenon joints between the trimmer and trimming joist, and also the trimmed joist. If a lift or stair passes through the floor, the method of trimming around the opening would be similar to that employed for the fireplace.

The binders may be wrought and moulded, or cased, if projecting below the ceiling. Fig. 52 shows an enlarged detail of the coggled joint between the binder and the bridging joist. The portion of the binder that projects below the ceiling is wrought, and a return bead is worked on each edge; this bead would be "stopped" near the ends of the binder.

Fig. 53 illustrates a rolled steel joist used as a binder. Wood plates are supported by the lower flanges, and are bolted together by a bolt passing through the web of the binder as shown. The bridging joists are notched to fit over the top flange and are spiked to the plates. The lower part of the binder would be cased with wood or plaster.

Fig. 54 shows a section through a rolled steel binder, with bridging joists, and the necessary cradling for supporting the casing when cased with wood or plaster.

BINDER WITH CEILING JOISTS. When ceiling joists are used the passage of sound is reduced to a minimum, but the depth of the floor is considerably increased. Fig. 55 shows a 12 in. by 9 in. binder with the bridging joists coggled into its top edge. On the right of the binder a ceiling joist is shown fixed in position, and by its side a similar joist showing the joint. When this method of fixing the ceiling joists between the binders is adopted, to enable the joists to be placed into their position after the binders are fixed, *chase mortises* (as shown) must be cut in one of the binders so that the joist may be

pushed round into position, or they may be fitted on to a fillet nailed to the binder as shown on the left side; this latter method could be adopted at both ends, and a good fixing obtained by nailing through the lip portion of the joist into the binder.

Fig. 56 shows a rolled steel joist, with the ceiling joists notched out to fit over the flanges, the bridging joists resting on the top flange. A

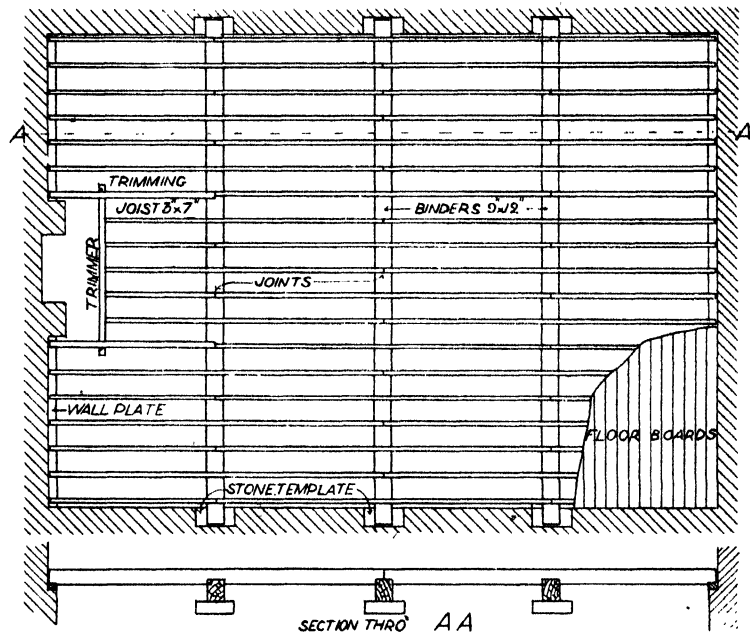


FIG. 51. PLAN AND SECTION OF A DOUBLE FLOOR

suitable method of jointing the latter joists is shown. The joists would be fixed temporarily till the strutting was in position. A floor board with a splayed heading is shown. An alternate method is shown in Fig. 57. In this case the rolled steel joist has angles riveted to the web, to support the bridging joists. The ceiling joists are notched, and carried by the lower flanges of the binder, as shown in the drawing.

Concrete Floors. Fig. 58 shows a sketch through part of a concrete floor, with dovetailed fillets (or joists) bedded in the concrete to form a fixing for the floor boards. Sometimes these fillets are flush with the concrete; at other times joists 2 in. to 3 in. deep are fixed on the top surface of the concrete floor. When wood blocks are used, the surface of the concrete is roughened, and the blocks are bedded in a mastic solution which forms a fixing.

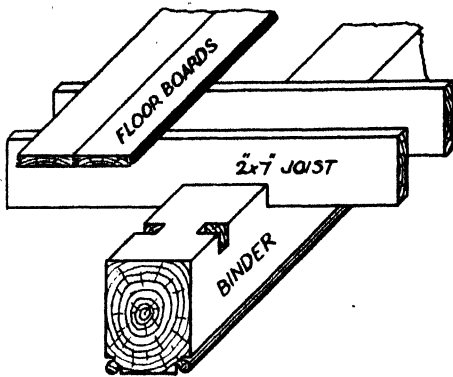


FIG. 52. DETAIL OF WOOD BINDER AND BRIDGING JOISTS

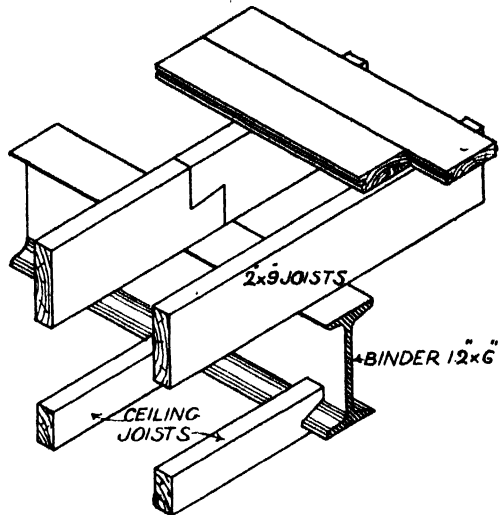


FIG. 50. STEEL BINDER, BRIDGING, AND CEILING JOISTS

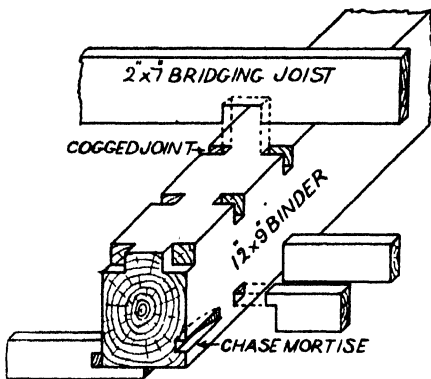


FIG. 55. WOOD BINDER, BRIDGING, AND CEILING JOISTS

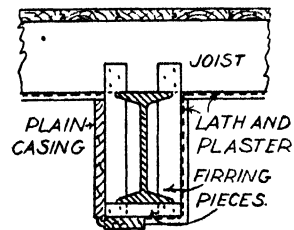


FIG. 54. CRADLING OF R.S.J. FOR CASING WITH WOOD AND PLASTER

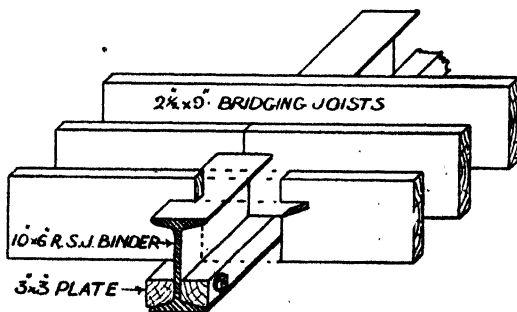


FIG. 53. DETAIL OF STEEL BINDER AND BRIDGING JOISTS

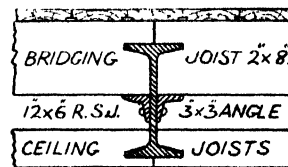


FIG. 57. ALTERNATIVE METHOD OF FIXING BRIDGING JOISTS

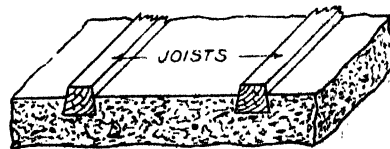
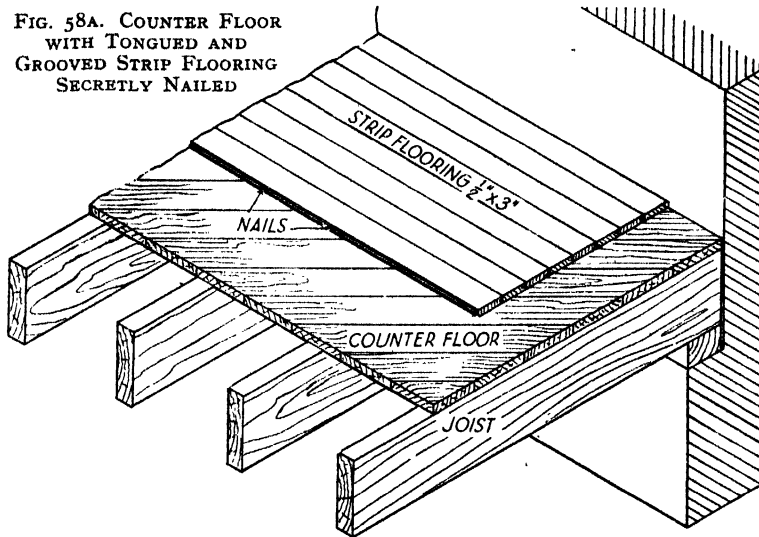


FIG. 58. SECTION THROUGH CONCRETE FLOOR, SHOWING JOISTS, OR FILLETS, BEDDED IN CONCRETE

Counter Floors. A counter floor (often referred to as a sub-floor) is the bottom layer when two thicknesses of flooring are used, and consists of

FIG. 58A. COUNTER FLOOR WITH TONGUED AND GROOVED STRIP FLOORING SECRETLY NAILED



ordinary square-edged pine floor boards, usually laid diagonally across the floor joists in order that none of the joints shall coincide with the layer above. The counter floor is cleaned off to form a true surface upon which to fix the top layer, which may be either of hardwood strip, or parquetry flooring.

Fig. 58A illustrates a counter floor with an overlay of strip flooring; the sizes of strip flooring vary from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. in thickness and 2 in. to $3\frac{1}{2}$ in. wide. The $\frac{1}{4}$ in. and $\frac{5}{16}$ in. thicknesses are square edged and fixed to the counter floor by gluing, and nailing through the face with panel pins, which would be punched in and the holes stopped before the surface is cleaned off and polished. The thicker sizes would be tongued and grooved and in this case secret nailed through the tongued edge as shown.

Parquetry Floor. This consists of various kinds of hardwood fixed to the counter floor to form a geometrical pattern, or decorative design. The parquetry may be laid direct on the counter floor in the same manner as that described above for strip flooring, or as an alternative method the parquetry may be first laid to the required design and glued on suitable plywood of stout thickness in sheets of about 18 in. by 18 in. and upwards. The sheets are then placed in a press, and when the glue has set the parquetry is cleaned off and the edges of the plywood grooved

for a tongue. These sheets are then glued and secretly nailed, *through the lower lip of the groove,* to the sub-floor; each sheet is jointed and glued together with cross tongues.

Wood Block Floor. This form of covering is used extensively for floors in all kinds of public and other buildings. It consists of small blocks of wood laid to a pattern on a concrete floor that has been floated over with cement mortar and "scratched" (roughened) to form a key for the mastic solution with which the blocks are fixed.

The blocks are either of soft or hard wood, and vary in size from about 9 in. to 12 in. long, 1 in. to $1\frac{1}{2}$ in. thick, and 3 in. wide, according to the kind of blocks used. There are several

patent blocks obtainable, the chief difference being in the jointing and fixing, e.g. tongued and grooved, dowelled and dovetail grooved.

Fig. 58B shows a sketch of part of a floor laid to a herring-bone pattern. These blocks have

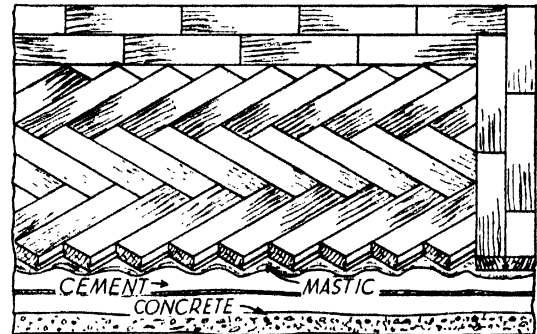


FIG. 58B. WOOD BLOCK FLOOR LAID TO A HERRING-BONE PATTERN, WITH BORDER SURROUND

small dovetailed grooves, along their edges near the bottom, which fill with the mastic solution as they are pressed into position. For laying these blocks, the mastic must be very hot, some of it spread on the cement, and the bottom of the block dipped into the solution and quickly placed in position. When the blocks are set, the floor would be cleaned off by planing and scraping and glass papering if the floor is to be polished.

Chapter III—PARTITIONS

WOOD partitions are frames of timber used for dividing the internal parts of a building into compartments. These partitions are covered either with laths and plaster, match-boarding,

placed at intervals of two, three or four bricks' length. *Nogging strips* are fixed to the studs about every eight or nine courses of brickwork to give additional stiffness to the partition, and

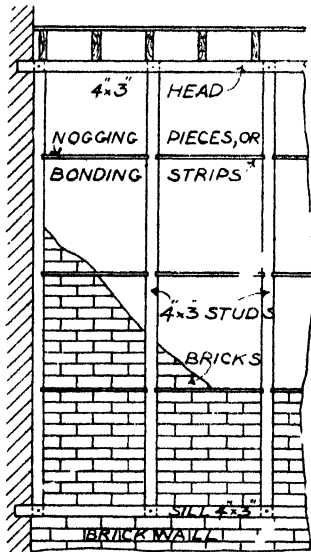


FIG. 59. BRICKNOGGED PARTITION

asbestos sheeting, or one of the many forms of patent compo boarding that are now available.

They have the advantage of being light as compared with other forms of partition, they can be erected in any convenient position, and supported at their ends by the walls, or throughout their length by the floor.

Partitions may be classified as *bricknogged*, *common or quarter*, and *trussed*.

Bricknogged Partitions. Bricknogged partitions are only suitable for ground floors or when carried by a wall or a girder, as they must be supported along their entire length. These partitions are fire resisting, and more sound-proof than those made entirely of wood. They consist of a sill, head, and vertical members called *studs*, and if provision has to be made for a doorway, a doorhead and posts are required. The thickness of the partition should be the same as the brickwork, i.e. $4\frac{1}{2}$ in., or if the bricks are to be laid on edge, 3 in. The studs are

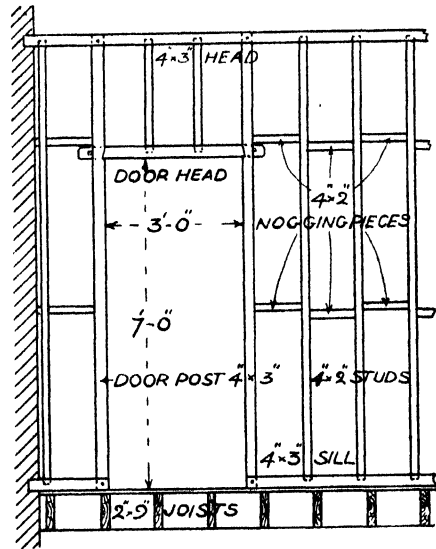


FIG. 60. COMMON OR QUARTER PARTITION

as a bond to the brickwork. Hoop-iron is often used instead of the wood nogging strips, the ends of the iron being turned up and nailed to the studs. Fig. 59 shows a bricknogged partition carried by a brick wall. The ends of the head and sill should be built in the wall as a fixing for the partition.

✓ **Common, or Quarter, Partitions.** These partitions are constructed similarly to the bricknogged partition, except that the studs are placed nearer each other, at a distance of 12 in. to 18 in. centres, according to the length and size of the laths to be used (when the partition is to be plastered). The sizes of the sill, doorposts, and doorhead are usually 4 in. by 3 in., and the studs 4 in. by 2 in. Nogging pieces are cut in tight between the studs, and are nailed to them at distances of 3 ft. to 4 ft. apart. The nogging pieces act as stiffeners to the partition, and so help to make it rigid.

These partitions must be supported throughout their length on a wall or girder; or by the

floor joists, the partition being either at right angles to the joists, or directly over one of them, or by bearers fixed between two of them.

it is made fast with a wooden pin (draw-bored) or nails. On the right of the figure the detail of the joint between the sill and a stud is seen.

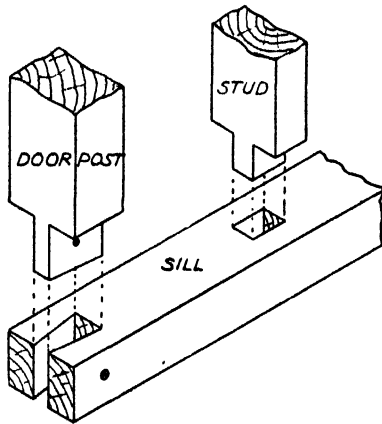


FIG. 61. JOINTS BETWEEN DOORPOST, STUD, AND SILL

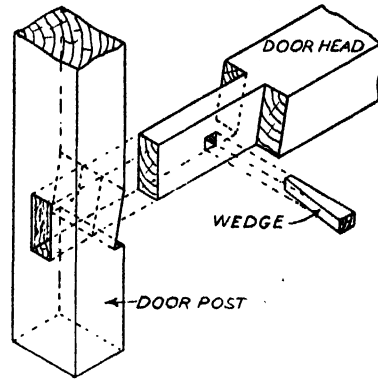


FIG. 62. JOINT BETWEEN DOORPOST AND DOORHEAD

Fig. 60 illustrates a portion of a common partition having an opening for a door near the end. The partition is supported by the floor joists, and is suitable for a dwelling-house. The names and the sizes of the members are indicated

A similar stumped tenon joint is used at the head.

Fig. 62 shows how the joint between the doorhead and the doorpost should be constructed. The shoulder in the head is bevelled and is sunk

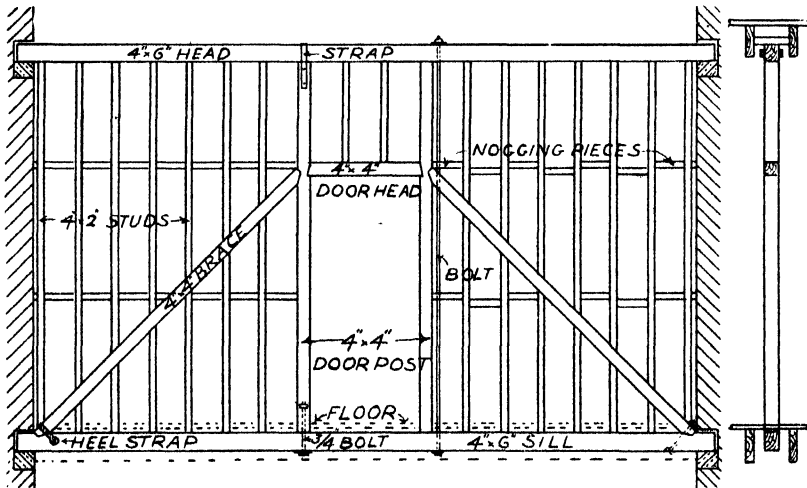


FIG. 63
SELF-SUPPORTING PARTITION

FIG. 64
SECTION THROUGH DOORWAY

in the drawing. Where the doorway occurs, the sill has been cut away to prevent obstruction.

Fig. 61 shows the joint between the doorpost and the sill, the tenon on the post being dovetailed to fit a corresponding slot in the sill, and

about $\frac{1}{2}$ in. into the post for support. The tenon is left sufficiently long to pass through the mortise, and the joint made secure by a wedge. **Trussed Partitions.** These partitions may be trussed to support their own weight, or, in

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addition to the weight of the partition, to support the floor and ceiling.

Owing to the more general use of rolled steel

at the same time to form a rigid frame. In order to ensure the latter, the truss must conform to a triangle or a series of triangles ;

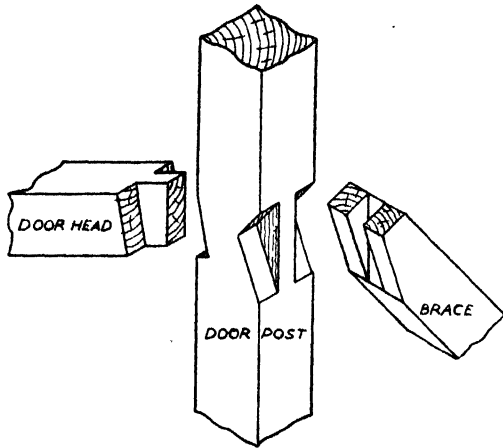


FIG. 65. DETAIL OF THE JOINTS BETWEEN DOORPOST AND BRACE AND DOORHEAD

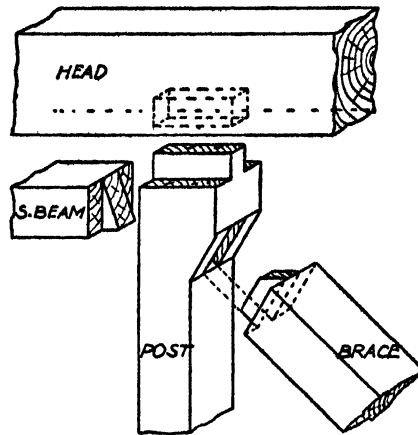


FIG. 67. JOINTS AT HEAD OF POST WITH BRACE AND STRAINING BEAM

joists as girders and binders (as mentioned earlier in the chapter on floors), trussed partitions to carry the floors are becoming obsolete,

the triangle being the only frame that will not alter in form unless stressed beyond its power of resistance. For this reason the joints must

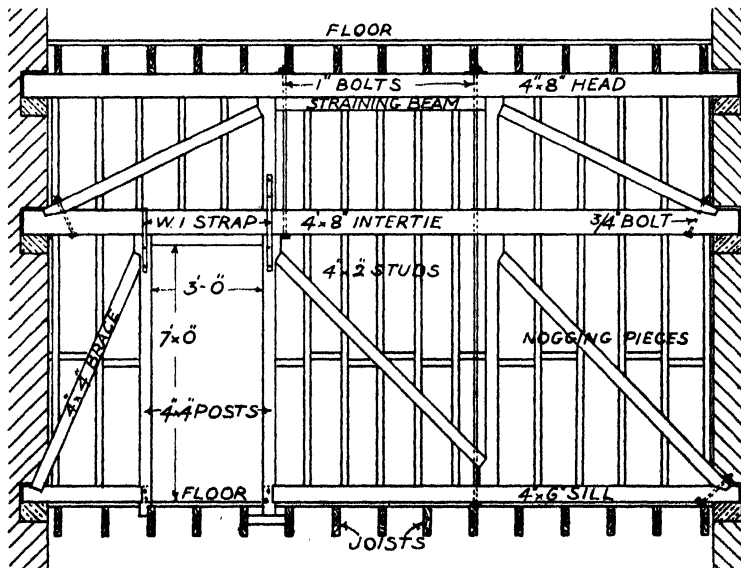


FIG. 66. TRUSSED PARTITION TO CARRY FLOOR

but the principle of trussing will be understood from the one given in this chapter. The object of trussing is to arrange the main timbers in such a manner that the weight is transmitted by the member directly on to the supports, and

be held together by bolts, or wrought-iron straps and bolts.

Fig. 63 shows a self-supporting partition running in the same direction as the floor joists. It consists of sill, head, doorposts, doorhead, and

braces, the spaces being filled in with studs and nogging pieces. In the left half of the drawing the joint at the foot of the brace with the sill, and the joint between the doorpost and the head, are shown secured by straps and bolts. The joint at the foot of the doorpost is fastened to the sill by a bolt with a square head and nut, as shown by the dotted lines. On the other half of the drawing an alternate method of tightening the joints is shown. The brace at the foot is secured to the sill by a bolt, and a long bolt running the full height of the partition is used to tighten up the joints at the head and foot of the doorpost. This is the better method, for if any shrinkage in the head and sill takes place before the plastering is done, the bolts can again be screwed up tight. When straps are used this cannot be done, and the heads of the bolts are difficult to hide by the plaster, on account of their projection from the face of the partition. Alternate methods of fixing the nogging pieces are shown; those on the right allow for better nailing.

A section through the doorway is shown in Fig. 64. The sill rests on a stone template between the joists, with its top edge kept down so as not to interfere with the floor boards. The head is kept in position by short pieces of studding, cut in between the joists and spiked to the head. A fillet is nailed on each side of the head to form a fixing for the laths.

The detail of the bridle joint, between the brace and the doorpost, is shown in Fig. 65; also the mortise and tenon joint between the doorhead and post. The studs are stumped tenoned into the head and sill, and cut to the level of the brace, and fixed to it by nailing.

Fig. 66 shows a partition trussed to support its own weight and a floor above, and running at right angles to the floor joists below. Owing to the doorway, the sill cannot run from wall to wall, and an intertie has to be introduced so that the top portion may be trussed to form a girder to carry the floor, and also to support part of the weight of the lower portion of the partition by the long bolts, while the other part is carried by the braces. The ends of the doorposts are notched and mortised to take the ends of the sill, which are fastened either by wooden pins or bolts. The ends of the posts are kept in position by fixing a bearer fitted between two joists, or to a joist itself (whichever is the more

convenient), as shown in the figure. All the joints are mortised and tenoned.

Fig. 67 shows the arrangement of the joints between the post and head, the straining beam, and the top end of the brace. The joint between the bottom of the brace and the intertie is shown in Fig. 68; a bolt passing through both makes the joint secure.

Where the surfaces of the timbers used are wide, as in the cases of the head and intertie,

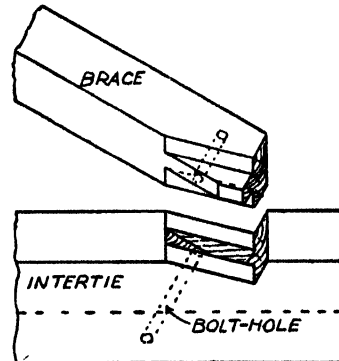


FIG. 68. JOINT AT FOOT OF BRACE

they would be *counterlathed* to allow for a key for the plaster.

Sound-resisting Partitions. To prevent the passage of sound, partitions may be constructed by fixing two sets of studs (staggered) into the sill and head in such a manner that the laths and plaster are only fixed to one edge of the studs. To do this, one set of the studs is arranged as in the common partition, Fig. 60, and in between these studs other studs are fixed projecting sufficiently forward so that the back edges of each set of studs do not come in contact with the laths on the other side of the partition.

Double Partitions. In large houses sliding doors are often introduced between two rooms, so that when open one room is obtained. These doors slide back in the centre of the partition and are hidden from view. The partition would be constructed in two parts, and placed side by side at a distance apart to allow for the sliding of the door. The insides of the partition should be lined with boarding as a precaution against the plaster falling on the track and fouling the sliding of the door.

Chapter IV—ROOFS

TERMS

THE uppermost part of a building, to which a suitable covering is fixed, to prevent the lower part being damaged by exposure to the weather, is called the *roof*.

Owing to the introduction of steel, as mentioned previously in the chapters on floors and partitions, modern roof construction has changed. Whereas at one time timber was the only material employed, its use is now confined to comparatively short spans or when a decorative or architectural feature is required. Wood

example, *one-quarter pitch* means that the rise or height of the ridge above the wall-plates is one-fourth the span; *one-third pitch*, the rise is one-third the span; and *half pitch*, that the rise is equal to one-half the span. In the last-mentioned case it would be 45 degrees.

The slope adopted for the roof is determined by the material with which it is to be covered, and may vary from being in nearly a horizontal

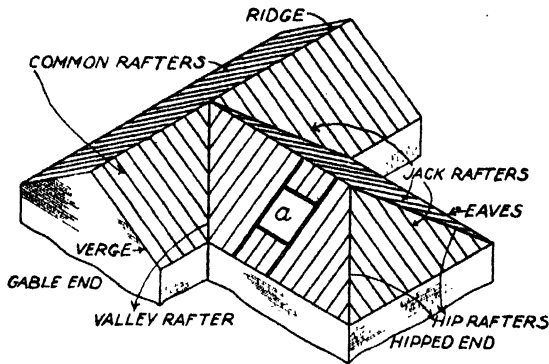


FIG. 69. SKETCH OF A ROOF

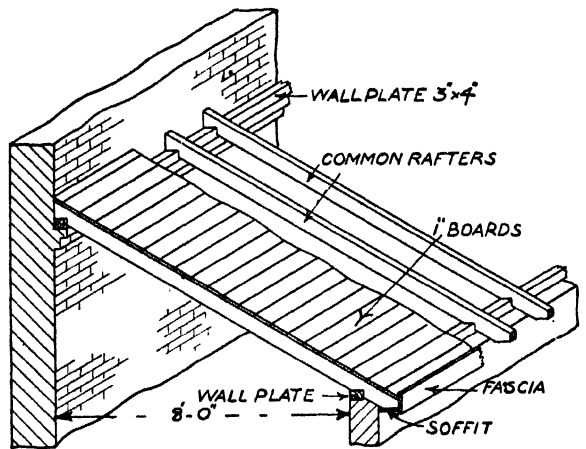


FIG. 70. LEAN-TO ROOF

roofs do, however, still play an important part in modern construction, but are confined chiefly to country houses and domestic dwellings, or in conjunction with steel trusses. The construction of the roof depends chiefly upon—

- (a) The plan of the building, and the style of the architecture.
- (b) The span, and the climatic conditions.
- (c) The covering to be used.

SPAN. The *clear span* is the horizontal distance between the walls, or other supports. The *effective span* is the horizontal distance between the centres of bearing on the supports.

PITCH. The slope of a roof is termed "the pitch," and may be expressed either in terms of degrees of inclination to the horizontal, or in terms of the ratio of the rise to the span; for

position, as in the case of a flat roof, to almost vertical, as in the lower part of a mansard roof.

The minimum inclination on which the material used for covering the roof should be laid are shown below in degrees—

Lead	3/4°
Asphalt	3/4°
Slates (large)	22°
Slates (ordinary)	26 1/2°
Pan tiles	33 1/2°
Plain tiles	45°

Where the roof is in an exposed position and slates or tiles are used, the pitch should be steeper than given above, otherwise the rain is liable to be driven in the roof by the wind. When the roof is of steep pitch, advantage may be taken of forming a room in the roof, light

being obtained through a dormer window or a skylight fixed in the roof.

The sketch, Fig. 69, shows a roof from which the roof-boarding and battens have been removed to make plain the arrangement of the rafters. One portion of the roof intersects

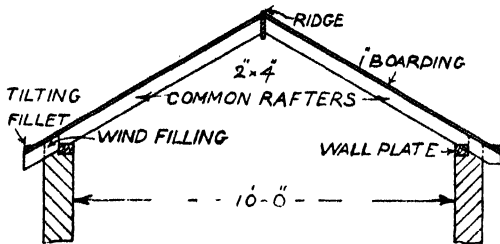


FIG. 71. COUPLE ROOF

the main roof, forming a *valley* on each side by the intersection of the sloping surfaces. At the end of the branch roof the slope is carried around and so forms a *hipped end*. Where the rafters are fixed over the wall, and the brickwork is carried up as shown on the left side of the drawing, a *gable end* is obtained. The *verge* is seen to be where the roof terminates at the gable end. The highest part where the two sides intersect is called the *ridge*, and the lowest part where the rafters meet the wall is called the *eaves*; the eaves may or may not overhang the surface of the wall.

The names of all the members are indicated: the *common rafters* are of the same length, one end being fixed to the *ridge board* and the other end to the *wall-plate*. The *hip rafters* and the *valley rafters* run from the angles of the wall to the ridge and are fixed by nailing, and to these rafters one end of the *jack rafters* is fixed. In some districts, the jack rafters that have one end fitted to the valley rafter are known as *cripple rafters*, owing to "having no foot," or no foot fixed on the wall-plate. The double lines at *a* show how the rafter would be trimmed around a chimney, or for a skylight. The trimming rafters and trimmers are $\frac{1}{2}$ in. to 1 in. thicker than the common rafters, and are mortised and tenoned at the joints.

Roofs may be classified as (a) of simple construction, (b) trussed, and (c) composite (wood and steel). Simple roofs consist of common rafters, wall-plate, and ridge, with or

without purlins, and either boarded and batted or batted only.

SIMPLE ROOFS

Lean-to. The simplest form of roof is the lean-to roof, or pent roof; it is generally used for sheds and buildings which are attached to the main building. Fig. 70 illustrates a form of roof suitable for spans up to 8 ft.; if of more than 8 ft. span, purlins should be used. The rafters are shown bird's-mouthed over a wall-plate at the top, and also at the bottom. The feet of the rafters overhang the face of the wall, with *soffit* and *fascia* attached, to form the eaves and to carry the gutter. The roof is boarded ready for the slates to be fixed in position. Other methods of carrying the wall-plate at the top may be adopted; the method shown in Fig. 33 is to be recommended when a good job is required and the wall is already built. Often a board is spiked to the wall and used as a fixing for the rafters.

Couple Roof. Couple roofs, as their name implies, are roofs consisting of pairs of rafters fixed at their feet to the wall-plate and pitching against the ridge, as shown in Fig. 71. They are only suitable for spans up to about 10 ft., owing to the danger of the walls spreading due

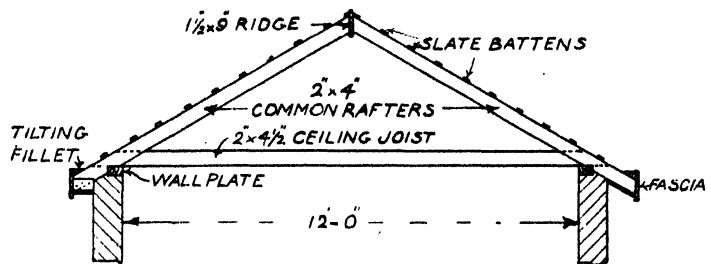


FIG. 72. COUPLE-CLOSE ROOF

to the thrust of the rafters, unless the walls are sufficiently strong to resist this thrust. Alternate methods of finishing the feet of the rafters are shown, with boarding and *tilting fillets* ready for the slates. To prevent the wind from blowing in and also to keep the birds out, the brickwork is carried up right to the underside of the boards, as shown by the dotted lines.

Couple-close Roofs. These roofs are suitable for spans up to about 12 ft., and are similar to couple roofs, but with a tie fixed to the feet of the rafters; this tie prevents the feet from spreading, and thus the danger of the walls overturning is avoided; and the ties also act

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as ceiling joists when required. Fig. 72 shows a couple-close roof, with rafters and ceiling joists secured to the wall-plates, and battened ready for the slates. Two different methods of finishing the eaves, with soffit and fascia board, are shown.

