ACOUSTICS

By the same Author

VENTILATION, INCLUDING AIR CONDITIONING
CHIMNEYS AND FLUES
PRACTICAL BUILDING TERMS
THE PRINCIPLES OF PLANNING BUILDINGS
THERMOMETRIC CONVERSION CHART

ACOUSTICS

A HANDBOOK FOR ARCHITECTS AND ENGINEERS

by

PERCY L. MARKS

REGISTERED ARCHITECT

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“ The sound must seem an echo to the sense ;
Soft is the strain when Zephyr gently blows.”

ALEXANDER POPE

PREFACE

In submitting this book to the public, it will become evident upon reading it, that, so far from any endeavour being made to deal exhaustively with the subject of Acoustics, the author has devoted his attention to presenting mainly a basic consideration.

Before going further, it is desirable to call readers' attention to the important nature of the contents of the Appendixes, which deserve to be consulted equally with the general body of the text.

Part I of the book is in the main composed of the views of those who have approached the subject of Acoustics by way of research; the contents of Part II are excerpts from literature embodied in the very informative booklets issued by firms associated with various systems or materials of an acoustical character. But it is not suggested, that the publications of further firms might not have (indeed, would not have) furnished additional valuable information, and from the ready response with which the author met such co-operation would probably have been experienced, as in the case of those who complied with the request for information.

It is necessary to remember, that until within recent years the treatment of Sound problems was largely empirical, and the success attained with the acoustical conditions of a few buildings, such as, for example, the Free Trade Hall in Manchester, may have been fortuitous, more or less. At the same time, it is not to be overlooked, that in the days of Classic practice a knowledge of the science of Acoustics obtained, which only the subsequent period of the Dark Ages allowed to pass into oblivion.

To-day, however, the scientific approach to the subject under consideration is fully in evidence, and intensive progress assures, that the period of mere empiricism has passed. The result is, that acoustical satisfaction may be almost as fully anticipated to-day, as we have learnt long since to expect in regard to structure and sanitation. It is surely preferable, that Sound insulation and Sound transmission should be pre-arranged properly, than that they should be the subject of later adjustment. Truly, prevention is better than cure.

The author must gratefully acknowledge the great kindness of Dr. L. E. C. Hughes in reading through the manuscript of Part I, and offering valuable suggestions. The Department of Scientific and Industrial Research gave permission for introducing its valuable "Notes upon the Design of concrete floors to reduce the Transmission of Sound," together with the diagrams, and furthermore offered to supply additional information, if desired. Whilst such, and similar, offers, were highly appreciated by the writer, advantage of them has not been taken, since for a book professing no more than to afford a general survey, the multiplication of details was preferably to be avoided.

Two of the Appendixes to which special attention may be here directed are: (1) that containing extracts from Professor Floyd Watson's well-known work, "Acoustics of Buildings," including three charts, and (2) the extracts (amounting to the bulk of the article) from Mr. Frederick Gibberd's contribution to the "Architects' Journal" for May 19th, 1938, on the treatment of new flats for acoustic satisfaction. In this connection, too, thanks are accorded to the proprietors of the journal for permission to make use of the article.

The following, also, were equally responsive to the author's request for specific extracts from their writings, with use of sundry diagrams: Dr. A. H. Davis, Mr. C. W. Glover, Mr. A. G. Huntley, Dr. N. W. McLachlan, Dr. G. A. Sutherland and Dr. Albert B. Wood. And final mention of thanks must be made to the Royal Institute of British Architects and to the proprietors of the "Architect and Building News" for permission to use some of the above contributions.

PERCY L. MARKS.

10, Matheson Road,
West Kensington, W.

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ACOUSTICS

PART ONE

It may not be a matter of particular moment, but it will be as well to commence this short treatise with a very few words as to the desirable pronunciation of the word associated with the subject. Both " er-cows'-tix " and " er-coohs'-tix " are recognised as being correct, but the former should be preferred as emphasising the derivation of the word from the Greek ἀκούειν = to hear.

The signification of Acoustics is the science of sound, and its consideration must follow along various paths, principally, however, accepting the classification (*a*) positive and (*b*) negative. Positive acoustics implies the provision of sound waves along particular routes, whereas Negative acoustics, on the other hand, implies the prevention of sound waves from entering defined areas.

Sound is mostly propagated by *waves* of vibration. Lord Rayleigh, in his invaluable book, " Theory of Sound," points out, that it requires almost as extreme conditions to produce rays in the case of Sound as it requires in Optics to avoid producing them. Sir Isaac Newton demonstrated, that the propagation of Sound waves depends upon the elasticity of the conducting medium; the sound-source condenses the adjacent portions of the medium and *almost* simultaneously drives them backward and forward. Each separate portion is thus moving to and fro, and this brings about alternate condensation and rarefaction, thus creating Sound waves. The humidity of the atmosphere is also considered as favouring the propagation of sound.

It is necessary to differentiate between sound and vibration. Though the former is necessarily accompanied by, or rather is the result of, vibration, it does not follow that the latter produces sound. As Pietro Blaserna observed in his book on the subject, Vibration is *objective*, existing in sounding bodies independently of a listener; whereas Sound is *subjective*, being produced in the ear. For a deaf person vibration is a fact but Sound does not ensue, and thus it may be noted, that vibration is the cause, and ensuing sound is the effect.

According to Sir Christopher Wren, a Frenchman can be heard at a greater distance than an Englishman, as the former raises his voice towards the end of a sentence, as distinguished from the method of voice production by the latter.

The medium for the conveyance of vibrations may be either liquid, gaseous or solid. Professor Roger Smith, who devoted considerable attention to the science of Acoustics, wrote, " The sense of hearing is really a refined and delicate sense of touch, and the impressions made upon the ear are due to actual motion made sensible through a conductor. Any medium which conveys the sensation of motion to the ear conveys the sensation of sound." This must be read as implying not merely the conveyance of the sensation of motion, but its conveyance to the *ear*. On the other hand, it might be gathered from what was said above, that the origination of sound is unassociated with its reception aurally; and further it might perhaps be urged, that vibrations taking place in a sound-producing body or medium, Sound follows the vibration, whether audible or inaudible. In truth, the argument on either side does not seem to be capable of proof in the present state of knowledge.

It may be argued on the one hand, that if some material object—say, a church—is erected, it exists, if only as a general sensation, and whether or not anyone beholds it; therefore, mutatis mutandis, as vibration originates sound, the latter follows the former inevitably irrespective of whether or not anyone hears it. The argument may be carried even further; for let it be supposed, that there is a heavy surge of the ocean and a pedestrian hearing the plash of the waves gradually recedes from the shore until quite out of hearing, but at the very moment when the sense of audition is lost let it be supposed, for argument's sake, that another pedestrian enters within range of the vibration and that consequently the sensation of sound is continuous. When, however, this second pedestrian passes out of range it may be further assumed, that an interval occurs before any other pedestrian takes up the audition actively, though there may be, argumentatively, a deaf person on the sea-shore hearing nothing whatever. Had the last-named possessed the sense of hearing, the audition would still have been continuous. What is the fair inference to be drawn? And yet, if sound is truly only a perception, how can there *be* Sound where there is no perception? It is much to be feared, that the problem must be left unsolved.

Herschel noted, that the intensity of Sound in receding from the source of origin decays as the square of the distance increases, and that its intensity increases with the increasing density of the air. It travels one-millionth the rate of light, and at a uniform rate for any particular temperature, though its intensity, or strength, is constantly diminishing. Its rate of progression, however, varies according to the temperatures through which it is passing, and varies also with the transmitting medium. At 32° Fahr. the velocity of sound through air is nearly 1,100 feet per second (that is, about 750 miles per hour). As an approximate memorandum it may be accepted, that the velocity in feet per second is in direct ratio to the temperature difference in degrees Fahrenheit; that is to say, there is roughly one foot difference in velocity for each degree difference in temperature on the Fahrenheit scale, for rise or fall. This is, however, not *quite* accurate, and it will be better to state, that for every ten degrees on that scale there is registered a rise or fall respectively of eleven feet. The velocity of sound through other media than air is mostly much more rapid, but in the case of iron it tallies very closely. Through water the velocity is between three and four times greater.

Regarding audition it has been demonstrated, that, with a minimum of thirty vibrations per second *audible* sound is produced; in other words, whilst some consider, that sound needs the precedent condition of a susceptive ear, the opinion apparently prevails, that sound exists when the vibrations are fewer than thirty per second, but that it is, as it were, more or less, latent. Whilst the view that sound is the outcome of a susceptive ear seems eminently practical, the idea as to latency is certainly disputable. Sound is a form of energy and is indestructible in the sense that energy itself is indestructible. But it seems more rational to submit that the energy which may produce sound may also in turn transform it into another condition where it may be heat or perhaps some other form or state, no longer existing as sound. It appears to accompany nearly all motion, and it may be readily conceived, that there are, in fact, movements of too feeble a character to be capable of reception by some, indeed by many, ears, though quite audible to more delicately sensitised hearing apparatus. Consequently, it may be accepted, that there is a great deal of what may be termed acoustic relativity that must be taken into account. " Eyes have they but they see not, ears have they but they hear not " does not merely apply to idols.

The following excerpt from a paper written by Dr. G. A. Sutherland, for the R.I.B.A. Journal, may be quoted here: " If to a balloon or bubble containing a mixture of oxygen and hydrogen in suitable proportions a flame be applied, a sound is heard by everyone in the room in which the experiment is performed. The chemical union of the gases produces a sudden evolution of heat, and this heat causes the gases to expand. The sudden expansion of the sphere produces a compression in the shell of air just surrounding it, and this shell, being elastic, on recovery passes on the compression to the shell of air next outside it, and so the compression travels outwards in ever-widening spherical shells until it impinges on the tympanum of someone's ear, and the sensation of sound is experienced. The expansion of the original gases leaves a void or rarefaction behind, and in recovering from their compression they overshoot the mark, and by a repetition of the process the rarefaction is propagated outward on the heels of the condensation. The condensation and rarefaction together constitute what is called a wave of sound . . . When a source commences to emit sound waves, the sound heard first of all grows in intensity, and during this growth the rate of emission is greater than the rate of absorption. Then a maximum is reached, and in this condition energy is being emitted and absorbed at the same rate. This condition persists until the source is stopped, when the absorption continues, and the sound gradually dies away to inaudibility. Both the growth of the sound and its decay are due to the many reflections it undergoes."

In the present book it is intended to exclude all excepting the most casual references to open-air conditions. Bearing this in mind, it may be now noted, that were sound to proceed towards the auditor from one direction only, its practical treatment would be simplified. As matters are, however, there are various paths which it takes, namely, the straight route forward from the originating source, and its reflection from different lines, including the flanks, and top and bottom surfaces of the apartments, not overlooking that from behind the Sound source.

Mr. C. W. Glover, in "Practical Acoustics for the Constructor," remarks, "The ear perceives on a logarithmic basis, and one hundred musical instruments only sound twice as loud as ten; one thousand instruments only three times as loud as 100, and so on." One effect of inadequate acoustical adjustment is, that a speaker's voice does not carry properly; in consequence, a practised orator will test the acoustical condition when commencing to speak, by giving utterance to some unimportant matter in testing the voice for satisfactory pitch.

Regarding reflection it is generally accepted, that this must act not later than about one-fifteenth of a second after the original utterance, so that Echo may not ensue. Accepting the velocity of sound through air at approximately 1,100 feet per second, a travel of about 75 feet obtains as being the limiting distance desirable between the source and the audience, whether the latter consist of one individual or of many.

The following brief extract is quoted by permission from the "Encyclopædia Britannica": "The chief conditions for good hearing in an auditorium are (1) loudness should be adequate, (2) no perceptible echoes or focussing, (3) no undue reverberation, that is, each speech sound should die away quickly enough to be inappreciable by the time the next is uttered, (4) where the best music is concerned the hall should be non-resonant and as uniformly reverberant as possible for sound of all musical pitches and (5) the boundaries be sufficiently soundproof to exclude extraneous noises."

In order to render an auditorium (using the word in its widest significance) acoustically satisfactory, the reflective action from one utterance must have ceased before the next utterance commences, so that confusion may not result, for such confusion is apt to occur, when a number of notes or syllables follow each other in too rapid succession.

Dr. G. A. Sutherland notes that " the splaying of the side walls may be of advantage, since it reflects some of the sound to the seats at the back of the room, instead of to the front, where it is not required. The most suitable angle for the splay will be that which confines the reflected sound as far as possible to the part of the room where it is most needed."

Before dealing with other points, some remarks upon echoes may well find a place here. The late Professor Wallace C. Sabine thus defined it: " The term echo will be reserved for that particular case in which a short, sharp sound is distinctly repeated by reflection, either once from a single surface, or several times from two or more surfaces."

Dr. G. A. Sutherland describes it thus: " Echo, in its simplest form, is a doubling of sound. The ear seems to add up impressions reaching it within about a twentieth of a second, but any sound reaching it after that is in the nature of a confusion. If the following sound is at all comparable in loudness with the original sound and is delayed by as much as a fifteenth of a second a distinct doubling will be heard; even before this condition is reached some confusion is apparent."

It would seem to the present writer, that no such exact conditioning as to time period can be established beyond dispute, but all the same, it is desirable that some such period should be in general accepted as a useful guide.

Let a quotation from Professor Floyd R. Watson's valuable work "Acoustics of Buildings" be now entered: "An echo is set up by a reflecting wall. If an observer stands some distance from the front of a cliff and claps his hands, or shouts, he finds that the sound is returned to him from the cliff, as an echo. So, in an auditorium, an auditor near the speaker gets the sound first, directly from the speaker, then, an instant later, a strong repetition by reflection from a distant wall. This echo is more pronounced if the wall is curved and the auditor is at the point where the sound is focussed. An echo becomes noticeable when the interval of time between the reception of the direct and reflected sounds is about one-sixteenth of a second, *although this varies with the individual.*" (The italics are the present writer's.) "This would correspond to a difference in path between the direct and reflected sound of about 60 feet. Practically, in an auditorium, this value may be extended to a somewhat greater value, perhaps 75 feet . . . Echoes are very annoying and, as a defect, may be considered second in importance to reverberations. Two methods may be considered in correcting them. One method consists in changing the form of the wall, so that the reflected sound no longer sets up the echo. This is done either by changing the angle of the wall, so that the reflected sound is sent in a new direction, where it may be absorbed or where it may reinforce the direct sound, or else by modifying the surface of the wall by relief work or by panels of absorbing material, so that the strong reflected wave is broken up and the sound is scattered. The second method is to make the reflecting walls strongly absorbent, so that the incident sound is weakened and little or none reflected. These methods have been designated as ‘ surgical ’ and ‘ medicinal ’ respectively. Each method has its disadvantages : changing the form of the walls in an auditorium is likely to do violence to the architectural design ; on the other hand, there are no perfect absorbers, except open windows, and these can seldom be used. The correction in each case is, then, a matter of study of the special conditions. Usually a combination of surgical and medicinal procedures is adopted. For instance, coffering a wall so that panels of absorbing material may be introduced has been found to work well in improving the acoustics ; also, in many cases, it harmonises with the architectural features.”

Roger Smith defined Echo as a reflected repetition of an original sound heard sensibly *after* that sound. Mr. A. G. Huntley thus expressed himself in an article contributed to “ The Architect and Building News ” : “ In buildings having large seating capacity, it is at times impossible to keep the difference between the direct and reflected paths below 75 feet, and, therefore, conditions tending to produce echo will result unless precautions are taken. Also, perhaps, these surfaces cannot be made absorbent, as sufficient absorbing units are already present, so that a deadening effect would result if more were added. This difficulty is overcome by ensuring that the sound or reflection shall be dispersed in all directions, and this is brought about by coffering or otherwise breaking up the surfaces in question. To secure adequate dispersal it is important to see that the coffers or indentations are sufficiently deep or they will not be effective."

The *production* of an echo requires that the reflecting surfaces shall be sufficiently removed for the inducing sound to have died away before the reflected sound impinges upon the ear; for were the inducing sound still active at the time of reflection, the two sounds would mingle, and no echo would result.

It may be noted at this place, that where a physical obstacle has caused the deflection of a sound, which penetrates beyond the obstacle there may be observed a tendency for such sound to spread in a fan-wise formation, thus encroaching upon the so-called "Sound-shadows."

Acoustical corrections are not as a rule made in the case of small or unimportant apartments, as it may be remembered that Echo is not noticeable unless the reflecting surface is at least 45 feet distant from the inducing agency. In fact, it has been stated, that monosyllabic utterances need a minimum of about sixty feet and polysyllabic utterances fully twice that distance.

Woven fabrics of a porous nature encourage the gradual diminution of Sound-energy during successive reflections, and thus serve to lessen any hitherto prevalent Echo.

A very few lines respecting what has been termed "Interference" will suffice, the first quotation being from the late Professor Sabine's Collected papers, and introduced here by the kind permission of Harvard University: "During the constancy of an element, either of music or of speech, a train of sound-waves spreads spherically from the source . . . Different portions of this train strike different surfaces of the auditorium and are reflected. After such reflection they begin to cross each other's paths. If their paths are so different in length that one train has entirely passed before the other arrives at a particular point, the only phenomenon at that point is prolongation of the sound. If the space between two trains be sufficiently great, the effect will be that of an echo. If there be a number of such trains thus widely spaced the effect will be that of multiple echoes. On the other hand, if two trains have travelled to nearly equal paths that they overlap, they will, dependent on the differences in length of the paths which they had travelled, either reinforce, or mutually destroy, each other. So two sounds coming from the same source in crossing each other may produce silence. This phenomenon is called interference . . . Of course, it has its complement. If the two trains so cross that the crest of one coincides with the crest of the other, and trough with trough, the effects will be added together. If the two trains be equal in intensity, the combined intensity will be quadruple that of either of the trains separately, or zero, depending on their relative retardation. The effect is to produce regions in an auditorium of loudness and regions of comparative, or even complete, silence. It is a partial explanation of the so-called deaf regions in an auditorium."

And Dr. G. A. Sutherland thus refers to the phenomenon: "If two waves of any kind are superposed the resulting wave is an addition to the effects of both. Should the waves be of the same length and in the same phase—i.e. if condensation falls upon condensation and rarefaction upon rarefaction, then the result is an intensification of the sound. If, however, the waves be out of step by half a wave-length, so that the condensation of one falls on the rarefaction of the other, and *vice versa*, then, if the original intensities of the sounds be just equal, the two will neutralise each other, and there will be silence." This process of neutralisation, as has been said above, is known as *interference.*

A few remarks upon the quality of Resonance are due to be considered. It may be first postulated, that there has been more than a tendency to fail in discrimination between this quality and that known as Reverberation (which will shortly be taken under review).

As to resonance, Professor Sabine remarked, that it is "the growth of a vibratory motion of an elastic body under periodic forces timed to its natural rates of vibration." Mr. A. G. Huntley (before quoted) remarks upon resonance, using as an illustration an excerpt from Sabine's writings: "As an illustration of this, take a large bowl of water and strike the surface of the water in the centre with the palm of the hand. This will cause a wave to spread, which, reflected at the edge of the water, will return to the hand. If, just as the wave reaches the hand it again strikes the water, it will reinforce the wave, which going out stronger than before, returns again. It is evident that if this process is repeated a considerable wave can in time be created. It therefore follows that resonance will alter the total amount of sound in a room and will always increase it. From the foregoing it will thus be apparent that resonance is an important factor; but the difficulty is that a body is only resonant under those forces timed to its natural rate of vibration, and, therefore, as far as sound is concerned, will only reinforce certain tones of a complex sound, and consequently will exert an unbalancing and distorting effect. This action of resonance may also be caused by the air enclosed in a room, so that every room has a definite pitch to which it responds; the smaller its volume, the higher the pitch. Of resonating material used in building construction, wood is the most important, as, of course, it usually occurs in considerable areas, as, for example, in floors and panelling. As its coefficient of absorption is double that of ordinary plaster, its use as an interior finishing is of considerable value as an absorbent, also its general re-inforcing effect due to its resonance very much outweighs any disadvantage that may be produced by distortion. As an example, it is particularly useful in the construction of platforms. For platform construction, whether for speech or music, it has been found from practical experience that considerable reinforcement of sound can be obtained if the floor of the platform is of wood carried on at least 6 in. joists, thus providing a 6 in. air space below the floor. Also, when panelling is used at the back, and at the front between the platform and the main floor, it should be fixed as positively as possible both to the platform and in the latter case to the main floor as well."

Upon the same subject, Dr. G. A. Sutherland remarks, " A resonating body will perform the desirable function of acting both as an increaser of intensity and a decreaser of reverberation. The same will be true of forced vibrations, but in a much less degree. The resonator will be most effective when placed near the sounding body, and wood panelling should, therefore, be placed near the orchestra to get the best effect. In any case, it should not be placed too far from the orchestra, otherwise the direct and the resonated sound may reach part of the audience at such an interval of time that an echo or confusion results. Of course, any sound transmitted through the framework of the building will reach the audience practically as soon as the direct sound."

The higher the absorption factor is, the greater is the security against resonance. A high ceiling is apt to produce too much of this quality. Where there is too much, fabrics may be used advantageously to lessen it. Large spaces of air frequently become resonant, and this, whilst impairing distinctness of sound may yet improve its quality; so that it will be clear, that such large spaces are more objectionable where speaking is concerned, than where music is the main object. In fact, a degree of resonance is desirable in a music room.

At this stage some notes concerning Reverberation will be entered.

Dr. N. W. McLachlan thus defines it in " The New Acoustics " (Oxford University Press): " Reverberation can be defined broadly as the time taken for a very loud sound to die away to inaudibility after extinction of the source. It is dependent upon the absorption coefficients of the various materials which constitute the inner surfaces. The absorption coefficient is the ratio of the sound energy absorbed by a material to that impinging upon it, and varies with the angle of incidence."

The following is abstracted from a paper by Dr. G. A. Sutherland, contributed to the R.I.B.A. Journal: " The effect of reverberation on speech is easily understood. A speaker can deliver three syllables in a second. If the reverberation of a sound spoken in an ordinary tone of voice lasts for five seconds in any given room, then the sounds of fifteen successive syllables will be heard simultaneously, a state of affairs that militates quite intolerably against our second desideratum—viz. distinctness. Clearly, then, for speech reverberation must be reduced to the minimum consistent with adequate loudness. In a small room this should be less than one second. In a large room a longer period is tolerable, probably because in a large room the speaker realises the necessity of clear and slow enunciation. In music the case is slightly different. Reverberation produces an effect similiar to that of the loud pedal in a piano. Some prolongation and blending of notes in music is desirable, but the mixing of words in speech is never an advantage. If a hall is to be used for both, a middle course must be steered. The reverberation must be made somewhat too long for speech, somewhat too short for music, yet fairly satisfactory for both." Dr. Sutherland's definition of this quality is worth transcribing: "Reverberation is the persistence of sound with gradually decreasing loudness owing to successive reflections from the boundaries of a room with comparatively little absorption at each reflection, and produces a sort of undercurrent or background above or against which the sound has to be heard. Excessive reverberation is the commonest defect in an auditorium. The reverberant character of an empty house is well known and also the improvement that is effected by introducing furnishings."

Mr. A. G. Huntley, elsewhere quoted, may be also quoted here on this point: "It is a common thing to find a building with a reverberation of between 10 and 11 secs. (the building being, of course, empty). The confusion produced by such reverberation may easily be imagined when it is realised that the normal rate of speech is three to four syllables a second, so that in such a building, by the time a speaker has reached his 39th syllable the first one he uttered together with all the intermediate ones are each contributing their quota of sound, through and above which it is necessary to hear and distinguish the ordinary procession of the syllables . . . For music, a long period is necessary in order to give weight of tone, that is, to give the various tones time to blend, to enrich the whole volume."

Reverberation, as Sabine noted, is in direct proportion to the volume of an apartment and is inversely proportional to its absorbing power.

In an Appendix an extract, of too lengthy a nature for inclusion in the body of the text, will be found dealing with the problem of reverberation, permission for which has been obtained from the author, Professor Floyd R. Watson. (See page 109.) The following is an extract from Dr. A. H. Davis' valuable work, "Modern Acoustics": "As a matter of experience, it is generally agreed, that for halls of moderate size up to, say, 40,000 cu. ft. in volume, which are to be used for both speech and music, a standard period of about one second (calculated by the Sabine formula) represents the optimum condition when the audience is present. For a hall of 200,000 cu. ft. the preferred period is apparently about 1½ seconds, and for very large halls of 1,000,000 cu. ft. a period of approaching 2 seconds is indicated. Acceptable halls which are used for music alone appear to have reverberation periods some 25% greater than the values indicated above, and where speech alone is concerned, the periods may, with advantage, be less. Excessive reverberation is the more serious defect where speech is concerned; insufficient reverberation is unacceptable for music."

An excess of reverberation produces sound-reflection backwards and forwards without adequate reduction in intensity. Of course, a method whereby reverberation may be reduced consists in reducing the cubical contents of the apartments, or alternatively, in increasing the absorbent power of its details. Rooms which are badly proportioned or have plain unbroken surfaces are very subject to reverberation. Large lantern lights also may give rise to the same defect. Dampness, too, even if only temporary, may prove to be another source of annoyance, and it may be desirable in this connection to hang drapery on the walls of new houses whilst they are drying out.

Here follows a further quotation from the "Collected Papers on Acoustics," written by Sabine, dealing with the subject of reverberation: "In general, reverberation results in a mass of sound filling the whole room and incapable of analysis into its distinct reflections. It is thus more difficult to recognise and impossible to locate. In the general case of reverberation we are only concerned with the rate of decay of the sound. In the special case of the echo we are concerned not merely with its intensity, but with the interval of time elapsing between the initial sound and the moment it reaches the observer."

The Celotex Corporation, to whose acoustical products reference is made in a later portion of this book, includes in the attractive publication, "Less noise, better hearing," some interesting information; as the Corporation was good enough to forward this information to the present writer for him to extract such particulars as seemed to be desirable, the following remarks about the subject of Reverberation are abstracted from that source: "There are a number of factors which govern the choice of an acceptable reverberation time for a given room. Such factors include the volume of the room, the effect of the audience in changing the reverberation time, the range of audience sizes for which good acoustics must be provided, and the use to which the room will be put, that is, whether for speech or music, or both, and whether for direct or reproduced sound, or both. In general, a somewhat higher reverberation is desirable for music than for speech, for direct sound than for reproduced sound, and for organ, choral and heavy orchestral music than for solo and chamber music. However, in most rooms a variety of uses and audience sizes will be encountered. Moreover, considerable latitude in reverberation time is allowable without any noticeable effect on hearing conditions. For these reasons, the chart here given (Fig. 1) shows a range of acceptable reverberation times, rather than a single value, for rooms of different sizes. The values shown refer to the standard frequencies of 512 cycles per second, and may be used for any type of auditorium.

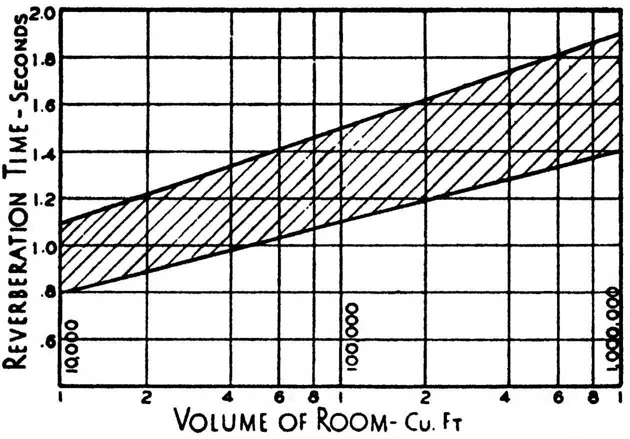

FIG. 1.—Acceptable reverberation times for Auditoria of different capacities. (Frequency of 512 c.p. sec.)
(*From a chart prepared by the Celotex Corporation.*)

For a given room an acceptable reverberation time should be chosen according to the probable use of the room as outlined above, and the correction should be worked out so that this time is obtained with an audience of the most probable size present. At the same time, the reverberation time for the empty room should be held below a certain upper limit in order to insure intelligibility of speech at all times. Experience, as well as tests on speech intelligibility, places this limit at 2·5 to 3 seconds."

One form of acoustical defect is what is termed Deadness. This is a form of voice-resistance, curable by improving the method of ventilation. Deadness may be regarded as the antithesis of echo, reverberation and resonance. Professor Floyd R. Watson, referring to ventilation in his book on " Acoustics of Buildings," remarks as follows : " Under special circumstances, the heating and ventilating systems may prove disadvantageous. A hot stove or a current of hot air in the centre of the room will seriously disturb the action of the sound. Any irregularity in the air currents that causes alternate sheets of cold and heated air to be set up will modify the regular progress of the sound and produce confusion. The object to be striven for is to keep the air in the room as homogeneous and steady as possible. Hot stoves, radiators, and currents of heated air should be kept near the walls and out of the centre of the room. It is of some small advantage to have the ventilation current go in the same direction as the sound, since a wind tends to carry the sound with it." (Note.—The last-mentioned view has, however, been controverted.)

Professor T. Roger Smith, a well-known architect and author of the middle half of the nineteenth century, wrote a book upon Acoustics, and respecting ventilation be made the following statements : " An ill-ventilated room is likely to prove bad for audition. Even a very gentle current of air exercises a strong influence upon the course of sound ; it will be better to avoid a current setting in from the direction of the audience or athwart the audience in favour of a current towards the latter from the direction of the speaker."

Dr. Sutherland, elsewhere quoted, remarks in this association, " Particular attention must be paid to ventilating ducts. They act like speaking tubes, and bends in them are not effective in preventing sound transmission. Acoustical attenuation may be obtained by using long ducts of small section lined with absorbing material."

It is natural for writers to refer to Vitruvius, whose general knowledge regarding matters affecting architects was of an extensive nature, and for want of record of any earlier investigator into the science of Acoustics, he is to be taken as the pioneer. Consequently the following brief quotation should prove to be interesting (it is an accepted translation from the original Latin text): "There are some conditions which offer obstructions to voice projection—(1) Interference, where the original sound strikes against solid bodies, and on reflection checks the rise of succeeding sound, (2) Reverberation, where the voice spreading in all directions is reflected into the centre, where it disperses, dying away in sounds of indistinct impression, (3) Resonance, where the voice encounters some solid body and, in reflecting, produces an echo; but with (4) Consonance (that is, agreement) the voice is strengthened and reaches the ear distinctly."

A few remarks respecting the proportioning of apartments for obtaining satisfactory acoustic conditions may be entered. Bad proportions induce reverberation, as the reflecting angles are not regulated to control the passage of notes. For concert halls, etc., the ratio of length to width to height has been advocated at 4 (or 5) : 3 : 2; for lecture theatres (where, of course, speech is the controlling factor) the ratio advocated is 4 : 3 : 2. The Manchester Free Trade Hall measures 135 feet by 78 feet by 52 feet (the ratio being about 5 : 3 : 2); the Royal Institution Lecture theatre is 60 feet by 45 feet by 30 feet (4 : 3 : 2).

As remarked in a pamphlet produced by May Acoustics Limited, "Uneven distribution of reflected sound is usually produced by the shape of the building. This may cause the sound reflected by the surfaces to be concentrated in certain places to the consequent detriment of the remainder. Alternately, the proportions may be such as to cause the sound reflected from one part of the building to react against the sound reflected from another." Mere approximation to advocated proportions has, curiously enough, been regarded as being worse than total disregard. The ratios of 1 : 1 : 2, 2 : 3 : 4 and 2 : 3 : 5 have been variously recommended, but the difficulty expressed by Sabine is one that must be remembered. " Such advice is rather difficult to apply," he remarks ; " should one measure the length to the back or to the front of the galleries, to the back or front of the stage ? Few rooms have a flat roof ; where should the height be measured ? "

When the important question of Absorption is approached, its direct association with the quality of Reverberation is made manifest. As is generally known, Professor Wallace C. Sabine was the modern pioneer in research work, having for its object the correction of acoustical defects, thus paving the way for meeting in advance the defects which so easily occur, and enabling architects to produce satisfactory buildings, instead of leaving to others the correction of their faults. The great desideratum is the adjustment of reverberation, and in recognising, that the latter and the degree of absorption are in inverse relation, the ground is cleared for satisfactory research.

In a series of experiments, Sabine was able to induce a relation between " t " as the time of reverberation expressed in seconds, " V " as the volume of the auditorium expressed in cubic feet, and " a " giving the absorbing power per square foot of the various materials or objects affecting the acoustical relations.

Thus he finally obtained the relation, $t = \cdot 05\ Va$, or it may be stated this way:

$$\frac{\text{Absorbing power} \times \text{Time of reverberation}}{\text{Volume}} =$$

a constant quantity.

As Professor Floyd Watson points out, "For good acoustic conditions, the time of reverberation should be short, and therefore the volume of the auditorium should not be too large, and absorbing materials should be present in sufficient quantity." But reverting to Sabine's researches, he determined the absorbing coefficients for the different materials usually found in auditoria. Calling an open window of 1 sq. ft. in area a perfect absorber of sound (and thus equal to unity) the results for the most common materials are given in a Table on pp. 27–29, exhibiting the coefficients for the pitch of 512 vibrations per second, one octave above middle C. These coefficients, together with the formula, allow a calculation to be made in advance of construction to specify the amount of Sound absorbent needed to give a satisfactory acoustic effect. (See footnote on page 24.)