Collar-tie Roof. To economize in space and to increase the height, a room is sometimes partly formed in the roof. When this is required, a collar-tie roof, as shown in Fig. 73, is used, and the ceiling is obtained by lathing and plastering the underside of the collars and the rafters down to the wall. The collars are generally placed about one-third to one-half the height of the ridge above the wall-plates. This causes the rafters to tend to spread from the tie downwards, and therefore to thrust the wall outwards, as in the couple roof. To minimize this tendency, the rafters should be made stouter than usual; and care should be taken, when making the

advantage being taken of any partition, or wall, to support the ceiling joists and rafters by struts or ties. Fig. 74 illustrates a roof suitable for a span up to about 30 ft. The rafters are

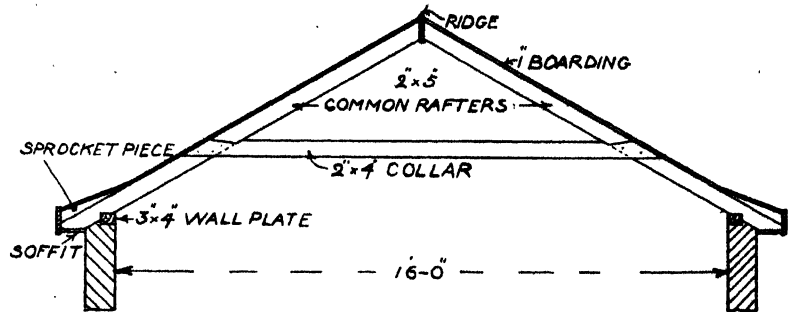


FIG. 73. COLLAR-TIE ROOF

supported by a purlin, which rests on the collar and struts and at the ends on the walls. The collars and struts would occur about every fourth or sixth rafter, and in the case shown the ends of the strut are bird's-mouthed over a plate fixed to the ceiling joists. The ceiling joists rest on a partition and are in two lengths, one running past the other to ensure good

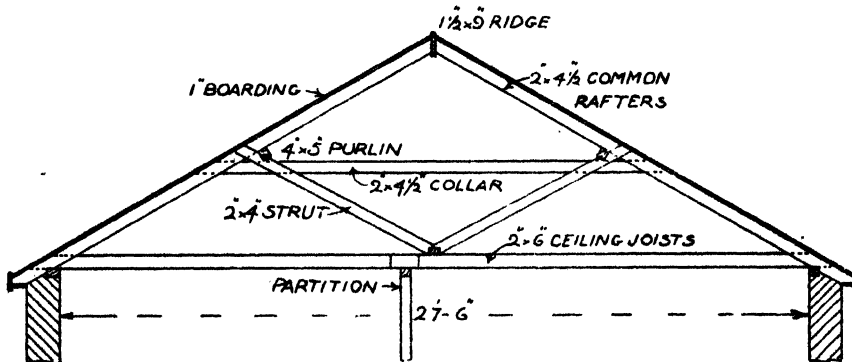


FIG. 74. COLLAR-AND-TIE ROOF

joint with the collar, not to weaken the rafter more than necessary. The collar is shown dove-tailed and sunk into the rafter (about $\frac{1}{2}$ in. being taken out of each and well nailed); often the collar only is reduced and then nailed on to the face of the rafter. These roofs are suitable for spans up to about 16 ft.

Collar-and-tie Roof. When the roof exceeds the span of the last-named, a combination of collar-tie and couple-close roof is introduced, and is used for cottage and villa construction,

nauling. The ceiling joists could be supported at their centres by hangers fixed to the purlins or struts, to prevent them from sagging.

EAVES AND PREPARATION FOR COVERINGS. Figs. 75 to 78 show various methods of preparing the roof for slates and tiles, and also different finishings that can be used at the eaves. In Fig. 75, the rafter is shown bird's-mouthed over the wall-plate and projecting beyond the face of the wall. The feet of the rafters are prepared for a soffit board and a fascia board. The

rafters are covered with rough boarding, and the top edge of fascia board is kept up so as to give a tilt to the slates, which are nailed direct to the boarding. Boarding of the roof is to be recom-

fascia board fixed at the eaves. The roof is covered with rough boarding, and on it felt is laid. The tile battens are then spaced to the required gauge, nailed to the boards. This

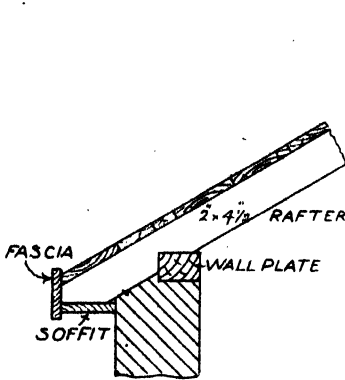


FIG. 75. OVERHANGING EAVES BOARDED FOR SLATES

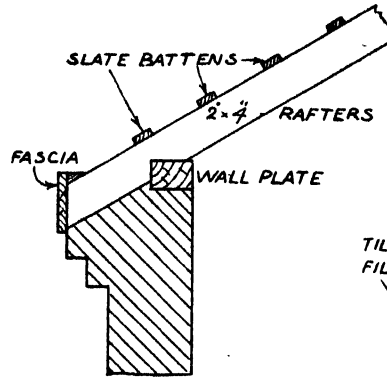


FIG. 76. SECTION THROUGH EAVES FLUSH WITH WALL

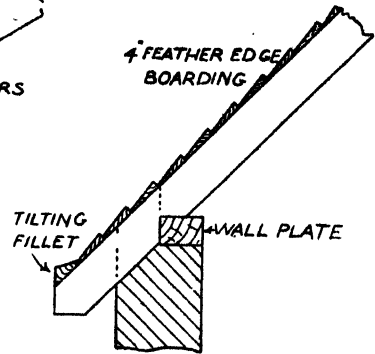


FIG. 78. SECTION THROUGH ROOF WITH OPEN EAVES

mended, as it keeps out the dirt and draughts much better than where only battens are used.

Fig. 76 shows another method of preparing the roof for slates. In this case battens are fixed to the rafters, at distances apart equal to the gauge of the slates used. A tilting fillet and

method keeps the roof weather-tight and free from draughts. There is, however, danger of the water lying in the channels formed by the battens and the felt, should a tile get broken or displaced or snow be driven in under the tiles. To prevent this from occurring, fillets are fixed over the felt, and in the same direction as the rafters. On these fillets the tile battens are fixed, and therefore ensure a space between the battens and the felt, so that any water that may find its way under the tiles can run down the roof. For cheap construction, roofs are often battened when tiles are used, in the same way as that shown for slates in Fig. 76.

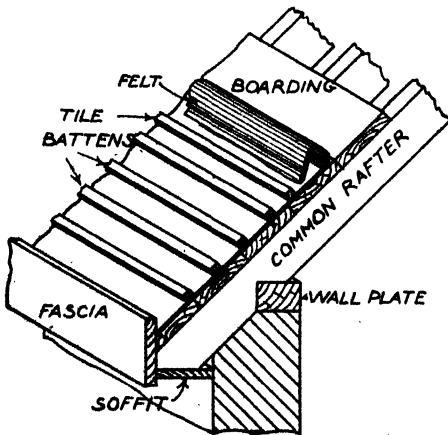


FIG. 77. SKETCH SHOWING OVERHANGING EAVES, ETC.

fascia board are fixed to give the required tilt to the slates, and also to carry the rain-water gutter. The feet of the rafters are cut flush with the oversailing courses of the brickwork.

Fig. 77 illustrates the lower portion of the roof of a good class job. The rafters are bird's-mouthed over the wall-plate, with soffit and

A better method and not much more costly is shown in Fig. 78, feather-edge boarding 4 in. wide being used as shown. This boarding not only covers the roof, but at the same time forms a ridge for the laying of the tiles, the width of the boards being equal to the gauge of the tiles; considerable time is thus saved in the fixing, compared with the fixing of the battens, as each batten has to be spaced before it can be nailed. A tilting fillet is fixed at the feet of the rafters, which are open and overhang from the face of the wall. Wind filling is shown by the dotted lines.

Fig. 79 shows a section through the eaves of a roof covered with tiles, with an asphalt gutter constructed in the cornice. As will be seen, a gutter bearer is halved into an upright piece of timber, which is well nailed and fixed to the rafter and a batten on the wall. The soffit and

MODERN BUILDING CONSTRUCTION

gutter boards are fixed to the bearer, and the lower part of the moulded cornice is fixed to a block on the leg of the bracket, which rests on the brickwork.

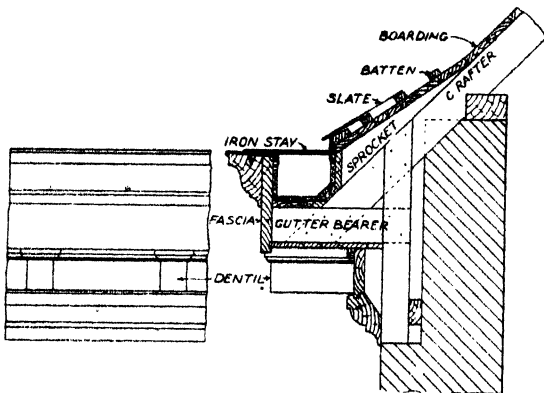


FIG. 80. PART ELEVATION

FIG. 79. SECTION THROUGH EAVES WITH ASPHALT GUTTER FORMED IN THE CORNICE

Sprocket pieces are nailed to the rafters, and a board fixed to their ends forms one side of the gutter. The other side of the gutter is the back of the fascia board. A large moulding is screwed to the top edge of the fascia board, and is held in position by iron stays, screwed to the mould-

TRUSSED ROOFS

When the span exceeds that suitable for the collar-tie and couple-close types of roofs, unless there are cross walls, partitions or other supports for the purlins and ties, *trusses* are introduced for economy and strength. The advantage is that the total weight of the roof is carried vertically on the walls. Trussing consists of framing timbers together in such a manner that the frame when subjected to the loads will not alter in shape. The theory of trussing has been briefly explained in the chapters on joints and partitions. The trusses should be placed not more than 10 ft. apart. This distance will be influenced by the openings and piers in the walls. The tie beam should be supported about every 15 ft.; this will determine the kind of truss to be used.

King-post Roof Truss. These trusses may be used for spans up to about 30 ft. Fig. 81 shows the elevation of a king-post truss suitable for a span of 20 ft. The roof has overhanging eaves on one side, and on the other side a parapet wall and tapered gutter. The names and sizes of all the members are given. The roof is boarded and prepared for slates. As will be seen in the drawing, the weight of the roof is concentrated at five points, that is, on each wall, the two purlins, and at the ridge, so

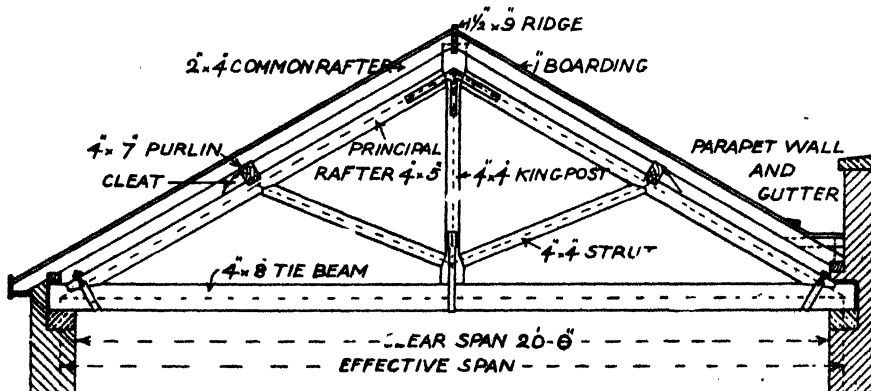


FIG. 81. KING-POST ROOF TRUSS

ing at one end and made fast to the rafters at the other end. The top of the moulding falls backwards to the gutter and is covered with lead. Dentils, placed about 12 in. apart, are fixed to the soffit, and moulding is mitred round their top edge. Part elevation of the cornice and the dentils, with moulding returned round the ends, is shown in Fig. 80.

that the truss will have to bear three-quarters of the load, the other quarter being borne by the walls.

To explain how the weight is transmitted through the members to the wall, first take the weight at the ridge. This is carried down the *principal rafters* to the *tie beam*, which prevents the feet of the rafters from spreading outwards.

Secondly, the total weight carried by the purlins is placed in the centre of the principal rafter, which tends to bend under the load. The *struts*,

to form an abutment for the end of the principal rafter. A wrought-iron *heel strap*, with the ends forged and threaded, passes under the tie beam.

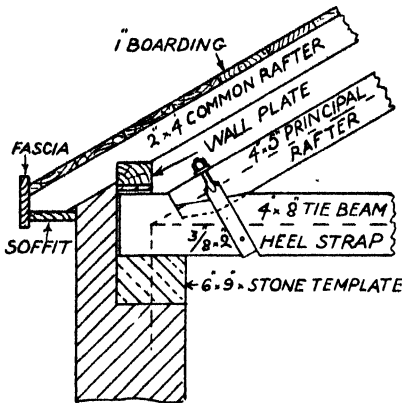


FIG. 82. SECTION THROUGH OVERHANGING EAVES

however, prevent them from bending, and therefore convey some of the load down to the foot of the *king post*; but, owing to the design of the joints, the king post is suspended from the principal rafters, and therefore all the load that is taken to the foot through the struts is trans-

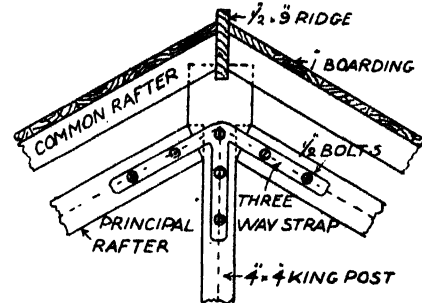


FIG. 84. JOINT AT HEAD OF KING POST

A plate is placed over the ends, and the joint secured by the screwing down of the nuts. To prevent the strap from sliding, if shrinkage should occur, a hole is made in the strap so that a screw may be driven through it into the tie beam. The common rafters are bird's-mouthed over the wall-plate, and the feet are covered with soffit and fascia boards.

Fig. 83 shows a section through the parapet wall and the gutter. The joint between the

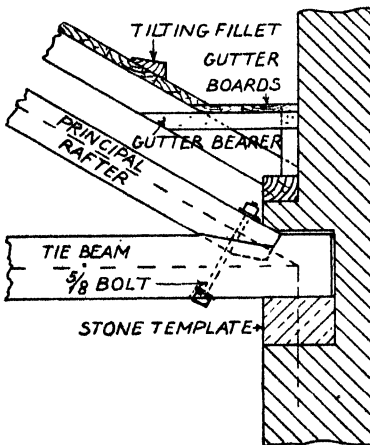


FIG. 83. SECTION THROUGH TAPERING GUTTER WITH PARAPET WALL

mitted through the king post and down the principal rafter to the tie beam at the supports. The tie beam often carries the ceiling joists, and is supported at its centre by the king post.

Fig. 82 shows an enlarged detail of the joint between the principal rafter and the tie beam, an oblique mortise and tenon joint being used. In addition, a piece is cut out of the tie beam

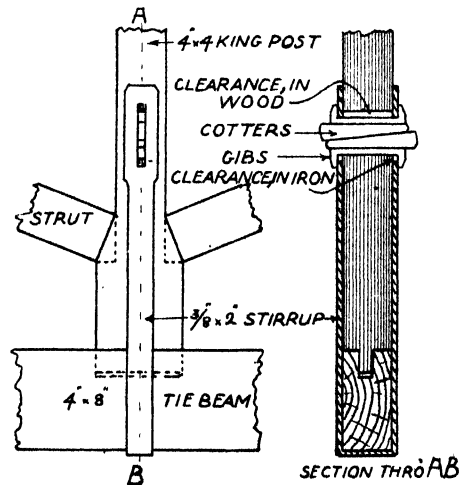


FIG. 85. JOINT AT FOOT OF KING POST

principal rafter and tie beam is the same as described in Fig. 82, but in this case a bolt is used as an alternative method of securing the joint. The wall-plate is bedded on the wall, and the feet of the rafters are bird's-mouthed on to it. Gutter bearers and upright supports are halved together, and fixed to the common rafters to the required *fall* of the gutter. The

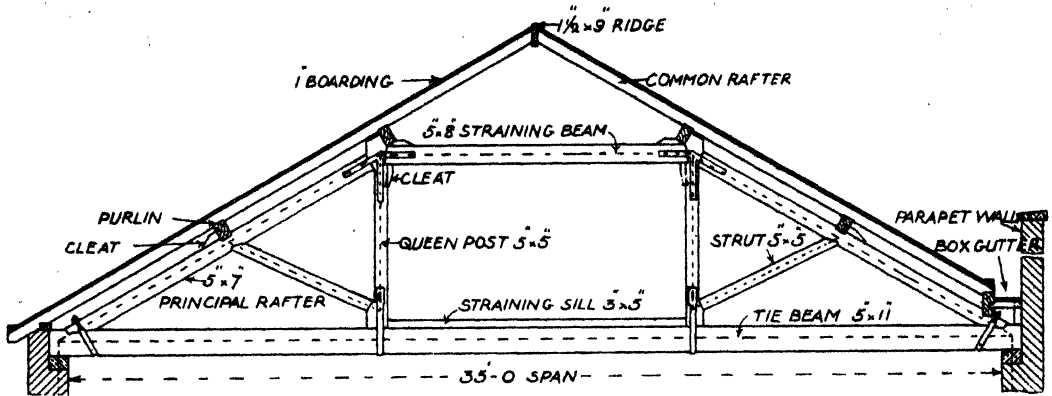


FIG. 86. QUEEN-POST ROOF TRUSS

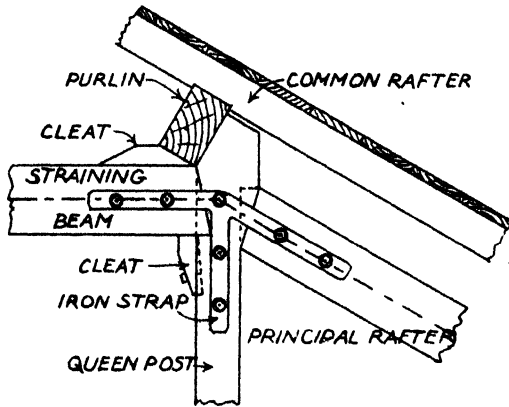


FIG. 87. JOINT AT HEAD OF QUEEN POST

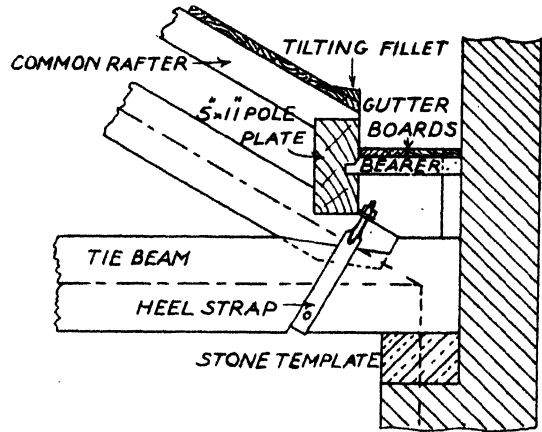


FIG. 88. SECTION THROUGH BOX GUTTER

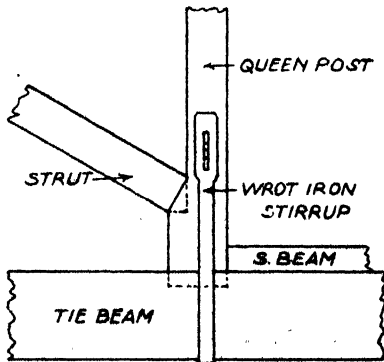


FIG. 89. JOINT AT FOOT OF QUEEN POST

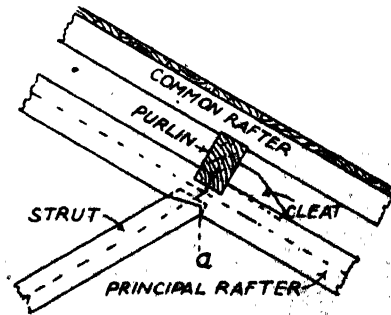


FIG. 90. JOINT BETWEEN STRUT AND PRINCIPAL RAFTER

gutter should not be less than 9 in. at the narrowest part. A tilting fillet is fixed about 4 in. up the roof, over which the lead or zinc would be dressed.

Fig. 84 shows the construction at the head of the truss. The king post is of sufficient width to give an abutment to the principal rafters, the joints being mortised and tenoned as shown by the dotted lines, and secured by two three-way straps and bolts. The ridge rests in a slot cut in the top of the king post, and the common rafters are fixed to it by nailing.

The lower end of the king post is shown in Fig. 85. A mortise and tenon joint is used at the junction with the tie beam, and is drawn up tight by the aid of a wrought-iron stirrup, with *gib* and *cotter* joint. A section through *AB* is shown on the right of the figure, with the gibs and cotters in position when the joint fits. In making this joint care must be taken to provide *clearance*, both in the wood and iron, so that if any shrinkage in the tie beam takes place, the cotters can be driven in and again make the joint secure. The tie beam should be *cambered* about $\frac{1}{4}$ in. for every 10 ft. of span, to allow for any settlement in the truss. The king post, having to support the tie beam at the centre, and also the struts, is subjected to tensional stress, and it should be noticed that the fibres that affect the strength have not been cut when making the mortises for the principal rafters and the struts.

Queen-post Roof Trusses. Queen-post trusses may be used for spans up to about 45 ft. They are seldom used now for large spans, but can be employed with great advantage where a lantern light has to be fixed in the centre of the roof. Fig. 86 shows the elevation of a truss suitable for a span of 35 ft.; the roof is prepared for slates, and has overhanging eaves on one side, and a parapet wall with box gutter on the other side. The names and sizes of all the members are indicated in the drawing. The tie beam is supported by two posts, and if the timber available is not long enough, it may be jointed in the centre of its length by a suitable scarfed joint. (See chapter on "Joints.")

A *straining sill* is spiked to the top edge of the tie beam, to assist the queen post in resisting the thrust of the struts, and a *straining beam* is used at the head of the posts to resist the thrusts of the principal rafters. The purlins are arranged so that the bearings for the common rafters are about equal distances apart.

Fig. 87 shows the joint at the head of the

queen post with the principal rafter and the straining beam. The principal rafter is stumped tenoned into the queen post, and the straining beam has a bridle joint, and a cleat to give additional support. A three-way wrought-iron strap is placed on each side and bolted as shown. The purlin is supported by the head of the queen post and a cleat nailed to the straining beam; the common rafter and boarding are also shown.

A section through the parapet wall and gutter is shown in Fig. 88. The joint between the principal rafter and tie beam is similar to that explained in the king-post truss. The feet of the common rafters are bird's-mouthed on to a *pole plate*, which is fixed to the lower end of the principal rafters. The pole plate is mortised for one end of the gutter bearers, the mortises varying in height according to the *fall* of the gutter; the other end of the bearers may be halved to an upright leg, or fixed to a batten resting on the wall. The gutter boarding and tilting fillet is shown in position, and prepared for the dressing of the lead.

Fig. 89 shows the joint at the foot of the queen post with the tie beam, and held in position by the iron stirrup. The strut is tenoned into the queen post as shown by the dotted lines.

Fig. 90 shows the joint between the strut and the principal rafter; a mortise and tenon joint is shown, but a bridle joint could be used. To prevent the strut from dropping out of its position, the angle between the strut and the principal rafter should be bisected to give the direction of the joint on the lower side, as at *a*.

APPROXIMATE SIZES OF TIMBERS. The sizes of the timbers for the king-post and queen-post roof trusses can be found either graphically or by calculation, but by applying the following rules, approximate sizes may be obtained which will generally give satisfactory results, where Northern pine of average quality is used.

Rule 1. To obtain the thickness of the truss, divide the number of feet in the span by 5 for the king-post roof truss, and by 7 for the queen-post roof truss. This will give the thickness in inches.

Rule 2. The area of the section of the principal rafter in inches should equal span in feet.

Rule 3. The section of the king and queen posts and struts should be square.

Rule 4. The depth of the tie beam in inches should be from 2 to $2\frac{1}{2}$ times the thickness of the truss; the depth of the straining beam about three-quarters the depth of the tie beam.

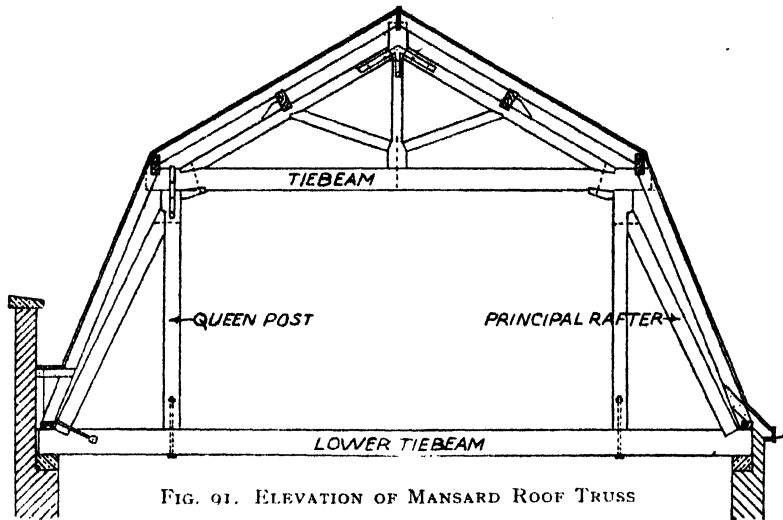


FIG. 91. ELEVATION OF MANSARD ROOF TRUSS

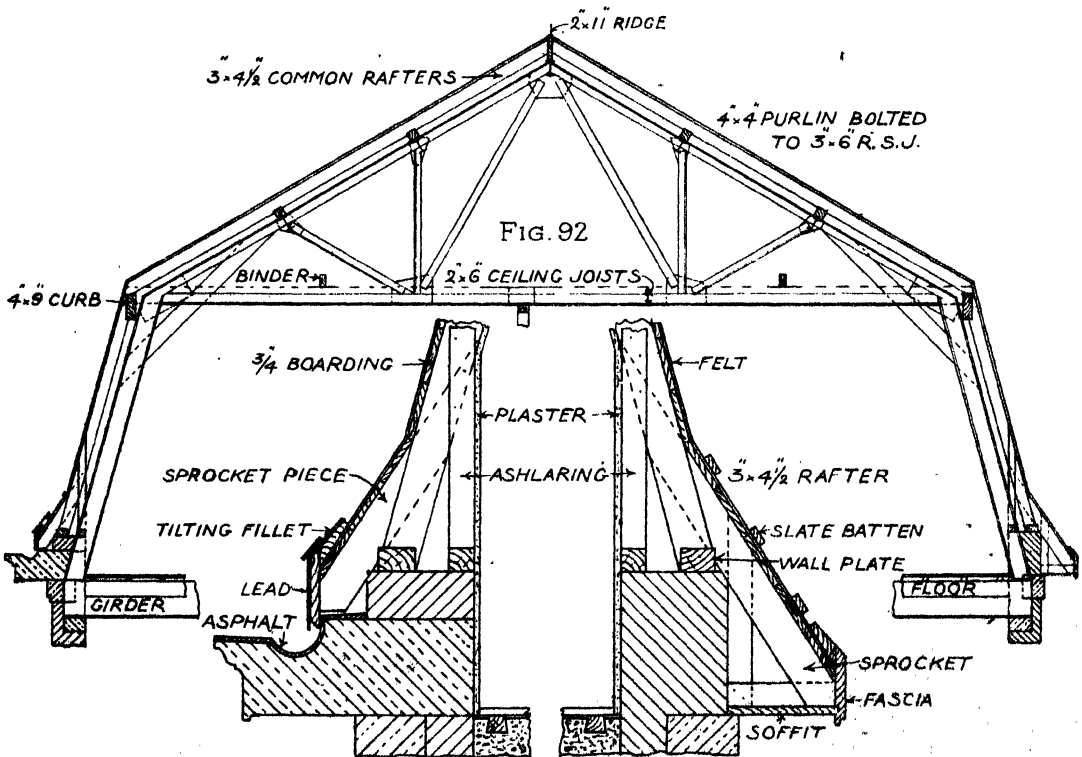


FIG. 92. ELEVATION OF A STEEL-FRAMED MANSARD ROOF TRUSS WITH TIMBER ROOF

FIG. 93. DETAIL AT FOOT OF TRUSS SHOWING GUTTER IN CORNICE

FIG. 94. DETAIL SHOWING SECTION THROUGH OVERHANGING EAVES

Chapter V—SPECIAL TRUSSED ROOFS: FLAT ROOFS

Mansard Roof Trusses. These roofs are sometimes known as *curb* roofs, the outline being approximately obtained by placing a king-post roof truss on the top of a queen-post truss. When these trusses are used, advantage is taken of the space enclosed to form a room or attic in the roof, light being obtained through a dormer window. The lower pitch should not be greater than 75° to the horizontal, the upper pitch generally being about 30°.

Fig. 91 shows the elevation of a mansard roof truss with a tapered gutter and parapet wall on one side, and an eaves gutter on the other side. The construction will be readily understood from the drawing. The details of the joints are similar to those explained for the king-post roof trusses.

STEEL MANSARD ROOF TRUSS. Fig. 92 shows the elevation of a mansard roof truss constructed with steel for a span of 33 ft. All the other parts of the roof are of timber. The principal rafters are braced at the angle (curb) by a plate,

and the feet of the lower principal rafters are bolted to the girder supporting the floor, which also acts as a tie beam for the truss.

Fig. 93 shows the left-hand side of the roof to a larger scale, with details at the feet of the

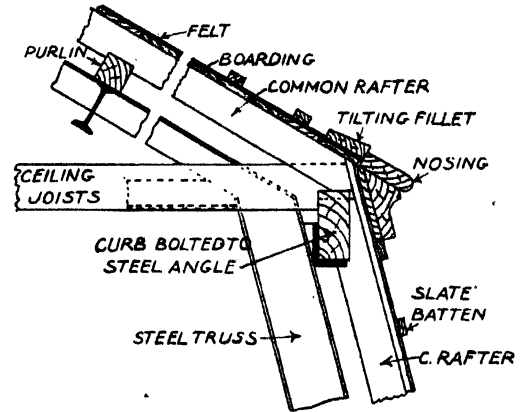


FIG. 95. DETAIL AT CURB

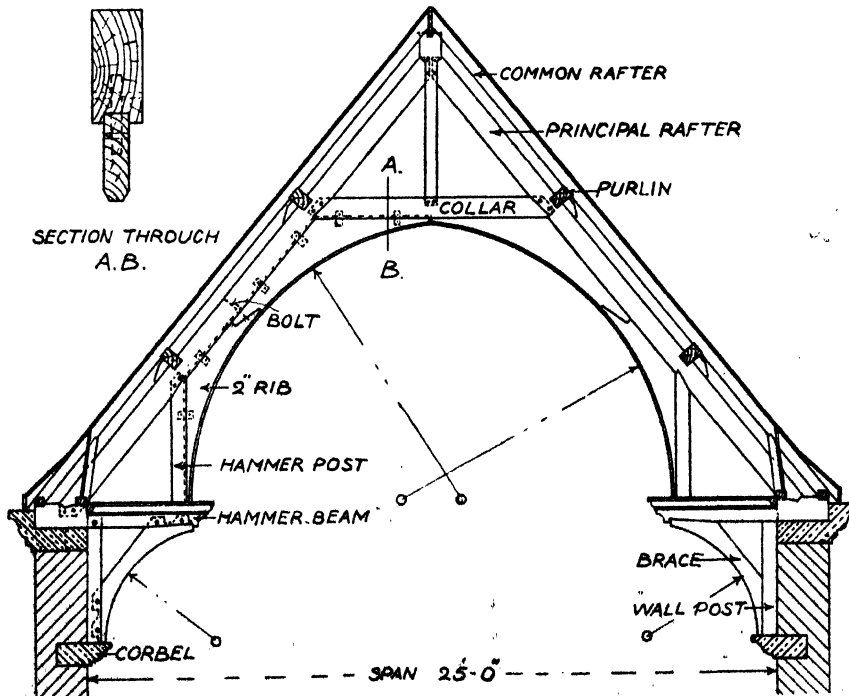
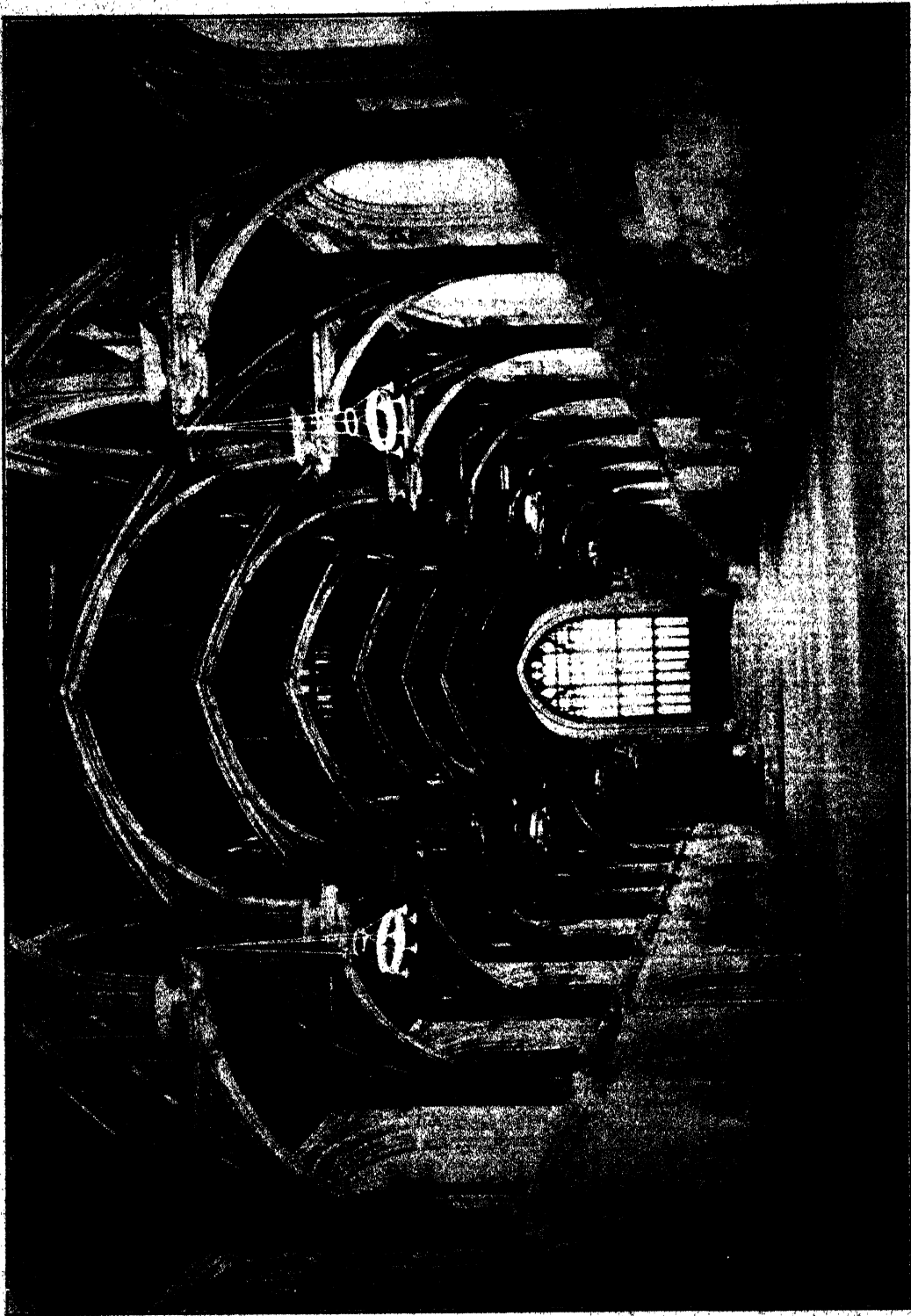


FIG. 96. HAMMER-BEAM ROOF TRUSS



INTERIOR VIEW OF THE HAMMER-BEAM ROOF AT WESTMINSTER HALL
By the courtesy of H.M. Office of Works

rafters, sprocket pieces, and fascia board, together with the arrangement for carrying away the water by a gutter formed in the stone cornice.