A few of the coefficients given later express individual objects, as will be patent; ·05 is the constant where the English measure is concerned, whilst it is proper to substitute 0·164 where the French unit (a square metre) is employed.

Not alone does the pitch of sound affect the matter of reverberation, but this is also affected by the size of the audience and the nature of the performance. Consequently, the principle of compromise was utilised in preparing the coefficients, with generally favourable results.

To give practical application of the results of Sabine's research, the following extract from Professor Watson's book before mentioned, and introduced by his permission, will serve usefully for the purpose: "Small Chapel Room.—Consider the Chapel at the University of Illinois. This room is rectangular in shape, 76·5 feet long, 59·5 feet wide, and 17·75 feet high, with a volume of 80,800 cubic feet. The floor, benches and stage are constructed of wood while the walls and ceiling are of plaster. The seating capacity is 550. With no audience present, there are 740 units of absorbing material, as given in the accompanying tabulation.

Material	Area	Coefficient	Absorption
Wood . .	6928 sq. ft.	·061	423 units
Plaster .	7440	·033	246
Metal . .	628	·01	6·3
Glass .	408	·025	10·2
Seats . .	550	·1	55
			740 units
Audience . (average)	185 (out of 400)	(4·7—·1=4·6)*	=851
		Total	1591 units

* Each auditor adds only the difference between his actual absorption (4·7) and the seat he occupies (0·1), which has already been counted.

The time of reverberation, according to Sabine's formula, is: $t = {\cdot}05 \times 80{,}800 \div 740 = 5{\cdot}46$ seconds.

With an average audience of 185 people present, the absorption is increased $185 \times 4{\cdot}6 = 851$ units, giving a total of $740 + 851$, or 1591 units. The time of reverberation is reduced to $t = {\cdot}05 \times 80{,}800 \div 1591 = 2{\cdot}54$ seconds.

Referring now to Fig. 18, the time of reverberation for one-third audience, for a hall of volume 80,800 (cube root = 43·3), is 1·7 seconds. The room is, therefore, too reverberant, and absorbing material must be added to reduce the time to 1·7 seconds. The amount needed is calculated by Sabine's formula, as follows: $1{\cdot}7 \text{ seconds} = ({\cdot}05 \times 80{,}800) \div a$

which gives $a = 2380$ units. From this should be subtracted the 1591 units already available when an audience of 185 is present, leaving 789 units to be supplied. If bare hairfelt one inch thick, with a coefficient of 0·55, is installed, there will be needed $789 \div .55 = 1430$ square feet. This could be installed on the ceiling in decorated panels. If a decorative membrane is used over the felt, the coefficient is reduced to 0·45, and $789 \div \cdot 45 = 1750$ square feet will be needed. The chapel would then be largely independent of the audience. With no audience present, the absorption would be $740 + 789 = 1529$ units, and the time of reverberation :

$$t = \cdot 05 \times 80{,}800 \div 1529 = 2{\cdot}64 \text{ seconds,}$$

and the room could be used for rehearsals when only a few people were present. It would also be good with the maximum audience of 550 present. For optimum conditions, it would be necessary to have a total of 2700 units of absorption (Fig. 19), so that approximately 1200 units should be added to the room."

The efficiency of a sound-absorbing material or article may be said to depend as a rule upon its porosity. In an auditorium this contributes notably to procuring acoustic satisfaction. The present writer has had unpleasant experience (as doubtless many others have had), in one case in a public hall set out with bare wood chairs, no draperies disposed anywhere and the walls seemingly opaquely painted ; the acoustic results may be imagined.

Most coefficients as given by the various investigators, must be regarded as adaptable factors, seeing that they depend upon varying conditions of "pitch," * methods

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* Pitch may be defined as the effect of the number of vibrations occurring in the (selected) period of time (one second) ; the speed of the vibrations decides the relative depth or height of the sound (the greater the number of the vibrations the higher will be the pitch, and vice versa). At an octave interval the number of vibrations will be either double or half, according as that octave is higher or lower. The periodicity of the vibrations is regular throughout.

of fixing, thickness of materials, size of audience, etc. According to Dr. A. H. Davis, even non-porous materials can, in a sense, prove to be absorbent if the incident sound should vibrate the material. The extent of absorption is also affected by the damping (that is to say, the resistance to motion, otherwise, the loss of energy) to which the vibration is subjected in the material itself.

In this association a quotation may be suitably made from a pamphlet prepared by the Celotex Corporation, which kindly supplied some particulars to the writer: " All acoustical materials show more or less variation in absorption at different frequencies, and since a material is expected to be effective in absorbing noise at all frequencies, it is necessary for comparison purposes to assign the material a coefficient which is an average of the coefficients at the various frequencies. The Acoustical Materials Association has recommended that the average to the nearest 5 % of the coefficients 256, 512, 1024 and 2048 cycles be used as a so-called 'Noise Reduction Coefficient,' for comparing the noise quieting values of materials."

Professor Wallace Sabine drew attention to the fact, that " the absorption of sound by a wall surface is structural and not superficial. That it is superficial is one of the most widespread and persistent fallacies." Elsewhere he remarked, that " Sound, being energy, once reduced to a confined space, will continue until it is either transmitted by the boundary walls or is transformed into some other kind of energy, generally heat. This process of decay is called absorption." And referring to a later investigation of the Professor's, Mr. A. G. Huntley, in an article he contributed to the " Architect and Building News," remarked, that Sabine's note that the absorbing power varies according to the

" pitch " of sound, brought to light another difficulty. " Suppose a material has a high coefficient of absorption, but only in the higher registers, and that considerable quantities of it are present in a room in which a violin and a bass viol are being played " (this was Sabine's own basis of comparison) " the result would be that the notes from the violin would be rapidly absorbed whilst the viol would be unaffected, which would immediately throw the music out of balance by giving undue prominence to the viol. To counter this effect it might be conceivably necessary to increase the number of violins." And further, Mr. Huntley noted, " All materials used in building construction are Sound absorbent, though as a rule only to a very small degree ; hard plaster, for instance, only absorbs 2½% of the incident sound, glass even less, whilst wood, on the other hand, absorbs anything up to 6 per cent. Were it possible to construct a building of non-absorbent surfaces a sound produced in it would be audible for ever, whilst were its surfaces entirely absorbent, then open-air conditions would be produced . . . As the common building materials possess such low coefficients of absorption it is left to the furnishings, fittings and the audience to supply the major portion. As the audience supplies about 83 per cent. of the absorption, most buildings are good (or, at least, passable) when full ; as they, however, are more often than not used with, say, one-third only of their full complement, it is here that difficulties arise. The above does not, of course, apply to such types of buildings as Council chambers or Board (or Committee) rooms, where nearly always the seating capacity is totally disproportionate to the volume and consequently the acoustics are generally faulty. A partial remedy for lack of audience may be found in upholstered seats and in carpets, both good absorbents, but these, of course, only come into play when not screened by an audience; so that they will partially take the place of the audience when it is absent." In his "Elements of Engineering Acoustics," Dr. L. E. C. Hughes remarks, "In an auditorium the audience contributes in no small measure to the absorption. It follows that if it is required to make the acoustic properties of the enclosure independent of the size of the audience, the absorption of a seat should be adjusted to the absorption of a person occupying it."

The following Table includes not only absorption coefficients initially established by Sabine, but is brought up to date by the inclusion of later tests made at Research stations for various firms, though many of these are reserved in this book for the details entered under Practical Research, later (see pages 64–107). It is, however, only right to recognise, that perhaps the greatest credit attaches to pioneer investigation, such as that of Professor Wallace Sabine, who set others upon the direct path enabling valuable additions to be made to the original list.

The cycle of frequencies of the following is 512 per second.

MATERIAL OR OBJECT	Refer also to	Per sq. ft. or per sq. metre
Open window		1·000
Absorbex	Page 64	0·4 to 0·63
,, (Heraklith) . . .	Page 65	0·48 to 0·58
Acousti-Celotex	Pages 66–67	0·48 to 0·98
Air-acoustic sheets	Page 68	
Akoustikos felt	Page 69	
Akoustolith tile	...	0·382
Asbestonite	Page 88	
Asbestos Spray	Pages 72, 88	
Audience (as ordinarily seated) .	...	0·96
Brick set in Portland cement .	...	0·025
,, wall (18") set in cement .	...	0·032
,, ,, ,, ,, ,, painted 2 coats oil . .	...	0·017

Material or Object	Refer also to	Per sq. ft. or per sq. metre
Open window		1·000
Broadbestos quilt	Page 73	
Burgess Acousti-pad	Page 73	
C-sound plaster	Page 74	
Cabot's quilt	Page 75	0·74
,, ,, 2 layers, 3-ply	...	0·60
Calicel tiles	Page 76	0·57 to 0·83
Calistone	Page 77	0·6 to 0·77
Capacoustic tiles	Page 78	
Carpet (0·8 cm. thick)	...	0·20
,, lined	...	0·20
,, unlined	...	0·15
Celotex	(See pp. 64,	66, 76, 77, 102)
Cheese cloth	...	0·019
Cocoa matting, Lined	...	0·17
Concrete	...	0·015
Cork (1″) loose on floor	...	0·16
,, tiles	...	0·03
Corquilt	Page 78	
Cretonne cloth	...	0·15
Curtain, Chenille	...	0·23
,, in heavy folds	...	0·5 to 1·0
,, Shelia	...	0·23
Dekoosto Acoustic plaster	Page 78	
Euphon quilt	Page 79	
Felt, Cullum Acoustic	Page 78	
,, , Hair (1″)	...	0·52
,, ,, (1″) mounted 6″ from wall	...	0·68
,, ,, (1″) painted membrane	...	0·18 to 0·77
,, , Insoquilt Insulation	Page 82	
,, , Jute	...	0·25 to 0·45
,, , Maycoustic	Page 88	
Flax (1″) with painted membrane	...	0·55
Glass (single thickness)	...	0·027
Glypklith tiles	Page 80	
Heraklith Acoustic tiles	Page 81	
,, insulation slabs	Page 81	
Insulation board, L.W.	Pages 84–85	
,, ,, , Lloyd	Pages 86–87	
,, ,, , Maftex	Page 87	
,, ,, , Treetex	Page 101	0·30
Insulex	Page 82	
Insulwood	Pages 82–83	0·22
Linoleum	...	0·03
,, loose on floor	...	0·12
Marble	...	0·01
Oil painting, with frame	...	0·28
Paxfelt	Pages 90–91	
Paxtile	Page 91	
Plaster on hollow tiles ⅝″ coat and ⅛″ finishing coat	...	0·020

MATERIAL OR OBJECT	Refer also to	Per sq. ft. or per sq. metre
Open window		1·000
Plaster on metal lath, 2″ cavity and 14″ centred studs	...	0·033
Plaster; Sabinite acoustic	Page 92	
Plaster on wood laths, 2″ cavity and 14″ centred studs	...	0·034
Plaster, all as last but with ⅛″ finishing coat	...	0·028
Rockoustile	Page 92	
Rug, Carpet (about ·8 cm.)	...	0·20
„ , Oriental (extra heavy)	...	0·29
Sanacoustic Holorib	Pages 93–94	
„ panels and tiles	Page 93	
Slag wool	Page 94	
Slagbestos	Pages 95–96	
Sound-isolation blanket (Johns-Manville system)	Page 96	
Stage opening, depending upon Stage furnishing	...	0·25 to 0·40
Thermacoust	Pages 97–100	
Transite acoustical panels and tiles	Pages 100–1	
Treetex insulation board (under "I")	Page 101	
Vibrafram tiles	Page 102	
Wellinlith	Pages 104–6	
Wood sheathing, ⅝″ pine on 14″ centred studs	...	0·061 to 0·104
„ varnished	...	0·03

INDIVIDUAL OBJECTS

	Per individual unit.
Adult person	4·7
Chair; Ash bentwood	0·0082
„ upholstered with hair and leather	1·10
Cushion; Elastic felt, per seat	0·20
„ ; Hair, per seat	0·21
Settee; Ash, per single seat	0·0077
„ ; Hair and leather, per single seat	0·28

NOTE.—Dr. G. A. Sutherland gives the following coefficients for "Spatial" units :

	Feet	Metres
Audience per person as ordinarily seated	4·73	0·44
Audience per isolated man . . .	5·16	0·48
Audience per isolated woman . .	5·80	0·54
Chair ; Ash	0·17	0·016
,, upholstered (Hair and leather) .	3·22	0·30
Cushion ; Cloth (For single seat) . .	1·45	0·135
,, ; Elastic cotton (Covered with canvas and short nap plush) . .	2·04	0·19
Cushion ; Hair (For single seat) . .	1·77 to 1·93	0·165 to 0·18
Settee ; Upholstered (Hair and leather) Per seat	3·01	0·28

It is perhaps not easy to differentiate between loudness and noise. In the first place, it may be noted, that just as Sound itself may be regarded as merely an effect for which capacity to hear is the originating essential, so, too, in the case of loudness it is, in fact, a matter of comparison, a matter of more or less intensity. Weber's Law crystallises this, namely, "The increase of stimulus necessary to produce a just perceptible increase of sensation is proportional to the pre-existing stimulus." Loudness is the combined effect of intensity of origin and receptive power of the ear. For if the latter be organically defective, whilst the intensity remains unaltered, the effect of loudness will be proportionately modified. As has been shown, intensity varies inversely as the square of the distance ; or, in other words, a sound of given loudness at a certain distance is one-quarter the intensity at double the distance.

Pietro Blaserna pointed out that, "the loudness of a sound is represented by the amplitude of the vibrations causing it and depends also on the nature and density of the transmitting body." (Note.—The accuracy of the above view has been contested in the light of later investigation.)

It may be said, that Noise may be defined as consisting of a pronounced, but unregulated, emission of sound, where Loudness may be taken to suggest sound-production of a measured nature. It is not assumed here that the above definitions will be invariably approved, but to an extent they are explanatory. As generally understood, Noise is an irritating factor that disturbs the nervous equilibrium of the normal human being by introducing an atmosphere of uncertainty in regard to the volume of Sound to be anticipated from moment to moment.

It might assuredly be regarded as difficult to establish a workable distinction between mere sound on the one hand and Noise as constituting a nuisance on the other. In certain public places the definite prohibition of street cries and of vocal and instrumental " music " is comprehensible, even if it is to be regretted as involving interference with the liberty of the subject. But it is probably impossible to differentiate accurately and legally between what constitutes a nuisance and what is a mere harmless exhibition of individual or collective attempt to gain the ear of the public. For *where* is the line of demarcation between a nuisance and a sonal appeal to that public? People's nerves in these days are often so highly strung that various noises are considered unbearable which were formerly accepted as matters of course. The use of compressed-air drills (which our ancestors knew not) during the ordinary hours of business is certainly trying; but if not used in the daytime, their performance during other hours would no less encroach upon the hours of relaxation. Work must be done, and the drill is a very good servant. After all, is it more exasperating than the performance of a dog baying the moon, or than the sole or concerted efforts of cats when Morpheus is being wooed by his devotees? And though the Law tries to express what constitutes a legal nuisance, the definition will not deter anyone from seeking the aid of the Courts by means of a suit.

Obviously, the total prohibition of street performances in certain areas is a ready way of preventing the trouble locally, but that leaves untouched the larger question of scientific means of cure. Windows kept shut will only prove a palliative, not a panacea, nor would even double windows. The noise arising from wheeled traffic, which may be said to consist of both impact-sound and air-borne sound, will certainly be considerably modified by the use of suitable road surfacing, of which rubber bricks are probably the most effective, as well as being of a durable nature; asphalte road paving is also very good. And thus the conclusion is reached, that as far as may be possible, sound-annoyances should be dealt with at their source.

The character of sound depends upon (1) Pitch, or frequency of vibrations, (2) Intensity and loudness, and (3) Quality. Pitch itself depends upon the number of vibrations which a sounding body makes in each unit of time, the customary unit being one second. The greater the number of vibrations the higher will be the pitch. In his " Elements of Physics," the well-known Dr. Arnott described an instrument for obtaining relative pitch, and this instrument may be seen in one of the exhibition cases in the Science Museum, London. The description attached is as follows: " If a wheel with teeth be made to turn, and to strike a piece of quill with every tooth, it will, when moved slowly, allow every tooth to be seen and every blow to be heard separately; but with increasing velocity the eye will gradually lose sight of the individual teeth, whilst the ear, ceasing to perceive each separate blow, will at last only hear a smooth continuous sound, called a tone, of which the character (that is, the *Pitch*) will change with the velocity of the wheel."