Fig. 95 shows an enlarged detail at the junction of the two slopes. The curb is fixed to a steel angle which is bolted to cleats fixed to the truss. The ceiling joists are notched and

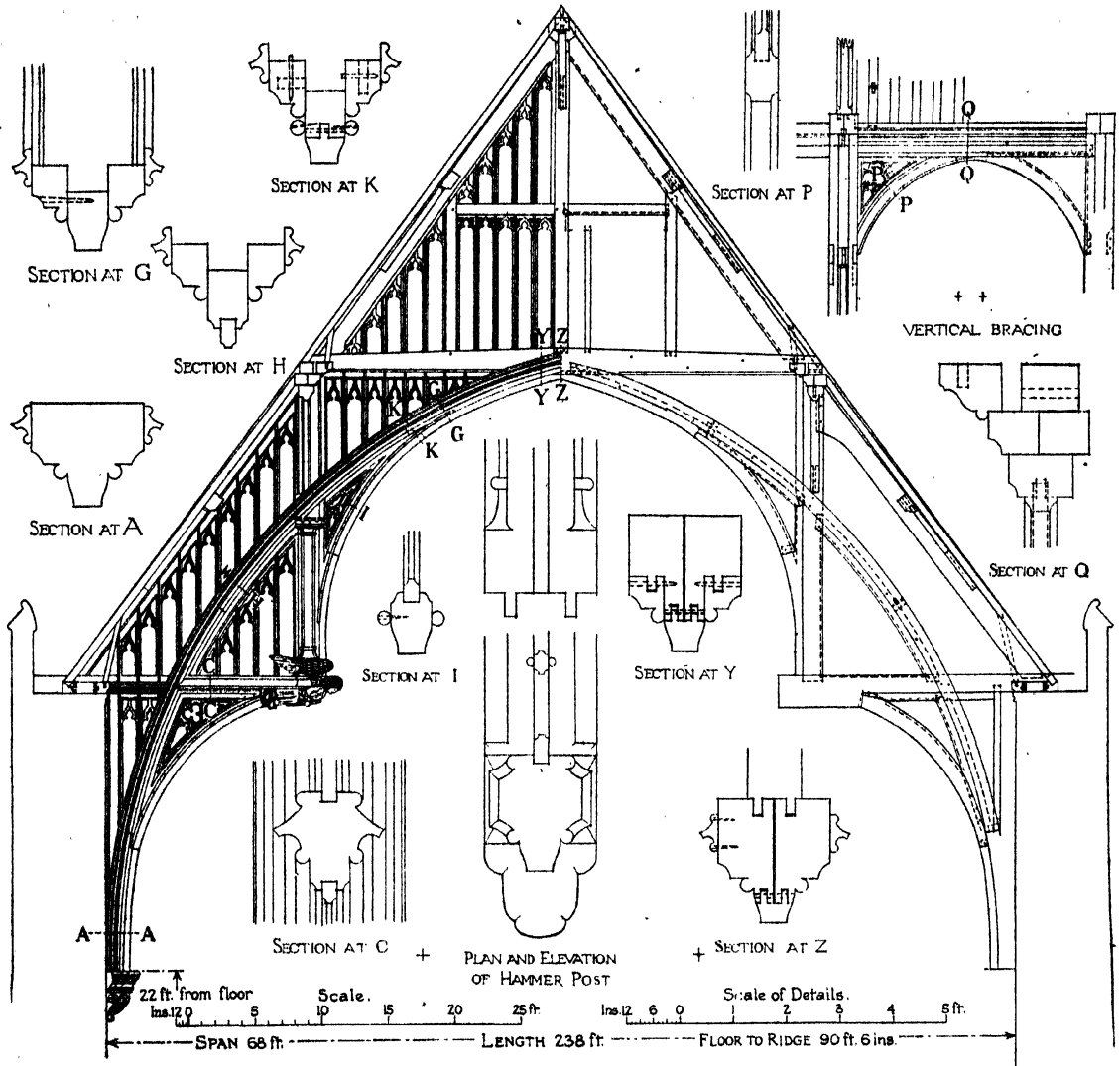


FIG. 97. ELEVATION OF ROOF TRUSS, WESTMINSTER HALL
By the courtesy of H.M. Office of Works

Fig. 94 shows a section through the eaves on the right-hand side of the drawing. The soffit boarding is fixed to bearers that are supported by the sprockets, and the roof is boarded and covered with felt. To allow for the circulation of air in the roof, holes of about $\frac{3}{4}$ in. diameter should be bored through the soffit or fascia boards.

housed into the curb, so that their under edges are brought down to clear the under edge of the steel tie. They are supported at their centre by a partition, and in addition they are stiffened by binders fixed to their top edges. The purlins are bolted direct to the top flange of the rolled steel joists, these joists being fixed to the principal rafters. The roof is

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shown completed and ready for the plumber and slater.

A simply constructed mansard roof, such as would be used for small terrace houses and tenement buildings, where the cross partitions and party walls provide a bearing for the curbs and purlins, would be constructed similar to those shown in Figs. 91 and 92, but without the trusses. The ceiling joists would prevent the feet of the rafters from spreading at the curb, and would be supported by, and fixed to, the cross partitions.

Dormers have to be constructed in these roofs and may have either pitched or flat roofs. The method of constructing a dormer is shown later.

Hammer-beam Roofs. When the building is of a public character, such as a church or hall, and an architectural feature has to be made of the roof, and also to obtain greater apparent height by the omission of the horizontal tie beam, a hammer-beam roof is often introduced. The tie beam is replaced by two short *hammer beams* projecting from the wall (very much as if the centre of a tie beam had been cut away).

These hammer beams rest on the wall, and also on a wall post, which runs down to a corbel fixed in the wall. A strut from this corbel helps to support the free end of the hammer beam, which carries the *hammer post*. The principal rafter is fixed to the hammer beam and its weight tends to support the free end.

To prevent the feet of the rafters from spreading, we depend upon the stability of the wall to resist the horizontal thrust of the principal rafter. The walls are often strengthened by buttresses being added.

Fig. 96 shows a simply constructed single hammer-beam roof truss suitable for a small span. All the members have been mortised and tenoned together and secured by wooden pins (trenails). Both sides have been prepared for an eaves gutter. The names of all members are given; ashlaring is shown, and a cornice moulding is fixed between the trusses, and returned around the hammer beams.

Of the fine examples of hammer-beam roofs in this country, one of the earliest, and almost certainly the largest, is that of Westminster Hall (see illustration on page 496), which, begun in the fourteenth century, replaced that constructed by William Rufus in 1097. The timbers were of English oak, but it was found in 1913 that they had been attacked by a wood-boring insect and extensive repairs were necessary.

Steel plates and ties were fixed to the timbers

in such positions that they are invisible from the floor of the Hall. All the original timbers that were capable of being re-used were re-fixed.

The photograph appearing on page 496 was taken on the completion of the work, and a drawing of one of the trusses is shown in Fig. 97. One half illustrates the position of the joints, some of which are extremely ingenious and are mortised and tenoned together.

The other half shows the tracery, the panels, and the mouldings applied over the framework; special attention is drawn to the figure of the angel at the end of the hammer beam, carved out in one solid piece of wood.

It will be observed that the principal rafters are in two lengths, the lower portion extending between the wall end of the hammer beam and the upper end of the hammer post. The lower end of the upper section rests on the top of the collar beam, while the upper end is fixed into the key post. Detailed sections through the principal members are given.

A hammer-beam roof more decorative in character is that covering the Great Hall at Hampton Court Palace (see Fig. 98). It was built during 1593-94 by Henry VIII, and is somewhat similar in construction to the roof at Westminster Hall but on a much smaller scale; the principal rafters, for instance, are in one timber.

In addition to the carved brackets extending from the wall post to the hammer beam, and from the hammer beam to the collar beam, there are other curved brackets, extending from the hammer beam to the under sides of the purlins.

It is to be noted also that the whole of the constructional timbers are hidden by tracery panels. One notable feature is the provision of the very ornamental pendants.

Collar-beam Roof. A fine example of this type of timbered roof construction is shown in Fig. 99. It is covered with glass and is fixed over a gallery in a large building. The trusses are of the arched collar-beam type of construction, the curved ribs springing from corbels fixed to the massive posts that support the roof. These timbers were once the timbers used in the construction of the old "men-of-war." The trusses and the lower part of the roof are filled in with tracery panels, and a large moulding is fixed around the gallery.

Dormers. When a room has to be included in the roof a dormer is generally constructed to obtain light and ventilation. The roof of the

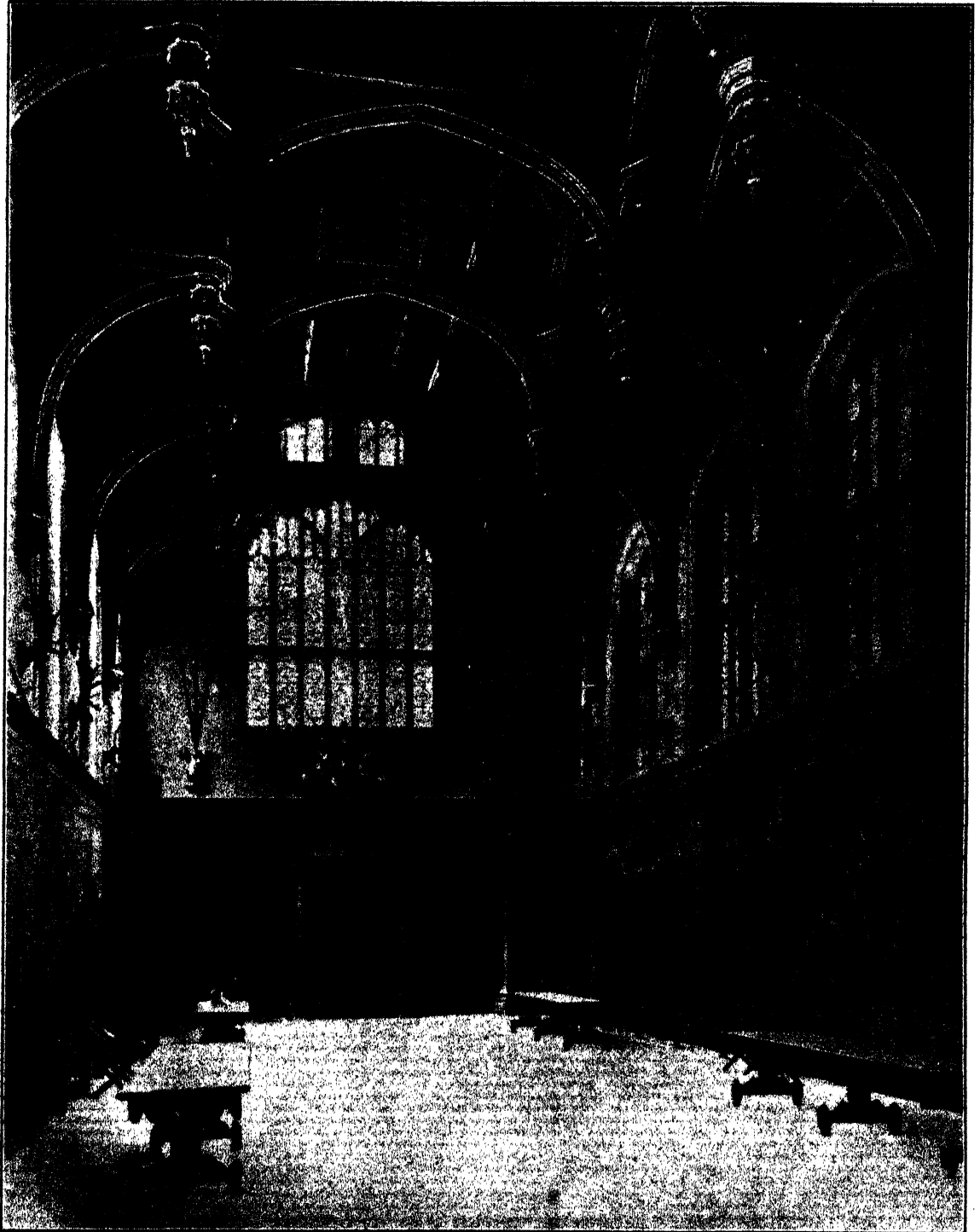


FIG. 98. INTERIOR VIEW OF THE HAMMER-BEAM ROOF IN GREAT HALL,
HAMPTON COURT PALACE
By the courtesy of H.M. Office of Works

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dormer may be either *flat*, *round*, or *pitched*, according to the style of architecture.

Fig. 100 shows the vertical sectional elevation through a dormer constructed in a roof of half pitch, the roof of the dormer being of the same pitch. In the example shown, the ceiling of the room and the dormer are at the same level, and the ends of the ceiling joists are supported by

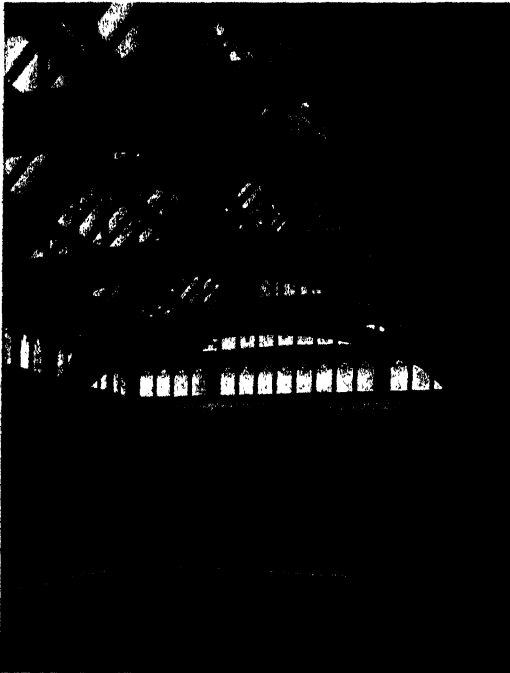


FIG. 99. COLLAR-BEAM ROOF
By kind permission of Messrs. Liberty & Co.

the head of the frame. The studs are notched on to the trimming rafter, and are tenoned into the plate which supports the rafters of the dormer.

Half of the front elevation and the section on *AB* is shown in Fig. 101. A barge board is fixed to the face of the rafter, but the other boarding has been omitted to show how the rafters are trimmed for the opening. A fillet is nailed to the lower edge of the rafter, as shown in the section *AB*, and a similar fillet is fixed to the plate so that the end of the laths can be fixed. The cheeks of the dormer are lathed and plastered on the inside, and the outside is boarded and covered with lead (tiles or slates are often used), as shown by the enlarged section through the angle post and window frame.

Flat Roofs. These roofs are constructed in very much the same manner as the floors previously described, with the exception that the upper surface is arranged with a sufficient fall, so that the water will run off rapidly. They may be covered with lead, zinc, or asphalt.

Fig. 102 shows the plan of a flat roof to be covered with lead and falling in both directions to a gutter at each end. It is trimmed for a lantern light to be fixed in the centre of the roof. On the right of the drawing the arrangement of the timbers is shown, with the trimming joist and trimmer, also the gutter bearers and the cesspool; the gutter bearers are fixed to battens fixed on the wall and joists. The joists are *furred* up to obtain the required fall; about 1 in. to 1½ in. of fall in 10 ft. will be found sufficient.

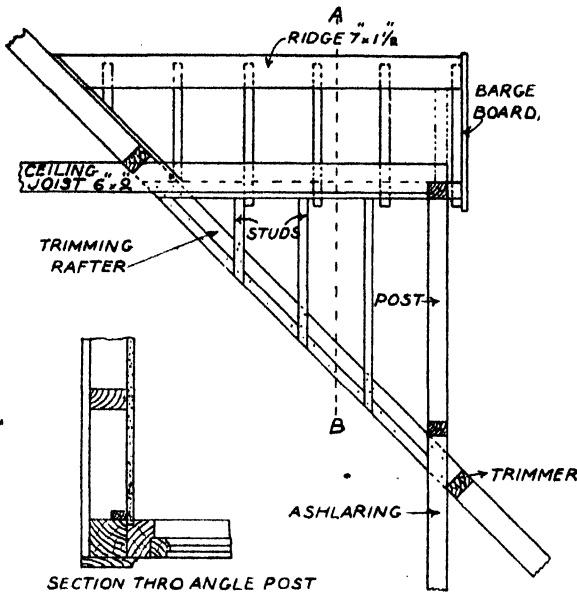
The gutter bearers would be fixed to the line of the fall, and the drips should not be less than 2 in. deep. On the left-hand side of the drawing, the roof is shown boarded and finished with drips and rolls ready for the plumber. Where possible, the surface of the lead should not exceed the sizes figured in, owing to the expansion and contraction and the economical use of the lead.

Fig. 103 shows a section through the flat on the line *AA*, illustrating how the joists are furred up to obtain the required fall and drips, and also how the curb is fixed to ensure that the sill of the lantern light is sufficiently high to prevent the water getting in through the joint.

TAPERING GUTTER. Fig. 104 shows the lower portion of a roof, illustrating how a tapering gutter behind a parapet wall would be constructed. The gutter is arranged to fall in both directions from a *roll*, fixed in the centre of its length, to a cesspool at each end. A portion of the wall has been omitted to allow the construction to be seen; the names of the various parts are given, and the construction needs no further explanation. It will be noticed that only one end and one side of the cesspool are shown, as the wall forms the other side and end. This is considered the better method, but the rafter, owing to its having been cut away for the cesspool, would need supporting by a strut or other convenient method.

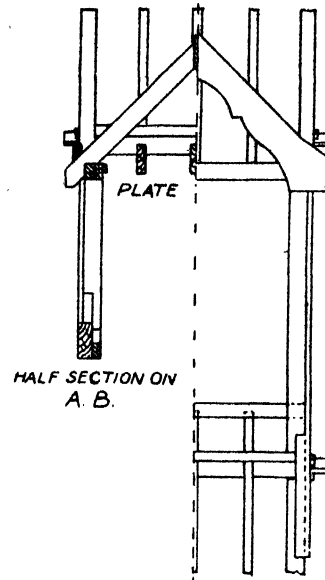
Fig. 105 shows a section through the cesspool, with hole cut through the bottom and *dished out* ready for the dressing of the lead. An enlarged section through the drip, gutter boards, and bearers is also shown.

Turrets. Turrets are small towers which often



SECTION THRO ANGLE POST

FIG. 100. VERTICAL SECTION THROUGH DORMER IN ROOF



HALF SECTION ON A. B.

FIG. 101. HALF ELEVATION AND SECTION OF DORMER

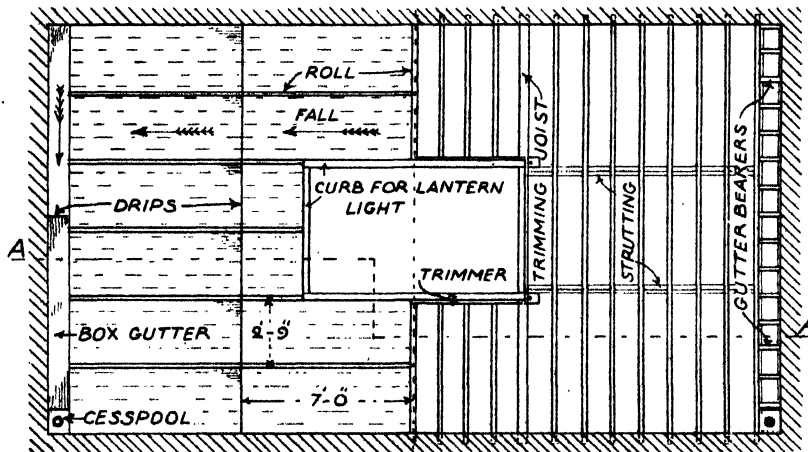


FIG. 102. PLAN OF FLAT ROOF TRIMMED FOR LANTERN LIGHT

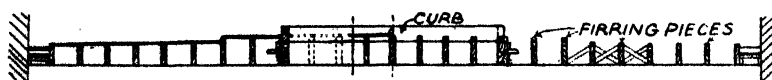


FIG. 103. SECTION ON LINE A A

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project above the roof of a building. They are designed both for use and as an ornamental feature, and may be used as a means of ventilation or to contain a bell, or for both purposes. Owing to their exposed position, it is essential that they should be well braced and anchored down to the main structure.

The drawing for a ventilating turret that could be fixed over a small public hall is given.

boarding, fixed diagonally in opposite directions to give the necessary bracing to the turret.

The rafters of the turret roof are fixed to a post which is bored for a *finial*; the post is supported and held in position by two diagonal ties, which are fixed to the head of the turret and the hip rafters. The roof is boarded, and the whole turret would be covered with copper or lead.

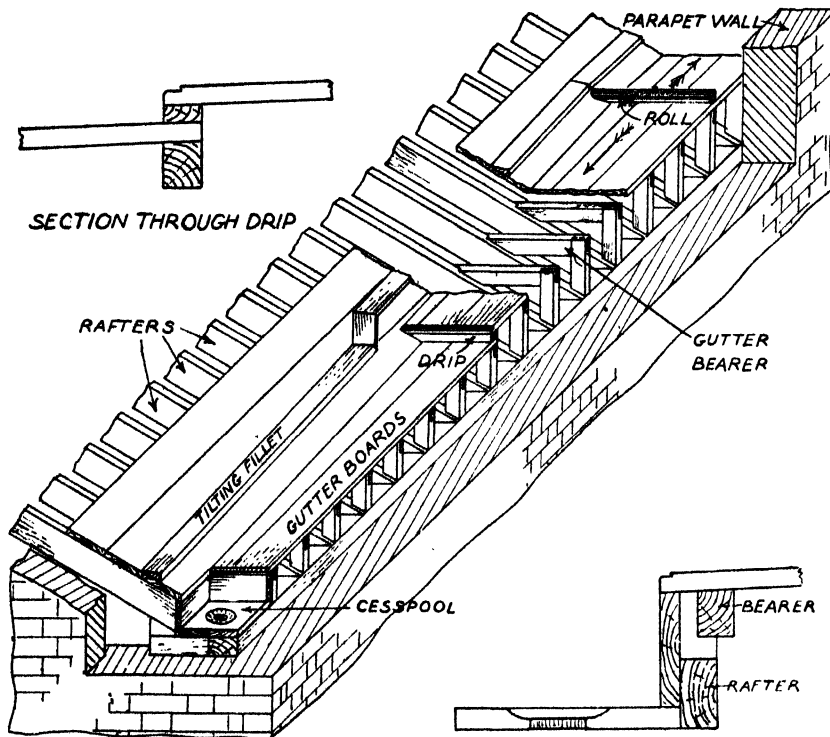


FIG. 104. SKETCH SHOWING TAPERING GUTTER BEHIND PARAPET WALL

FIG. 105. SECTION THROUGH CESSPOOL

Fig. 106 shows the vertical section through the roof, the turret being fixed to two collar-beam roof trusses that are built to support the turret; these trusses are fixed to large wall-plates, which are anchored down by bolts built in the wall. The other rafters have collars, and also additional ties for support, and as a means for fixing the curved rib filling (bracketing) for the ceiling. The posts are fixed to the sill and principal rafters by angle irons and bolts, and the sill is bolted to the collar beams.

Louvre frames are fitted in two sides of the turret, and the remainder is filled in with studding, and covered inside and out with

Fig. 107 shows a half section on *AA* and a half section on *BB*, showing the collar ties trimmed so that a grid can be fixed in the ceiling.

Fig. 108 shows the elevation of the turret and part of the main roof, one-half ready for the boarding, and the other half when completed.

The plan of the turret roof is shown in Fig. 109, and needs no further explanation.

Belfast Roof Trusses. Sometimes known as *bowstring*, or *lattice*, these light roof trusses are built up with small scantlings, and have the upper edge curved, or "bowed"; the rise in the centre is equal to about one-eighth the span.

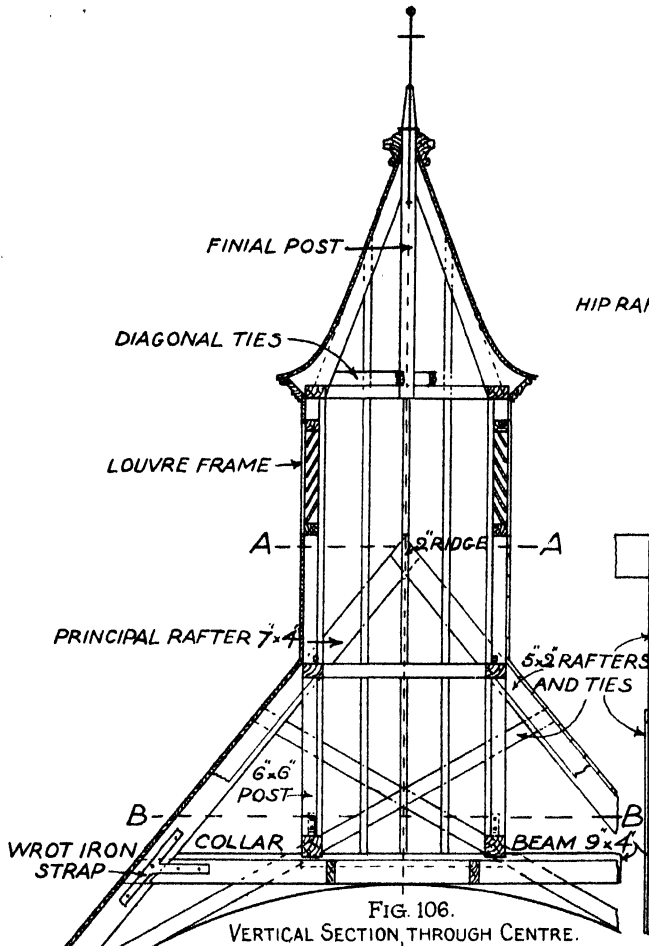


FIG. 106.
VERTICAL SECTION THROUGH CENTRE.

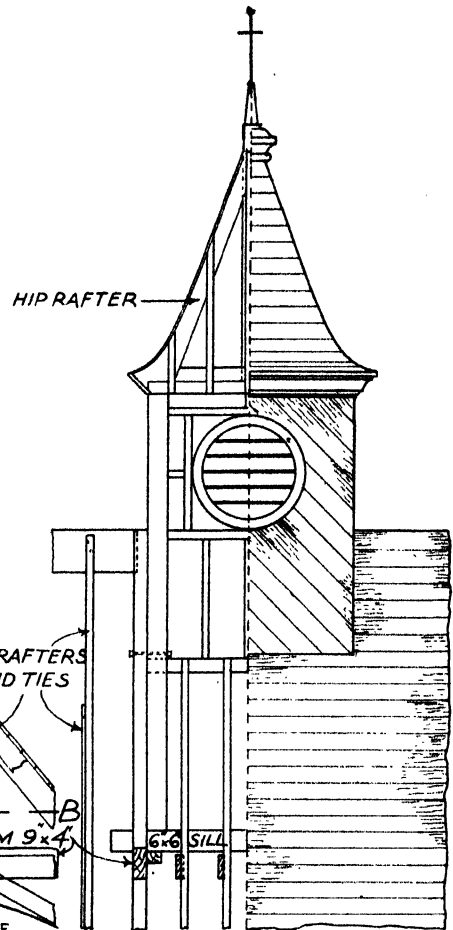


FIG. 108. ELEVATION OF TURRET BEFORE AND AFTER BOARDING.

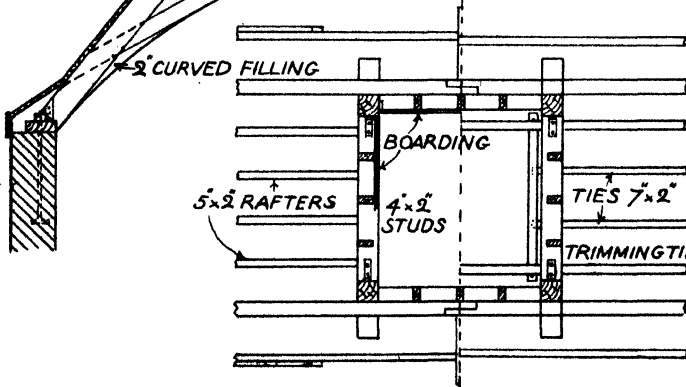


FIG. 107.
HALF SECTION THROUGH A.A. HALF SECTION THROUGH B.B.

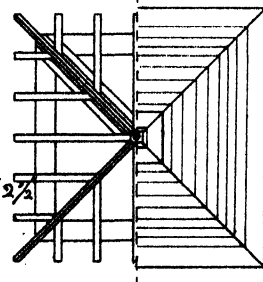


FIG. 109
PLAN OF TURRET ROOF.

VENTILATING TURRET

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They are constructed for spans up to 100 ft., and can be covered with galvanized corrugated iron or with boarding and roofing felt.

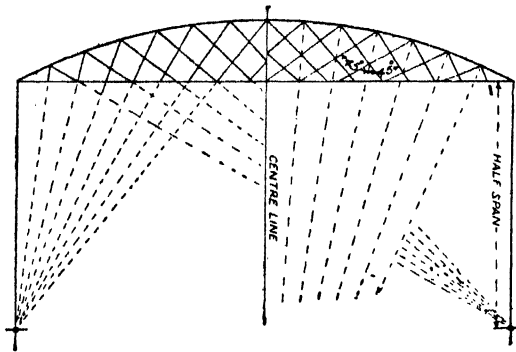


FIG. 110. LINE DIAGRAM OF BELFAST ROOF TRUSS, SHOWING ALTERNATIVE METHODS OF SETTING OUT LATTICES

The outline for this roof is shown in Fig. 110, which gives alternative methods of determining the direction of the braces, or "lattices." As shown on the left of the drawing, after the curve

two bows and two strings, with lattices fixed between them.

For the construction of one of these trusses, it is necessary to "set out" the roof on a floor or other suitable surface, giving the string a slight "camber" (about $\frac{1}{2}$ in. in 10 ft.). Short blocks are then firmly fixed to the floor at intervals along the curve of the bow, inside and outside. Between these blocks the bow is bent and forced down to the floor, the ends then being cut to the top edge of the string and fastened to it by screwing or nailing. "Filling pieces" are next fixed to each end of the string, and short pieces of purlins are temporarily fixed as a guide for cutting the lattices; these are fixed to the bows and strings and to each other where crossing. Packing pieces should be freely used to obtain a good bearing and fixing to the bows and strings. The remaining bow and string would then be fixed to the lattices, and the ends of the lattices cut off flush with the underside of the strings. All the trusses should be constructed to the same mould and fixed in position at distances not exceeding 10 ft. apart.

These trusses, owing to their lightness, have

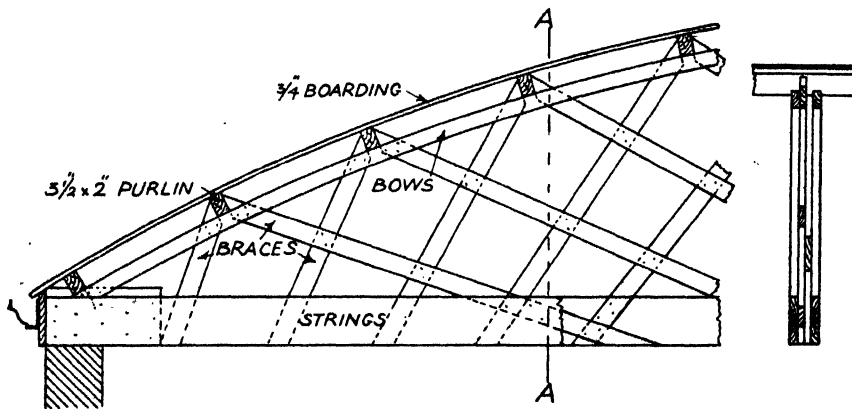


FIG. 111. BELFAST, OR BOWSTRING, ROOF TRUSS

SECTION THROUGH AA

has been drawn, the position of the purlins would be marked on it from 2 ft. to 3 ft. apart; and from these points lines are drawn to points marked below the springing at each end, equal to a distance of half the span. These lines give the centre lines of the braces. On the right of the drawing, the centre lines of the braces are obtained by drawing lines making angles of 45° with the radiating lines, as shown. A sketch showing the construction of one end of a truss is seen in Fig. 111. Each truss consists of

a tendency to "whip" or buckle laterally; to prevent this, continuous ties should run the full length of the roof and be fixed to the strings of each truss. A few cross braces fixed between the trusses to the bows and strings would stiffen the whole roof and prevent "racking" sideways.

The sizes of the various members will vary with the space as follows: Strings $\frac{3}{4}$ in. by 3 in. to $1\frac{1}{2}$ in. by 11 in. Bows $\frac{3}{4}$ in. by $1\frac{1}{2}$ in. to $1\frac{1}{2}$ in. by 3 in. Lattices $\frac{3}{4}$ in. by 2 in. to 1 in. by 4 in. Purlins 2 in. by 3 in. to 2 in. by $4\frac{1}{2}$ in.

Chapter VI—THE STEEL SQUARE

Types of Steel Square. The carpenter's *steel square*, illustrated in Figs. 112 and 113, is used chiefly for obtaining the lengths and the bevels of the various timbers in roof construction and similar work. It is made by cutting from a

obtained with various tables marked upon them. Among these are to be found rafter tables; brace, Essex board, and octagon measures; and degrees.

The squares are obtainable in a number of

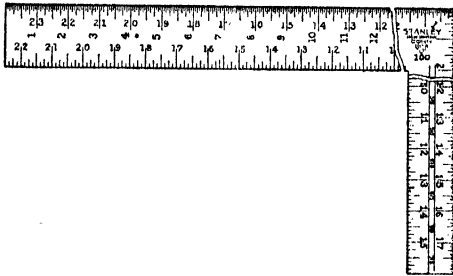


FIG. 112. FACE OF SQUARE

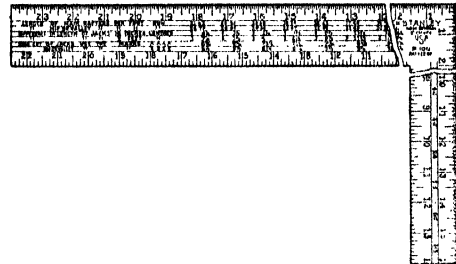


FIG. 113. RAFTER OR FRAMING SQUARE

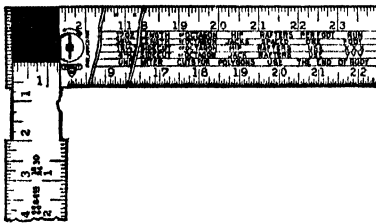


FIG. 114. STANLEY'S "TAKE-DOWN" STEEL SQUARE

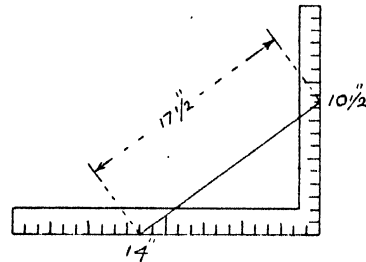


FIG. 115. SHOWING HOW HYPOTENUSE IS OBTAINED

sheet of steel a right angle with two arms in the form of the letter "L." The arms vary in length, but generally the arm called the *blade* is 2 ft. long and 2 in. wide, and the other arm called the *tongue* is 16 in. or 18 in. long and $1\frac{1}{2}$ in. wide; these arms taper in thickness from the angle (*heel*) outwards, for lightness and the better handling of the square.

For convenience of carrying, some squares are made to take to pieces (called take-down squares) by jointing the tongue to the blade (see Fig. 114).

The edges of the square are divided into inches and subdivisions of the inch, that is eighths, tenths, twelfths, sixteenths, and thirty-seconds of an inch. In addition, the squares can be

finishings, as polished steel, nickel plated, galvanized with red markings, blued with white markings, and royal copper with white markings.

The object of this chapter is not to deal with the tables and other markings found on the square, or to be obtained in printed form, but to encourage the student to work out and obtain for himself the required lengths and bevels of any timbers with which he may have to deal.