In a booklet prepared by Newalls Insulation Company occurs the following: "In an enclosure sound-waves cannot disperse as in free air, but are reflected back. Due to these reflections a higher level of sound-energy is built up. The level will continue to increase until there is a balance between the rate at which energy is being produced at the source, and the rate at which it decays, owing to the presence of sound-absorbent materials in the room. Therefore, a room with hard walls and floor and a lack of sound-absorbing surfaces will always be noisier than a room with plenty of sound-absorbents."

Time was (and not so many years ago) when the idea of establishing any ratio of noise-effect or intensity of loudness did not exist, except possibly in the heads of some scientists. And even when the idea received more or less concrete form, it was for some period limited to the introduction from abroad of one unit for both purposes. At the present day there are two units employed, (1) the decibel (one-tenth of a bel), which was christened thus in honour of Alexander Graham Bell, the inventor of the telephone, and (2) the phon; and each of these two terms is supposed to possess restricted application, though this separateness is not invariably recognised.

As regards the difference to be established between intensity and loudness, Dr. A. H. Davis suggests that "the term *phon* should be used to express loudness and the *decibel* limited to intensity ratios. The name phon was suggested for the following reason. Originally a 'phon' had been used in Germany as a four-fold power ratio. Later it was employed as an equivalent of the decibel. If, therefore, the American term 'decibel' were employed for intensity ratios and the term phon for

Hospitals	15–20
Music studios	20–25
Private Offices	30–40
Public Offices, banking rooms, etc.	35–50
Studios for recording sound or broadcasting	15–20”

Another quotation may be here made from Dr. Davis’ writing, which will introduce definitely the treatment of auditoriums. “It may be taken that adequate loudness is assured in an ordinary auditorium if the room is so designed that no member of the audience receives within one-fifteenth of a second less sound than he would if he were distant not less than about 50 feet from the speaker. Out of doors in still air it is possible to hear further than this distance, but in a hall, with a certain amount of rustling and similar noises and a longer reverberation, 50 feet is a suitable standard to take. In small halls this presents no difficulty. All that has to be arranged for is that the speaker shall have an uninterrupted view of everyone in the audience, no member of which shall be at a greater distance than 50 feet.” There has been general agreement, from the time of Sir Christopher Wren onwards, that an auditorium should not have the line of occupation in front of the speaker exceed 70 feet (less has been recommended), the size of any audience, also, being desirably limited to two thousand people, thus keeping within range of direct natural radiation of sound. To maintain adequate intensity, it is well to keep the ceiling low, or comparatively so, thus promoting satisfactory acoustic reflection.

And it has been thought that acoustic conditions would be greatly benefited by introducing the ventilating inlets towards the point where the speaker’s platform is situated, extraction taking place at the opposite end of the hall, thus carrying the sound waves the length of the apartment, being assisted forward by the very act of projection of the various syllables. But according to Sabine, the great difference in loudness with the wind and against it is not due to the fact of such assistance or of such opposition, and he considered, that any improvement in acoustic conditions of a hall resulting from the utilisation of the motion of the air currents, even in the most advantageous way possible, is quite negligible.

One way of obtaining greater satisfaction as regards hearing conversation and speeches in Council Chambers, Legislative Chambers, etc., would be the Continental method, where each speaker in turn ascends a common tribune, instead of speaking from their individual seats.

Dr. G. A. Sutherland pointed out, that "wide experience goes to prove that curved walls are almost always a menace to good acoustics . . . One of the worst cases of the bad acoustics produced by curved surfaces is furnished by an auditorium in the University of Illinois. Here the form is roughly hemispherical, and from motives of economy the original intention of breaking up the walls was not carried out. The result was a chaos of sound. A speaker on the platform heard ten echoes of his own voice, and on one occasion the orchestra conductor heard the echo of an instrumental solo which was being rendered with orchestral accompaniment more strongly than the direct sound, and beat time with it, with what confusion can be imagined."

A description of Mr. J. Scott Russell's iseidonal and isacoustic curve (that is, one of equal seeing and equal hearing) will be not the less interesting that it so considerably antedates the general consideration given today to the question of acoustics. It indicates a method that has been employed at times for setting out the seating in an auditorium upon scientific principles.

The diagram (Fig. 3) makes it sufficiently clear in conjunction with the following description.

The main principle is, that each member of the assembly shall be able to take an easy position on any bench, whence it will ensure comfortable consideration of what is emanating from the platform. Consequently, the object is to ascertain in what manner the seating should be set out, so that throughout the whole of the tiers each individual shall see and hear without interruption from any others present. Experiments made showed, that the occupant of any seat should have a clear vertical unobstructed view over the crown of the head of the occupant immediately in front, not less than twelve inches and not exceeding eighteen inches, crown to crown.

But the same height and clearance must prevail throughout the tiers, so that the required scientifically-projected curve might be ensured, allowing for slight play. The overall spacing of tiers would be about 30 inches, and the desirable limit of approach of the front row towards the platform may be taken at about ten feet, or possibly a little nearer; but anything closer would entail a sense of discomfort to the occupants, though not infrequently this limit is encroached upon. The professor on the platform would be taken at a normal height, as at Z (in diagram) and the position suggested for the desirable front tier is at E F. With these details in mind, take a straight line from Z to the point E, which represents the normal position of crown of head for a person seated. Extend from E to H on the line of seat back of the tier immediately behind, and over that point, H, raise a height of eighteen inches to G, which will represent the position of crown of head of occupants in that tier. From Z take a straight line to G and continue to K on the seat back just in rear, and

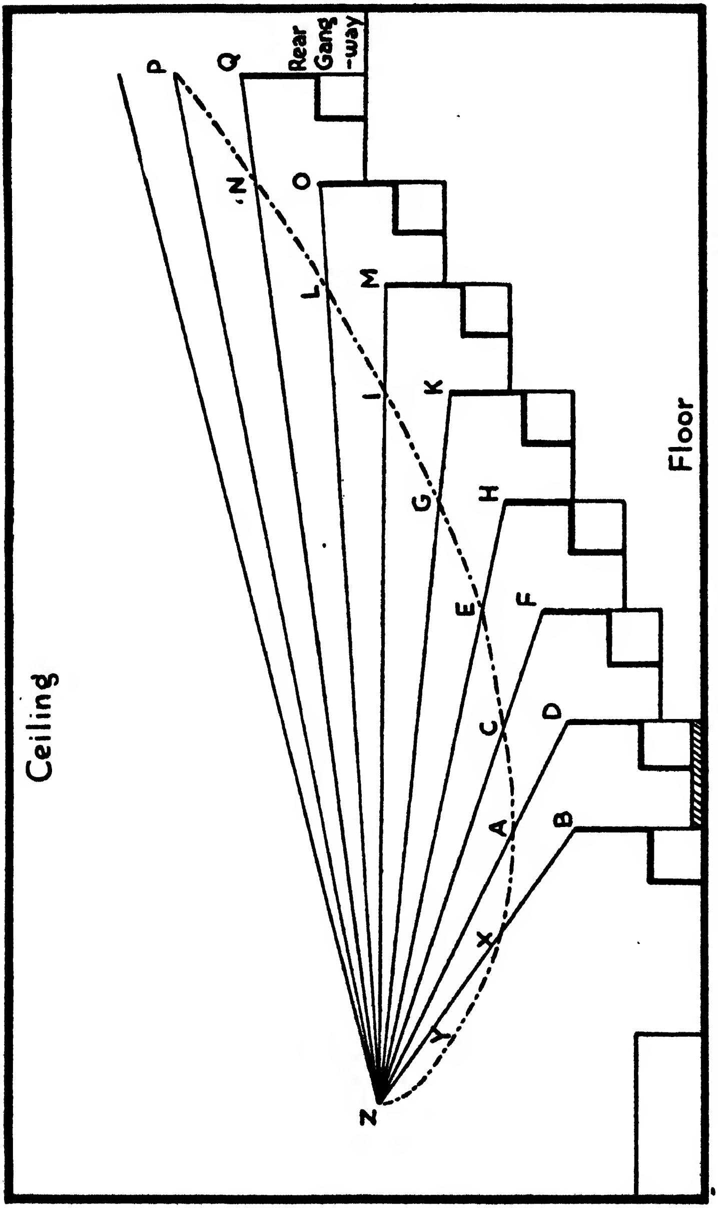

FIG. 3.—Setting-out of J. Scott Russell's Iseidonal and Isacoustic Curve. (*After an old diagram.*)

so continue tier by tier throughout. Thus a series of points (E, G, I, L, N, P) is obtained through which will be drawn the resulting curve, called the Iseidonal, or Isacoustic, curve. It will be observed, that any rows set in advance of the desirable front line provide a curve with a gradually ascending direction as it approaches nearer and nearer to the professor. The actual curvature of the Scott-Russell curve varies with the lay-out of the rows, but the main item of his scheme is the freedom for play of the head amounting to a maximum height of eighteen inches with a minimum of twelve inches. Such a hall, as illustrated in the diagram, having a height of sixteen feet, a length of 37 feet and a width of 24 feet, would satisfy acoustic proportions of H : W : L at 2 : 3 : 4½.

It may be added that the lecture theatre at the Royal Institution, London, was set out with this curve.

Respecting the limitation of the size of an auditorium, there is every advantage to be gained by taking note of what such a practical man as Sir Christopher Wren had to say on the subject. His experience in churches and lecture theatres was extensive, even if his earlier opinions may have had to submit to modification as a result of his own gradually widening proficiency. From a letter written by him with regard to churches, it appears, that he approved a more limited range of acoustic compass to suit a speaker's voice, than some later practitioners have adopted. At the same time it has to be borne in mind, that in the modern use of amplifiers and loud-speakers less is dependent upon the actual voice than was the case in the seventeenth century. Wren wrote as follows, "A moderate voice may be heard fifty feet distant before the speaker, thirty feet on each side and twenty feet behind the pulpit, and not this unless the pronunciation be distinct." He regarded

2,000 as approximating the upper limit in the size of a congregation if seeing and hearing were to be perfectly comfortable, placing his reliance mainly on natural radiation for the diffusion of the voice.

Church galleries facing the preacher are regarded as being good positions for audition, as ordinarily the voice is heard better by those above the level of the speaker than elsewhere. Side galleries, when used, should be shallow. The space beneath galleries usually constitutes the worst part of a church for audition. Generally understood, places of worship on a large scale are apt to suffer from long reverberation, owing to the indifferent absorptive powers of the walls. In the new Anglican cathedral at Liverpool, vast as it is, effective means have been taken to distribute sound, whether originating from pulpit, reading desk or organ. The use of sounding boards over pulpits for the purpose of concentrating the preacher's notes is to-day largely discounted in value.

In order to render an auditorium acoustically satisfactory, the reflective action from one utterance must have ceased before the reflection of the succeeding utterance is heard, so that confusion may not result. But that requirement is considerably modified where musical performances are to be considered, as a certain amount of sound-reinforcement of musical notes is to be desired. The Greek theatre is generally considered to have been an ideal plan for performances of stage plays. When, as in the earlier theatre, the constructive material used was wood, no adventitious means for strengthening the voice were required, but later, when marble or other stone was employed, the Greeks are said to have introduced between the seats sonorous vessels made of metal or earth, with the object of reinforcing the performer's voice. These vessels were called *echea* and were made in the form of a bell. It was a custom of the Greek actors to carry a sort of megaphone for the same purpose. An advantage of the open-air type of theatre was that neither echo nor reverberation arose. Even to-day there is a feeling of attraction for *alfresco* performances. Indeed, such a performance exceeds for perfection of audition any under-cover rendering. But the English climate (or samples of climate) does not favour the alfresco acting of stage plays. A great difficulty associated with open-air performances is the probability that the performers will quickly incur fatigue owing to the rapid absorption of sound, and thus the desirable intensity of the voice becomes lost.

In one of their business publications, Messrs. Johns-Manville (of New York), in offering some remarks upon auditorium acoustics, note that " the size and shape of the room are of paramount importance. The rectangular room is most desirable, since curved surfaces tend to focus sound, and echoes and dead spots result. The installation of corrective treatment to a troublesome curve minimises the sound focus and reduces the echo. However, the effect is more readily accomplished by a careful analysis before construction, calculated to adjust the radius of curvature of the surface or possibly to eliminate the curved surface entirely. Favourable factors for good hearing include proscenium openings with large splayed surfaces to add reinforcement to the sound and wide balcony openings to allow the entry of sufficient sound to reach the rear seats."

Professor T. Roger Smith in his informative work upon Acoustics, written about three-quarters of a century ago, pointed out the advantage of splayed reveals to window and door openings. He also advocated the substitution of plain ceilings for coffered treatment, and the fixing of horizontal glazed frames below top lights, which might otherwise be the cause of considerable tonal disturbance.

The distinction between insulation of sound (in other words, its anti-transmission) and its suitable control within the compass of a single auditorium is very definite. In the latter case reverberation, echo, reflection and absorption all need adjustment, so that the best results may obtain. There is a rather intimate association between the first three qualities named above; indeed, it may be predicated, that reverberation and echo are, as it were, first cousins, if not more closely related, reverberation being in effect an imperfect echo. Absorption is, of course, a more or less automatic consumption of sound.

It must be patent, that whereas audition is a necessary factor within the limits of a chamber, its total, or almost total, suppression as regards inter-communication between one part of a building and other parts is an object to be attained.

But there is more in it than that. Whilst sound is a necessary factor for the communication of speech and music, its suppression or reduction where general conversation or the noise of typewriters in general offices is concerned, is at once desirable and none too easy to ensure.

An extract may be given at this place from a lecture delivered by Dr. G. A. Sutherland, wherein he offered some remarks about insulation, as follows: "Sound is transmitted into a room from outside in four different ways—(1) through openings such as windows, cracks, ventilating ducts, etc.; (2) by refraction and transmission through partitions; (3) by conduction through the structure of the building; and (4) by means of a diaphragm action of the walls. The steel and reinforced concrete frames used in modern buildings are excellent conductors of sound-vibrations. Noise originating in the structure and noises produced by lifts, etc., are transmitted and radiated into the rooms by the diaphragm effect of the walls. In order to obtain effective insulation the continuity of the structure must be broken up. This may be done by introducing some absorbent material at the source of the sound, e.g. carpets or porous mats may be placed under musical instruments and layers of felt or cork under machinery. Layers of absorbent may also be introduced at any point in the path of the sound, and any discontinuity in the structure, such as the juxtaposition of two materials differing greatly in elasticity and density helps to prevent the transmission of the sounds. The old-fashioned thick masonry wall was an excellent sound insulator. Modern thin walls and light partitions frequently act as diaphragms and transmit both air-borne and structure-borne sounds." He remarks elsewhere, " If a ten-inch opening transmits sound to give 50 decibels, a one-inch opening still gives 40 dbs. and a ·1 inch opening gives 30 dbs.; it is clear that the complete closing of all cracks produces a relatively large effect."

Respecting masonry, Sabine remarks " In the case of a solid masonry wall the transmission from surface to surface is almost perfect; but because of the great mass and rigidity of the wall, it takes up but little of the vibration of the incident sound."

Theoretically the troubles arise from insufficiently controlled reflection of emitted sound-waves, and theoretically also, the cure is to be found mainly by providing for such an amount of sound-absorption as will leave only a non-absorbed balance that sustains the desirable quantum of reverberation. Sabine's formula, namely, $t = \cdot 05 \times V/a$ (or, in the event of using the metre as a unit, $t = \cdot 164 \times V/a$) provides practical means for dealing with the amount of absorption required in order to bring to the proper level, whether by way of increase or decrease, the quantity of reverberation.

With the absorption question as affecting intramural distribution of sound, this book deals elsewhere. At this point the matter to be considered is the procedure to be followed for the insulation of sound so as to prevent its travel from one apartment to others.

In an interesting publication issued by Newalls Insulation Company occurs the following, which expresses aptly the point to be dealt with: "A floor may be set into vibration—(*a*) by impacts, such as footsteps; (*b*) by being connected rigidly with something which is vibrating; (*c*) by the force of air-borne waves. Timber floors are more or less vulnerable to all the influences mentioned, due mainly to lack of rigidity and mass. Concrete floors are usually rigid enough to resist air-borne sound, but are easily set into vibration by impacts or being connected rigidly to vibrating machinery. All such machinery should, if at all possible, be relegated to the basement, where it should be placed on massive foundations isolated by properly designed anti-vibration pads. Machines should never be connected to diaphragms, such as thin walls or floors, but should rest on massive, and if possible, independent beams or stanchions with adequate anti-vibration pads to isolate them. Care must also be taken to ensure that there shall be no rigid connection to piping, etc., which will serve to transmit vibrations from machines to any part of the building. Stanchions, bases and foundations should, in certain cases, be insulated where vibrations from external sources are likely to be appreciable . . . A wall is seldom subject to impacts, and, therefore, needs only to be insulated against effects of air-borne sound-waves as well as from vibrations of machinery, etc.