The use of the square, if properly understood, involves a knowledge of applied geometry and the properties of the right-angled triangle, and the student is advised to study the sections in MODERN BUILDING CONSTRUCTION dealing with

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these subjects. For example, the sum of the squares on the two sides of a right-angled triangle is equal to the square on the hypotenuse; therefore, if the lengths of the two sides are known, the length of the hypotenuse can be obtained by extracting the square root by calculation, or it can be readily obtained by measuring across the angle of the square shown in Fig. 115.

As an example, from the heel of the square take $10\frac{1}{2}$ in. along the tongue and 14 in. along the blade as being the lengths of the two sides

length, and the eaves overhang the face of the wall. If the roof was not square in plan the lengths of the hip and valley rafters would not be equal.

Fig. 117 shows the elevation of a common rafter of the roof shown in Fig. 116. The span of the roof is 17 ft. 4 in. between the walls and 18 ft. over the wall plates. The *run* of the common rafter is the horizontal distance taken from the outer edge of the wall plate to a plumb line from the centre line of the ridge. The *rise*

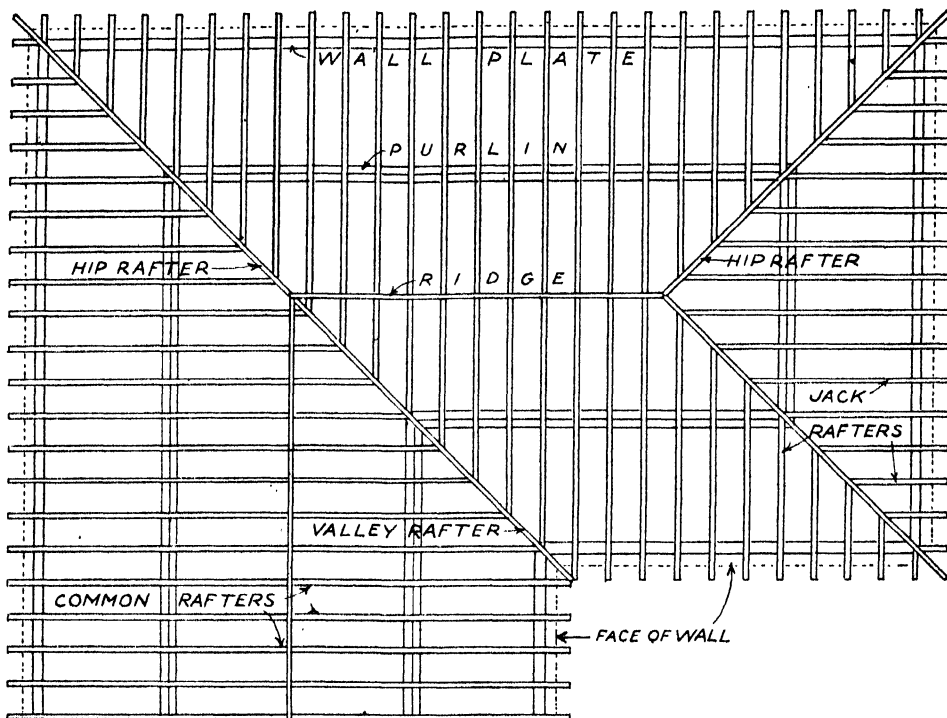


FIG. 116. PLAN OF ROOF SHOWING HIP, VALLEY, AND COMMON RAFTERS AND PURLINS

of a triangle, and the distance apart of these two points will be found to measure $17\frac{1}{2}$ in., which is the square root of $10\frac{1}{2}$ in. squared plus 14 in. squared, that is—

$$\sqrt{10\frac{1}{2} \text{ in.}^2 + 14 \text{ in.}^2} = 17\frac{1}{2} \text{ in.}$$

Run and Rise of Rafters. A plan of a roof of one-third pitch, showing all timbers that are generally found in construction, is illustrated in Fig. 116. This is all that is required when "setting out" the roof timbers with the steel square. It will be seen that there are three hip rafters and one valley rafter all the same in

of the rafter is the vertical distance measured from the centre line on the top of the ridge to an horizontal line drawn from a point on the top edge of the rafter immediately above the outer edge of the wall plate. In both cases one-half of the ridge has been included. This amount must be deducted from the rafter length.

The *pitch* of the roof is the ratio of the rise of the rafter to its span, and in this case it is one-third; the span being 18 ft. and the rise 6 ft., therefore the run of the common rafter will be 9 ft. and the rise 6 ft., or for each 1 ft. of run the rise will be 8 in.

The length of the rafter is taken as the

distance between the point at the centre of the ridge and the point on the top edge of the rafter as shown. The distance the rafter overhangs

square is used to obtain the bottom or heel, and top or plumb bevels (cuts) of the common rafter to fit on the wall plate and against the ridge

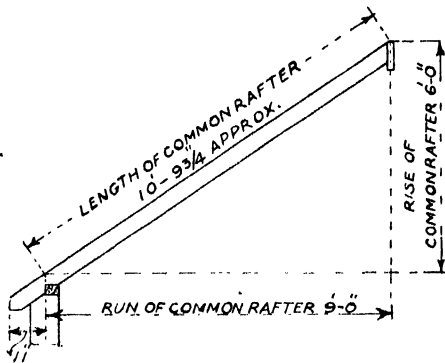


FIG. 117. ELEVATION OF COMMON RAFTER

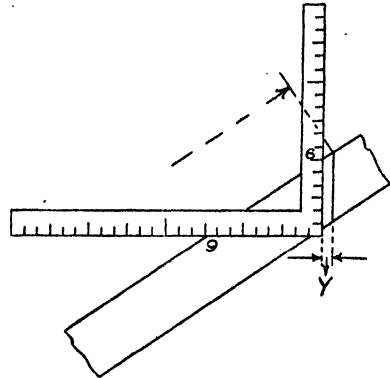


FIG. 120. SHOWING HOW DEDUCTION FOR RIDGE IS MADE

FIG. 118. SHOWING APPLICATION OF THE SQUARE ON RAFTER

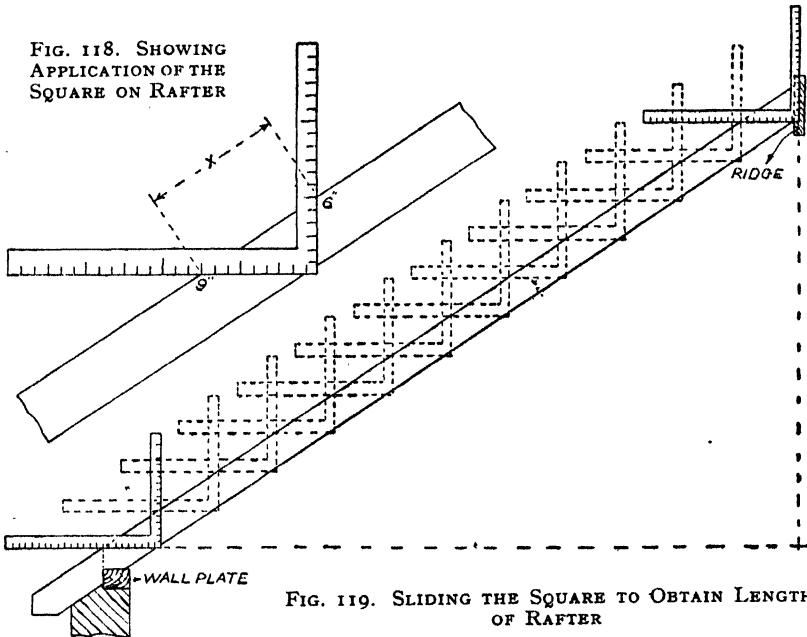
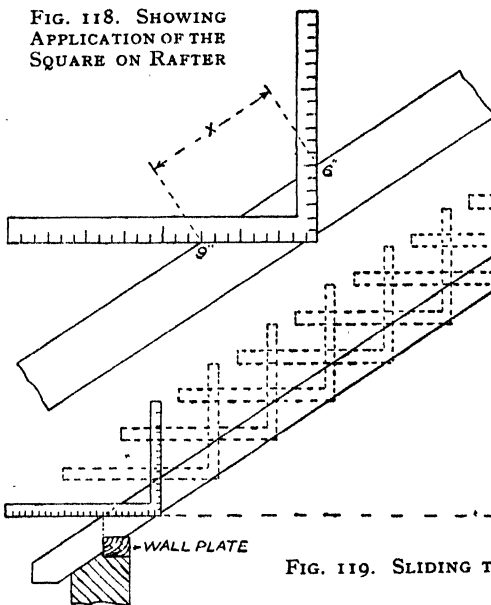


FIG. 119. SLIDING THE SQUARE TO OBTAIN LENGTH OF RAFTER

the wall plate can be readily added, as will be explained later.

The square may be used as a scale of 1 in. to 1 ft., or it can be used full size for the rise and run of 1 ft. The principles are the same in each case, though the latter method has some advantage over the former method, and it is the one more generally used when working to the lengths marked on the square.

Common Rafters. Fig. 118 shows how the

board respectively. For the given roof, take 9 in. on the blade and 6 in. on the tongue, and hold these points in position over the edge of the rafter as shown. A mark along the edge of the tongue will give the top bevel and along the edge of the blade the bottom bevel. The plumb bevel to fit against the wall plate will be the same as the top bevel, to fit against the ridge board.

The *length* of the rafter can be obtained (a) by

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sliding the square twelve times as shown in Fig. 119, or (b) by stepping off the length x (hypotenuse), Fig. 118, twelve times along the top edge of the rafter. The determination of the length of the rafter by either of these methods will depend upon how accurately the sliding of the square is done or the length x obtained. By calculation, the length is found to equal

$$\sqrt{9 \text{ ft.}^2 + 6 \text{ ft.}^2} = 10 \text{ ft. } 9\frac{1}{2} \text{ in. approx.}$$

By measuring x with a scale of 1 in. to 1 ft., 10 ft. 9 $\frac{1}{2}$ in. is obtained.

Note that if 12 in. and 8 in. are used, the square would have to slide, or the distance x be stepped off, nine times. As this length is taken to the centre line of the ridge board, a deduction has to be made. Fig. 120 shows how this is done, by sliding the square down the rafter till the distance y equals one-half the thickness of the ridge board (in this case $\frac{1}{2}$ in.). Fig. 121 shows how the projection for the overhanging eaves is obtained by sliding the square, so that the required distance is obtained and the rafter marked for cutting to shape of eaves.

Methods of Obtaining Roof Bevels. Before proceeding further with other lengths and bevels, consideration should be given to Fig. 122, as all the other lengths and cuts in the roof can be obtained when the run and the rise of the common rafter are known. This diagram will help to explain how the rules for the use of the square are obtained, and by the use of the various lengths the correct bevels are determined. The student should now be able to extract the length of the common, valley, and hip rafters, so that they can be used (as explained in detail later) in the following manner—

1. By taking the run of the common rafter on the blade and the rise on the tongue, the angles *A*, *bottom cut*, and *B*, *plumb cut*, are obtained. The distance between these points give the length of the common rafter.

2. The run of the hip or valley rafter is obtained by taking the run of the common rafter on the blade and the tongue. The distance between these points gives the required run.

3. The hip or valley run on the blade, and the rise on the tongue, give the angles *C*, *bottom cut*, and *D*, *plumb cut*, for the hip or valley rafter. The length is the distance between these points.

NOTE. The length of the hip or valley rafter can also be obtained by taking the length of the common

rafter on the blade and the run of the common rafter on the tongue; the distance between these points gives the required length.

4. The cut or bevel *E* for the edge of the hip or valley rafter to fit against the ridge, or to mitre with another hip rafter (before backing), is obtained by taking the length of the hip rafter on the blade and its run on the tongue.

5. To obtain the backing bevel *F* for hip, take the length of the hip rafter on the blade and the rise on the tongue.

6. The length of the common rafter on the blade and its run on the tongue gives the edge cut for jack rafter at *G*, and edge or top cut for purlin mitre, and the face cut of roof boards at *H*.

7. The length of the common rafter on the blade and its rise on the tongue gives the side cut for purlin mitre, and also the edge bevel for roof boards at *J*.

PURLIN BEVEL UNDER HIP OR VALLEY RAFTER. This bevel is obtained by drawing a line *op* at right angles to the common rafter at its foot *o* to meet the dotted line *mn* at *p*. This length *op* on the tongue and the run of the common rafter on the blade will give the bevel *K*, to cut the lip of the purlin to fit against the under edge of the hip or valley rafter. In roofs that are square in plan, the length of the line *mn* is the hypotenuse of the triangle having the rise and twice the run of the common rafter for its sides. It is also the length of the line *st*. Whether the roof is square or not in plan, a line drawn at right angles to the plan of the run of the hip rafter will give the point *n*, as shown by the dotted line *ln*.

As previously mentioned, the common rafter run and the rise will give the top and the bottom cuts, whether the whole run and the rise of the rafter is taken to a scale of 1 in. to 1 ft., or whether 1 ft. of the run and the rise (8 in.) for 1 ft. of the run is taken. When the lengths are determined this latter method is the one more generally used. Fig. 122 shows how all the lengths and bevels are obtained, whichever of the above methods is adopted.

COMMON RAFTER. Adopting the latter method, take 12 on the blade and 8 on the tongue. These points, being held in position on the edge of the rafter, will give the bottom and the top cuts similar to those shown in Figs. 118, 120, and 121. The length is the distance between the dotted lines in Figs. 120 and 121 and equals

$$\sqrt{\text{run}^2 + \text{rise}^2} = 10 \text{ ft. } 9\frac{1}{2} \text{ in. approx.}$$

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HIP AND VALLEY RAFTERS. For every 1 ft. run of common rafter the run of the hip rafter equals

$$\begin{aligned}\sqrt{\text{run}^2 + \text{run}^2} &= \sqrt{12 \text{ in.}^2 + 12 \text{ in.}^2} \\ &= 17 \text{ in. approx.}\end{aligned}$$

(and is equal to the diagonal of a square of 1 ft. side). Take 17 on the blade and 8 on the tongue, and a mark along the edge of the blade and the

equal to half the thickness of the ridge board, and measured at right angles to the plumb cut in a similar manner to that explained for the common rafter. For practical purposes this length could be taken as rather less than three-quarters the thickness of the ridge board.

EDGE JOINTS OF HIP AND VALLEY RAFTERS. Three methods are illustrated in Figs. 124, 125,

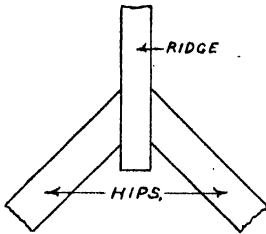


FIG. 124. SHOWING HIP SPLAYED ON TO RIDGE

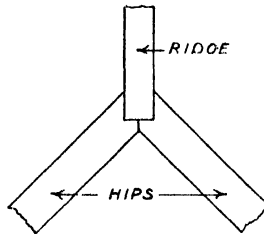


FIG. 125. SHOWING HIP BIRD'S-MOUTHED TO RIDGE

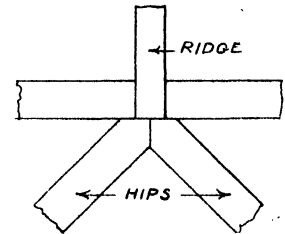


FIG. 126. SHOWING HIPS MITRED

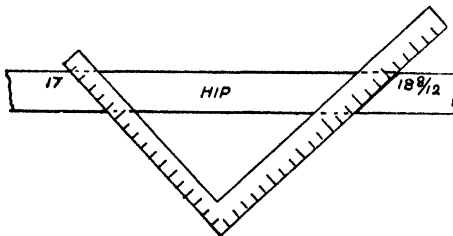


FIG. 127. SHOWING CUT FOR HIP SPLAY

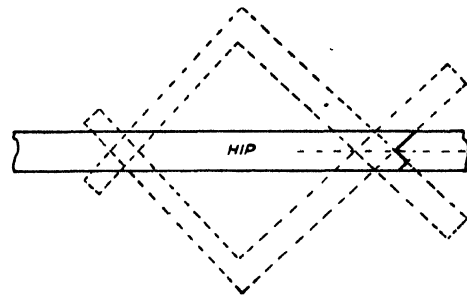


FIG. 128. SHOWING CUT FOR HIP BIRD'S-MOUTH

tongue will give the bottom and the top cuts respectively (see Fig. 123).

By multiplying 17 in. by 9, the run of the hip or valley rafter is found to equal 12 ft. 9 in.

The length of the hip

$$\begin{aligned}&= \sqrt{\text{run of hip}^2 + \text{rise of rafter}^2} \\ &= \sqrt{12 \text{ ft. } 9 \text{ in.}^2 + 6 \text{ ft.}^2} \\ &= \sqrt{\text{length of common rafter}^2 + \text{run of common rafter}^2} \\ &= \sqrt{10 \text{ ft. } 9 \frac{3}{4} \text{ in.}^2 + 9^2} = 14 \text{ ft. approx.}\end{aligned}$$

The length is also obtained by sliding the square nine times along the rafter, as shown in Fig. 119.

This gives the length to the centre line of the ridge. A deduction must be made for half the thickness of the ridge. This is equal to the length of the diagonal of a square with a side

and 126, showing how the hips are fitted to the ridge. Fig. 124 shows the hips splayed on to the ridge. This is also adopted for a valley rafter where a branch roof of the same pitch, but shorter span than the main roof, has to be constructed. The ridge for the shorter span would be lower than the main ridge. Fig. 125 shows the hips bird's-mouthed on to the ridge board. Fig. 126 shows the hips mitred together and fitting against the ridge and rafters. A valley rafter to fit against two ridge boards, running at right angles to each other, is cut in the same manner. Whichever of the above methods is adopted, the bevels will be the same and are obtained by taking the run of the hip rafter on the tongue and the length of the hip rafter on the blade; or 17 and 18 $\frac{1}{2}$, as shown in Fig. 127, which is the run and length of the hip rafter for 1 ft. run of the common rafter.

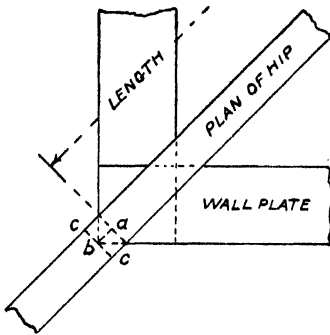


FIG. 129. ANGLE OF WALL PLATE WITH HIP

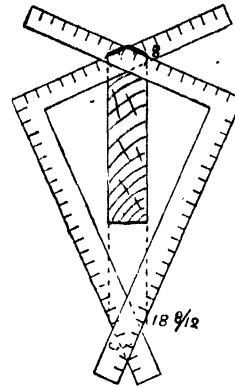


FIG. 130. SECTION OF HIP

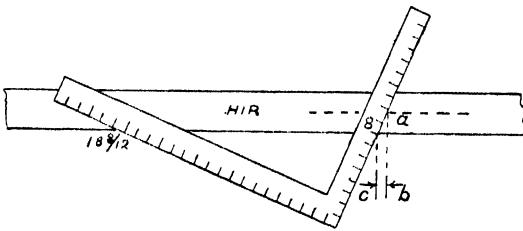


FIG. 131. OBTAINING BACKING BEVEL

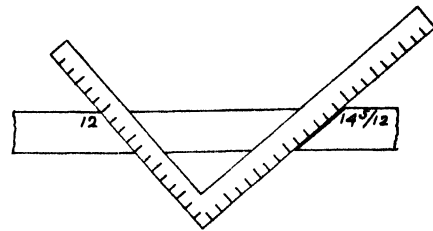


FIG. 132. CUT FOR JACK RAFTER

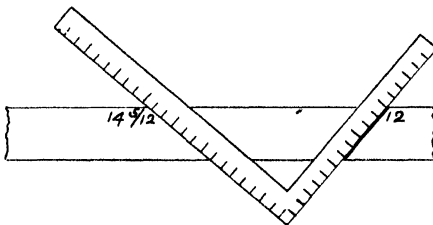


FIG. 133. CUT FOR EDGE OF PURLIN

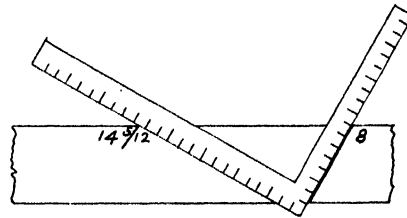


FIG. 134. CUT FOR SIDE OF PURLIN

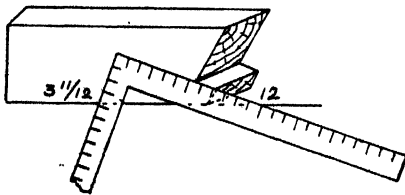


FIG. 135. SKETCH OF PURLIN SHOWING THE THREE CUTS

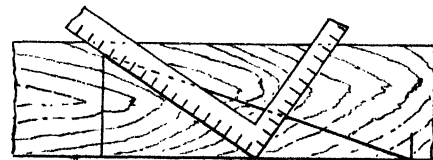


FIG. 136. PRACTICAL METHOD OF FINDING LENGTH FOR LIP CUT ON PURLIN

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NOTE. The above lines are applied on the edge of the hip before it is backed.

Fig. 128 shows the square in dotted lines placed on the edge of the hip where cut as shown in Fig. 125. The square is used in a similar manner for the hip in Fig. 126.

Fig. 129 shows the plan of the hip rafter at the angle of the wall plates. It will be seen that the length of the hip rafter (or valley rafter) is taken from the vertical line on the face of the rafter over the edge of the wall plate. This line should be the same vertical length above the wall plate as that for the common rafter, when the hip is not backed and the edges of the jack rafters finish flush. If the hip is to be backed, then this same vertical length must be taken at C to allow for the amount to be taken off. Often the angle of the wall plate is cut away to save the bird's-mouth as at A, or the wall plates run past each other about 4 in. and the hip cut similar to the top end, and to the same bevel as shown in Fig. 126.

BACKING FOR HIP. This bevel is obtained by taking the length of the hip (14 ft.) on the blade, and the rise of the common rafter (6 ft.) on the tongue, or $18\frac{2}{3}$ on the blade and 8 on the tongue as representing the length of the hip and rise for 1 ft. of common rafter.

Fig. 130 shows a section of the hip and how this bevel is applied. Owing to the difficulty of applying the square at the end section of the hip (or valley rafter), the square is applied on the top edge of the hip as shown in Fig. 131; then a line *ab* drawn from *a* will give the distance *bc* that a gauge line must be set to on both sides of the hip from its top edge before it can be backed.

JACK RAFTER. The plumb bevel to fit against the hip or valley rafter, and the bevel at the foot, are the same as for the common rafter. The bevel for the edge cut is obtained by taking the length of the common rafter (10 ft. $9\frac{1}{2}$ in.) on the blade and the run (9 ft.) on the tongue; or when 1 ft. of the rafter run is taken $14\frac{1}{2}$ on the blade and 12 on the tongue, as shown in Fig. 132.

PURLINS. For the *edge bevel* of the purlin, the lengths to be taken on the square are the same as those for the edge of the jack rafter, but the cut would be marked along the other arm of the square as shown in Fig. 133. The same bevel will give the cut for the face of the roof boarding to mitre at the hip or valley rafter, and also the bevel for the cut on the edge of the top end of

the hip to fit against the ridge board when the hip is backed before cutting.

PURLIN SIDE BEVEL. Fig. 134 shows how this bevel is obtained by taking the length of the common rafter on the blade and the rise on the tongue; or $14\frac{1}{2}$ in. on the blade and 8 in. on the tongue, the rafter length and rise for 1 ft. of rafter run. A mark along the edge of the tongue will give the required cut, and also the cut for the edge of the roof boarding to mitre at the hips.

Fig. 135 shows a sketch of the end of the purlin cut to the two preceding bevels, and how the square is applied to obtain the bevel to mark the *lip* cut to fit against the under edge of the hip rafter. To find the required lengths, take a piece of board and along one edge mark off the rafter run or 1 ft. of run, twice; set out the rise and the length of the rafter, as shown in Fig. 136. From the top end of the rafter draw a line to the second length of run; then a line drawn from the foot and at right angles to the rafter to cut this line will give the length to take on the tongue of the square. This length is found to be $3\frac{1}{2}$ in. for 1 ft. of rafter run, the other length being 12 in. These lengths are used as illustrated in Fig. 135.

NOTE. For roofs that are not square in plan, the first length will be obtained as explained in Fig. 122.

The last three bevels mentioned are for purlins when fixed at right angles to the slope of the roof. When fixed vertically in roofs square in plan the edge cut will be a true mitre (45°), and the side cut square to the edge of the purlin.

When the foregoing has been fully mastered, there should be no difficulty in obtaining any cut or length on any timber likely to be met with on a building.

Fence for Square. There are a number of fences that are obtainable for fixing to the square, or one can be easily made by running a saw kerf a distance down the ends of a piece of wood about 2 ft. in length and 1 in. square in section, to slip over the arms of the square. This fence is made fast by screws driven through the ends in such a manner that the wood grips the square.

The fence will be found useful where a fixed bevel is required, or when the square is used as a pitch board for "setting out" strings for stairs or similar work.

Chapter VII—CENTRES FOR ARCHES

Definition. *Centres* are temporary structures used to support brick, stone, or concrete arches during their construction. The upper surface of the centre conforms to the under side (soffit) of the arch.

The design of the centres will vary with the outline ("intrados"), span, and the weight to be supported; but in all cases the chief points to be borne in mind are that the centre should be rigid, and that it must not alter in form during the building of the arch. As an example, consider the semicircular centre illustrated by Fig. 139. As the building of the arch around the centre proceeds, the weight tends to compress the centre at its haunches and so force up the crown. This tendency is reversed as the arch nears completion. In arches of semicircular, equilateral, or similar outline, the weight of the lower *voussoirs* are not supported by the centre until the *joint planes* of the *voussoirs* exceed an angle of about 30° (angle of repose).

Turning Pieces. When the centre is for a camber arch or for a flat segmental arch half-brick thick, it can easily be constructed by cutting to the required curvature one edge of a plank 2 in. to 3 in. thick as shown in Fig. 137.

Small Segmental Centres. Fig. 138 shows how a centre for a small segmental rough brick arch, 9 in. or more in thickness, is constructed. Two boards having their upper edges cut to the required curvature are connected by open *laggings* nailed to the curved edges. The *laggings* should be kept back about $\frac{1}{2}$ in. from the face of the brickwork, so that they will not be in the way of the line and plumb rule used by the bricklayer. The centre is supported at each end by props. Folding wedges for "easing" are placed on the props under the centre.

The ribs of centres for brick and stone arches for spans up to about 15 ft. are built up with two thicknesses of boards 1 in. to $1\frac{1}{2}$ in. thick and 7 in. to 11 in. wide, well nailed together and "breaking joint" (i.e. the ends of two boards fixed to another board in the centre of its length). The lower ends of the ribs are prevented from spreading by fixing them to a horizontal tie 1 in. to 2 in. thick and 7 in. to 9 in. wide. To ensure that the outline will not alter in form and also to give rigidity to the centre,

braces are fixed to the rib and tie. The braces must be capable of resisting either a tensional or a compressional stress. The joints in the ribs, and the centre lines of the braces, should be normal to the curve wherever possible.

When the arch is not more than 6 in. thick one of these ribs would be used; but if the arch was 9 in. or over in thickness two or more ribs would be required, the ribs being connected by *laggings* nailed to their curved edges; these *laggings* range in size from narrow strips to battens, according to the size and nature of the work. Provision must always be made for adjusting, "easing," and "striking" the centre by the use of folding wedges, placed on the top of the posts or props on which the centre is supported.

Semicircular Centre. The elevation and vertical section of a centre for a semicircular brick arch $1\frac{1}{2}$ bricks thick is shown in Fig. 139. The ribs are cut from boards 1 in. thick, and built up in two thicknesses and "breaking joint," the dotted lines showing the inner boards and joints. The centre is shown with open *laggings* for a rough brick arch; but if for a gauged brick arch it would be close lagged as shown in Fig. 141. Braces are fixed to the ribs and ties, and short pieces of board are nailed to the under edges of the ties to form a bearing surface to rest on the folding wedges. Fig. 140 shows a vertical section through the centre, showing how the *laggings* are kept back from the faces of the arch, and how the centre is supported; the folding wedges rest on a cross-piece of timber fixed to the top ends of the props.

When the arch is constructed of stone and the *voussoirs* are large, *laggings* are often omitted (the ribs being connected by a few cross-pieces to keep them parallel) and folding wedges used instead, so that the *voussoirs* can be more readily adjusted. In this event the centre acts only as a support, and not as a mould for the arch.

Elliptical Centre. Fig. 141 shows the elevation of an elliptical centre for a gauged brick arch with a span of 12 ft. The construction is similar to that described for Fig. 139, but in this case the *laggings* are closed, short pieces of thin board being fixed as shown; any unevenness

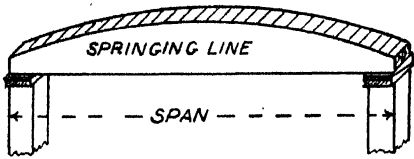


FIG. 137. TURNING PIECE

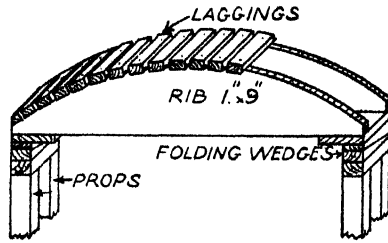


FIG. 138. SMALL SEGMENTAL CENTRE

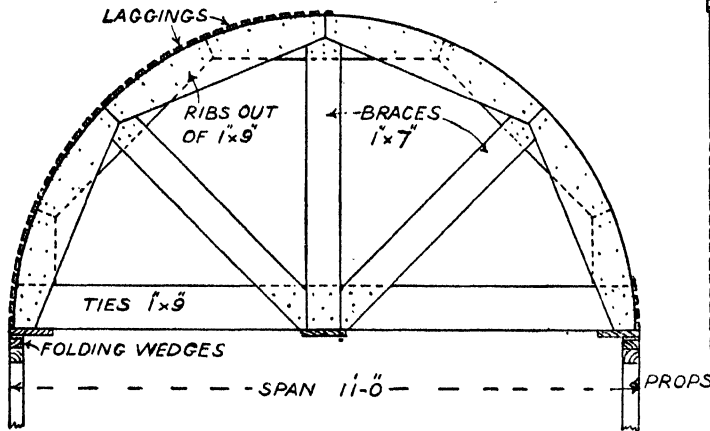


FIG. 139. ELEVATION OF SEMICIRCULAR CENTRE



FIG. 140
SECTION THROUGH
CENTRE

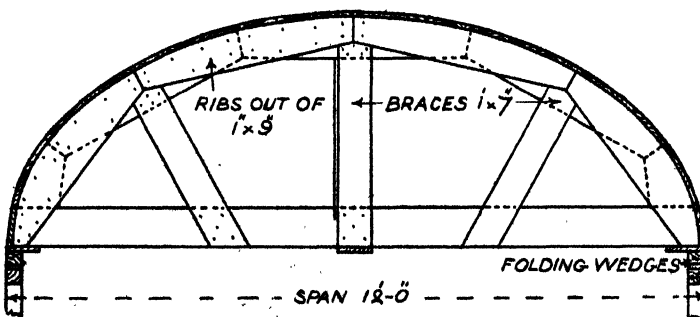


FIG. 141. ELEVATION OF ELLIPTICAL CENTRE



FIG. 142
VERTICAL SECTION

in the surface would be planed off. The braces are fixed normal to the curve; the method of obtaining normals to an ellipse will

where the laggings would intersect when fixed in position.

When the span of the arch exceeds 15 ft. to 20 ft., or when the voussoirs are very heavy, as is the case in some stone arches, the centres would be "trussed," the members being held together by iron bolts, plates, and iron dogs, and supported by stiff timbers wherever possible, according to the design of the centre.

A centre for an arch over the entrance to a building is shown in Fig. 143A. On one face the elevation of the intrados of the arch is semi-circular and on the other face semi-elliptical, due to the jambs being splayed at the springing and the soffit being level at the crown of the

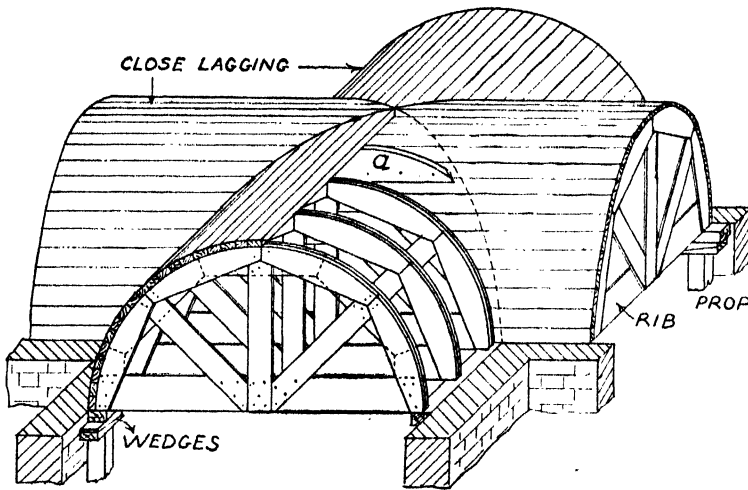


FIG. 143. SKETCH OF CENTERING FOR SEMICIRCULAR VAULTS

be found in the section dealing with "Builders' Geometry" on page 86. When the distance between the ribs are such that there is a possibility of the centre "racking" sideways, braces are fixed to each rib similar to that shown in the vertical section, Fig. 142.

Centres for Barrel-headed Vaults. A sketch illustrating the centering for two semicircular headed vaults of equal radii that cross and intersect at right angles with each other, is shown in Fig. 143. The centre for the main vault would be constructed with a number of ribs with laggings fixed similarly to that described for previous centres, and long enough to extend well beyond the intersections of the cross vaults. It would then be fixed in position on stiff timbers, and supported at intervals by props and folding wedges. The ribs for the cross vaults would then be fixed, one rib being placed as near as possible to the centre (already fixed) and the other spaced as required.

The laggings are then laid on the ribs and slid along till the ends come in contact with the main centre, to which they are scribed and fixed. A small rib *a* is fixed to the main centre to support the laggings as they near the crown. A portion of the laggings have been omitted to allow the construction and the arrangements of the ribs of one of the cross centres to be seen; the dotted line on the main centre shows

arch. *Note.* If the arch were splayed at the crown in the same manner as at the springing,

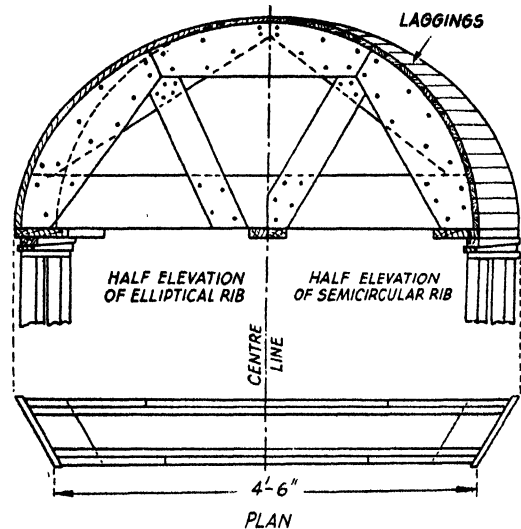


FIG. 143A. CENTRE FOR ARCH, SPLOYED AT THE SPRINGING, LEVEL AT THE CROWN

both elevations would be semi-circular, and the surface formed by the laggings would then be conical.

Chapter VIII—LAMELLA TRUSSLESS WOOD ROOFS

THE principle of the lamella roof depends on two simple structural devices: the arch and the network, the advantages of each, as regards strength and stability, being combined.

The roof is built up with short uniform members called "lamellas" which, when bolted together, form a rhomboidal network, conforming to a barrel-like surface of mutually braced and stiffened timbers, arching over the area to be covered, as illustrated in Fig. 144.