The air-borne sound-waves due to ordinary speech are quite sufficient to set a 9 in. brick wall into vibration, but these could not be transmitted with sufficient intensity to be troublesome, were it not for the phenomenon of resonance. Any sound-wave having the same periodicity of vibration as the natural or resonant vibration period of a wall or diaphragm will be able to set up much greater vibrations in it than those due to sound-waves of different periodicity. Mass and rigidity are obviously of importance, but it is not practicable in many cases to increase the thickness and weight of the walls sufficiently to get the amount of sound-insulation required. The latter is, therefore, a matter of finding means to prevent walls being set into vibration at all, especially by resonance, or, if they do vibrate, of minimising the magnitude of the vibrations.

One method of increasing sound-insulation is to laminate the wall by dividing it into two independent layers isolated from one another by air cavity or by other means. On no account should there be metal ties or other bridges between the two layers."

It should be noted that approximately 70% more sound is transmitted through contact points than elsewhere; it is, therefore, important that, wherever possible, contacts shall be broken.

It may be almost predicated, that absorption, in reducing reverberation, tends to transmit the sound thus absorbed; so that it is necessary to consider transmission and absorption values side by side when making adjustments. Sound, of course, diminishes in intensity as the air vibrations weaken, and this decay of amplitude is measured by what is known as the "damping coefficient."

As regards the interception of sound, the pugging of joisted floors is a method long since introduced, and the use of slag wool or silicate cotton is also well known. Formerly a method at times employed consisted in packing small shells (such as cockle shells) between the joists, but this device is now superseded by more modern ideas. In London there were notable instances at Chesterfield House, Mayfair (recently demolished) a house built for the well-known Earl of Chesterfield in the eighteenth century, and houses in Whitehall Gardens, demolished to make room for new Government buildings.

A particular case of transmission of sound through a party wall may be noted. The wall was well and strongly built and ran through five storeys. The lowest level was a coal cellar, where coal was constantly being broken, and this was at last found to cause great annoyance to occupants of the top storey on the other side of the party wall, whilst simultaneously occupants of an upper room of the house itself found the transmitted sound irritating. The Information Bureau of the Building Research Station drew attention to a somewhat similar result, remarking, that " the floor itself acts as a *source*, and the sound permeates the building structure to such an extent that it is common for occupants of neighbouring rooms to suffer, whether rooms by the side and above or those beneath."

The use of metal wires along the upper portion of an auditorium was for a time, regarded as valuable for correcting, or else for preventing, acoustical defects. Sabine, however, expressed his views thus, respecting this device and the use of sounding boards : " Two old, but now nearly abandoned devices . . . are stretched wires and sounding-boards. The first is without value, the second is of some value, generally slight, though occasionally a factor in the final result. The benefit to be expected from the sounding-board may be greatly overrated." Dr. A. H. Davis remarks, " It is frequently thought, that defective acoustics in a hall can be cured by stretching wires to and fro near the ceiling. It is, however, very problematical whether they have any value at all—certainly they do not reduce reverberation."

Sounding-boards, when used, should have the slabs of wood to be jointed together cut thin, be thoroughly well-seasoned and be fixed in as few pieces as possible.

In the booklet before mentioned, prepared by the Celotex Corporation, a few remarks are made about sounding-boards, *inter alia*, " A scheme which has a legitimate scientific basis but is often erroneously applied, is the use of sounding-boards, that is, large plane or curved reflectors placed over the head of the speaker. When properly used a sounding-board tends to reinforce the sound of a speaker's voice, and therefore, may be useful in very large rooms where it is difficult to make the voice carry to the farthest corners. However, increasing the loudness may do more harm than good if the reverberation is excessive, and it is this mistake that is frequently made in the use of sounding-boards."

Some consideration may be devoted here to the subject of voice amplifying and the use of " loud-speakers." For some purposes and under modern conditions Sound needs amplification irrespective of its natural tendency to decay; and whilst the introduction of amplifying equipment is not a universal panacea in the control of reverberation it has its advantages; Dr. A. H. Davis, in his article upon the subject in the " Architect and Building News," stated, that loud-speaking equipment is not to be regarded as a cure for excessive reverberation, and he adds, that " whilst the apparatus promotes loudness, it does nothing to hasten the decay of the sound, which already emitted, persists sufficiently to cause confusion."

An amplifying system must reinforce the original pitch of the voice to such an extent as will enable the sound to reach a much larger audience than unaided voice production could provide. Amplification has to be controlled carefully, as otherwise the lower-pitched tones would appear to be out of focus (if this expression may be admitted).

For lack of adjustment the microphones and loudspeakers in co-operation often prove acoustically unsatisfactory.

The use of this amplified production of the voice has a large field of operation in the open air, but in the main the following remarks will be concerned with intramural employment.

It might not seem correct to say that greater attention should be accorded to one apartment as compared with another, and yet that is what it amounts to in practice as regards sound-amplification. An ordinary (or indeed any) Committee room would have to be very ill-designed before it could need equipment for sound-correction. A lecture theatre, again, provides for but one station from which to speak to the whole assembly, and adequate means for ensuring the comfortable reception of the voice have been mentioned elsewhere in the text. And even in the normal place of worship there are but limited positions whence the voice will issue. In Council Hall debates, however, as carried on in England and in the supreme debating chamber of all, the House of Commons, speaking takes place from the various spots where the individual members are disposed; and though members, in speaking, will address the presiding genius, yet the effect will be such as to render acoustic satisfaction difficult, under ordinary conditions. The practice in those continental countries where there is a common tribune, is far preferable. Even in the latter case, amplification is a desideratum, and in the others referred to, it is more than a desideratum. The present writer recalls attending (as a member of the general public) many years ago a Council meeting at the County Hall on the Embankment, when it was impossible to get a clear impression of the debate owing to acoustical defects, the only speaker at all satisfactory being Mr. John Burns. But improvements have been effected in later years.

Dr. A. H. Davis has kindly permitted various quotations to be made from his writings, and some follow here: "If loud-speakers are used the volume of sound is artificially increased, and providing the amplifying system is always in operation, the need for ceiling reflection is eliminated. For uniform distribution of sounds it is essential that focussing effects be avoided. It should be noted that for natural effect the intensity at the ears of the listeners must have approximately the same loudness as the original sounds at the microphone. Unnatural loudness results in apparent distortion of sounds, low-pitched constituents becoming unduly prominent. It is, therefore, necessary to amplify only to an extent such that remote listeners can just hear with comfort, and so to direct the projectors—which should be situated well above the speaker's head—that the sound is not excessive for hearers near the platform. The majority of the audience then has the impression of listening to only one source of sound—the speaker himself. The facias of the loud-speakers should be diverted from the platform. Where galleries are provided, two rows of projectors are often installed, one being inclined downwards towards the main auditorium and the other upwards towards the gallery."

As regards a definition for the word diaphragm, the words employed by Dr. L. E. C. Hughes may be quoted: "That part of an acoustic system which by virtue of its size generates sound-power when driven in the direction perpendicular to its area." He also has something to say about the loud-speaker in its early days : " The first loud-speaker was a horn fitted to a telephone receiver. The function of the horn is to act as an *acoustic transformer* between the low impedance of the outer air and the relatively high impedance of a small metal diaphragm, so that the latter is more effectively loaded . . . There are two main forms of reproducers, the telephone receiver, which is applied directly to the ear, and the loud-speaking receiver which generates sound-power by vibrating a surface and disturbing the normal distribution of the molecules of the air."

The inception of the telephone receiver with its sound-pressure carried direct to the ear cavity dates back well over half-a-century. It has the disadvantage (as some regard it, where wireless communications are concerned) that it limits sound-conveyance thereby to one individual, whilst the loud-speaker provides distributed, that is, general audition. Some further remarks by Dr. A. H. Davis may be entered at this place : " It is probably true, that hearing at the back of large reverberant halls or in transepts of churches may be improved to some extent by utilising the telephonic properties of the system, and putting actual voice-projectors fairly near to the unhappily-situated hearers ; nevertheless, it must be recognised, that the use of a telephone is limited by the fact, that if projectors in a room are separated by marked distances, effects of repetition similar to echo will arise. Where loud-speakers are used, throughout the hall, separated by small distances —such as 20 ft.—each loud-speaker being only of moderate or local power, this echo effect is eliminated and good hearing is often obtained." He adds elsewhere, " Amplified speech has an advantage over actual speech in that loudness is adequate without ceiling reflectors, and since the speech projectors are usually placed high above the speaker's head late echoes from the ceiling are largely eliminated. However, if the ceiling is raised, additional absorbent will need to be introduced to keep the reverberation low. Thus it is still indirectly desirable to avoid a hall of great height. Moreover, a low ceiling will be required for ordinary speech if the amplified system is out of action or discarded."

When cinematograph projections were first exhibited, the display was restricted to optical effects, and the incidents to be shown successively were explained by preliminary captions thrown upon the screen. There are possibly not a few people who regretted the advent of the Sound film, including amongst these being, undoubtedly, the bulk of the deaf portion of the population who might care to attend the "pictures," and this regret would prevail despite the provision of instruments to overcome the effects of deafness. However, had the "talkie" not been invented, the science of acoustics would have been deprived of some very interesting manifestations.

In connection with this branch of the subject, the following description may be given regarding a Sound-film reproducing-unit emanating from the Radio Corporation of America and accompanying a model exhibited at the Science Museum, London: "In talking-picture work Sound and speech are either recorded on a 16-inch disc similar to a gramophone record, or photographed simultaneously with the picture, on a strip of the film one-tenth inch wide, borrowed from the picture width. This is known as 'sound-on-film recording.' * The sounds to be recorded are picked up by a microphone which converts them into minute varying electric

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* This method has since been superseded (or at any rate, modified).

currents; these are amplified, and in variable-density recording are made to operate a special type of glow-lamp, or a light-valve, thus causing fluctuations in the brightness (or, in the case of the light-valve, the amount) of light passing through a narrow slit, behind which the film is moved at a constant speed of 90 feet per minute. In the variable-area system the currents from the microphone, after amplification, pass through an oscillograph, the mirror of which is thus set into vibration. The sound-unit consists of a constant light-source or 'exciting lamp,' the light from which is concentrated by a lens system into an extremely narrow beam which falls on the sound-track portion of the film at the sound-gate—a strip of metal in which a bevelled slit is cut to permit the passage of the light-beam. The film is drawn down smoothly at the correct speed by a continuously running sprocket wheel, hence the sound-track as it passes the light-beam causes variations in the amount of light passing through. These fluctuations fall on the photo-electric cell and are converted by it into variations of electric current, which after conversion into voltage fluctuations are amplified considerably and translated by the loud-speaker into the corresponding sound-wave."

Mr. C. W. Glover, in his book, "Practical Acoustics for the Constructor," offers some interesting remarks about loud-speakers, of which the following are a permitted selection, and the two diagrams are prepared from original diagrams kindly lent by him. "The construction of the electromagnetic or electrodynamic microphone used for the measurement of sound is essentially the same as that of the loud-speaker movement. used for the generation of sound on the corresponding principle (see Fig. 4). In the microphone the variations in acoustic pressure on the diaphragm cause this to vibrate, which in turn causes a vibration in the magnetic flux between the poles of the magnet. This induces an alternating E.M.F. in the windings round the magnet, the modulation corresponding to that in the acoustic excitation. Used as a loud-speaker, the movement is operated by a current in the windings which, by changing the magnetic attraction on the diaphragm, causes this to vibrate in a manner corresponding to the modulations in the actuating current. The movement of the diaphragm is conveyed direct to the air in the form of sound-waves. This type of instrument is liable to distortion, due to resonance and temperature changes . . . . Fig. 5 shows an electrodynamic (moving-coil) microphone or loud-speaker, in which a corrugated and non-magnetic diaphragm carries a small coil which moves in a constant magnetic field. The instrument is sensitive, and being reasonably constant over a wide range is very suitable for purposes of sound-measurement."

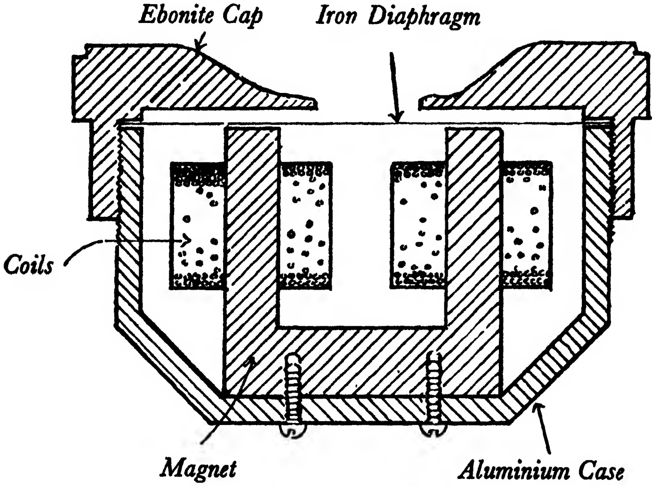


Fig. 4.—Electromagnetic Microphone or Loud-speaker.
(By kind permission of Messrs. C. W. Glover and Partners.)

In his "Textbook on Sound," Dr. Albert B. Wood describes the following microphone, which is similar to those in general use in telephony. "A carbon or metal diaphragm [see (*a*) in Fig. 6] about two inches in diameter serves to receive the sound-waves and to compress the carbon granules by its vibrations. The diaphragm is suitably damped by means of flannel, or cotton-wool, washers, to avoid pronounced resonance effects, which would tend to distort the voice of a speaker." The diagram also shows at (*b*) the button microphone, ½ in. to ¾ in. diameter, which is "designed for attachment, as required, to a diaphragm or any other form of vibrator. Two parallel carbon discs are supported in a little brass capsule, one on a mica disc, the

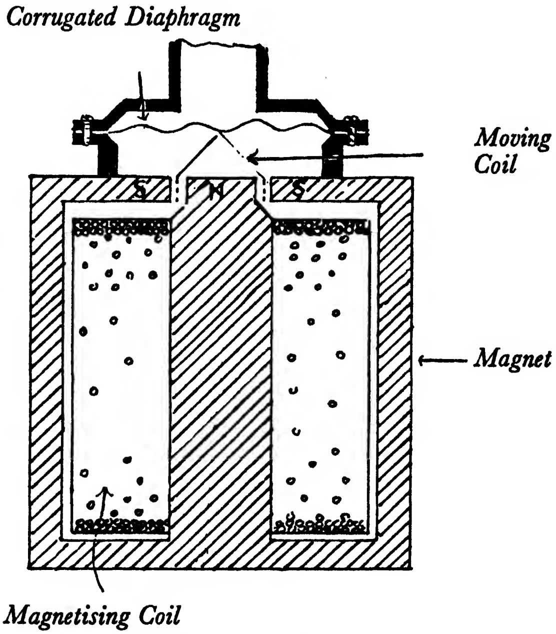


FIG. 5.—Electrodynamic Microphone.
(*By kind permission of Messrs. C. W. Glover and Partners.*)

other soldered to the brass body. A soft felt ring surrounds the carbons, and presses lightly on the mica disc. Two-thirds of the cavity thus formed is filled with carbon granules or pellets . . . Such microphones attached to diaphragms form very sensitive receivers of sound, but have drawbacks. One trouble is known as ‘packing,’ the carbon granules clinging together, due to moisture or wedging in the lower part of the cavity. In such a case the resistance falls to an abnormally low value and the microphone becomes insensitive.”

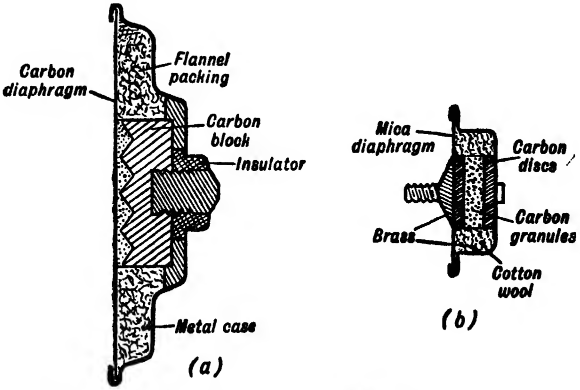


Fig. 6.—Sections through Microphones.
(*From Dr. A. B. Wood's “ Textbook on Sound.”*)

In “ The New Acoustics,” Dr. N. W. McLachlan remarks, “ the development of ‘ speakers ’ for domestic use has proceeded on totally different lines from those for public address and cinema work. Horn speakers are bulky and costly, so in general they are not to be found in the average household. Consequently, development of the large hornless diaphragm type has taken place. Horn loud-speakers are designed in much the same way as moving-coil microphones and telephone receivers.” This mechanical system is shown diagrammatically in Fig. 7.

It is intended to finish these notes upon microphones and loud-speakers by some assembled quotations from the writings of Dr. A. H. Davis, whose kindly co-operation in this respect is very highly appreciated, equally with the ready assistance afforded by the other authors mentioned in various places: "Among the microphones with a stretched metal diaphragm is the electrostatic, or condenser, microphone described by E. C. Wente in the Physical Review in 1917. An early form of the instrument is illustrated in Fig. 8. It consists essentially of a tightly stretched thin steel diaphragm separated from a metal back plate by about one-thousandth inch air-gap. The plate and the diaphragm form the two plates of an electrical condenser, which is charged by being permanently connected to a battery of about 200 volts through a high resistance. When the diaphragm vibrates under the action of sound, the capacity of the condenser varies, and an alternating electromotive force is set up. Annular grooves cut into the face of the backplate give the diaphragm the requisite degree of damping. Moisture is excluded from the

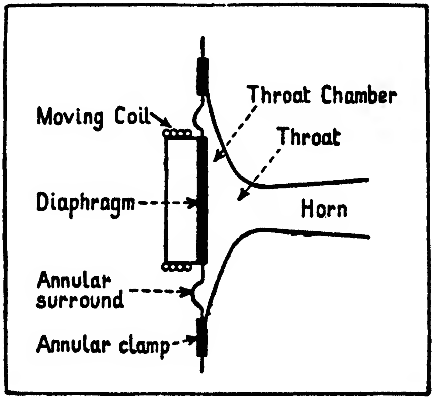


Fig. 7.—Horn Loud-speaker.
(*From Dr. N. W. McLachlan's "The New Acoustics."*)

space surrounding the backplate by means of a thin rubber sheet, which, being flexible, maintains the pressure within the air-gap of the instrument substantially atmospheric. Owing to the tight stretching of the metal diaphragm, its natural frequency of vibration is very high —some 10,000 to 20,000 vibrations per second, and so the microphone, although somewhat insensitive, is almost uniformly responsive to sound over a wide range of acoustical frequencies. The microphone changes but little with time and atmospheric conditions, and is used with amplifiers, which themselves, when properly designed, will maintain constancy for a long period." . . . "For electrical loud-speakers a moving-coil type is preferable for measurement purposes. In this, as in the moving-coil receiver, a non-magnetic diaphragm carries a coil of wire moving in a constant magnetic field." (Fig. 9) . . . "A loud-speaker movement of high efficiency working on the moving-coil principle has been described by Wente and Thuras (see Fig. 10) in *Bell System Tech. J.*, 1928. It was intended primarily for public address in large halls and for use in conjunction with a large horn. By the use of a special type of dished aluminium diaphragm and an annularly flared

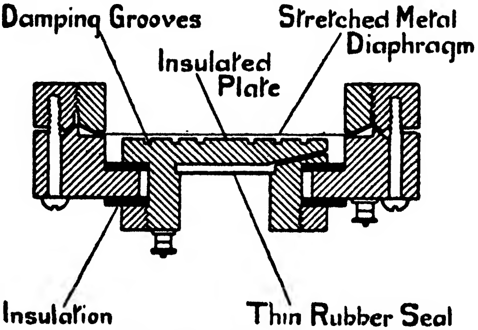


FIG. 8.—Electrostatic Microphone (Wente).
(*From Dr. A. H. Davis' "Modern Acoustics."*)

unit for acoustically coupling the diaphragm to the horn, it is ensured that pressure variations set up by the inner and outer portions of the diaphragm reach the throat of the horn approximately in phase up to high frequencies . . . This type of horn is self-supporting, no spool being required." . . . "In hornless loud-speakers, where 'moving-coil,' 'moving-iron' or 'moving conductor' movements are used as the driving movements of large light diaphragms, the diaphragms may be stiff paper in the form of a shallow cone, but R. W. Paul and B. S. Cohen have contrived one in which the diaphragm is a light disc of Balsa wood; it is said to be relatively too powerful in the upper register." . . . "For paper diaphragms the conical form is preferable

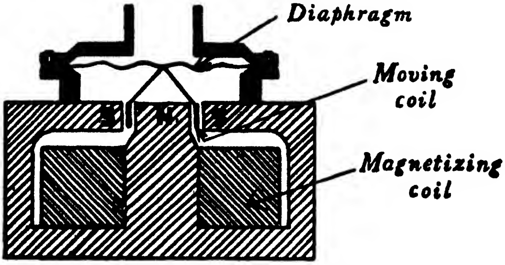


Fig. 9.—Showing movement of Moving-coil Loud-speaker. (*From Dr. A. H. Davis' "Modern Acoustics."*)

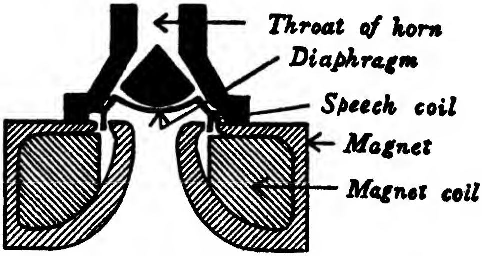


Fig. 10.—Moving-coil Loud-speaker (Wente and Thuras). (*From Dr. A. H. Davis' "Modern Acoustics."*)

to that of a flat plate, because the curved surface is more rigid to flexural vibrations and breaks up into resonant modes of vibration at higher frequencies. Aluminium has been used as the material of the conical diaphragm in order to provide greater mechanical stiffness, and thus to raise the pitch of the resonances still further and to give greater output in the region of 10,000 cycles per second. Conical diaphragms may be supported at the base by thin leather or rubber in a manner which imposes but little restraint. For precision in acoustical work in which constancy from day to day is advantageous, diaphragms and controls of paper or leather would appear to have disadvantages. The difficulty with diaphragm type loud-speakers is to produce uniform amplitude at different frequencies. The horn type is more efficient within the range of the horn, since a greater amount of acoustic energy is utilised . . . Dr. D. A. Oliver designed a microphone of the Wente type in which the diaphragm is only very slightly recessed, and is practically flush with the case (Fig. 11).

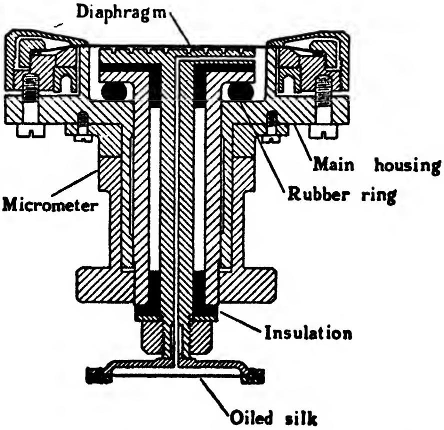


Fig. 11.—Dr. D. A. Oliver's Improved Condenser Microphone.
(*From Dr. A. H. Davis' "Modern Acoustics."*)

The intrument is used in an oval shield, which fits over the whole of the back of the instrument."

In the *Architects' Journal*, dated May 19, 1938, especial attention was devoted to the treatment of acoustical problems under various aspects, and it is safe to remark, that the collective value of the text and diagrams and other illustrations cannot well be exaggerated. From the contents of the pages so allocated it is a privilege to have received permission to make use of Mr. Frederick Gibberd's very practical contribution respecting the synthesis of certain blocks of flats viewed from the standpoint of preventing Sound-penetration. Detailed acknowledgment for such permission is elsewhere recorded.

A remark made in the contribution by Mr. John Barton proclaims those to be Philistines who delight in Noise. Without pretending to be such a Philistine, it is permissible to deprecate the excessive attention being paid to-day to the elimination of noise. We read in the Pentateuch, that " the poor ye shall always have with you," and similarly it might be thought that a certain amount of noise will be always with us. It is possible to go further and assert, that it is indeed a matter of desirability, that a certain amount *should* be ever present under normal conditions.

Absolutely unbroken silence would tend towards cerebral atrophy, and there are not a few who would agree that the stimulus of Noise—within limits—is a valuable aid to the well-being of the individual. For the whole world to be wrapped, as it were, in cotton wool would be destructive of one of the inherently-precious natural provisions of human existence.

Whilst it must be regarded as of prime importance to remove the nerve-racking noises produced by road drills, heavy road transport, heavy machinery in buildings and other such agents of the Noise fiend, it is a different matter to suppressing street noises resulting from vocal and instrumental performances, in so many instances the honest efforts of those seeking a livelihood. But the public nerves have to-day become so highly strung, that these endeavours at self-expression are being denied outlet.

Medio tutissimus ibis! By all means silence the big noises, but the attention being directed to the silencing of switches, door furniture and some other items of equipment seems to be like cutting blocks with a razor.

There is altogether too much talk about neurosis and allied nervous affections. An excess of quietness, a state of complete noiselessness, is but conducive to melancholia, whose cessation may be readily procured by the welcome intervention of some source of Sound, be it the song of birds or the notes of the human voice.

The truth is, that any excess is to be deplored, and though the campaign against undue Noise is fully admirable in its essence, its over-expression must be deprecated.

PART TWO

In this section of the present work, the writer includes a large and representative compilation of methods and materials dealing with the acoustical conditions affecting buildings. The particulars have been furnished by various firms with a readiness and liberality which merit the cordial recognition here accorded.

It will be clear, of course, that the writer himself does not advance the claims of any one material or system beyond any other, but submits all of them to readers for equal consideration before any selective treatment is attempted.

The official tests to which most have been subjected will also prove interesting when submitted to comparison.

Generally understood, there are three distinct types of materials to be dealt with, namely : (1) Good reflectors in areas where the original sound needs to be reinforced, (2) Good absorbents for areas where echoes or undue reverberation might be raised, and (3) Good insulators where it is required to prevent transmission of sound. For example, concrete is very reverberant in nature, and should be subjected to sound-insulation to render it satisfactory.

ABSORBEX

(The Celotex Corporation : Chicago)

Absorbex is a cement-timber product, made by a process which shreds timber into long and tough fibres and then passes the latter through a binding emulsion of high temperature cement. The mass is then formed between rolls and steel belts at a temperature of 500° Fahr. into fire-retarding slabs of uniform thickness containing innumerable minute air cells, which afford high insulation of great acoustical value. Absorbex affords no food value to attract insects ; it is not recommended for use where continual excessive humidity exists.

The standard sizes are 9″ × 9″, 18″ × 18″, and 18″ × 36″, and the thickness is 1″. There is a standard $\frac{3}{16}$" bevel on all four sides of the tile.

In the accompanying Table are given some representative Official tests :

Thickness Types	Absorption Coefficients cycles per second					Noise-Reduction Coefficient	Weight in lbs. per sq. ft.
	128	256	512	1024	2048		
*A. 1″	0·18	0·26	0·63	0·96	0·77	0·65	2·63
*C. 1″	0·15	0·23	0·40	0·66	0·62	0·50	2·01
†F. 1″	0·11	0·17	0·49	0·68	0·63	0·50	2·14

* Cemented to plaster board. Considered equivalent to cementing plaster or concrete ceiling.

† Nailed to 1″ by 2″ wood firring 12″ o.c., unless otherwise indicated.

ABSORBEX (HERAKLITH) SLABS

(Messrs. Honeywill and Stein, Ltd.)

The treatment of these slabs varies according to requirements. In the case of panelling Beam-ceilings with unplastered slabs: If the beams are at more than 20″ centres, 4″ × 1″ counter-battens must be fixed at 20″ centres to the underside of the beams, and then to these must be nailed standard 1″ slabs, bonded, without mortar in the joints, and pressed tightly together. But if to be coated with acoustic plaster, then on the slabs stick strips of hessian over the joints and coat the whole soffit thinly with acoustic plaster which should be as porous as practicable.

The Acoustic Materials Association tested some of these slabs in their Laboratories in Illinois, and found that the repeated application of colour failed to reduce the coefficient of absorption; in fact, over the most material range of frequencies, the value actually rose. The results as certified by Dr. Paul E. Sabine are here given:

Frequencies (cycles per second)	128	256	512	1024	2048
1″ Absorbex "B," 2 coats . .	0·20	0·25	0·48	0·80	0·79
with 3 extra coats . .	0·19	0·23	0·58	0·86	0·76

ACOUSTI-CELOTEX TILES

(The Celotex Corporation)

These tiles are made either of cane (C-series) or of mineral (M-series), the descriptions being given below. The most distinguishing characteristic of the product is its perforations (patented); they are of definite diameter, depth and spacing. Because of this feature the tiles can be repeatedly painted with any standard paint without impairing the sound-absorbing efficiency. Paint does not seal the openings to the tubular channels through which the sound-waves enter the porous block and are absorbed.

The C-Series is made of tough cane fibres, called Bagasse. In the minute interstices between the fibres, sound is dissipated by friction. By the patented Ferox Process a method has been obtained whereby the individual fibres, in their wet state and before formation into a board, are coated with a chemical complex which is toxic to fungi and other organisms.

The M-series is made of mineral fibres (Rockwool) felted similarly to that used in the manufacture of the C-Series. This binder is added to provide in the finished product the strength and toughness inherent in the bagasse fibre used in the C-Series. Sound is dissipated by friction as in the other series.

The accompanying Tables are condensed from the originals to a slight extent. They show the results of official tests, so far as absorption capacities are concerned and will prove interesting upon comparing the tests elsewhere given for other materials or methods.

The types of mounting are: (1) as cemented to plaster board. Considered equivalent to cementing to plaster or concrete ceiling, and (2) as nailed to 1″ × 2″ wood firring 12″ o.c., unless otherwise indicated.

The unit sizes tested were all 12″ × 12″.

C Type	Surface	Thickness	Mounting as above	Absorption Coefficients in cycles per second					Weight in lbs. per sq. ft.
				128	256	512	1024	2048	
	Perforated with 441 holes p.f. sup. $\frac{3}{16}$" diam. ; $\frac{3}{8}$" deep. Painted with oil-base paint	$\frac{1}{2}$"	1	·24	·27	·48	·57	·59	·84
	Same as above in all respects . .	$\frac{1}{2}$"	2	·36	·58	·51	·52	·62	·84
	All as above, except perforations $\frac{1}{2}$" deep	$\frac{5}{8}$"	1	·19	·20	·69	·85	·65	·97
	All as last	$\frac{5}{8}$"	2	·40	·59	·68	·81	·66	·97
	All as last, except perforations $\frac{11}{16}$" deep	$\frac{13}{16}$"	1	·25	·27	·76	·88	·60	1·03
	All as last, except perforations 1 $\frac{1}{16}$" deep	1$\frac{1}{4}$"	1	·37	·43	·98	·79	·57	1·50
	Perforated with 441 holes p.f.sup. $\frac{1}{4}$" dia. $\frac{5}{8}$" deep. Unpainted . . .	$\frac{13}{16}$"	1	·14	·35	·63	·83	·90	0·95
	All as last, except perforations 1" deep Unpainted	1$\frac{1}{4}$"	1	·19	·41	·91	·92	·92	1·37

M Type	Surface	Thickness	Mounting	Absorption Coefficients in cycles per second					Weight in lbs. per sq. ft.
				128	256	512	1024	2048	
	Perforated with 676 holes p.f. sup. $\frac{5}{32}$" diam. ; $\frac{1}{2}$" deep. Unpainted . .	$\frac{5}{8}$"	1	·17	·29	·58	·82	·82	1·43
	Perforated as last. Painted with oil-base paint	$\frac{5}{8}$"	1	·14	·24	·58	·93	·83	1·53
	Perforated with 676 holes p.f. sup. $\frac{5}{32}$" diam. ; 1$\frac{1}{8}$" deep	1$\frac{1}{4}$"	1	·37	·51	·88	·80	·82	2·34

ACOUSTIC FELT

(Messrs. Horace Cullum and Co., Ltd.)

(*See* under Cullum Acoustic Felt)

AIR-ACOUSTIC SHEETS

A Johns-Manville system of Sound control

(Agents : Messrs. Douglas R. Smart and Son, Ltd.)

These are non-combustible, moisture-resistant, Sound absorbents made in rigid form from Banroc wool (rock wool) and a suitable binder. Banroc has long been known as a Sound-deadener. It is a chemically pure sulphur-free mineral product actually blown from molten rock.

The net weight of the sheeting is 1½ lbs. per sq. ft. in the 1″ thickness. The sheets are manufactured in ½″, 1″ and 1½″ thicknesses and are 24′ × 36′. They are used chiefly inside air-conditioning units and ducts. They may be either cemented in position, or else be bolted in place, using galvanised discs or large washers to increase the bearing surface.