The shape and size of the lamella unit is designed and standardised for each roof, and the units are identical throughout any one roof, except that the lamellas may be either right- or left-handed.

A lamella is shown in Fig. 145. It is curved on the top edge, bevelled and normal to the curvature at the ends; it has a hole at each end and a slot in the centre for a bolt. Lamellas may, however, if desired, be curved on both edges.

The lamella construction allows the use of comparatively small timber sections for large span roofs. The sizes of the lamellas are from 8 ft. 3 in. to 10 ft. 3 in. in length, 1 in. by 8 in. to 2 in. by 14 in. in section, and varying with the span, the width of the mesh, and the ratio of the rise to the span. For example, for a roof of 150 ft. span, 2 in. by 11 in. will in many cases be found satisfactory.



FIG. 144. CHURCH HALL ROOF

There are two principal arrangements possible—

(a) A segmental or barrel-vaulted roof (two hinged arch).

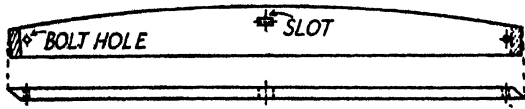


FIG. 145. A LAMELLA

(b) The Gothic type or three hinged arch, which is merely two segmental lamella surfaces leaning against each other at the ridge.

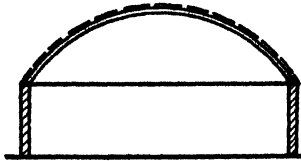


FIG. 146. SEGMENTAL ROOF WITH TIE-RODS

The roofs may be continuous from end to end, or may have rectangular or multi-sided hipped ends. In each case the ratio of the rise to the

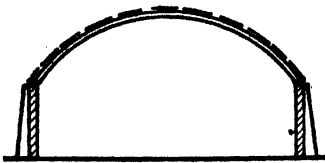


FIG. 147. SEGMENTAL ROOF WITH BUTTRESSES

span can cover a wide range varying from 1:2 to about 1:8.

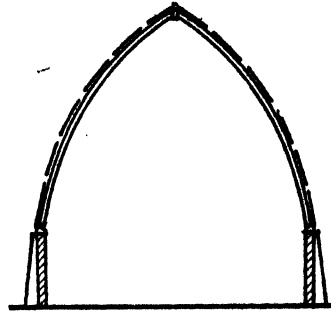


FIG. 148. GOTHIC ROOF WITH BUTTRESSES

The stresses in the lamella units are compression and bending, and, therefore, being subjected only to these stresses, the timber is used to its best advantage with regard to sizes.

The arched construction produces an outward thrust on the supports, and unless the arch is carried right down to the ground level, it is necessary to provide means of taking up this thrust.

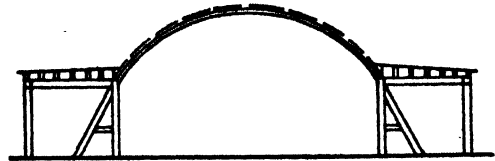


FIG. 149. SEGMENTAL ROOF WITH "A" FRAMES

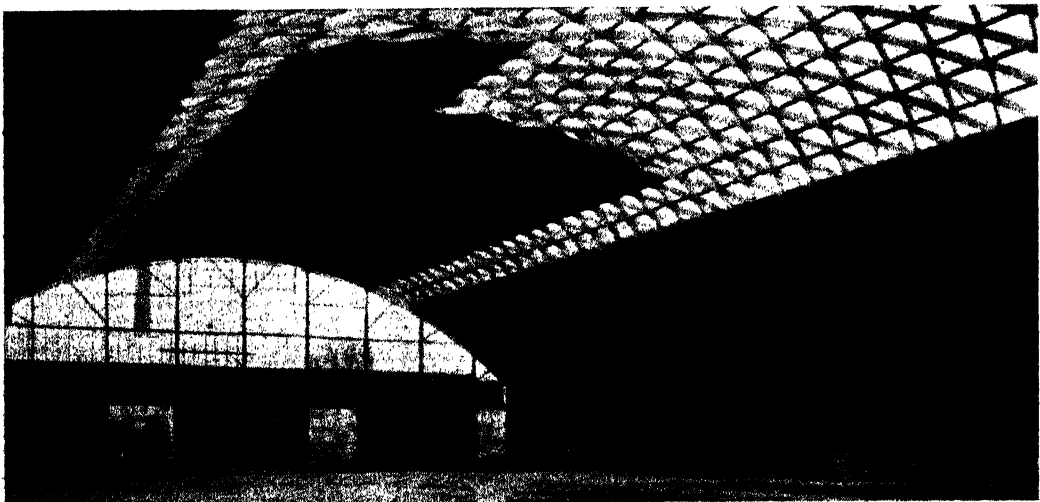


FIG. 150. ROOF NEARING COMPLETION, SHOWING GLAZING

MODERN BUILDING CONSTRUCTION

Constructional Methods. The following are the structural systems usually adopted—

(a) Tie-rods spaced at 12 ft. to 15 ft. intervals, and secured to the wood plate beams. This method is used mainly for industrial buildings, where the appearance of ties are of no great importance, and where clear roof and floor space are not absolutely essential.

(b) Steel stanchions supporting a steel beam to which the wood plate is fixed. This is an economical method provided the height of the side walls is not too great.

(c) Steel or timber "A" frames, or struts. This method is suitable in cases where offices or workshops, which can be housed in the bays, are required down the side walls. Steel "A" frames are most suitable for large-span roofs, the strut member being designed to take the thrust in a direction tangential to the roof at

ported by walls, with buttresses to resist the thrust.

A Gothic roof illustrated in Fig. 148 has walls with buttresses for its support.

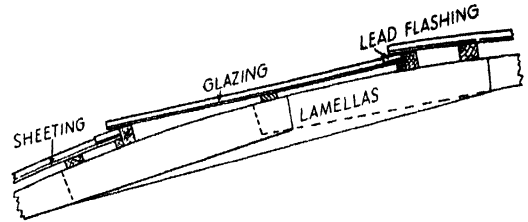


FIG. 151. SECTION THROUGH GLAZED PORTION OF ROOF

Fig. 149 shows a segmental roof supported on "A" frames with side bays roofed over to give additional floor space.

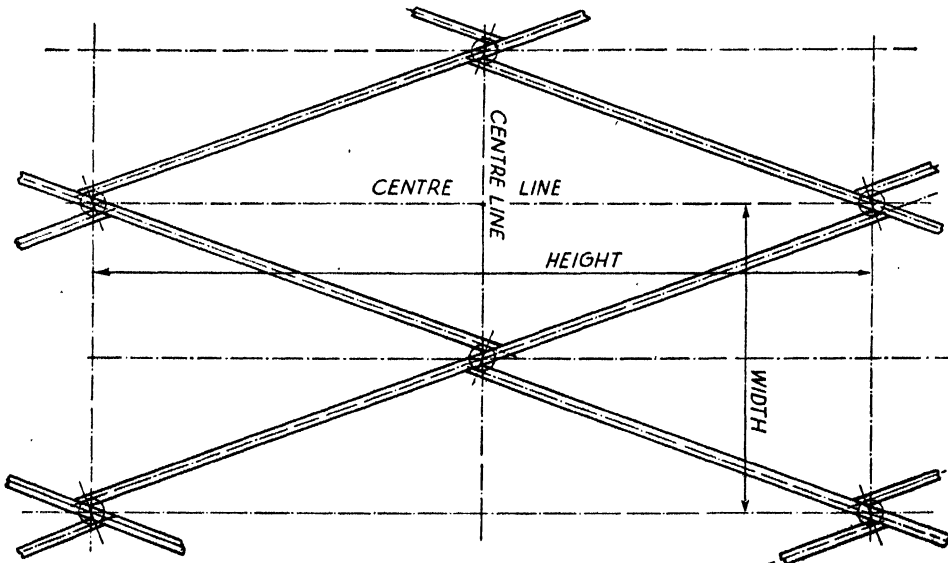


FIG. 152. "SETTING-OUT" LENGTH OF LAMELLAS

the point of support and thereby simplifying the stress to one of compression.

(d) Reinforced concrete or brick buttresses at intervals along the walls.

Some of the above mentioned methods of support and the outline forms of the roof are illustrated as follows—

Fig. 146 shows a segmental roof supported by walls or stanchions, with tie-rods taking up the thrust.

In Fig. 147 a segmental roof is shown sup-

Lamella roofs are adaptable to all suitable types of covering, including boarding and felt, tiles, slates, or corrugated asbestos or metal sheeting. This sheeting would be manufactured to the curvature of the roof, and fixed to battens nailed over each lamella joint. The battens also serve as a bracing to the roof.

Roof lights and ventilators can be superimposed on the roof, or if desired, lamellas may be cut away and the opening trimmed to take the lights, etc. Fig. 150 shows a roof nearly

completed, with two rows of glazing running the full length of the roof. The roof has a clear span of 115 ft. and the thrust is taken up by the struts

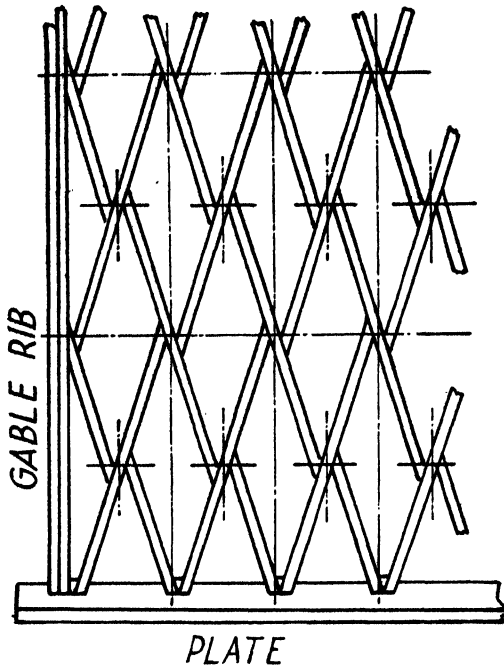


FIG. 153. DIAGRAMMATIC ARRANGEMENT OF LAMELLAS

and framing, which can be seen at the sides of the building. The roof was constructed for the large warehouse of The Merchant Trading Company, who are the sole licensees and designers of lamella roofs in this country. A detailed section

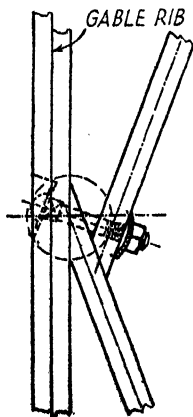


FIG. 154. LAMELLA FIXING TO GABLE RIB

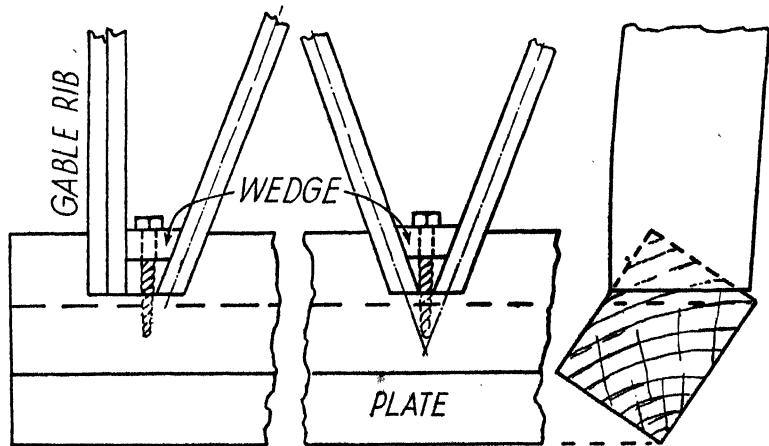


FIG. 155. METHOD OF FITTING AND FIXING LAMELLAS TO PLATE

through the glazed portion of the roof is shown in Fig. 151.

In deciding the ratio of the rise to the span, it must be borne in mind that the flatter the arch, the greater will be the horizontal thrust; and

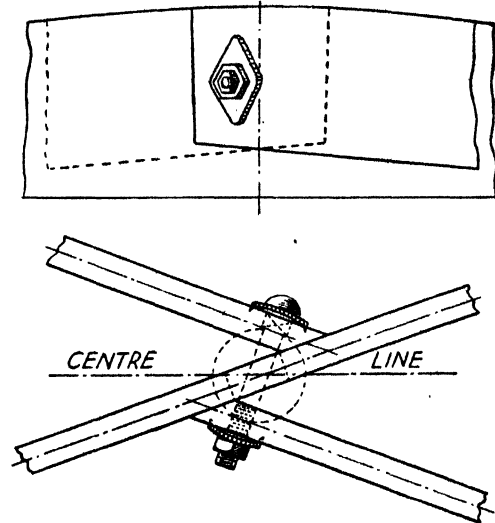


FIG. 156. STANDARD JOINT

the higher the arch, the greater will be the superficial area, and therefore the necessity for larger dimensioned lamellas. When tie-rods are used, the most suitable rise is one-sixth to one-seventh the span.

Constructional Details. The roofs are designed for each particular building to ensure symmetry. The length of the building, and the length of the arc of the roof, are each divided

MODERN BUILDING CONSTRUCTION

into an equal number of meshes, to obtain the length and shape of the lamellas required. One of these meshes is shown in Fig. 152. The width

nail distance pieces with bevelled ends to form the notches.

Fig. 156 shows a standard joint. The large

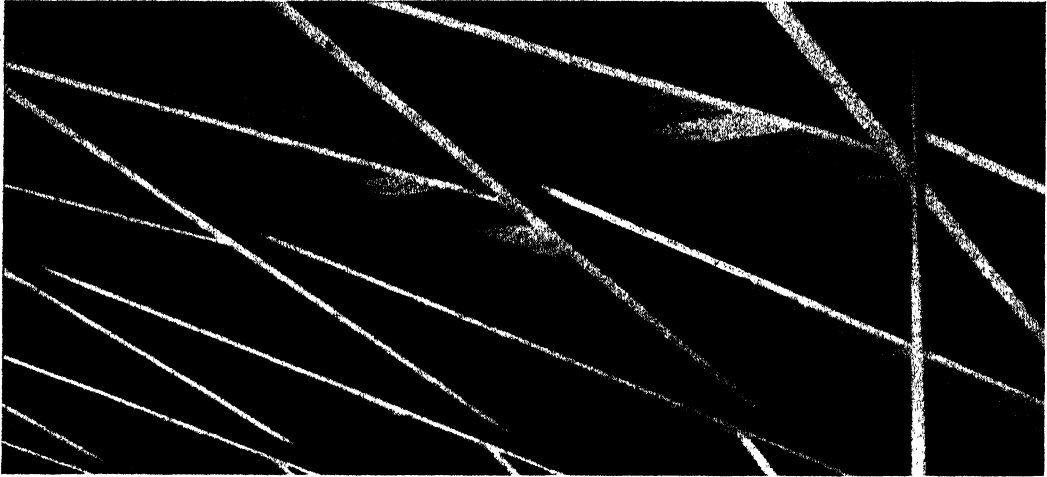


FIG. 157. CLOSE-UP VIEW OF LAMELLAS IN ROOF

of the mesh is taken along the length, and the height of the mesh over the arc of the roof.

Fig. 153 shows a diagrammatic arrangement of the lamella for one corner of a roof, with the lamellas and half lamellas trimmed to the gable rib and plate. The gable rib is built up in two thicknesses to the outline of the roof, and the lamellas are bolted to it as shown in Fig. 154.

Fig. 155 shows how the ends of the lamellas

washers are slightly curved and have bent-over corners which are forced into the timber by the tightening of the bolts. A close-up view of a portion of a roof is seen in Fig. 157, showing the lamellas bolted together in position.

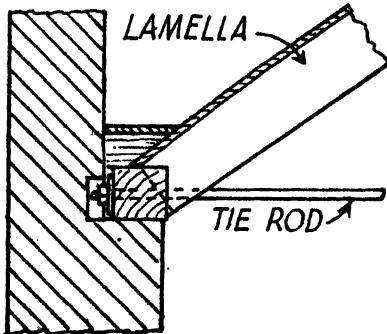


FIG. 158. PLATE SUPPORTED BY WALL

are fitted into notches cut in the plate, and secured by hard wood wedges bolted to the plate. An alternative method, and one often adopted to avoid cutting the notches, is to bevel or cant the plate so that the surface is normal to the curve of the roof, and on this surface to

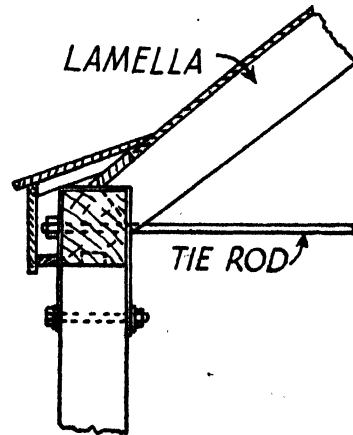


FIG. 159. PLATE BEAM SUPPORTED BY WOOD STANCHIONS

Fig. 158 shows a section through the lower portion of a roof with a parapet gutter. The wood plate is resting on the wall. In Fig. 159 the plate is supported by wood stanchions. In each case tie-rods are used to take up the thrust of the arch.

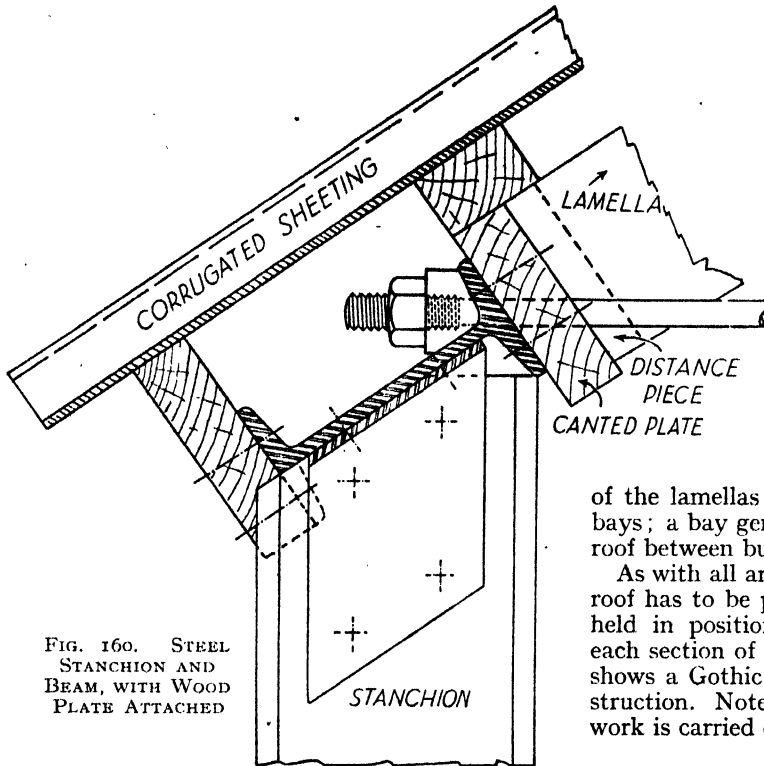


FIG. 160. STEEL STANCHION AND BEAM, WITH WOOD PLATE ATTACHED

Fig. 160 shows a steel stanchion supporting a rolled steel beam fixed at an angle, in such a way that the upper surface of the wood plate, when in position, is normal to the curvature of the roof. In this example the lamellas are cut on to the plate, and fit into notches formed by distance pieces.

Erection. In erecting these roofs, the first operation is to fix the plates in position. The end segment, or gable rib, is then set up and fixed, either to a gable wall or to temporary strutting. For the fixing

of the lamellas the building is divided up into bays; a bay generally being that portion of the roof between buttresses or ties.

As with all arch construction, each bay of the roof has to be put together piece by piece, and held in position by temporary strutting until each section of the arch is completed. Fig. 161 shows a Gothic arch roof in the course of construction. Note the scaffolding from which the work is carried out.



FIG. 161. ROOF IN COURSE OF CONSTRUCTION

MODERN BUILDING CONSTRUCTION

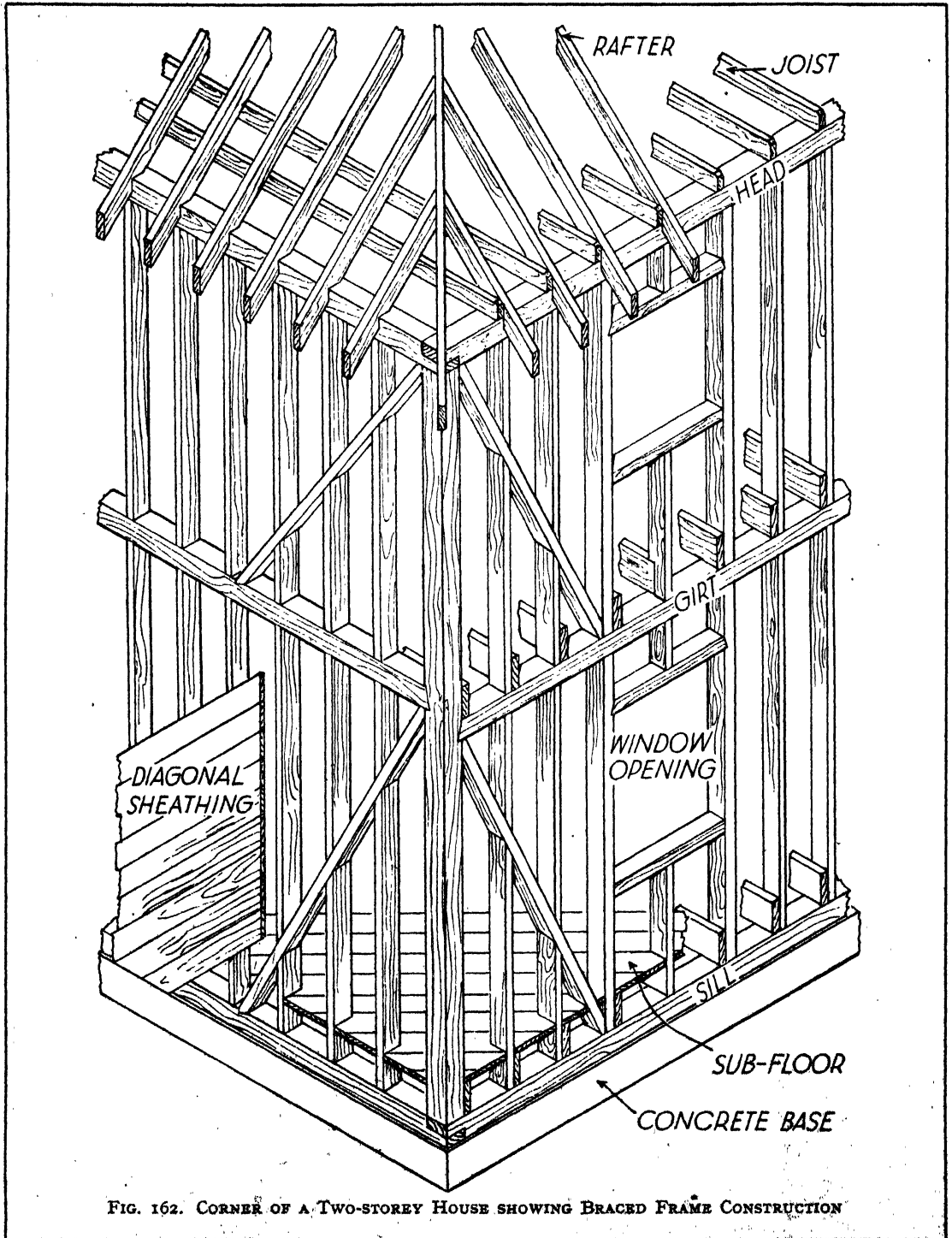


FIG. 162. CORNER OF A TWO-STORY HOUSE SHOWING BRACED FRAME CONSTRUCTION

Chapter IX—TIMBER HOUSES

THE methods adopted in the construction of timber houses vary considerably. In recent

years, because of the numerous systems of pre-fabrication which have been developed, especially in the United States of America, timber houses have assumed an importance unthought of ten years ago. Some of these systems make extensive use of plywood and wood-fibre board, the section being built up in the workshop on mass production lines ready for erection on site.

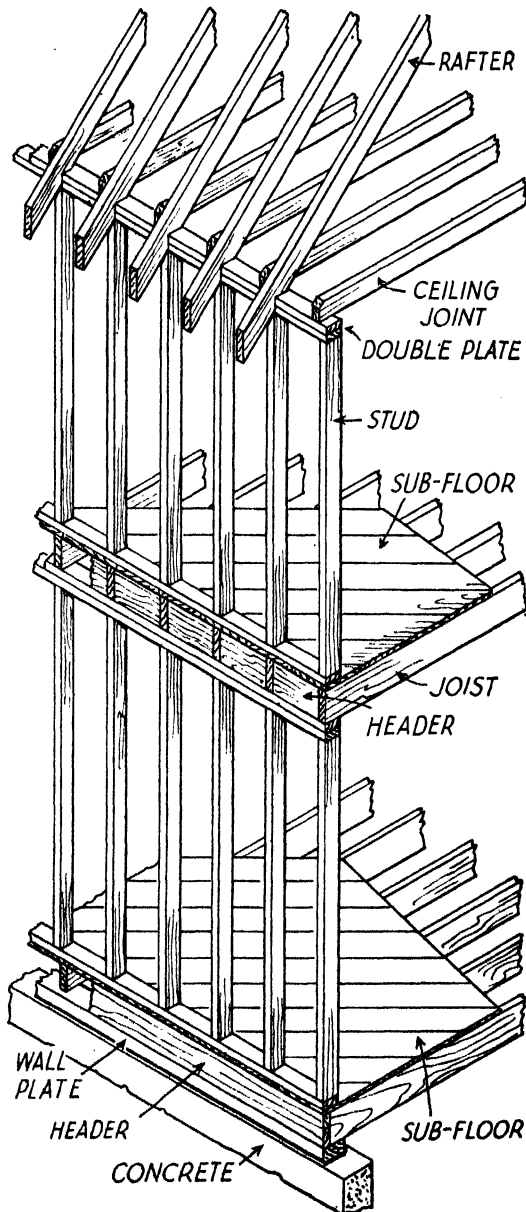


FIG. 163. ISOMETRIC SKETCH OF PLATFORM OR BOXED FRAMED HOUSE CONSTRUCTION

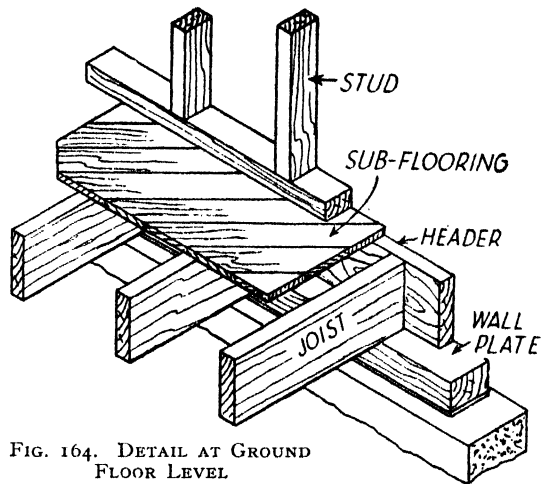


FIG. 164. DETAIL AT GROUND FLOOR LEVEL

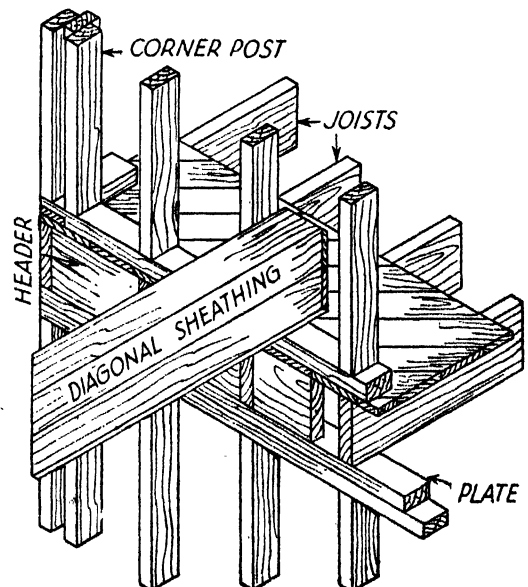


FIG. 165. DETAIL AT FIRST FLOOR LEVEL

MODERN BUILDING CONSTRUCTION

Braced Frame Construction. The type of building shown in Fig. 162 consists of walls composed of comparatively light braced frames, with solid corner posts extending from the

diagonally to give stiffness to the building; on this sub-floor ordinary strip flooring would be fixed.

Platform Framed Houses. Fig. 163 illustrates

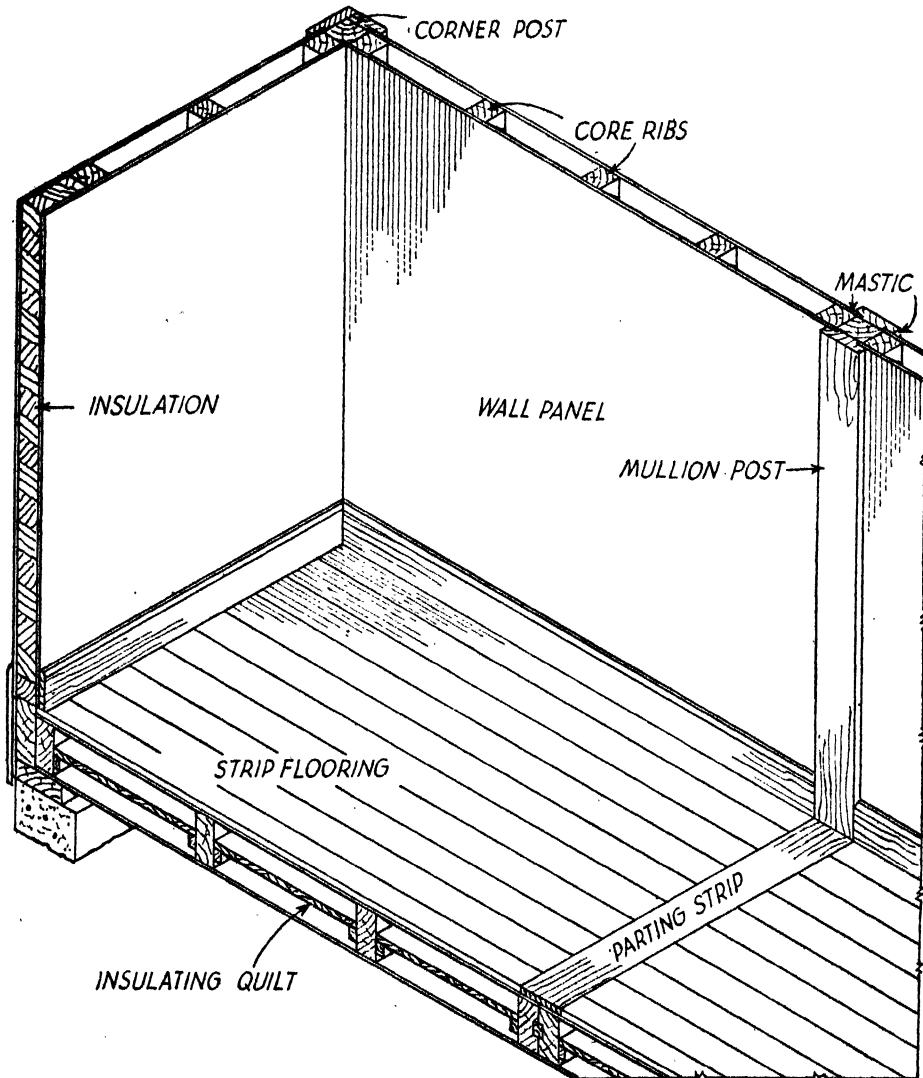


FIG. 166. STRESSED SKIN CONSTRUCTION (PREFABRICATED)

foundation to the eaves; into the corner posts "girts" are framed to support the first floor joists. The sills and heads are halved together at the angles and the whole framing is fitted together with mortise and tenon joints and pinned where necessary.

In the illustration, sub-flooring is shown laid

the usual type of construction adopted for platform or box framing, each storey being built as a separate "box." The ground floor is first built on the foundation walls as though it were a platform; the sub-flooring is laid diagonally. On this platform the side walls for the first storey are fixed in position and temporarily

braced. The first floor joists and sub-floor are then fixed, followed by the side walls for the second storey. When this is completed the ceiling joists and rafters can be added, and sheathing nailed to the studding to give the necessary bracing and rigidity to the building.

Often this sheathing is fixed before the rafters are placed in position, thereby saving time and labour in cutting to fit around the feet of the rafters. The rafters are then bird's-mouthed over both the plate and the sheathing.

Fig. 164 shows a detail of the construction of the ground floor. The wall plate is made wide enough to obtain sufficient bearing for the floor joists and to enable the use of a continuous header, as distinct from the short headers cut in between the joists at the first floor level.

A detail of the angle of the building at the first floor level is illustrated in Fig. 165. The angle post shown is made up with three 2 in. by 4 in. timbers nailed together in such a manner as to allow for the fixing of lath and plaster or wall board as an inside surface. The diagonal sheathing ties the two "boxes" together and gives rigidity to the whole building. The outside covering is not shown, but the weather boarding or other material to be used would be fixed direct to the sheathing.

Balloon Framing. This is a cheap and rapid method of timber house construction chiefly practised in America. It is somewhat similar to the British platform system, but the studs are not in two lengths and run through the two storeys from base to eaves of the house.

Stressed Skin Construction. This is one of the prefabricated systems previously mentioned, and is illustrated in Fig. 166. The basic principle is that the outer and inner coverings, or skins, of plywood assist in carrying the loads superimposed on the walls. This principle is explained in Fig. 167. If the wind blows against the wall the tendency will be to bend the wall inwards, and thus compress the outer skin and stretch the inner skin. The plywood resists these binding stresses, as well as acting as a support to the roof; it also provides an outer surface to keep out the weather, and an inner surface finish to the room. The roof and floor act in a similar structural manner.

The wall panels are 4 ft. wide, by 8 ft. high, and 2 in. or more in thickness. The outer skin is of resin-bonded plywood to resist the weather, and the inner skin also of plywood, though it

may be of the ordinary type. These two skins are securely glued and nailed to an inner core, consisting of small wooden ribs placed at suitable distances apart. When the glue has set the completed panel is rigid and acts under stress as one unit. If desired, insulation may be used as illustrated. These panels are erected as shown, with all outer joints sealed with mastic.

The roof and floor panels are built up in a similar manner to the walls. The floor panels are 4 ft. wide, jointed together as shown, and have oak strip flooring glued to the plywood. Parting strips are laid in floor to line up with the mullions in the walls.

A modern form of stressed skin construction has recently been used, in which the walls, partitions, and floors consist of a composite board, 1½ in. thick; this board is made up of exterior and interior "skins" of thin plywood between which is a sandwich of wood fibre something like a thick and soft wood-fibre board. This composite board is strong and does not need any framing to support it; it has good insulating value; and it has two finished surfaces. It is, in fact, though thin, a complete and self-supporting wall unit.

External Finishes. The usual finish for timber houses is "weather" or "clap" boards, the boards being thinner at the top edge than the bottom edge and laid with a lapped horizontal joint.

Sometimes the outside boards are fixed vertically, often with a cover strip nailed over the joints; this method is largely used in Sweden.

In America, resin-bonded plywood has been used, and if the bonding adhesive is phenol formaldehyde the plywood is water-resistant.

The disadvantage of timber houses is usually cost of upkeep, due to the necessity of repainting every few years, but a few timbers, notably Western red cedar, oak, and teak, do not require painting.