The accompanying particulars are worth transcribing :

Frequency in cycles per sec.	128	256	512	1024	2048	4096
Absorption percentage for ½″ sheets . . .	14	19	61	69	67	78
Absorption percentage for 1″ sheets . . .	22	41	64	72	70	84

AKOUSTIKOS FELT (ASBESTOS AKOUSTIKOS FELT)

A Johns-Manville system of Sound control

(Agents : Messrs. Douglas R. Smart and Son, Ltd.)

This is a special punched felt of chemically cleaned goat's (or other selected) hair and asbestos fibre. It is cemented to the surface to be treated, and it may be applied to curved surfaces. It is supplied in thicknesses of ¼", ½", ¾" and 1". In the details given below, Type A shows a membrane of pre-bleached muslin, which may be painted either to resemble smooth plaster, or it can be painted with sand paint to simulate sanded plaster. Type B 332 has a perforated washable sanitas or cribble cloth membrane. Other membranes employed are canvas, burlap, hessian, brocade, etc.

The following are sample test results :

Material	Thickness	Weight per sq. foot	Surface Finish	Absorption Coeffs. at c.p.s.				
				250	500	1000	2000	4000
Type A .	¾"	10 oz.	Painted muslin	·25	·60	·78	·67	·62
,,	1"	13 oz.	,,	·30	·75	·85	·70	·65
Type B332	¾"	10 oz.	Perforated sanitas	·24	·53	·73	·64	·60
,,	1"	13 oz.	,,	·20	·65	·85	·90	·80

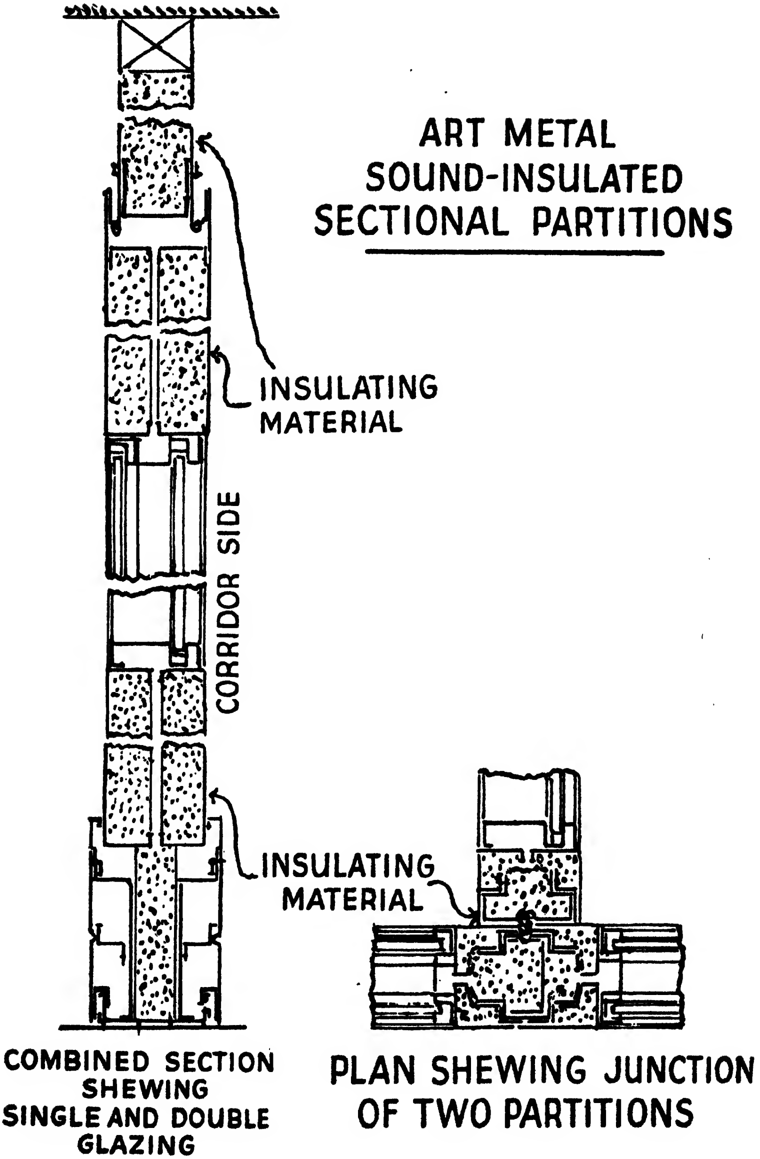
ART METAL SECTIONAL PARTITIONS

(The Art Metal Construction Company)

These consist of steel-made details, three types having sound-insulating panels. They are fully insulated, two of them being 3″ panel partitions, the other type having 1¾″ panels with visible posts between, and flush door. Panels can be interchanged at will, and the partitions can be taken down and reconstructed upon a fresh site when desired. The insulating material used is Celotex, and is regarded as " extremely effective in absorbing and deadening noise ; the partitions are insulated and engineered to meet office acoustic problems."

There is a fourth type, but that is not provided with sound-insulating material. The " K " type here illustrated (Fig. 12) is made up of completely concealed posts with insulated 3″ panels ; it is of flush wall appearance from base to ceiling, and the insulating material is said to be 90% sound-absorbing. Each panel face is an individual unit and is separately insulated.

A patent has been applied for.



COMBINED SECTION SHEWING SINGLE AND DOUBLE GLAZING

PLAN SHEWING JUNCTION OF TWO PARTITIONS

Fig. 12.—Insulated Partition of the Art Metal Construction Company.

ASBESTOS SPRAY

(Newalls Insulation Company)

"The application of asbestos fibre by the Spray Process is effected by discharging the fibre from a nozzle, the stream being intersected by a spray of adhesive discharged simultaneously from a spraying gun; these thoroughly intermingle before striking the surface to be treated, and finally adhere to it. In this way a jointless layer of acoustic material is built up of any thickness." The following Tables give the result of reverberation method:

Frequency in cycles per second	250	500	1000	2000
Sound-absorption with—				
½ inch thickness . .	30%	35%	50%	60%
¾ ,, ,, . .	55%	60%	50%	60%
1 ,, ,, . .	60%	65%	60%	60%
2¾ ,, ,, . .	85%	95%	90%	80%

The results of tests on 1″ asbestos spray, decorated, are given below. Tests were made on four panels keyed to 1″ wood laths, each panel measuring 5′ 2″ × 5′ 2″, framed in wood frame and screwed into position so as to form a square 10′ × 10′.

Material as tested	Equivalent number of years' decoration	Absorption coeffs. (to nearest ·05) for frequency bands in region (cycles per second)			
		250	500	1000	2000
Blue asbestos, covered with thin layer of white asbestos fibre	0	·60	·65	·60	·60
Ditto, with 3 sprayed coats waterpaint . . .	1 year	.65	·70	·60	.60
Ditto, with 8 ditto . .	10 years	·60	·65	·60	·60
Ditto, with 14 ditto . .	20 years	·55	·65	·60	·60

BROADBESTOS (SLAG WOOL) SOUND-DEADENING QUILT

(Messrs. J. C. Broadbent and Co., Ltd.)

This is a form of slag wool made in four thicknesses, ¼″ to 1″, and in suitable lengths up to 15′, and in any width up to 3′. The standard size is 10′ × 2′.

It is made from Cleveland blast furnace slag, which contains a very large percentage of silica and alumina. There is no organic matter in its composition, and it does not support either animal or vegetable life, thus rendering it free from dry rot and mustiness. It cannot attract vermin of any kind.

Blast furnace slag is a good non-conductor, and in the process of manufacture is turned into hair-like fibres and is a mass of air-cells. "It is a scientific truism that confined air (which does not circulate) has no rival as a non-conductor."

It can be rolled and unrolled like a carpet.

BURGESS ACOUSTI-PAD

(Burgess Products Co., Ltd.)

A Sound-absorbent blanket covered with a perforated facing (Burgess Acousti-plate). Sound waves trickle through the perforations. Sound-absorption co-efficients approved by the Acoustical Materials Association give the following results:

Frequency in cycles per second	256	512	1024	2048
Coefficients	29%	62%	80%	72%

Average coefficient . . 60%

C-SOUND PLASTER

(Messrs. J. H. Sankey and Son, Ltd.)

The plaster consists of thousands of tiny Ceiba vegetable fibres combined with a gypsum base, and its application produces a surface reflecting the sound back to its source. The fibres are hollow, each containing a multitude of air cells giving great insulating efficiency.

Independent tests under actual working conditions prove that " this plaster eliminates 84% of noise passing through partitions." Noise, as has been written elsewhere, is measured in decibels (ratio intensity). " The sound-resistance factor of a partition is measured by placing it between a noise of a known constant value and a microphone, which will register the intensity of the sound after transmission. Thus, if a noise of a loudness of 80 decibels (noisy typewriting room) is transmitted through a C-sound plastered partition, the nett transmission will be 30 decibels (very quiet room), as C-sound plaster has a reduction of 50 decibels." The following are test results at the Nat. Phys. Lab. for a partition 6¼″ made of T.C. blocks rendered with ½″ cement and sand and plastered both sides with C-sound plaster, smooth finish.

Frequency in cycles per second . . .	200	300	500	700	1000	1600	2000	4000
Sound-reduction in decibels . . .	42	45	40	55	62	58	53	58

Average decibels . . 51·63

CABOT'S QUILT

(Messrs. Huntley and Sparks; May Acoustics, Ltd.)

"A felted matting of cured eel-grass stitched with strong thread and securely fastened between two layers of strong and tough 'Kraft' paper. The eel-grass fibres are long and flat, and they cross one another at every angle, forming a thick resilient cushion of small and irregular cells of dead air confined by the ribbons of eel-grass." This serves to muffle noise, assisted furthermore by the large number of minute "dead air" spaces in each separate blade of the so-called grass. Valuable qualities are non-decay, non-harbourage of insects, etc., non-flammability, toughness and elasticity.

"Cabot's Quilt is supplied in three thicknesses, namely, Single ply, Double ply and Triple ply. It is packed in rolls of 250 feet super, and is approximately three feet wide. Each roll contains a packet of tin washers to be used for preventing nail heads piercing the quilt."

Side by side with prevention of sound-transmission is the question of sound-absorption, and also the damping of outside traffic noise. The following results of tests are illuminating:

For the quilt: 3-ply in two layers $1\frac{1}{2}''$ from the wall and canvas cover $1''$ distant:

Frequency in cycles per second .	256	512	1024	2048	4096
Absorption coefficients . .	0·42	0·74	0·77	0·69	0·44

CALICEL

(A Celotex Corporation Product)

Calicel is basically a highly expanded stone. It is a cellular mineral formed at temperatures in excess of 2,000° Fahr., and so cooled that the molten mass is expanded from ten to forty volumes. This highly cellular structure somewhat resembles a petrified sponge. Subsequent refining and grading operations produce finished Calicel which serves as an aggregate for Calicel acoustical materials.

The aggregate is carefully graded for size and colour, thus making possible a wide variation of natural colours and textures in the finished product. The actual production of the tiles is by thoroughly mixing the aggregate with a time-tried mineral bonding agent, then moulding with hydraulic presses, after which the tiles are cured, or dried in kilns. Lacking mechanically-made perforations of definite diameter, depth and spacing, Calicel does not possess the same degree of " paintability " as Acousti-Celotex.

The following Table gives useful data: For 12″ × 12″ unit cemented to plaster board, equivalent to cementing to plaster or concrete ceiling.

Material	Surface	Thickness	Absorption Coefficients cycles per second					Average* Noise Reduction to nearest 5%	Weight in lbs. per sq. foot
			128	256	512	1024	2048		
Standard	Unpainted	¾″	0·16	0·19	0·57	0·95	0·71	0·60	2·06
”	Painted Oil base paint	¾″	0·15	0·22	0·58	0·96	0·76	0·65	2·12
”	Unpainted	1″	0·20	0·29	0·76	0·97	0·79	0·70	2·75
”	Painted Oil base paint	1″	0·20	0·27	0·76	0·99	0·81	0·70	2·56
Tapestry	Unpainted	¾″	0·13	0·20	0·64	0·89	0·65	0·60	1·96
”	”	1″	0·18	0·32	0·83	0·82	0·67	0·65	2·84

* The noise reduction coefficients refer to the frequencies from 256 to 2048 cycles inclusive.

CALISTONE

(A Celotex Corporation Product)

It is made from selected Calicel aggregates (see under "Calicel") to which are added certain Portland cements. The material is moulded with hydraulic presses and cured in kilns under steam pressure. "Calistone possesses the resistance to moisture and the abrasive and wearing strength of natural stone, which permits wall and wainscot acoustical treatment . . . Calistone permits the architect the same latitude he has enjoyed in the design and specification of natural stone. Its appearance is similar to that of any sand-finished stone and special textures and colours can be produced."

It is made in a minimum thickness of 1″, and in sizes and shapes to meet special designs. It is not made in any standard sizes. "Sizes and shapes can be prepared within the limits of any standard stone and erected in the same manner."

The following Table supplies information as to coefficients of absorption and other details concerning Calistone laid direct on the laboratory floor, and of a unit size of 12″ × 12″:

Surface	Thickness	Absorption Coefficients					Aver. Noise Reduction Coeff. given to nearest 5% for the four higher frequencies	Weight in lbs. per sq. foot
		128	256	512	1024	2048		
Unpainted	1″	0·16	0·28	0·60	0·89	0·66	0·60	4·61
,,	2″	0·36	0·58	0·77	0·69	0·63	0·65	9·82

CAPACOUSTIC TILES

(Messrs. Horace W. Cullum and Co., Ltd.)

They are made with a hard perforated face and are screwed to battens. The standard size of a tile is 18″ × 18″ × 1″ thickness. Special sizes are, however, manufactured according to requirements. The weight is 3½ lbs. per tile. The acoustic efficiency is stated to be 75 % at 500 cycles per second.

COCOSQUILT, CORBASE and CORMAT

(See page 107)

CORQUILT

(Messrs. Vibro-Insulations, Ltd.)

Specially designed to prevent sound-transmission through floors, and available for concrete or wood floors. It incorporates granules of natural corkwood between layers of thick felt paper, and it permanently retains its natural elasticity and efficiency.

CULLUM ACOUSTIC FELT

(Messrs. Horace W. Cullum and Co., Ltd.)

Finished in cribble cloth (perforated oil cloth) or in muslin. It provides a smooth continuous surface without joints over any area. It is made in thicknesses of ½″, ¾″ and 1″. It is used for the Cullum floating floor under the Cullum Sound-proofing Patent System. Its absorption coefficients as tested at the National Physical Laboratory were found to be 0·35 to 0·90 according to the thickness finish and vibration frequency.

DEKOOSTO ACOUSTIC PLASTER

(Messrs. Honeywill and Stein, Ltd.)

" This is a porous gypsum plaster which is applied to Paristone plaster base coat to a thickness of ½″. Its rough porous surface provides the following absorption coefficients :

Frequency (cycles per second) .	250	500	1,000	2,000
Coefficients	0·15	0·35	0·40	0·45

It can be decorated with good quality thin distemper applied by means of an air spray without impairing its coefficient of absorption to any marked degree." It is used for all types of acoustical correction.

EUPHON QUILT

(Glass Fibres, Ltd.)

Made from glass drawn into long flexible fibres possessing a high tensile strength. The fibres are spread to the required thickness and are covered with treated "Kraft" paper and stitched with thread to form a strong and durable quilt, which possesses a high sound-insulating value. Glass silk is incombustible, chemically inactive and odourless. The ideal form of construction is to have the actual surfaces of the wall or ceiling completely separated, and to incorporate in the air space provided material of high sound-absorption value. Whilst this complete separation is often impossible to attain, excellent results can be obtained by partial separation and the careful choice of materials.

With regard to the transmission of sound through walls and ceilings, this is principally effected (*a*) by direct transmission through the air, (*b*) transmission through the structure of the building. In the first case, it can be generally stated, that the greater the density of the construction, the less sound will be transmitted. When uncompressed, the "Light" quilt is ¾″ thick, the "Medium" is 1″ thick and the "Thick" is 1¼″. The "Light" grade should be used for all ordinary work. Metal washers for fixing are provided with each roll. The rolls are one yard wide.

GYPKLITH ACOUSTIC PRODUCTS

(Messrs. Honeywill and Stein, Ltd.)

Gypklith is a structural material which has been scientifically developed for, *inter alia* (1) Sound-insulation, and (2) Sound-absorption. " The closely matted texture of the material forms numerous minute cavities which enhance its insulation value." Gypklith, which is left unplastered for acoustic treatment, is made of finer fibres than that used for structural slabs.

Its weight is approximately 37 lbs. per cubic foot; or calculated superficially, is : 32 lbs. per square foot in 1″ thick material; 47 lbs. in 1½″ material; 61 lbs. in 2″ material, and 84 lbs. in 3″ material. It is made in standard lengths of 4′, and in widths of 1′ 4″ and 2′ 8″.