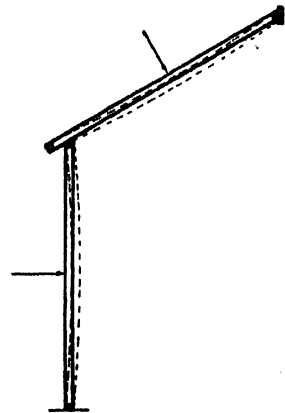
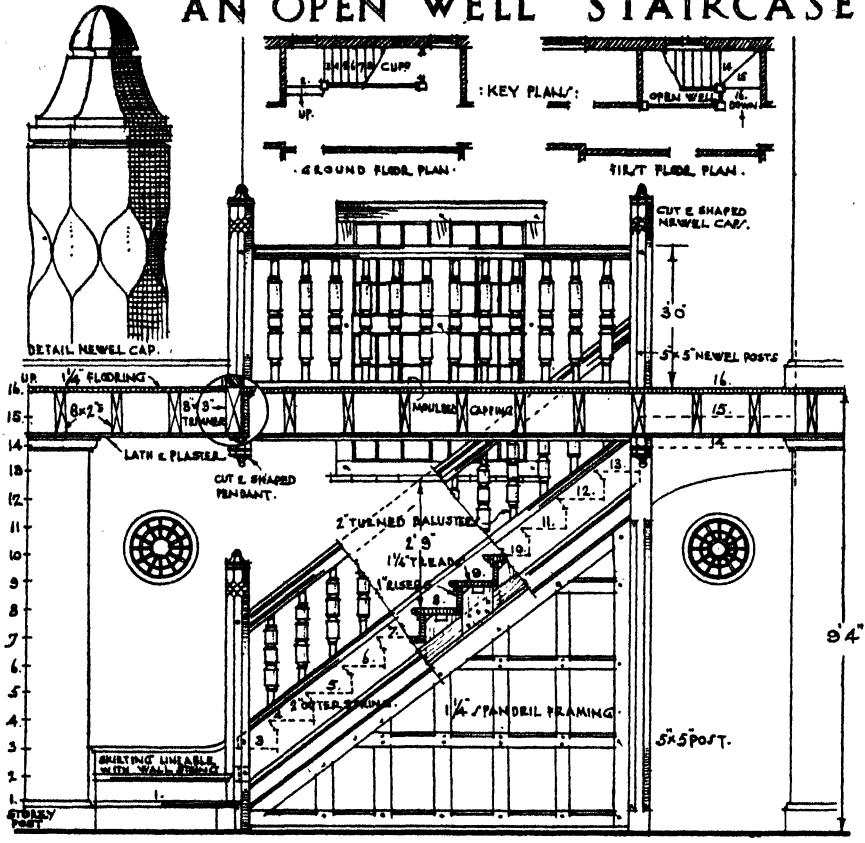
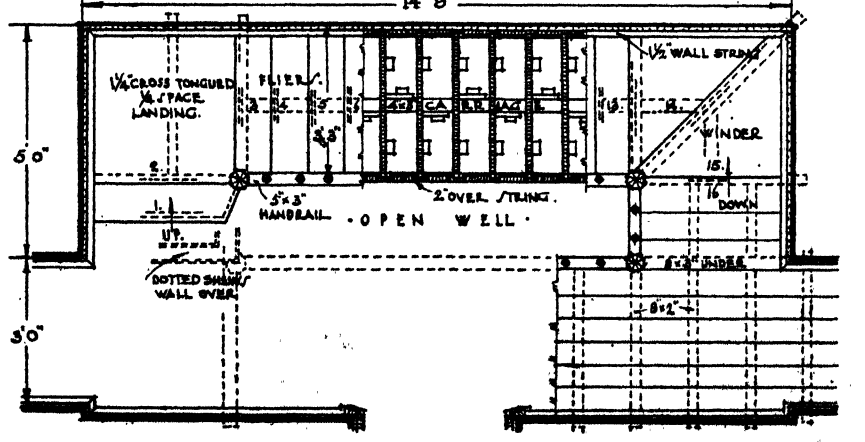


FIG. 167. PRINCIPLE OF STRESSED SKIN CONSTRUCTION

AN OPEN WELL STAIRCASE



· ELEVATION ·



· PLAN ·

INCHES 1 2 3 4 5 6 7 8 9 10 11 FEET. NORMAN HARRIS 1949

Stairs and Handrails

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Chapter I—TERMS: STAIR STRINGS: TYPES OF STAIRS

THIS subject, Stairs and Handrails, is generally supposed to be the most difficult branch of joinery. Actually the usual types of straight stairs are not difficult to construct, but when the stairs are curved in plan and the inclined handrail curved in plan, then a considerable knowledge of geometry is required.

Stairs are inclined at different pitches, good-class stairs usually being less steep than inferior types, because the steeper the pitch the harder the stairs are to ascend, but they take up less plan space and require less timber. Thus, important stairs might have steps 10 in. wide and $6\frac{1}{2}$ in. high, whereas a cheaper type of building might have stairs with steps 8 in. wide and $7\frac{1}{2}$ in. high. Note in each of these cases that twice the height (rise) plus the width (going) is 23 in. This is a common rule for the sizes of steps, but there are other rules, thus that going multiplied by rise equals 66 in. The reason for the first rule is said to be that an average pace is 23 in. and it is twice as hard to move vertically as horizontally. A flight of stairs should not have more than 15 steps. It is advisable not to have the going less than $8\frac{1}{2}$ in. Treads should not be less than 1 in. thick and risers $\frac{3}{4}$ in.

TERMS

Stair. A series of steps affording the means of ascent and descent between floors or landings.

Staircase. The complete construction appertaining to a stair, as the stair, balustrade, spandrel framing, landings, etc.

Stairway. The space provided to contain the stair.

Flight of Stairs. An unbroken series of steps. Fig. 7.

Tread. The horizontal part of a step. Fig. 1.

Riser. The vertical member of the step between two consecutive treads. Fig. 1.

Step. Combined tread and riser.

Flier. A parallel step in the straight part of a stair. Figs. 7, 8, 10, 12, 13, 15.

Winder. A tapering step at the position in which a stair changes direction. Figs. 9, 11, 14, 16, 17, 18, 19.

Stair String. The inclined member of a stair supporting the ends of the steps. Figs. 2, 3, 4, 5.

Cut, or Open, String. A string in which the upper edge is cut away to receive the steps. Figs. 2, 4, 5.

Close, or Housed, String. A string, with straight parallel edges, into which the ends of the steps are housed. Fig. 3.

Rough Strings. Rough timbers placed immediately on the inside of the strings close up to the back lower arris of the tread to give additional support to the steps. Similar timbers between the rough strings are usually called *carriages* or *carriage pieces*. Fig. 6.

Wreathed Strings. Strings curved in plan; they may connect straight strings, or they may form a continuous curve throughout the flight as in spiral stairs. Figs. 10, 11, 16, 18, 19.

Nosing. The part of the tread projecting beyond the face of the riser and the face of a cut string. Figs. 4, 5.

Handrail. The inclined rail, usually moulded, over the string, to serve as a guard rail, and at a convenient height for the hand to grasp during ascent and descent. Figs. 20 to 25.

Baluster. One of the comparatively slight fillings between the string and the handrail. Fig. 21.

Newel Posts. Stout upright members into which the ends of the strings and handrails are framed. Figs. 21 to 24.

Balustrade. The combined framework of handrail and balusters. Fig. 21.

Landing. Horizontal platform between two flights of stairs, to afford opportunity for rest during the use of stairs, or to give change of direction. Figs. 8, 10, 12, 13, 15, 17.

Bullnose Step. A step at the bottom of a flight and projecting in front of the newel, the end forming a circular quadrant in plan. Figs. 8, 26, 27, 28.

Round-ended Step. As in the foregoing, but with semicircular end or ends. Fig. 9.

Curtail Step. The lowest step in a flight, having the plan outline of its end or ends conforming to the plan outline of a handrail scroll, the latter usually being the form of handrail terminal above the curtail step. Figs. 10, 11.

Commode Step. Two round-ended steps at the bottom of a flight, the lower step having twice the radius of the upper step. Fig. 16. The term is sometimes applied to a step having a curved riser.

Rise. The *rise of a step* is the vertical distance between the upper surfaces of two consecutive treads. Fig. 6. The *rise of the flight* is the vertical distance between the floor or landing surfaces connected by the flight.

Going. The *going of a step* is the horizontal distance between the faces of two consecutive risers. Fig. 6. The *going of a flight* is the horizontal distance between the faces of the first and last risers in the flight.

Forms of Stairs. Stairs having continuous strings or handrails around changes of direction are known as *geometrical stairs*; examples are shown in Figs. 10, 11, 16, 18, 19. Other stairs may be referred to as *newel stairs*.

STAIR STRINGS

When one string of a stair is kept close to a wall, it is called a *wall string*, and is always housed. The upper edge of the string is fitted with a moulded capping to intersect with the skirting board at the extremities of the stair.

The outer string may be either *open* or *close*; when close, the upper edge is fitted with a moulded capping to harmonise with the moulded wall string.

Open strings are known as *cut and mitred*, or *cut, mitred, and bracketed*, according to the manner in which the end of the step is finished.

A cut and mitred string is shown in Fig. 4, and it should be noted that the vertical part of each notch is bevelled to form a mitre with the riser. The end of the tread is square and flush with the outer face of the string, and is finished with a return nosing, tongued and nailed or slot-screwed in position after the balusters have been inserted in the dovetailed slots made in the end of the tread for that purpose.

The more ornamental finish, shown in Fig. 5, illustrates a cut, bracketed and mitred step.

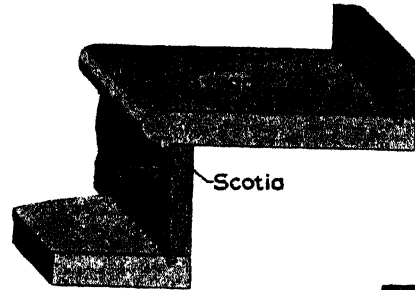


FIG. 1

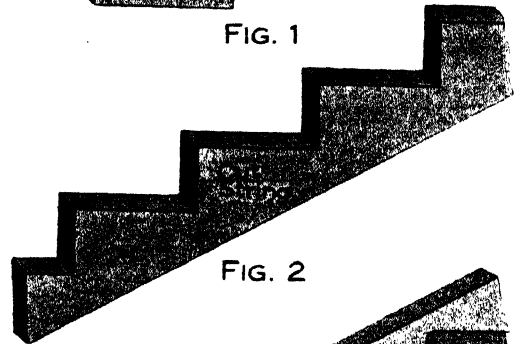


FIG. 2

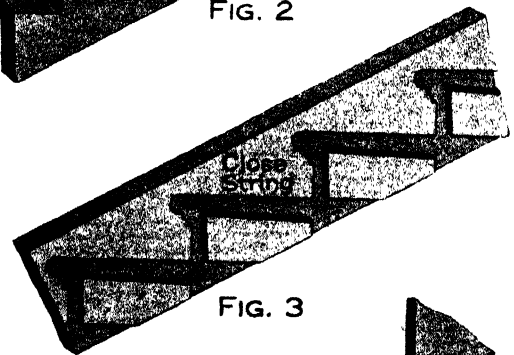


FIG. 3

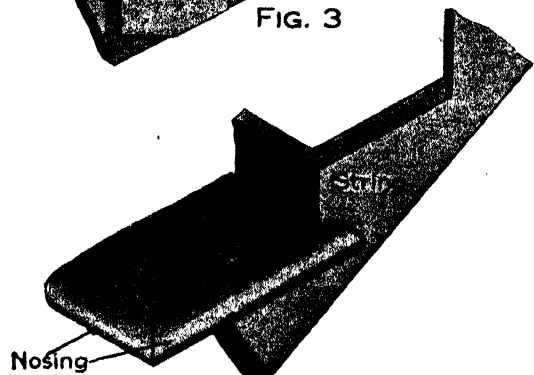


FIG. 4

In this arrangement the riser is formed with a lip on the end; the lip is made long enough to pass across the vertical part of the notch in the string and mitre with an ornamental bracket

MODERN BUILDING CONSTRUCTION

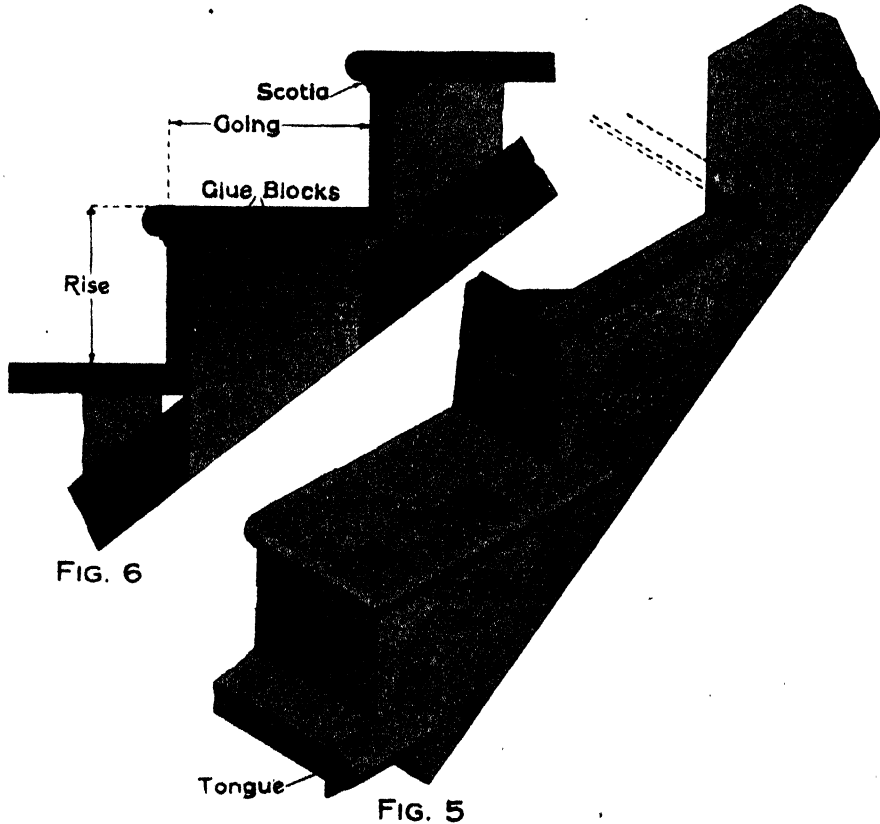
planted on the face of the string, the lip and bracket being usually of equal thickness.

To allow the toe of one bracket to pass under the heel of the bracket immediately above, the string may be cut to allow the back edge of the tread to be carried through beyond the outer face of the string, as shown by dotted lines. The end of the tread is allowed to stand beyond the face of the string an amount equal to the

TYPES OF STAIRS

A straight stair is shown in Fig. 7, but straight stairs may consist of several flights connected by landings.

Turning stairs are referred to as *quarter-turn*, *half-turn*, *three-quarter-turn*, and so on, irrespective of the manner in which the turn is effected, that is, by landings or winders. A stair turning through one right angle is a "quarter-turn," and



thickness of the bracket, so that the end of the string and the face of the bracket form one flat surface, upon which the return nosing may be fixed. This is rendered necessary by the scotia moulding, which is invariably introduced below the moulded nosing in stairs of this type, as shown in Figs. 1, 3, and 5.

The return end of the nosing fixed to the end of the tread is made long enough to pass across the thickness of the bracket and finish on to the face of the string. The figure should explain any further points in this connection.

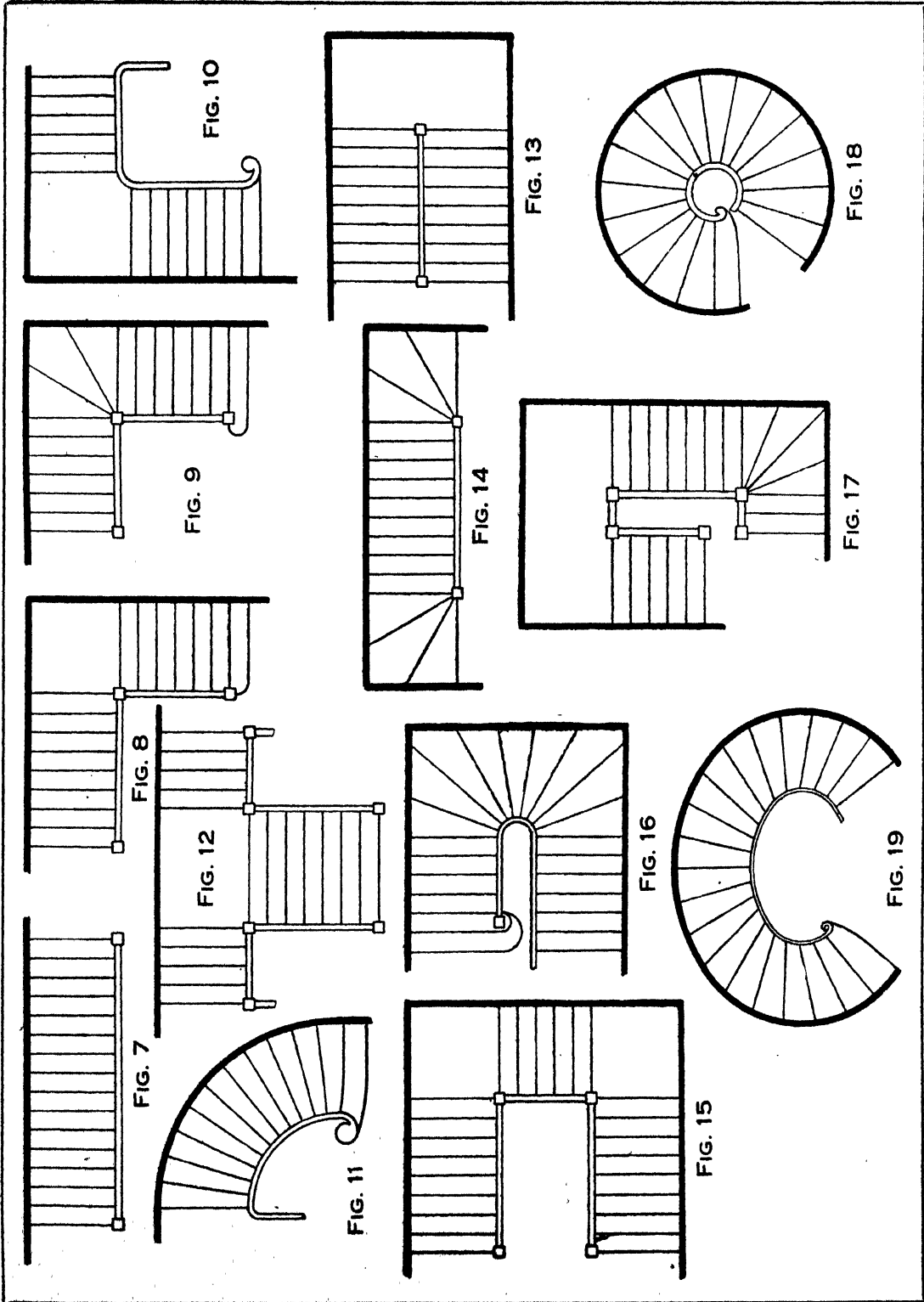
each of the examples shown in Figs. 8, 9, 10, 11, and 12, are of this type, Fig. 12 being a stair with two quarter-turn side flights.

Half-turn stairs are stairs which turn through two right angles, as shown in Figs. 13, 14, 15, and 16.

Fig. 17 shows a three-quarter turn stair, that is, turning through three right angles.

Fig. 18 is the plan of a *circular, or spiral stair*, and may be continued through any desired number of turns.

Fig. 19 is the plan of an *elliptic stair*.



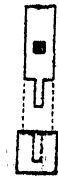


FIG. 24

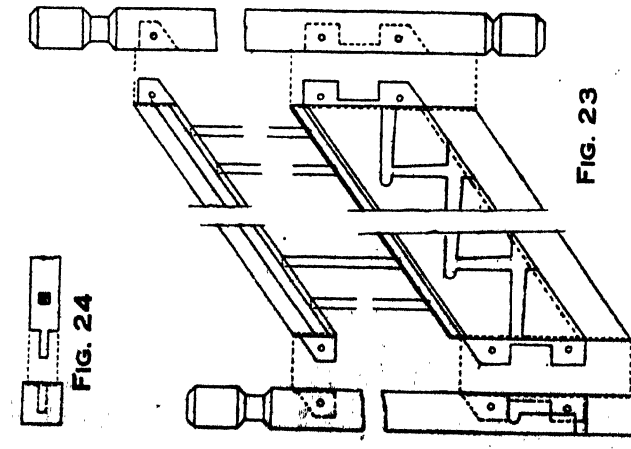


FIG. 23

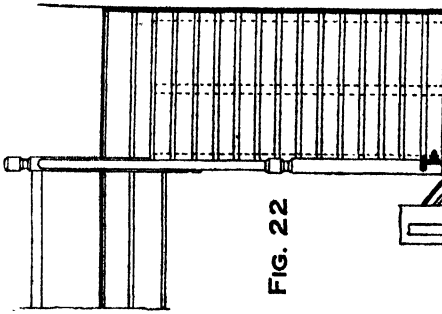


FIG. 22

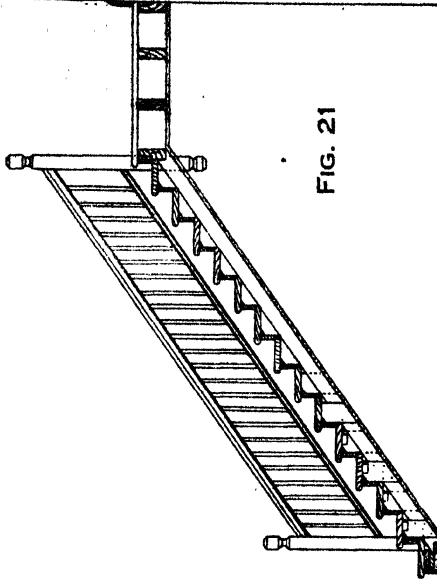


FIG. 21

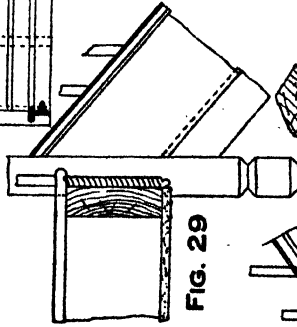


FIG. 29

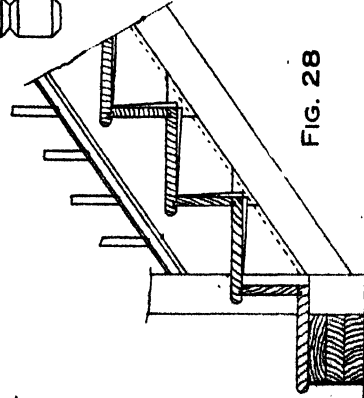


FIG. 28

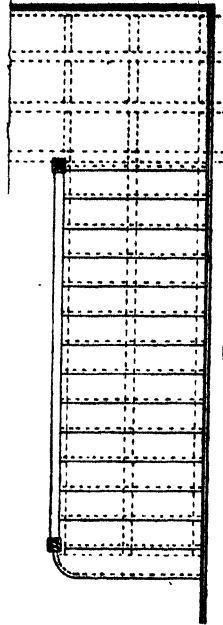


FIG. 20

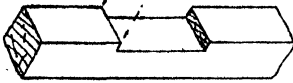


FIG. 30

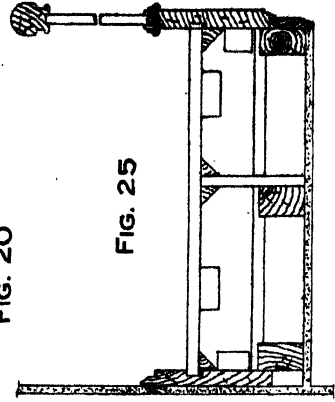


FIG. 25

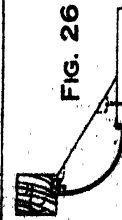


FIG. 26

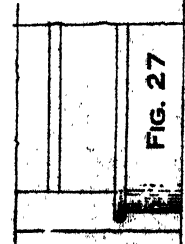


FIG. 27

Chapter II—CONSTRUCTION OF STAIRS

NEWEL STAIRS

If sufficient attention be given to the general methods involved in the construction of an ordinary straight flight of stairs, as shown in Figs. 20 to 30, little difficulty will be experienced in dealing with any form of newel stairs, since the constructional details are practically the same in all examples.

PLAN. Fig. 20 is the plan of a straight stair comprising fourteen treads and fifteen risers. The going of the step is 9 in., and the rise 7 in.; therefore the going of the flight is 10 ft. 6 in., and the rise of the flight is 8 ft. 9 in. The lowest step is a bullnosed step.

The rough strings, carriage piece, and landing timbers are shown by dotted lines, as are, also, the riser faces.

SECTION. A longitudinal section at any point between the wall string and the carriage is shown in Fig. 21. It will be seen that the rough strings and the carriage are bird's-mouthed on to the trimmer at the upper end and on to a fillet screwed to the floor, at the lower end. The rough brackets and glued angle blocks are shown on the six lower steps, but are omitted above for greater clearness in the illustration.

An enlarged view of the rough brackets is given in Fig. 6, and it is important to note that the direction of the grain in a rough bracket must be vertical, so that shrinkage will not affect its close contact with the under side of the tread. The rough brackets should be placed alternately on each side of the carriage and secured to the latter with screws, glued angle blocks being fixed on each side in the angles made by the faces of the brackets and the under sides of the treads.

Both strings, in this example, are close strings. The upper newel is notched over the face of the landing trimmer, as shown to larger scale in Fig. 29.

ELEVATION. A front elevation of the stair is shown in Fig. 22. The detail of the apron lining on the face of the trimmer is shown to larger scale, in section, in Fig. 29, and in isometric in Fig. 30. The landing balusters are omitted in Fig. 22 to give an uninterrupted view of the landing skirting.

Details. Figs. 23 and 24, drawn to a

larger scale, explain the method of framing the string and handrails into the newels. The tenons should be glued and pinned into the mortises, and the full sections of the string, handrail, and apron, or carriage lining, are sunk about a $\frac{1}{4}$ in. into the face of each newel, as shown by the dotted lines. The apron or carriage lining referred to is grooved to the under edge of the string, as shown in section in Fig. 25, and extends downwards to cover the rough string and form a finish to the ceiling on the stair soffit.

Fig. 25 is a cross section of the stair showing the sections of the strings, capping, handrail, carriage and rough bracket. The glued-blocks between tread and riser, tread and string, string and riser, tread and rough bracket, are shown in this view. The plaster laths for the ceiling are nailed to the rough strings and the carriage.

Fig. 26 is a plan of the bullnosed step with the tread removed. The step is made by reducing the part of the riser round the curve to the thickness of a stout veneer, usually about $\frac{1}{8}$ in., and cutting a solid block, which may be built up as shown in section in Fig. 28, to the shape indicated in Fig. 26; after bending the veneer around the block, the end and straight portion of the riser are secured to the block by screws. The veneer should be rendered pliant by steam or hot water; and after securing the end of the riser to the block, the veneer should be well glued, and rolled on a smooth flat surface into close contact with the block, and then drawn tight by a pair of slightly tapering folding wedges, as shown, before the block is screwed to the straight portion of the riser. An elevation of the finished step is given in Fig. 27.

FIXING STEPS. Fig. 28 shows the method of wedging the ends of the steps into the string housings; the strings are kept tightly down on the ends of the steps during wedging operations by a special cramping device fitted to a stair bench designed expressly for that purpose. One may sometimes be required to glue up stairs without this convenience, when the necessary pressure may be obtained by struts from a firm beam in the upper part of the workshop.

In addition to glued blocks, screws should

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be freely used in securing the parts of a stair together. The back edge of the tread should be screwed to the under edge of the riser, and pocket screws inserted through the back upper edge of the riser into the front edge of the tread. Pocket screws should also be used to fix the steps to the newels since wedging is not practicable for this purpose owing to the newel requiring to be cut away to allow it to be placed and fixed after the stairs are wedged up.

WREATHED STRINGS

The usual method of building a wreathed string is to reduce the curved portion to the thickness of a stout veneer, the thickness varying with the nature of the material used and the degree of curvature required; the string is then bent around a specially made drum or cylinder, the thickness of the string being restored by gluing staves (narrow strips of wood) to the back of the veneer. The staves should be very accurately fitted together, and made long enough to allow a screw to pass through them at either end into the drum, clear of the veneer. When the glue is hard, the string is removed from the drum, and the ends of the staves are cut to the veneer or to lines set out on the veneer.

The steps may be set out on the veneer either before or after bending. When the former method is adopted, a tracing of the developed lines may be made and glued to the face of the string. If the setting out is performed after bending, a flexible pitch board is used.

Development of an Open String for a Quarter-space Landing. See Figs. 31, 32, and 33. The quarter circle, ac , centre o , is the plan of the face of the curved portion of the string; 3, 4, 5, and 6 are the plans of the lines in which the risers would, if produced, meet the face of the string.

Produce co to d , making od equal to half oc . With d as centre and dc as radius, draw the arc cf , e being in the normal bisector of the arc ac , and f in the normal bisector of the arc $4c$. With e as centre, turn the points 3 and a to $3'$ and a' respectively, in the tangent $6c$ produced. With f as centre turn 4 to $4'$.

Make $3'2$ equal to the full width of the required tread, and make $3'3''$ equal to the width of the required riser.

Erect perpendiculars from a' , $4'$, 5, c , and 6; and draw a horizontal from $3'$ to meet the perpendicular from $4'$ in i . Make $i4''$, $5'5''$, $6'6''$ each equal to $3'3''$.

Draw the dotted lines $23''$ and $5''6''$, and draw parallels to them at a distance W equal to the required width of the straight strings, to meet the springing lines AA' and CC' at A and C ; join AC .

Introduce slight tangential arcs at A and C to connect the straight lines AC , Ag and AC , Ch , as shown.

Draw the joint lines $3'g$ and $6'h$ at right angles to the lower edge of the string.

To prepare the string, select a straight even-grained piece of material of a thickness equal to that of the straight strings, and large enough to contain the part of the developed string, Fig. 32, lying between the lines $3'g$ and $6'h$. On the trued-up material set out the tread and riser lines, the joint lines, and the springing lines, AA' and CC' . Square the springing lines over on to the opposite side of the material. Gauge the thickness of the veneer, $\frac{1}{8}$ in. to $\frac{3}{8}$ in., according to the degree of curvature and the nature of the material, from the face of the string between the springing lines.

Fix the material face downwards on to a flat board or surface with handscrews or G-cramps, and remove the back of the string between the springing lines by making frequent saw cuts and chiselling. Finish the back of the veneer with shoulder and thumb planes to secure a perfectly even thickness throughout.

Prepare a smooth-faced drum, as shown in Fig. 33, exactly corresponding to the plan curve ac , long enough to contain the bent string, and having several inches of plane surface beyond each springing line.

Mark the springing lines on the drum, as shown in the figure.

Reduce the stiffness of the veneer by steaming, or bathing with hot water, and bend the veneer around the drum so as to make the springing lines on the string coincide with those on the drum.

Secure the solid ends of the string down on the plane faces of the drum, by screwing fillets to the drum across the ends of the string.

Restore the thickness of the string by gluing staves across the veneer as shown in Fig. 36. Each stave or alternate staves must be screwed to the drum as shown.

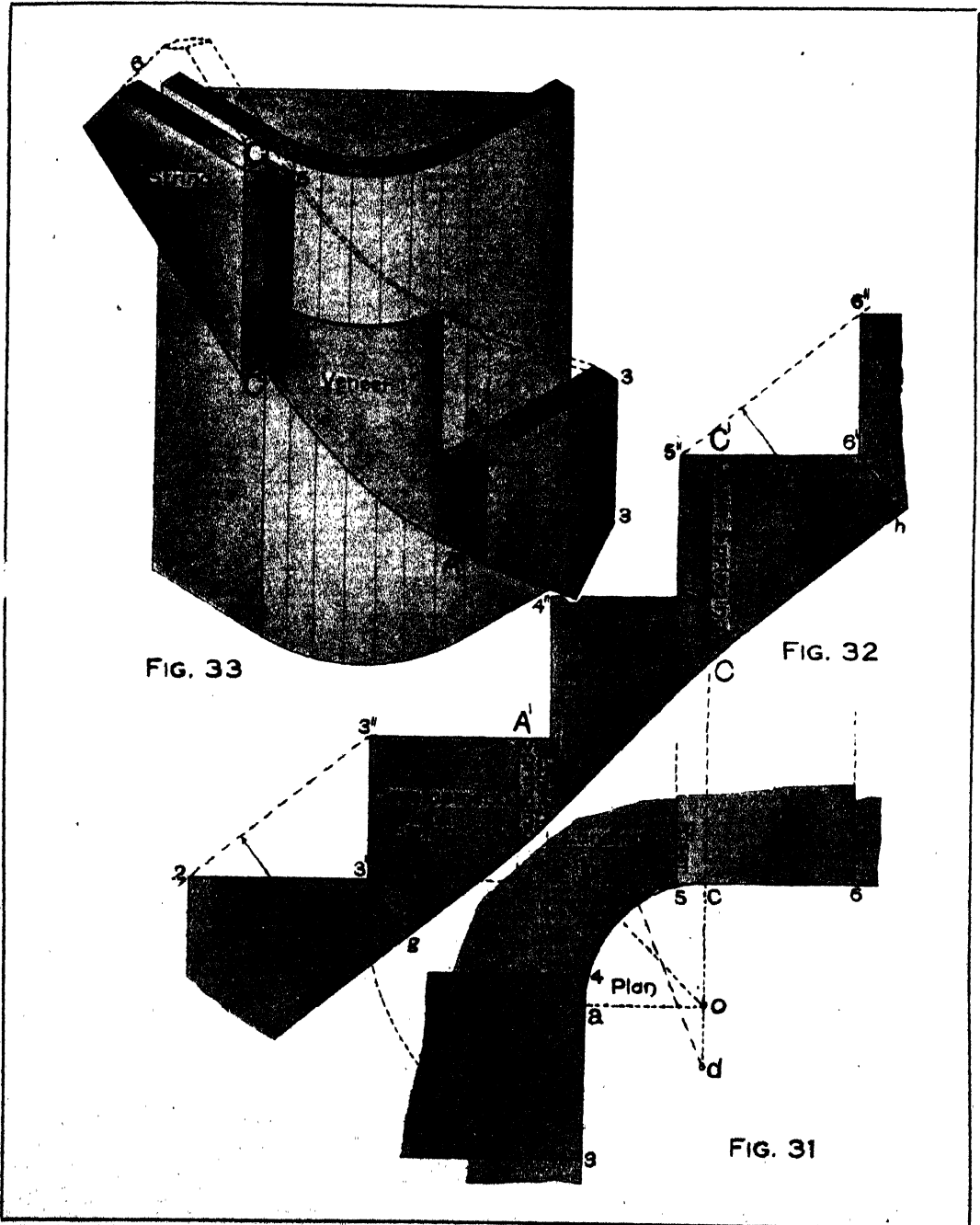
When the glue is hard the backs of the staves may be cleaned off and a piece of strong canvas glued completely over them.

The string may now be removed from the drum, and the tread, riser, and joint lines cut

STAIRS AND HANDRAILS

square or normal to the face of the string, or, in the case of cut and mitred string, the vertical cuts made to mitre with the risers.

Development of Wreathed String for a Quarter-space of Winders. See Figs. 34, 35, and 36. The circular quadrant ac , centre o , is the plan of the



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outer face of a wreathed string around a quarter-space of winders; the steps below $4L$ and above $8W$ are fliers.

To determine the number of winders required, the *walking line* WL is drawn about the centre o , at a distance of from 15 in. to 18 in. from the

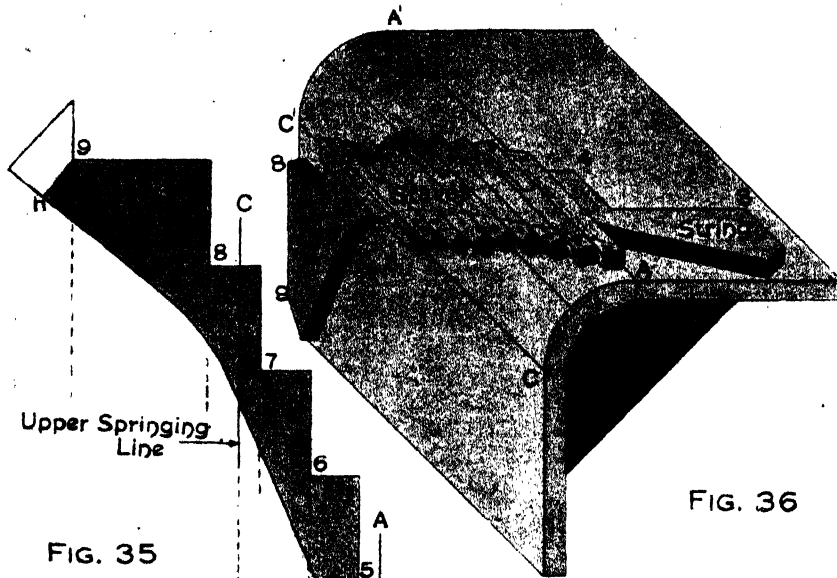


FIG. 36

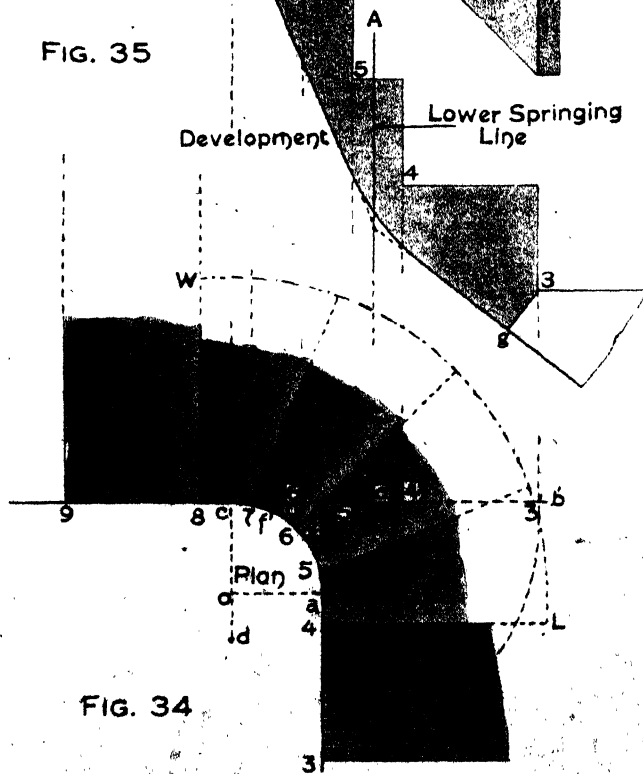


FIG. 34

string; this line is divided into the number of equal parts that will make each part as near equal to the width of the fliers as is possible. Here the number is four, and the line $aac8$ is divided into four equal parts; the points

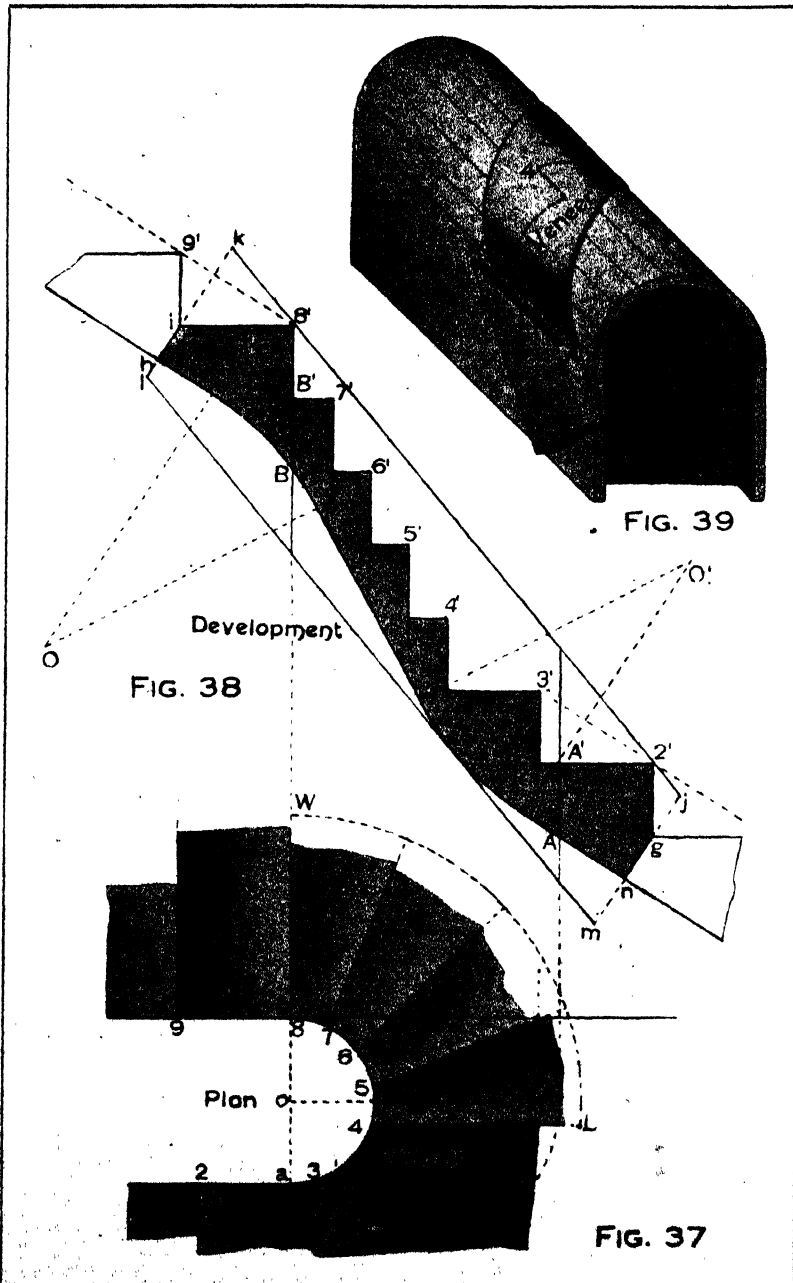
of division 5, 6, and 7 are joined to the corresponding points in the walking line, to give the required direction to the risers of the winders.

Produce the tangent at c to b' . Make od , in co produced, equal to half co ; and with d as centre draw the arc $cfne$, e being in the normal bisector of ca , n in the normal bisector of $c5$, and f in the normal bisector of $c6$.

With e as centre, turn 3, 4, and a to $3'$, $4'$, and a' respectively. With n as centre, turn 5 to $5'$; and with f as centre, turn 6 to $6'$. Then $c6'5'a'4'3'$ is approximately the straight line development of all the points between c and 3. Note that the point 7 is too near the tangent cb' to allow development in a small-scale drawing, but the same method as for other points may be used when necessary.

Erect perpendiculars from all points in gb' , and by setting up a succession of riser heights, as in the previous example, obtain the development of the intersections between the face of the string and the planes of the steps, as 3, 4, . . . 9, Fig. 35.

Draw the springing lines A and C from a and c respectively. The directions of the lower edges of the straight strings are parallel to a straight line joining 8 and 9. Theoretically, the lower edge of the curved portion of the string should be a straight line between the points in which the lower edges of the straight strings meet the



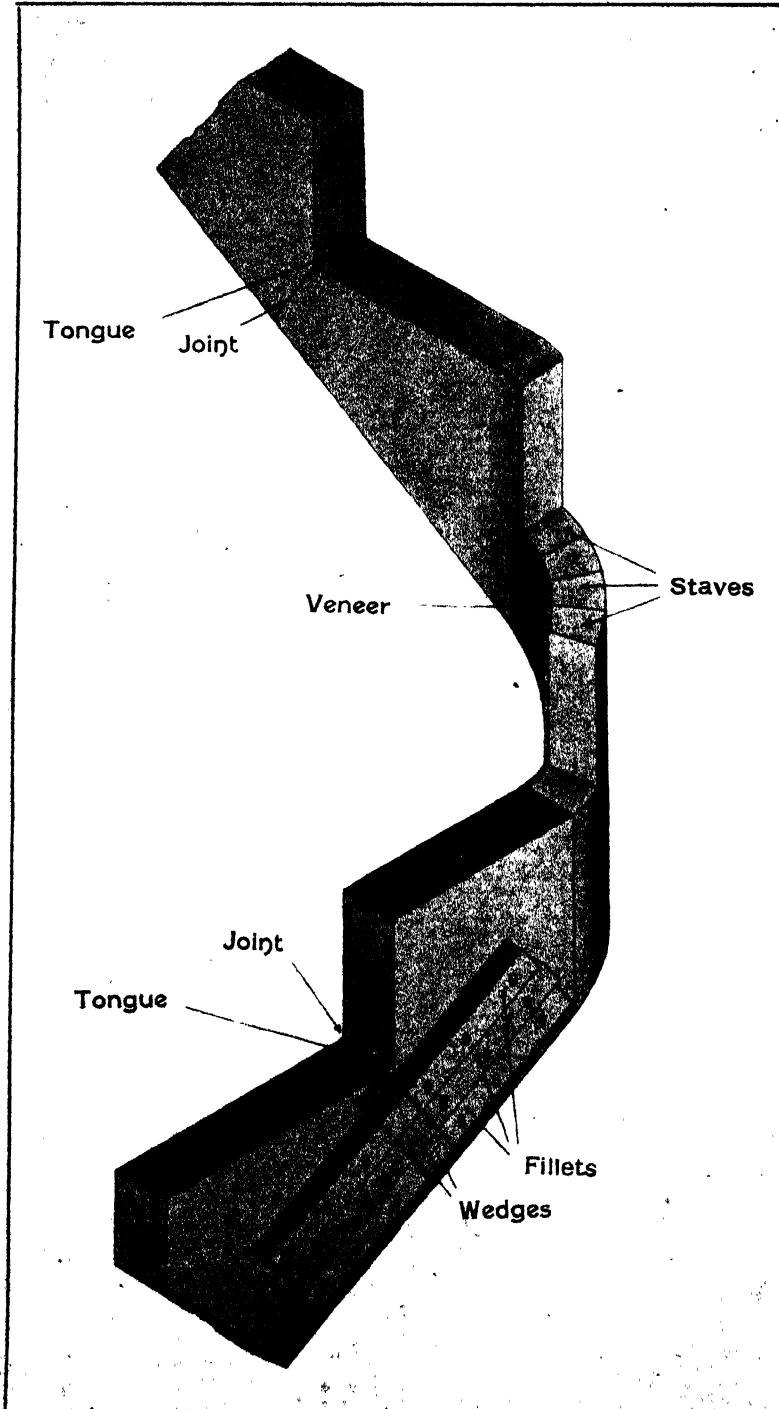


FIG. 40

springing lines, but obviously this would not give sufficient material below the steps. Therefore, the line shown is drawn parallel to a straight line through 5, 6, and 7, at a reasonable distance below these points, and circular curves drawn tangent to the straight lines complete the development.

Fig. 36 shows the veneer staved around the drum, with the tread and riser lines shown dotted.

It must be very clearly understood that the veneer is not cut to the step outline until after removal from the drum.

Development of String for a Half-turn Geometrical Stair. (See Figs. 37, 38, and 39.) Fig. 37 is the plan of a quarter-space landing and a quarter-space of winders arranged about a semi-circular well-hole.

The required number of winders is determined by dividing the walking line WL into that number of equal parts, which makes each part as nearly equal to the width of the flie as is possible. Point o is the centre of the plan semicircle, and a and b are the plans of the vertical springing lines across the face of the string.

With the mid-point of oa as centre, draw the arc bd , od being perpendicular to ab . With d a centre turn a to e in od produced, and erect perpendiculars to oe from b and e . Develop the points 4, 5, 6, and 7 into qd produced, by taking the

point in the arc bd equidistant from b and the point to be developed as centre, and drawing arcs as shown. To obtain the development of the point 3, make ef equal to a_3 by taking off with dividers; the arc is only drawn to indicate the relationship between the plan and the development. From each of the developed points erect perpendiculars, and by stepping up the height of a riser on each perpendicular obtain the points $2'3' \dots 9'$, Fig. 38. Draw the lower edges of the straight strings parallel to $2'3'$ and $8'9'$. Draw a straight line equidistant from $4'$, $5'$, and $6'$, the distance being as required to give the necessary strength to the curved portion of the string, and draw circular easings as shown about centres O and O' . Note that, theoretically, the under edge of the string between the springing lines AA' and BB' should intersect the under edges of the straight strings on the springing lines, but in this and most other cases this arrangement results in giving insufficient material for practical purposes. The position of the joints are shown at gn and hi , the required width of material being indicated by the parallels kj and ml .

Fig. 39 shows the veneer folded about a semi-circular drum ready for staving, the tread and riser lines being shown dotted and numbered to correspond with the plan and the development.

Methods of Jointing Strings. Fig. 40 is an isometric view of the string shown in Figs. 31 to 33 after it has been cut and jointed to the straight strings. The method of jointing shown is called a *counter-joint*, and is quite satisfactory for comparatively thin strings. After the three fillets have been prepared with equal mortises near the centres of their lengths, the two outer fillets are screwed to one section of the string, and the centre fillet to the other section; the mortise in the centre fillet is kept a little out of line with the other mortises, so that when folding wedges are inserted through the three fillets, and tightened, they cause the centre fillet to slide between the outer fillets in the direction required to tighten the joint between the sections. After wedging, the free ends of the fillets are screwed to the string as shown. Sometimes the fillets are housed across the face which makes contact with the string instead of being mortised, but this is undesirable as the wedges tend to bend the fillets and throw the strings out of truth.

In fairly thick strings the joints may be made with handrail screws, which from experience leads one to believe that this is the best form of joint.

Close Strings. When both faces of the string

require to be veneered, as is the case with a wreathed housed string, the development of the second face is carried out precisely as explained in the foregoing examples, but the complete length between the joints is staved and veneered, the backs of the staves being cleaned off to receive the second veneer.

NOTES ON STAIR DESIGN

Avoid introducing winders into stairs whenever possible.

When winders are unavoidable they should be placed at the bottom rather than at the top of the flight, the narrower end being made as wide as possible.

The inclination of a stair should be kept between 30° and 45° to the horizontal.

The product of the width of the tread and the height of the riser in inches should be 66 (approximately).

The height of the top of the handrail, vertically measured over the face of the riser, should be in the neighbourhood of 2 ft. 7 in.

Head room of at least 7 ft. vertically measured over the face of the riser, should be allowed.

Ample lighting should be arranged in every stairway, a skylight and counter-light being particularly suited for this purpose.

It is undesirable to have more than fourteen steps in one flight.

A single step should never be introduced for any purpose.

No stair should be less than 3 ft. wide.

In extremely wide stairs a centre handrail should be provided.

In designing stairs with continuous strings and handrails, a sound knowledge of the geometrical principles involved in the making of the stair and rail is essential. If the designer does not possess this knowledge, he should allow considerable latitude in the arrangement of the riser positions about the changes of direction of the stair, so as to enable the practical stairbuilder to secure a reasonable falling line. Where the turn is made by means of winders, the correct positions of the risers can only be determined by first making an approximate development of the string and vertical tangent planes (the latter are explained later), and then suiting the riser positions to a proper falling line arrangement.

Ninety per cent of the cases of unsatisfactory wreathed handrails are due to errors of design and not to poor craftsmanship, and, generally speaking, the less satisfactory the result, the more expensive is the process of producing it.

Chapter III—GEOMETRICAL HANDRAILS

THERE are two modern methods of producing handrail wreaths, each method having distinct advantages over the other.

The more usual method is known as the *square cut* or *tangent* system, the less usual being known as the *method of normal sections*.

From the point of view of economy of material there is nothing to choose between the two methods, both being capable of producing the finished wreath from practically the minimum thickness of material.

The necessary setting out required in the method of normal sections takes a little more time than is the case with the tangent system, but this is compensated for in working the wreath, since, in the former method, the elevation curves may be accurately plotted on to the material without distorting the solid, and the truly rectangular normal section of the rail makes the process of moulding comparatively easy.

Space will not allow a fully detailed comparative analysis of the two methods to be made, but the writer's opinion is that for moulded rails of fairly large radius the method of normal sections is the more satisfactory, whereas for wide rails of small radius there are certain geometrical and face-mould difficulties that do not occur with the tangent system. A little experimental work by the student will best explain the limitations of the two methods.

PRINCIPLES OF TANGENT SYSTEM. In the square cut or tangent system of hand-railing, the squared wreath is considered as part of a hollow cylinder having its axis vertical, and its inner and outer radii equal to the inner and outer radii of the plan of the wreath, and the edges of the squared rail are parts of the upright cylindrical surfaces. The upper and lower faces of the wreath are, theoretically, helical sections of the cylinder, made by two horizontal lines rotating about and moving along the axis of the cylinder. When the two ends of the wreath are equally inclined, that is, when the pitches are equal, the rail arrises are approximate helices of uniform pitch; when the inclinations vary, the arrises approximate to helices of varying pitch. The more nearly the arrises are made to conform to the true helix,

the better is the appearance of the rail, and since *falling moulds* (developments of the cylindrical edges of the wreath) are rarely used, there is considerable latitude allowed in forming the arrises.

The centre line of the wreath and the edges of the *face moulds* are actually elliptic arcs, being plane sections of the centre layer and the faces of the cylinder respectively.

The plane section of the cylinder required for forming the face mould is determined by supposing vertical planes to be arranged tangent to the centre layer of the cylinder, the lines of contact being the generators of the centre cylindrical surface that contains the extremities of the wreath.

The plane containing the upper edges of the tangent planes cuts the hollow cylinder in the section required for the face mould. In the ordinary form of wreath the joint planes are made perpendicular to the upper edges of the tangent planes, and the positions of the rail sections on the joint planes are determined by finding the dihedral angles between the section plane and the vertical tangent planes; these angles being called *twist bevels*. If a straight line is drawn through the centre of the joint plane to make the appropriate angle or twist bevel with the line of intersection between the joint plane, and the face of the plank from which the wreath is cut, this line will bisect the upper and lower boundary lines of the rail section; the boundary lines are equidistant from the centre of the joint plane.

PRINCIPLES OF NORMAL-SECTION METHOD. In this method also the centre line of the wreath is an elliptic arc tangent to the centre lines of the rails the wreath is required to connect, but the four surfaces of the wreath are, in this case, generated by a plane rectangle, equal to the straight rail section, moving with its centre always in, and its plane always normal to, the elliptic centre line. Therefore every normal section of the squared wreath is a rectangle equal to a right-angled section through the straight rail.

The face moulds required in this system are determined as follows. The angles the normal sections of the rail make with the plane containing

the centre line are determined at a number of chosen points along the wreath, and the sections are arranged with their centres in one straight line, and making the appropriate angles with the line. Parallels to the straight line containing the centres of the sections are drawn to contain all the sections, the distance between the parallels being the thickness of the required

ment of the centre line of the under surface of the wreath from the position immediately above the centre of the string, which tends to throw the balusters under the wreath out of true perpendicular.

The first objection is of no importance when the rail is of normal depth and moulded, and an expert would have difficulty in deciding which

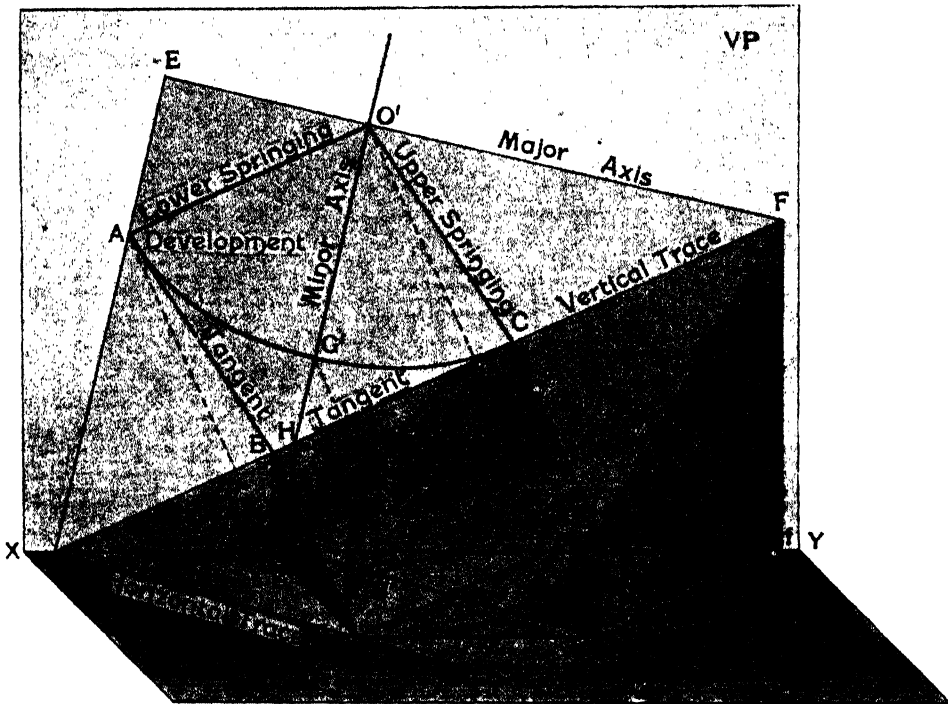


FIG. 41

plank from which the wreath is to be taken. When the section edges are produced to meet the parallels, and the centres of the sections are projected perpendicularly on to one parallel, the distances required in plotting the edges of the face moulds about the developed centre line are obtained, as are also the distances of the angular points of each section from the faces of the material.

The only real objections to the method are—

1. The edges of the wreath are not cylindrical and do not, therefore, conform to the cylindrical nature of the remainder of the balustrade, that is, the string and balusters.

2. There is a comparatively small displace-

ment of the two methods had been used in making the rail.

The second objection is equally unimportant for rails of moderate depth, since the defect may be modified by placing the tops of the balusters slightly out of the centre of the wreath, and even without modification the defect could only be discovered by testing with a plumb rule.

Equally serious objections to the tangent system are got over by distorting the true geometric solid, and no greater difficulty is experienced in correcting normal-section wreaths if the true nature and extent of the required distortion is understood.

Chapter IV—TANGENT SYSTEM OF HANDRAILING

Centre Line of Rail. Fig. 41 is a pictorial view of the principal lines involved in the tangent system. Let aB and CB be continuations of the centre lines of the straight rails to be connected by the wreath whose centre line is the elliptical arc aC , tangent to aB and CB at a and C respectively. Then if HP is the horizontal plane that contains a , and VP is the vertical plane that contains BC , and BC be produced to meet XY in d , then dC is the vertical trace, and da the horizontal trace of the plane containing the tangents aB and BC and the elliptic arc aC .

Let the circular arc ac , centre o , be the plan of the elliptic arc aC , and let ab and bc be the plans of the tangents aB and BC ; then the vertical planes aBb and $bBcC$ are tangent planes to the cylindrical surface containing the circular arc and the elliptic arc, and the latter may be regarded as the section of the cylinder by the oblique plane adC . Let o be projected vertically into the oblique plane at O ; then oO may be considered as the axis of the cylinder, and O is the centre of the ellipse of which aC is a part. Then the horizontal line in the oblique plane through O contains the minor axis of the ellipse.

Let OG be parallel to ad ; then because ad is the horizontal trace of the oblique plane containing OG , OG is horizontal, and is, therefore, the semi-minor axis of the elliptic arc aGC , and is equal in length to its plan og .

Join a to o , a to O , o to c , and O to C ; then aoO and $ocOC$ are the vertical springing planes of the wreath whose centre line is aC .

If og be produced to meet XY in h , and OG be produced to meet dC in H ; then hH is a vertical line, and the elevations of G and O (g' and o' respectively) are in the line from H drawn parallel to XY .

In orthographic projection the problem is: Given the plan $abco$ and the inclinations of the straight rails, to determine the true shape of the actual figure $aBCO$. There are several methods of solving the problem, the one shown in the figure being the method of rabatment

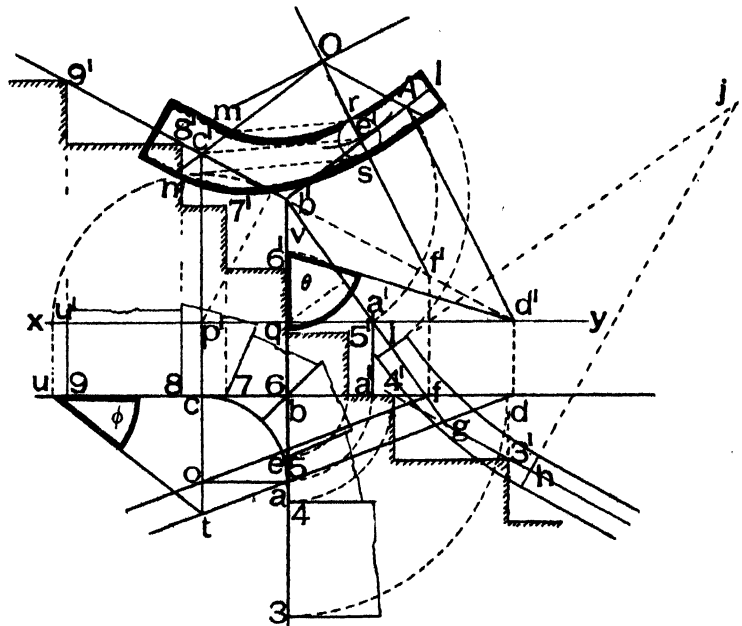


FIG. 42

about the vertical trace into the vertical plane.

In the present example aB equals BC , and the plan of the centre line is a circular quadrant; therefore the plans of the vertical tangent and springing planes form a square, with its side bc in XY ; and because parallel lines project parallel and in their true ratios, the actual figure $aBCO$ is a rhombus. Let this rhombus and the elliptic arc aGC turn about BC into VP ; then all points in the revolving figure will describe circular arcs, whose projections on VP (the plane containing the axis) will be straight lines perpendicular to the line BC , the axis of rotation.

First consider the point whose plan is a . Since ab and bc are both in HP and abc is a

right angle, the elevation of a is in the point b , and the projection of its circular locus will be the dotted line bA drawn perpendicular to the axis of rotation BC . But d is in CB produced and is in both HP and VP ; therefore, if aA in VP is equal to da in HP and A is in the perpendicular to BC from b , then dAB is the rabatment of the triangle daB into VP .

In the same way $o'O'$, perpendicular to BC , may be shown to be the projection of the locus of O , and if HO' is made equal to ho , and $O'G'$ is made equal to og , $O'C$ is the rabatment of OC , $O'A$ the rabatment of Oa , and $O'G'$ is the rabatment of the semi-minor axis. The direction of the major axis is, of course, perpendicular to the minor axis through O' , as shown at EF .

Wreath for a Quarter-space of Winders. This example gives the most characteristic diagram and if it is sufficiently studied, subsequent examples will present little difficulty.

In Fig. 42, the circular quadrant ac , centre o , is the plan of the centre line of the wreath; the points 3, 4, 5, 6, 7, 8, and 9 are the plans of the lines in which the planes of the riser faces meet the vertical tangent planes containing the centre lines of the straight rails.

With b as centre turn 3, 4, a , and 5 into cb produced. From any convenient point thus obtained in cb produced, as $4'$, draw a vertical line equal to the rise of the step; and by setting up a succession of similar distances on perpendiculars from the remaining numbered points in and turned into cb produced, obtain the shaded step development, 3', 4', 5', 6', 7', 8', and 9'.

Erect the vertical springing lines cc' and $a'a'$, and the intersection line bb' . Through 8' and 9' draw the straight line to meet the upper springing line in c' and the intersection line in b' , then this line gives the inclination of the upper straight rail, and $c'b'$ is the upper pitch of the wreath.

Draw the straight line through 3' and 4' to obtain the developed centre line of the lower straight rail. Since the centre lines of the two straight rails produced do not intersect, one or both of the straight rails must be provided with an *easing* or *ramp*; and since it is desirable to keep the rail higher over the winders than over the fliers, an easing below the wreath is better suited to the present case. From b' draw a straight line to pass above 4' and 5' at approximately the same distance as $c'b'$ is above 7', to meet the lower centre line in g . Make the distance gh on 4'3' produced equal to gi on gb' ,

the position of i being determined by the necessity for keeping the joint line through i just clear of the springing line $a'a'$. Thus draw ij perpendicular to gb' , and set out on this perpendicular half the thickness of the rail on either side of i . Draw hj perpendicular to gh , and with j as centre draw the circular arcs equidistant from i and h and at a distance apart equal to the rail. Note that it is desirable to have the shank of the wreath at the joint with an easing as short as possible, but the joint must be kept outside the springing plane.

Through a' , the point in which $b'g$ intersects $a'a'$, draw xy , and produce $c'b'$ to meet it in d' . Drop a perpendicular from d' to d in cb produced, and draw the straight line through d and a ; then da is the horizontal trace, and $c'd'$ the vertical trace of the plane containing AB and CD .

Draw of parallel to ad and erect a perpendicular from f to meet $c'd'$ in f' .

With b' as centre, $b'a'$ as radius, draw a circular arc (shown dotted) and determine A on this arc, such that $d'A$ equals da , and draw $b'A$. From f' draw a parallel to $d'A$, and make $f'O$ equal to fo . Join OA and Oc' ; then $c'OAb$ is the development into VP of the tangent and springing lines shown at $coab$ in plan. Of' is the direction of the minor axis of centre-line and face-mould ellipses, and $d'A$ is the development of the horizontal trace into VP . A perpendicular to Of' through O is the direction of the major axis.

Make Oe' equal to the plan radius, and about e' as centre draw a circle having a diameter equal to the width of the rail. Join $e'c'$; and from the points r and s in which the circle about e' cuts the line of minor axis, draw parallels to $e'c'$ to meet Oc' in m and n . Or is the semi-minor axis of the inside elliptic curve, and Os the semi-minor axis of the outside elliptic curve. The curves may now be trammelled, and the shanks drawn parallel to the tangent with the joint lines perpendicular to the tangents. The upper shank may be made any desired length, usually from 3 in. to 5 in., but the length of the lower shank must be determined by turning i about b' to cut the tangent $b'A$ produced in I .

The *twist bevells* are determined by finding the dihedral angles between the oblique plane containing the tangents AB and BC and the vertical planes containing these tangents.

To determine the upper twist bevel: With the point p' where cc' intersects xy as centre, and the perpendicular distance of p' from the upper

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particular plane is convex lengthways and concave across its thickness.

The expert handrailer frequently makes his own thumb planes, and must have a great

shark's-jaw wrench shown in Fig. 56. The slot for the round nut is made large enough to take the washer and permit the insertion of the handrail punch. Both slots are filled in with

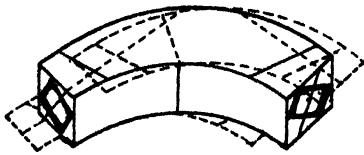


FIG. 52

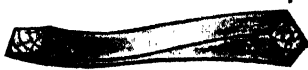


FIG. 53

variety of shapes to deal with the unlimited number of sections he is required to work.

Curved rasps and files, called *rifflers*, are of great assistance in moulding scrolls and very sharp twists of small radii.

The handrail screw, or bolt, used in jointing handrails is shown on page 399, Fig. 177, and is simply a bolt with a thread and nut on each end, one nut being square, the other round; the latter has grooves around its cylindrical surface to permit of it being tightened with a handrail punch (Fig. 92, on page 367). Both nuts are let into the bottom surface of the rail, the slot for the square nut being made small enough to prevent the nut turning while the bolt is being turned into it by means of the

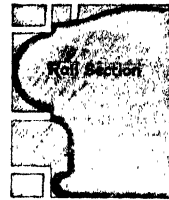
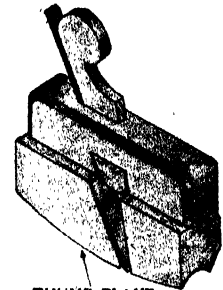


FIG. 54



THUMB PLANE

FIG. 55a

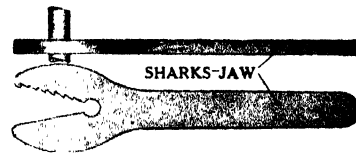


FIG. 56

material of the same kind as that from which the rail is made, and the grain of the fillings is arranged to run with the grain of the rail.

Two short dowels are usually introduced to prevent the rail turning about the bolt, and care must be taken to place them so as to allow the wreath to be moulded without exposing the end of the dowel; this is of importance in very sharp turns where very little shank is possible.

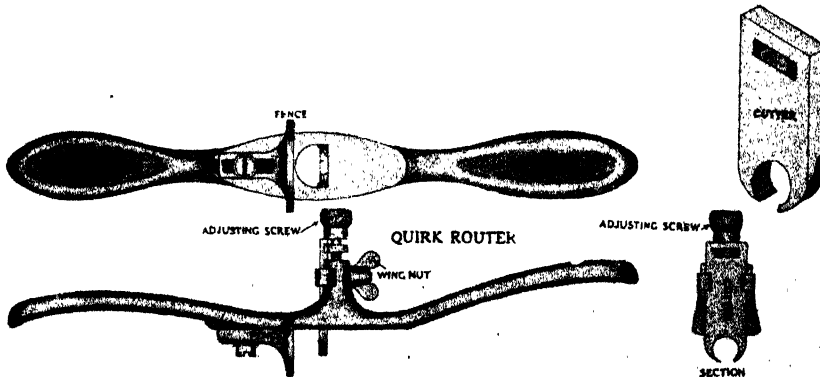


FIG. 55

Chapter V—NORMAL SECTIONS METHOD OF HANDRAILING

CHANGES in the angle between the tangent planes, and variations in the inclinations of the pitches, do not involve the same degree of modification in the setting out diagram in the normal sections' method as is the case with the tangent system.

In Fig. 57 the step development 4', 5', 6', 7', and the determination of the pitches $a'b'$, $b'c'$ are obtained precisely as in Fig. 42, Chapter III. The horizontal trace dp through a is also determined as before.

Draw $x'y'$ through o perpendicular to dp . Draw cc'' parallel to dp , cutting $x'y'$ in k , and make kc'' equal to the height of c' above xy . Join pc'' ; then pc'' is an edge view of the plane containing the upper edges of the tangent planes and the centre line ellipse whose plan is the circular quadrant $aefc$. Let e and f be the plans of any chosen points in the centre line. Draw gi and hj tangent to the plan centre line at e and f , respectively. Draw enu and fmv parallel to dpf and from n , m , and k draw parallels to pc'' to meet the plan circle, produced to t , in s , r , and q respectively. From o draw straight lines through t , s , r , and q , and at any convenient distance from the plan draw AC perpendicular to pc'' ; then the angles between the radials oC , oF , oE , and oA are the angles the normal sections of the squared rail make with the plane of the plank, from which the wreath is to be taken; corresponding letters indicate the approximate positions of the angles.

About the points A , E , F , C , as centres, set out the square section of the rail, so that the face lines of the sections are bisected perpendicularly by the radials oA , oE , oF , and oC .

Draw parallels to AC to contain all the sections, as shown; the distance between these parallels is the required thickness of the plank. Transfer the line containing the points p , u , v , c'' to any convenient position, as P , U , V , C'' , Fig. 58, and draw perpendiculars to it through each point. On the perpendicular through P , make PA and PA' equal to pa (Fig. 57); PG and PG' each equal to pg ; PH and PH' each equal to ph ; and PD and PD' each equal to pd . Make UE and UE' each equal to ue (Fig. 57); VF and VF' each equal to vf ; and $C''C$, $C''C'$

each equal to kc . Make $C''L$, $C''L'$ each equal to kl (Fig. 57), and draw straight lines through LA , $L'A'$, GE , $G'E'$, HF , $H'F'$, DC , and $D'C'$; these straight lines are the development of the tangents to the plan quadrant set out on either side of PC'' .

Draw ab perpendicular to LA through A ; cd through E perpendicular to GE ; ef through F perpendicular to HF ; and hg through C perpendicular to DC . Repeat these lines on the second tangent development as $a'b'$, $c'd'$, $e'f'$, and $g'h'$.

Referring again to the section diagram, Fig. 57, produce the edge lines of the sections to meet the face of the plank line in points w^1 , w^2 , . . . w^8 , and project the centres of the sections perpendicularly on to the same line at a_1 , e_1 , f_1 , and c_1 .

Now referring to Figs. 58 and 57 alternately, make Aa and $A'a'$ each equal to a_1w^1 , Ab and $A'b'$ each equal to a_1w^2 ; Ec and $E'c'$ each equal to e_1w^3 ; Ed and $E'd'$ each equal to e_1w^4 ; and continue in the same way with the remaining sections to obtain e , f , e' , f' , g , h , g' , and h' . Draw curves through $aceg$, $bdfh$, $a'c'e'g'$, and $b'd'f'h'$.

Draw an equal amount of shank on the two ends of each mould parallel to the end tangents, and draw the joint lines perpendicular to these tangents.

If either mould be turned into the plane of the second mould about the line PC'' , the relative positions of the moulds on the opposite sides of the plank are obtained, and when in this position the corresponding tangents will coincide.

A cutting-out mould may be obtained by projecting the two angular points of each section, which give the greatest width perpendicularly on the face line, and setting out the distances from the projected centre so obtained on the face-mould diagram; thus, if the angular point 2 (section A , Fig. 57) be projected perpendicular to and into the face line containing a_1 , the distance of its projection from a_1 must be set out on either side of A (Fig. 58), and similarly for the other sections.

The squared wreath is shown lying in the plank in Fig. 59, and points in the four arrises

Shop Fronts and Fittings

By B. G. WHATMOUGH

SHOP fronts may be classified into four main types: Single Fronts, Double Fronts, Recessed Fronts, and Arcade Fronts. They are all

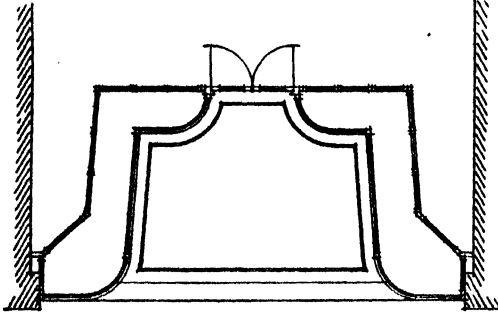


FIG. 1. RECESSED FRONT

capable of very varied design, both in the treatment of the elevation and plan. Many businesses nowadays have developed a more or less standard type of plan which is not only most suitable for its particular object, but has become associated in the public mind with that particular firm. These particular types are, however, generally a form of one or the other of those classified above.

THE SINGLE FRONT. This is constructed with a single window placed to one side of the opening, the remaining frontage being taken up with a lobby entrance. This type is economical in construction and quite suitable for a business which consists of one particular line.

THE DOUBLE FRONT is formed with a window on each side of the opening, the lobby being situated between. The windows are not necessarily of equal frontage, and may be varied to suit the particular requirements. This type is often used for a business which is engaged in a double capacity, such as costumiers and milliners.

THE RECESSED FRONT. An example of this is shown in Fig. 1. It is quite suitable for any business where the space will permit and where a comparatively shallow window is required. This not only has the advantage of giving a

greater window frontage for display purposes, but permits shoppers to withdraw from the crowded pavements for inspection of the windows.

THE ARCADE FRONT. This type is shown in Fig. 2. It is possible only where there is a comparatively large frontage and ample depth. It is a type particularly suited to drapers or to large multiple stores, since it is capable of giving a very large glass frontage with the added advantage of several separate windows for the display of different wares. It will be observed that this class of front is open to very considerable variation in order to suit the particular business for which it is required.

Plan Arrangements. The planning of fronts is open to such a wide range of treatment that it is impossible to lay down definite rules. Each particular case will need to be treated on its merits, and will be subject to the consideration of the size and position of site, type of business, and the mode of dressing to be employed. The

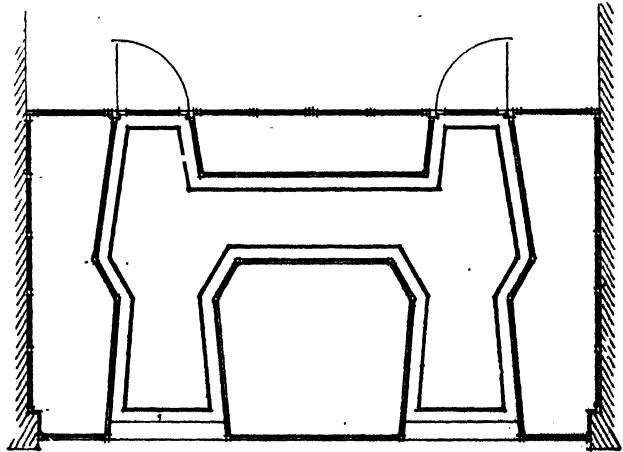


FIG. 2. ARCADE FRONT

chief points to be considered when planning fronts is the question of obtaining suitable window space, easy window dressing, and satisfactory vision from the street, together with a direct access to the interior. The smaller shop properties are frequently designed with living accommodation above, the more

SHOP FRONTS AND FITTINGS

modern ones being planned with access to the upper stories from the rear. In some of the older properties, however, access to these upper floors has been provided in the main frontage with a consequent loss of valuable window space. This could, however, be avoided in various ways, one example being shown in Fig. 3. A

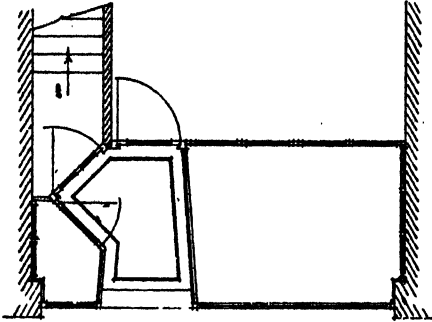


FIG. 3

simpler form is often made by designing a single front with the shop door in alignment with the return window in the lobby, the entrance door to the upper part being at the back of the lobby parallel with the front. Except, however, where the cost and other special considerations necessitate this plan, it is to be avoided, since the entrance to the shop should always as far as practicable be visible directly from the street.

When planning the windows, consideration

should be given to the lobby, which should not be sacrificed to window area, as it is important to provide easy and pleasant access to the shop. It should also be remembered that the return windows to the lobby form a valuable dressing, and the lobby should therefore be sufficiently spacious to allow of easy inspection. Certain classes of goods, such as gowns, require to be inspected from a distance in order to obtain a good effect, which is an added reason for a well-planned lobby. One often sees a very narrow entrance lobby with a comparatively deep window, the result being that it is rather like walking into a tunnel when entering the shop. The planning of windows will be subject to the consideration of the amount of dressing required and the type. Many firms have made a point of building their businesses around the name, with the result that actual window display, is, to a large extent, unnecessary. It is therefore impossible to lay down any rule as regards planning windows, as the requirements for a similar trade are often entirely different. Where a display is necessary, the size and shape will more or less be governed by the trade, the windows being planned to suit either a free dressing or a fixed dressing as required. *Free dressing* is that where articles are placed freely in the window in order to obtain the required effect; the *fixed dressing* being obtained by means of glass or wood shelves which are more or less permanently positioned.

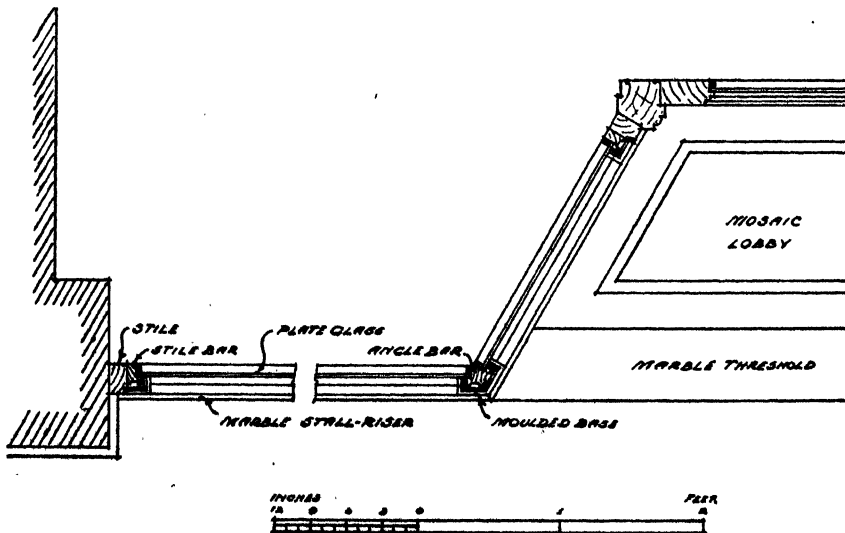


FIG. 4. SHOP-FRONT SASH

MODERN BUILDING CONSTRUCTION

The planning of the entrance doorway should be given careful consideration, particularly where only a small frontage is available and the method of sale is over the counter. Care must be taken to allow sufficient space for the wall

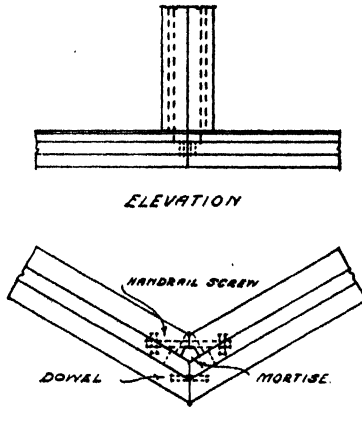


FIG. 5

fixtures, serving space and counter to be clear of the entrance; also, the door should be hung to open to give direct access to the counter.

DETAILS

Shop-front Sashes. The sashes are composed of a bottom rail, top rail, stiles, and angle bars. Transome rails may or may not be fitted according to height available or the display area required. Fig. 4 shows a half-sectional plan through shop front. In forming the sash the rails are mortised into the stiles and are mitred at the angles, the mitre being formed, as shown in Fig. 5, with a double-nutted handrail screw; a small dowel being used in the front to prevent twisting. The angle bars are then mortised into the rails, the bottoms of stiles and angle bars being fitted with moulded bases scribed to fit.

Where an extensive front is being formed, it is sometimes fitted with centre bars or mullions in order to reduce the length of the plate glass. The mullions are moulded to match the remaining bars, twice rebated for glazing, and are mortised into the rails.

Fig. 6 shows a vertical section through shop-front sash. It will be noted that stiles and angle bars are of quite light section; it is, however,

only necessary that they should be of sufficient size to secure the glass, as there is no question of any super-imposed load. The size of the members of the shop-front sash will, however, be varied to suit the general design. Many fronts are now being constructed without angle bars, the plate glass being carefully fitted and

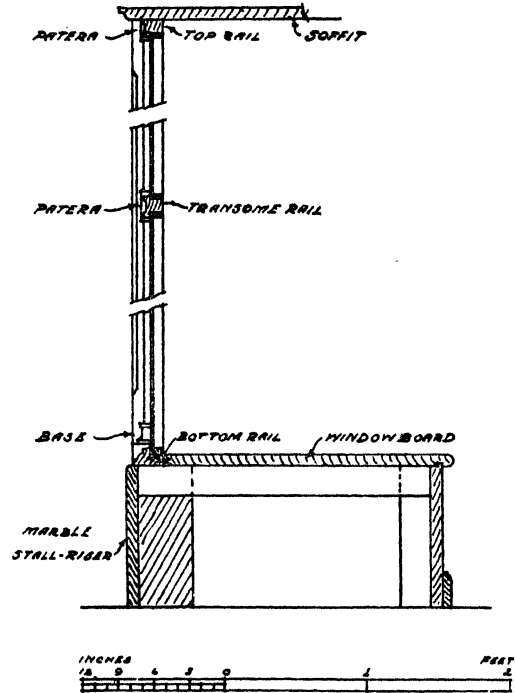


FIG. 6. SHOP-FRONT SASH

secured with small metal clips at the angles. This method is not to be generally recommended, as, unless exceptionally well constructed, the windows are not dust tight.

Shop-front sashes are generally constructed of hard wood, such as oak or mahogany, or in metal. Where metal is used the construction is practically the same as in wood, as the mouldings are formed in oak as a core and sheathed with metal as a facing. The junctions of transome and top rails with stiles and angle bars are then generally covered with a cast metal patera or boss, which is scribed to fit and screwed in position. The bases of stile and angle bars are fitted with a cast metal base scribed around mouldings and screwed on. Before bases or paterae are screwed they should be carefully counter-sunk, so that the metal

screw heads may be partially filed off so as to appear more or less invisible.

Glazing. Shop fronts should be glazed with polished plate glass at least $\frac{1}{4}$ in. thick. The glass is generally well bedded in coloured putty into the rebates, and secured with hard-wood beads, which are screwed on, the beads being fitted with small brass cups to take the screws. A better method is to set the glass in wash leather, as this gives a greater resiliency and takes up the vibration better than putty. Plate glass need not necessarily be used above the transome rails as this portion is not often used for display purposes, and can be divided into smaller sections which may be glazed with leaded lights or figured glass.

Stall Risers. The risers between the bottom rails of shop-front sashes and the paving are known as *stall risers*. They may be formed with various materials, such as wood panels, marble, granite, tiles, or various compositions. Where tiles are used, a brick or coke breeze backing should be formed; this backing is rendered and screeded in sand and cement to receive the tiling. Marble and granite should be treated in a similar manner, the joints being cramped and the material secured to the backing with small metal clips. Both these materials are frequently drilled for screws and secured to wood studding at the back. The screw holes are counter-sunk and afterwards filled in with coloured cement. This is a much cheaper method of fixing, but should not be employed in first-class work. Where marble or granite is used as a stall riser, it is usual to fix slightly in advance of the shop-front bottom rail, the top edge of the material being either chamfered or arched. Where a basement exists, it will be necessary to form a *bulk head* under the window board and allow for light and ventilation in the stall risers. This may be done by having openings cut in the riser and fitting glazed sashes or metal ventilators. Even where there is no basement it is advisable to allow for ventilation through the stall risers, as this enables the window to be ventilated through the window board, thus preventing condensation.

Lobbies. Shop lobbies should be formed with a solid foundation of at least 4 in. concrete, screeded with sand and cement and finished with tiles, mosaic or composition flooring. It will generally be found that the shop floor-level is above that of the pavement, and the lobby should be laid to a fall where possible to obviate

the necessity of a step. The fall should not exceed one in ten. The entrance to lobby should be fitted with a marble threshold to prevent the tiles or mosaic breaking away.

Entrance Doors. Shop doors should be constructed of material at least 2 in. thick. They may be of very varied design, but it is usual to form them as two-panel doors, the lower panel being constructed in wood and the upper panel glazed. They should be fitted with dead mortise lock, ball catch, barrel bolts, and grip handles.

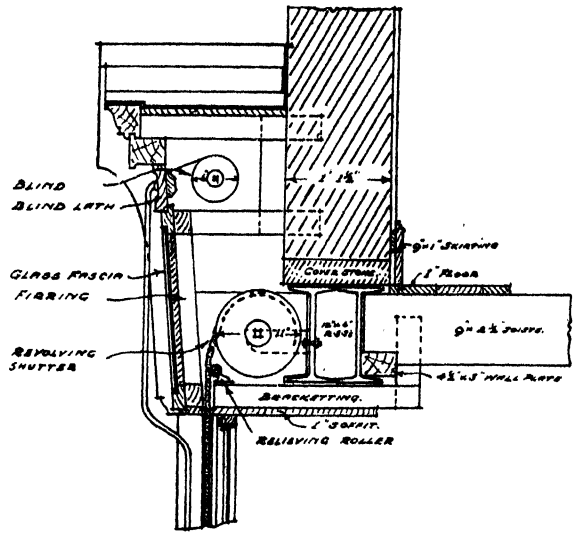


FIG. 7. REVOLVING SHUTTERS

Window Boards. These are built up with deal studs and small joists secured to the shop flooring, the joists being covered with 1 in. or $1\frac{1}{4}$ in. flooring. The flooring may then be covered with linoleum or finished with polished parquet. Many window boards are finished to the glass line with polished sloping hard-wood risers, as this gives a much better appearance and provides a very satisfactory surface for advertisement purposes. The back of the window board to the floor-level may be finished with wood linings and skirtings or panelling. Where the height of window boards permit, it is often desirable to provide opening or sliding sashes, the space below the window boards being utilized for storage purposes.

Fascias. Present-day shop properties are often designed with a stone or, in some cases, a marble fascia, and in this case they are generally fitted with either wood or metal letters.

MODERN BUILDING CONSTRUCTION

Where the fascia does not form part of the building work, it is, however, usual to fit either a wood or a glass fascia. Wood fascias are generally written in coloured or gilded lettering. Glass fascias are constructed with a hard-wood frame and deal back board and are glazed and beaded in from the front. Care should be taken to provide small fillets between the glass and back board to allow for condensation. The glass is generally of clear plate, the outline of lettering being formed with a burnished gold line with white or coloured filling and the ground painted in contrasting colour. This type is known as a *written glass fascia*. Another type is known as an *incised fascia*. In this case, a hard-wood back board should be fitted, in which the lettering is incised and enamelled or gilded, the outline corresponding with the outline of lettering on the glass; the lettering on the glass being left clear to show incised work. A third type of glass fascia is formed with white or coloured opaque glass, which is drilled and fitted with wood or metal letters screwed on with rubber washers between.

Fascias are secured above the shop front to *furrings*, or *furrings*; the top of the furring pieces is generally secured to a bearer built into the wall above the front, the lower portion being screwed to a plate bolted on to the girders supporting the superstructure. The fascias are secured by means of screwing to the furrings through the back board before being glazed. Where shutters are being fitted, it is usual to fix these behind the fascia in order to save loss of height in the shop front; the method of construction will then vary according to circumstances, one example being shown in Fig. 7.

Sun Blinds. Where revolving shutters are not being used, it is advisable to fix the sun blind below the fascia, as this enables the fascia to be seen when the blind is down. Where shutters are fixed it is more usual to arrange the blind box above the fascia.

Sun blinds to shop fronts consist of the blind box, metal spring roller, lath, blind cloth, and irons. The roller is suspended in the box by a central spindle, which is square on the ends and fits into small metal socket plates at the ends of the box. The canvas is sewn around the cylinder, the other end being secured to the blind lath by a fixing batten. The blind lath is secured at each end with the blind irons, which are in turn fastened to the pilasters at the side of the shop front or on the shop-front stiles.

It should be noted that sun blinds are subject to various regulations in different districts, the general rule being that when down the lath shall be at least 7 ft. above the pavement and 2 ft. 6 in. from the edge of the pavement. It will therefore be realized that where the height of the blind box is restricted, it will be necessary to provide slides on the side pilasters, in order to obtain the required projection from the front and maintain the necessary height from the pavement to comply with the regulations of the district.

Revolving Shutters. These are fitted to shop fronts as a protection against damage and burglary. The ordinary shutter is constructed out of wood laths from 2 in. \times $\frac{3}{4}$ in. deal. They are generally constructed in sections about 6 ft. or 7 ft. long. Greater lengths should be avoided on account of the weight and difficulty of operation. A separate section should be formed over lobby entrances, this section being fitted with a wicket gate. The shutters are composed of a number of laths which are rounded on the top edge and grooved on the lower. They are connected together by means of thin metal chain hinges, the back of the lath being chased so that the chain hinge may be screwed on flush. These are connected to the shutter coil by means of a small metal clip, which is riveted and soldered to the coil, the hinges of the shutters then being secured to clips with hinge pins. The shutter coil is composed of a metal cylinder fitted with central spindle, blocks, and coil spring. The spindle projects from each end of the cylinder, the projecting parts being made square to fit into sockets secured to strong brackets or cheeks at each end. When the shutters are drawn the spring is in tension, so that this helps to take the weight of the shutter when they are lifted. It is, however, generally advisable to place a certain amount of tension on the spring in addition to that given when the shutters are pulled down, as the latter is not normally sufficient to cause easy raising. The shutters are made to run in grooves at each end, the extreme ends running in steel shutter guides or channels fixed to the pilasters on each side of the shop front. Portable pilasters are fitted between sections, these usually being constructed out of 4 in. by 2 in. timber, grooved on each edge and fitted at the top with a metal stud which sets into a socket formed in the soffit. The lower back face of the portable pilaster is fitted with a barrel bolt which lets into sockets into the pavement. At a suitable

SHOP FRONTS AND FITTINGS

height from the bottom, a back plate is fitted which projects on each side of the pilaster and is drilled for bolts, which pass through from the front faces of the shutters and are secured with wing nuts to prevent shutters being raised. The section for entrance lobby is, as already mentioned, fitted with a wicket gate, the shutter

tised and tenoned together, short lengths of shutter laths being planted on the face. The gate is fitted with lift off butts and night latch or padlock as required.

The method of fixing the shutters will vary according to the particular conditions. It is really a question of constructional design

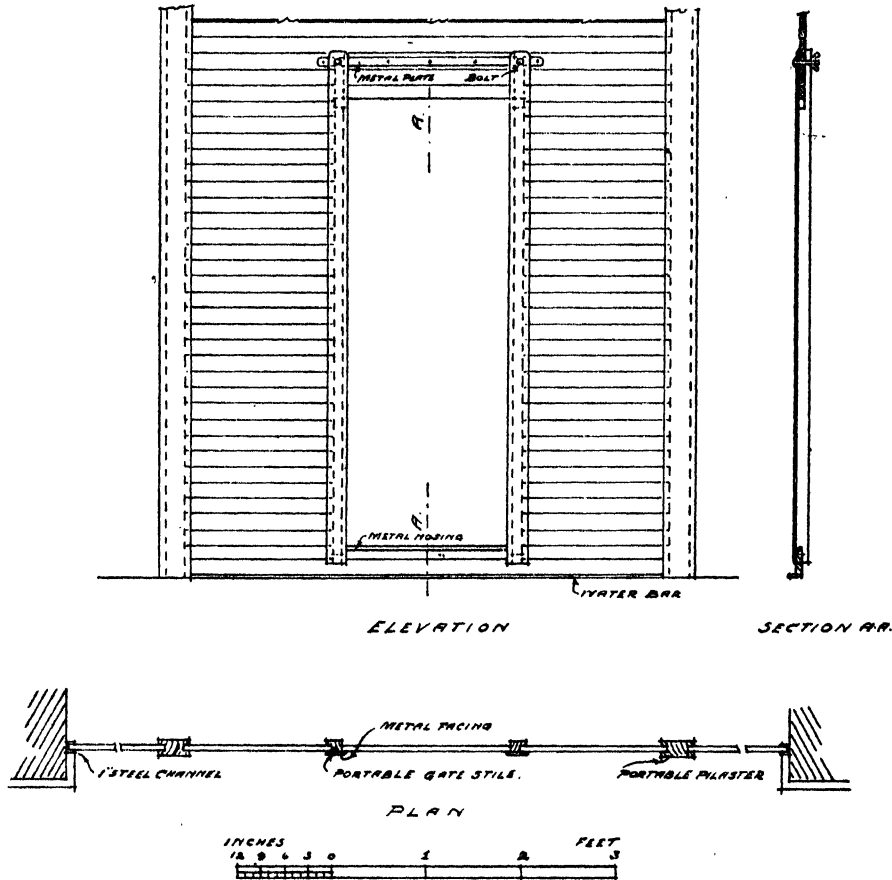


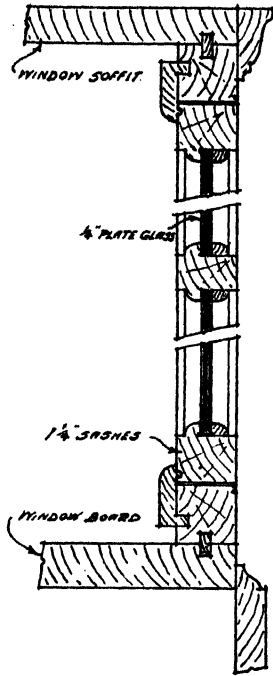
FIG. 8. WICKET GATE

laths being cut out above the bottom rail to form a small opening, as shown in Fig. 8. This opening may vary in size according to requirements, but should not normally exceed 4 ft. 9 in. in height and 2 ft. in width owing to the consequent weakening of the shutter. The opening when the shutters are drawn is fitted with portable door stiles on each side which project below and above the opening, thus enabling bolts to be fitted through the stiles and shutters and secured on the inside with wing nuts. The wicket gate is formed with a back frame mor-

rather than any specific rule, but an example is shown in Fig. 7. It may be reckoned that shutters require an inch to every foot of their height, so that where the height is 11 ft. from the pavement to the centre of the shutter, the complete coil will take up approximately a diameter of 11 in. Where the height of fronts is limited, it is a great advantage to fit the shutters in front of the steel girders or bressummer supporting the superstructure if possible, but this can only be done where the consequent projection will not exceed that laid

MODERN BUILDING CONSTRUCTION

down in the London Building Act or local by-laws. In the London area, where the street is under 30 ft. in width, the total projection of fascia or cornice for shop fronts must not exceed 13 in., but if the street exceeds 30 ft. the



VERTICAL SECTION.



HORIZONTAL SECTION

FIG. 9. WINDOW ENCLOSURE: AIRTIGHT PRINCIPLE

projection allowed is 18 in. over the ground of the building owner.

Window Enclosures. Enclosures to the windows will be constructed according to the design or special requirements; for instance, they are sometimes required to be carried to the full height between the window board and ceiling-level, or may be dwarf enclosures, these latter being frequently used in costumiers' and milliners' shop fronts. Where dwarf enclosures are fitted, they may be constructed with sliding sashes, since there is no question of the window requiring to be kept dust-tight. Jewellers' windows should always be fitted with enclosures

constructed on the air-tight principle, an example of which is shown in Fig. 9. The ordinary enclosure is constructed with a moulded and rebated frame and twice rebated transome. The lower portion is fitted with opening sashes,

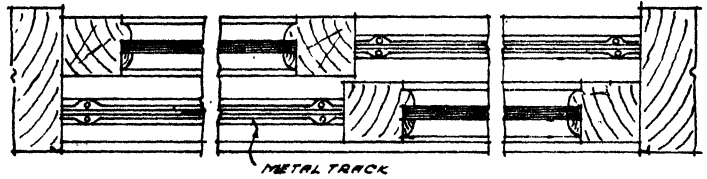
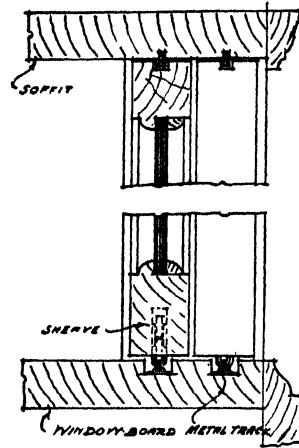


FIG. 10. SLIDING SASHES

which, owing to the comparative lightness of construction, should not exceed 5 ft. in height unless the sash is strengthened with a lay bar. The upper section of enclosure frame may be either fitted with fixed framing or a further set of opening sashes as required. Sliding sashes are constructed in the usual manner, except that the top rail is grooved to slide along a small tongue let into the underside of transome or top rail of the framing, as the case may be, the bottom rail of the sash being fitted with small ball-bearing sheaves or wheels to run on a metal track, which is screwed to the flooring, as shown in Fig. 10.

SHOP FITTINGS

Show Cases. Show cases comprise a very considerable range, of which there are more or less standard types. They should, however, be constructed with a minimum of woodwork and a maximum of glass, in order to give the fullest

vision of the articles shown therein. It should therefore be remembered that the glazing bars are used solely for that purpose, and do not need to be of heavy section, as, when they are glazed with $\frac{1}{4}$ in. plate glass, the frame is kept quite rigid by the glass itself.

Show cases, as apart from wall cases, should always be constructed with access at the back,

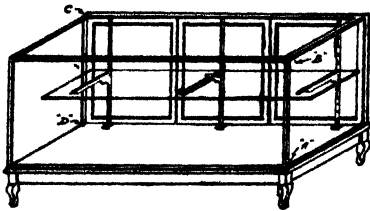


FIG. 11. FLOOR CASE

so that the framing of the sash does not cause any obstruction to the view.

The show cases most generally in use are the *Floor Case*, *Silent Salesman*, and the *Centre Case*.

FLOOR CASES. These are constructed in various lengths, 3 ft. high, and 2 ft. back to front (see Fig. 11). The case itself is approximately 2 ft. 3 in. high, and is fitted on a portable stand about 9 in. high, which is formed with four

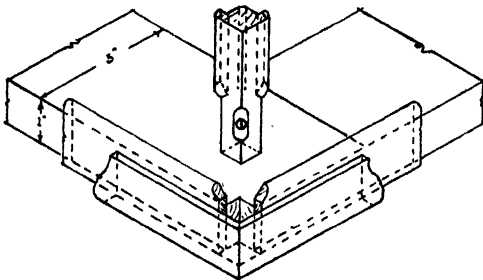


FIG. 12. DETAIL AT "A"

corner legs and $2\frac{1}{2}$ in. \times 1 in. rails, the rails being dove-tail housed into the legs; or, in cheaper-class work, dowels are used in place of the dove-tailed housing. The method of construction is shown in Figs. 12 to 15. The bottom of the case is made up of 3 in. \times 1 in. framing, mortised and tenoned or dowelled together and covered with a polished plywood lining or parquet, the glazing bars, top rails and mouldings being built up and fitted around this base as shown. The glazing bars are usually $\frac{1}{2}$ in. \times $\frac{1}{2}$ in., and the back rails $1\frac{1}{2}$ in. \times $\frac{1}{2}$ in. The case may be fitted with opening,

sliding or air-tight sashes as required, and the sashes glazed with mirrors with plywood panel backs or clear plate glass. When sliding sashes are fitted, it will be necessary to have 3 in. back rails instead of $1\frac{1}{2}$ in., to allow for the passing, one behind the other, of the sashes. Sliding

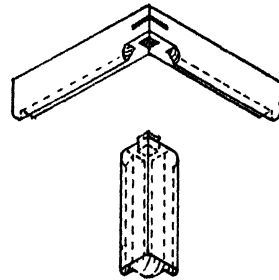


FIG. 13. DETAIL AT "B"

sashes should not normally be fitted except for reasons of lack of space, as they are not dust-tight. These cases are usually fitted with one or more shelves which are supported on adjustable brackets secured to tapped standard bars; the latter are screwed to the flooring at the back

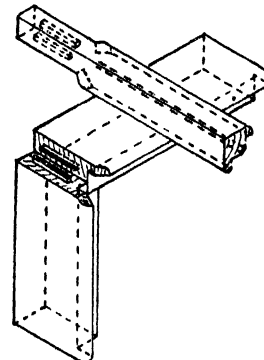


FIG. 14. DETAIL AT "C"

of the case and the under-side of the top back rail.

SILENT SALESMAN (see Fig. 16). This is usually 2 ft. square on the base by 6 ft. high. It is constructed in a similar manner to that shown for the floor case, but the shelving is supported on small angle brackets secured to the back of the glazing beads, or tapped bars may be screwed to these beads for the full height of the case and fitted with adjustable brackets. This type of show case is very useful where space is limited, owing to the small space which it takes up and because of its portability.

MODERN BUILDING CONSTRUCTION

CENTRE CASES. These are also constructed as described for floor cases, but are made in various sizes, a usual one being 4 ft. long, 20 in. back to front, by 5 ft. high. These cases are often used as a show screen, being suitable for placing opposite the entrance doorway. They

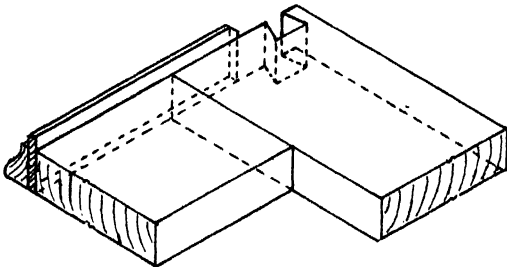


FIG. 15. DETAIL AT "D"

are particularly suitable for the boot and shoe trade, where it is desirable to obstruct the view when customers are being fitted. When used for this purpose the sashes at the back should be glazed with mirrors, or fitted with wood panels; the portable stand being constructed with a

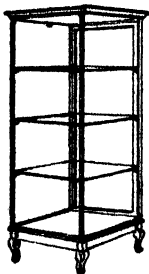


FIG. 16
SILENT SALESMAN

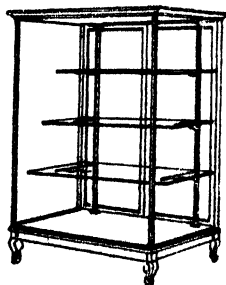


FIG. 17
CENTRE CASE

skirting instead of corner legs. These centre cases are often varied by fitting a convex front. (See Fig. 17.)

Counters. Various types of counters are in use, the principal ones being: panel-fronted wood counters, marble counters, and show-case counters.

PANEL-FRONTED COUNTERS. These are normally constructed 3 ft. high and 2 ft. back to front, and in varying lengths. They may be formed with rebated rails, stiles, and muntins, with moulding planted on around panels, or the mouldings may be worked on the solid. The panels may be of solid construction or three ply, the latter now being used for this purpose to a very great extent. The fronts and return ends are fitted with moulded skirtings, the top generally being of 1 in. material thickened with thumb moulding along the front and return ends. The back of the counter is fitted with flooring about 3 in. from the bottom, with a skirting board below, this flooring being known as the *pot board*. The remaining portion is then fitted up with open shelving or drawers as required.

MARBLE COUNTERS. These are more particularly used by specific trades such as dairies, provision merchants, and restaurants. They may be built up with a wood framing and the marble screwed on, the screw holes in the marble being counter-sunk and afterwards plugged with coloured cementing material, or they may be built up on a coke breeze backing. The front and return ends are generally panelled out with panels of a different colour to the surrounds and fitted with a chamfered or moulded skirting. The counter top should be of $1\frac{1}{4}$ in. marble, with moulded front and return ends.

SHOW-CASE COUNTERS. These are now largely replacing the wooden panel fronted type, the glass floor case being frequently used for this purpose, but where used as such the sashes at the back should either be fitted with wood panels or glazed with mirrors in order to prevent a direct view through. These cases are often fitted up as quick serving counters, in which event they are fitted with trays which are open at the front but are constructed to draw out at the back in a similar manner to the ordinary drawer. Between each set of trays is fitted a triangular-shaped framing which has small bearers planted along each side to act as runners for the trays. It will be noted that as the skeleton framings are triangular in shape, the trays, when viewed from the front, will set back in each tier so that the lower ones are visible.

Another type of show-case counter is generally used for chemists' shops. It is fitted up as an ordinary wood counter, with shallow cupboards in front, approximately 6 in. back to front, which have glazed opening sashes.