As regards sound-insulation (calculated in decibels) it has been found, that a partition formed of two 2″ slabs cemented together will provide a noise transmission-reduction of approximately 50 dbs. "With regard to sound-absorption in the tiles the coefficient has been shown to be 63 % over the middle range of frequencies, and in combination with the materials' dispersive qualities the shaped tiles provide an equivalent of 100 % absorption." Sound-insulation values under varying construction provide for walls, floors and roofs a range in decibels from 40 to 65. The Gypklith acoustic tiles (3′ 0″ × 3′ 0″ × 1″) have sound-absorption coefficients approximately the same as the Heraklith tiles. Gypklith fluted, or pipe, tiles are used for acoustic correction in cinemas, etc., for dispersing high-frequency waves from reflecting surfaces. Their absorption coefficients are:

Frequency (cycles per second) .	250	500	1,000	2,000
Absorption coefficients . .	0·3	0·45	0·70	0·55

HEERWAGEN TILES

(*See* under VIBRAFRAM TILES)

HERAKLITH ACOUSTIC TILES

(Messrs. Honeywill and Stein, Ltd.)

They are manufactured from wood fibres impregnated with magnesite cement and are fixed on battens (2″ × 1″) at suitable centres. When so utilised, the sound-absorbent coefficients are:

Frequency (c.p.s.) .	250	500	1000	2000	4000	6000	8000
Absorption coefs. .	0·25	0·35	0·55	0·55	0·55	0·65	0·65

Owing to the magnesite content these tiles resist dry rot and vermin. This material is extensively used for correction in all types of halls, classrooms, swimming baths, churches, etc., etc., and it is classed as a grade "B" material in the National Fire Brigades Association tests.

HERAKLITH INSULATION SLABS (STRUCTURAL)

(Messrs. Honeywill and Stein, Ltd.)

They are made 20″ × 80″ nominal by 1″, 1⅜″, 2″ and 3″ thick, being similar to the Acoustic tiles but having a much coarser texture in order that the surface can be plastered as with other building fibre boards.

They are used in a variety of ways, mainly for partitions, floor and ceiling construction. The sound-insulation of a 3″ partition, plastered both sides, provides a decibel reduction of 35. A partition constructed of staggered wood studs with 1″ Heraklith on both sides plastered will provide an insulation value of approximately 54 dbs.

INSOQUILT INSULATION FELT

(Messrs. Honeywill and Stein, Ltd.)

" This is composed of cocoanut fibres bound together to form a pliant matting, which is supplied 36″ wide in 75′ rolls. It is used mainly for insulating partitions or any partition construction as a barrier against sound-transmission, and can also be used very successfully when laid over the floor joists between the battens and the joists. It is not recommended for acoustic correction, as its appearance is unsatisfactory unless covered with canvas, and this cannot be successfully decorated."

INSULEX MINERAL INSULATION FILLING

(Messrs. Honeywill and Stein, Ltd)

This is a gypsum product used in floors and partitions for preventing Sound transmission. It is a white powdery material of the nature of rock wool and is usually poured in between the joists to a depth of 5″ or 6″, and has the effect of insulating sound.

INSULWOOD

(The Patent Impermeable Millboard Co., Ltd.)

Made of real wood fibre scientifically and chemically treated. It is pressed into large homogeneous sheets of suitable density. It is to be borne in mind, that it is not always the material which has the highest coefficient of sound-absorption under a given frequency that is the best one to use. *One* frequency is no correction at all; a material must possess nearly equal absorbing powers over the whole musical scale of frequencies.

When a sound is created in an enclosure, waves are equally distributed in all directions and very quickly strike the interior surfaces, and continue reflecting until they are dissipated beyond audibility. This constant reflection and inter-reflection is called reverberation. Investigations into the phenomena of Sound have made it possible to measure the amount absorbed by various materials, and the percentage of sound absorbed per sq. ft. of material is called the coefficient of absorption.

If speech or music is created in the open air and there is no immediate obstruction, no reverberation ensues. Hence 1 sq. ft. of open window is accepted as the unit of absorption and it approximates 100% efficiency. Various materials are compared with this unit. Thus, if a material has a coefficient of 0·25 it would require 4 sq. ft. to obtain open-air conditions, or, one sound-absorption unit. (Abstracted.)

The absorption coefficients for various frequencies as tested at the National Physical Laboratory are as follows :

For Insulwood applied to wood battens :

Frequency (cycles per second) .	256	512	1024	2048
Coefficients of absorption . .	0·30	0·22	0·27	0·27

The coefficients for Sound transmission through ½″ Insulwood are :

Frequency (c.p.s.) .	300	500	1000	2000
Transmission ratio .	0·025	0·01	0·00625	0·000625
Reduction factor .	40·00	100·00	160·00	1600·00
Reduction in dbs. .	16·00	20·00	22·00	32·00

The panel supplied for testing measured 5′ 9″ × 4′ 6″ : its weight was 19½ lbs., corresponding to about 0·75 lb. per sq. ft.

L.W. INSULATION BOARD

(Messrs. Brown and Tawse, Ltd.)

The raw material is composed entirely of the best quality timber from the pine forests of Sweden. The wood chips are passed through a screening machine and conveyed to the de-fibrating plant; they are softened by steaming, mixed with water and disintegrated into their constituent fibres, and this forms the actual raw material employed. The fibres are afterwards passed through a strainer into soaking chambers, and there they are proportioned as to fibres and liquid. The pulp-like mixture is fed between large rollers which press it to the required thickness. Then the boards are cut automatically to the required length and are conveyed to a large drying kiln, being finally sheared to size on a cutting table.

Insulation Board is made in thicknesses of $\frac{5}{16}''$ and $\frac{1}{2}''$, and in sizes varying from 6′ × 3′ to 14′ × 5′; it weighs about 7¼ oz. or 12 oz. per sq. ft. according to the thickness employed.

From tests made at the National Physical Laboratory two are selected and given below, and also some Sound-insulation tests.

The transmission of *Air-borne* sound through two double partitions using L.W. brand fibre board.

Description	Frequency (cycles per second)	Sound reduction Factor (R)	Sound reduction in decibels (10 $\log_{10}R$)
Double partition, 5′ 2″ × 3′ 10″ × 5″ thick, made of a layer of ½″ board on each side of 4″ × 2″ studding on about 14″ centres. Weight :— 4·7 lbs. per sq. ft.	200	400	26
	300	4,000	36
	500	10,000	40
	700	25,000	44
	1,000	320,000	55
	1,600	160,000	52
	2,000	4,000,000	66
	4,000	20,000,000	73
Double partition, 5′ 2″ × 3′ 10″ × 7½″ thick, consisting of a layer of ½″ board on each side of 4″ × 2″ staggered studding on about 14″ centres. Inner surfaces of partition separated by 5½″. Outer faces plastered to a thickness of about ½″. Weight :— 12·2 lbs. per sq. ft.	200	40,000	46
	300	1,000,000	60
	500	50,000	47
	700	100,000	50
	1,000	250,000	54
	1,600	4,000,000	66
	2,000	3,200,000	65
	4,000	25,000,000	74

Tests for Sound-absorption coefficients of same material, ½″ thick, by the Reverberation method.

Material as tested (10 ft. × 10 ft.)	Reverberation Absorption Coefficients (to nearest 0·05) Frequency bands in Region (cycles per second)				
	250	500	1000	2000	4000
Board nailed to 1⅞″ × ⅞″ vertical battens on 16″ centres, and similar horizontal battens on 10′ centres. Nails spaced at 4″ centres round edges and at 8″ centres elsewhere.	0·45	0·35	0·30	0·35	0·35

LLOYD INSULATING BOARD
(Lloyd Boards, Ltd.)

" This is made from long tough wood fibres, and having a cellular construction provides a medium for sound-insulation. The bituminous board is very similar to the Insulation board, but has in addition a bitumen content prior to being manufactured in Board form, each fibre being coated with a protective material. The bitumen is precipitated upon the fibre, hermetically sealing each individual fibre prior to its being felted into a board. Thus the bitumen is in the fibre itself and does not fill the cells in the cellular structure of the board. The board is, therefore, capable of absorbing far greater volumes than that of the bitumen present; should the latter become volatile owing to excessive heat, it will be taken up within the board itself and there will be no tendency to bleed.

The application of distemper, paint or plaster cannot be affected by the bitumen provided that in the case of paper or distemper a sufficient undercoat is applied to seal off the small amount of bitumen contained in the surface fibre."

Tables giving results of tests at the National Physical Laboratory as to *(a)* Absorption and *(b)* transmission of sound are appended.

(a) Material as tested	Absorption coefficients (to nearest 0·05) for frequency bands in region (cycles per second)			
	250	500	1000	2000
Insulation Board ½" thick approx. Nailed to 1⅞" × ⅞" vertical battens on 16" centres, and similar horizontal battens on 10′ centres. Nails spaced at 4" centres round edges and at 8" centres elsewhere	0·40	0·35	0·35	0·40

(*b*) Transmission of *Air-borne* sound through ½″ Insulating Board.

Description	Frequency (cycles per second)	Sound reduction factor(R)	Sound reduction in decibels (10 $\log_{10}$R)
Insulation Board, ½″ thick. Weight 0·77 lb. per square foot	200	80	19
	300	160	22
	500	160	22
	700	125	21
	1000	1600	32
	1600	2000	33
	2000	1250	31
	4000	2500	34

MAFTEX INSULATING BOARD

(Messrs. MacAndrews and Forbes, Ltd.)

Maftex is the " only felted root fibre board; it is homogeneous and unlaminated."

The following data respecting Sound-absorption tests made upon ½″ Maftex Insulating Board will be not only interesting in themselves, but also read in comparison with the tests instituted upon other insulating materials given elsewhere in this Section.

The results were " obtained by an eminent Authority."

Frequencies in cycles per second	128	200	300	400	500	600	700	800	900	1000	2000	3000	4000
Coefficients of Sound-Absorption for Maftex: Untreated	·22	·33	·34	·32	·30	·29	·28	·28	·27	·27	·28	·31	·34
Painted with 1 coat " Sunflex "	·22	·27	·33	·36	·36	·32	·26	·21	·18	·17	·21	·25	·27
Do. 2 coats " Sunflex "	·23	·30	·32	·31	·31	·30	·29	·28	·27	·26	·22	·26	·28
Do. 3 coats do.	·20	·26	·29	·31	·31	·31	·30	·29	·28	·27	·22	·25	·28
Do. 3 coats do. and 1 coat of hard Oil paint	·20	·28	·32	·32	·30	·29	·27	·26	·25	·24	·20	·22	·25
Do. 3 coats " Sunflex " and 2 coats hard oil paint	·25	·22	·26	·31	·32	·31	·30	·28	·26	·24	·17	·20	·24

Tests for Sound-transmission carried out by Public Testing Authorities.

Average results of Sound-transmission tests on Maftex.

The figures represent the proportion of sound which gets through the partition, which was one thickness of Maftex (½″) supported on light battens.

Frequency in cycles per second	512 C4	1024 C5	2048 C6	4096 C7
Percentage of Intensity reduction	·05	·05	·04	·02

"MAYCOUSTIC" PRODUCTS

(May Acoustics, Ltd.)

(1) Maycoustic Asbestonite is made by matting and consolidating asbestos fibre into slabs 1″ thick, which are stuck with mastic to any prepared surface and then covered with a fabric membrane to cover the joints and receive the decoration, which, when dry, is perforated with small pinholes. The average coefficient of absorption is 78 %.

(2) Maycoustic Felt is made in three thicknesses (½″, ¾″ and 1″). It is prepared similarly to the Asbestonite. It is fixed to dry surfaces, which have been screeded to a true face. The average coefficient of absorption for the respective thicknesses given above is 45 %, 60 % and 75 %.

(3) Maycoustic Spray (Asbestos) is composed of an asbestos fibre coated with an adhesive. The mixture is then sprayed by forced draught on to the surface to be covered. It can be fixed in all thicknesses from ¼″ to 3″. The average coefficient of absorption is 80 %.

(4) Maycoustic Stone can be made to any size up to 36″ × 15″, and its weight per yard superficial up to

18″ × 12″ is 33 lbs. The average coefficient of absorption is 40%.

Special shapes and sizes can be manufactured.

Note.—For remarks concerning (5) "Cabot's Quilt" and (6) "Sabinite" Acoustic plaster see, respectively, pages 75 and 92.

"NONPAREIL" CORK
(Newalls Insulation Company)

"A layer of 1½″ or 2″ cork is laid so as to 'float' on the upper surface of the concrete. This is screeded with a layer of bitumen which seals it and gives it a level surface on which to lay the flooring. If the flooring is linoleum, rubber, carpet or cork tiles, parquet or wood blocks, these are laid directly on the bitumen screed. If floorboards are used, battens are laid into the cork;

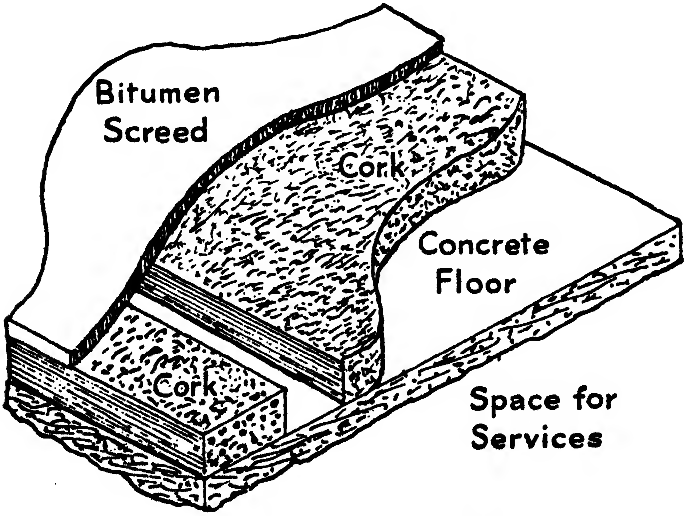


Fig. 13.—Nonpareil Cork Floor of Newalls Insulation Company.

in that case, the bituminous screed may be omitted and a cavity left between the cork and the floorboards. The whole surface of the cork and battens should, however, be painted with a coating of bituminous preparation. Channels for pipes, electric light conduits, etc., may be provided by leaving spaces between the alternate layers of the cork slabs. This type of floating floor only adds 5 lbs. to 6 lbs. per sq. ft. to the weight imposed on the structural floor, and gives about 20 decibels added insulation for moderate expenditure."

The accompanying illustration will help to make clear the method of construction involved in this type of flooring. (Fig. 13.)

PAXFELT

(Newalls Insulation Company)

"This is a pure asbestos material, made similarly to the 'Paxtile' but without the impermeable layer of flexible plaster on the surface." The usual standard size is 3′ × 2′; other standard sizes available are 3′ × 3′, 3′ 6″ × 3′, 6′ × 3′, and 7′ × 3′. Special sizes not exceeding 6′ in length and 3′ in width can be made to order. The thicknesses are ½″ to 3″; the weight of 1″ material is 12 oz. per sq. ft. The National Physical Laboratory tests by reverberation method gave the following results:

Frequency (cycles per second)	250	500	1000	2000	4000
Sound-absorption for 1″ thick on 2″ × 2″ battens . . .	50%	55%	65%	70%	75%
Ditto for 2″ thick ditto . .	55%	65%	75%	80%	80%

PAXFELT BLANKET (NEWALLS BRAND "CABOT'S" QUILT)

(Newalls Insulation Company)

Paxfelt Blanket is flexible, consisting of a layer of pure asbestos with or without hessian backing, and is made up in rolls, these being 18′ × 3′ for ½″ material and 18′ × 2′ 6″ for 1″ material. The weights per sq. ft. are 0·33 lb. and 0·74 lb. for ½″ and 1″ respectively. In using the blanket the timber studs to partitions should be of ample depth, say, 6″ × 2″, and the blanket is fitted to one side or both sides. Battens are fixed over and both faces covered with lath and plaster. The studs should be staggered. The following efficiency tests were made at the Nat. Phys. Lab. on a specimen about 113 sq. ft. in area.

Frequency (cycles per second) .	250	500	1000	2000
Sound-absorption . . .	20%	60%	65%	70%

PAXTILES

(Newalls Insulation Company)

"These are made of pure asbestos fibre covered with an impermeable layer of washable flexible plaster, and then perforated on the front surface with ⅛″ diam. holes, ⅝″ deep and at ⅜″ centres. The sizes of the tiles are 18″ × 18″ and 36″ × 18″. Half, quarter and special sizes are obtainable. The thickness is 1″, and the weight is 1·5 lbs. per sq. foot.

The sound-absorption coefficients are taken from the National Physical Laboratory tests. The tiles were laid, without fixing, on 1½″ × ¾″ battens on the floor.” The following results were recorded:

Frequency in cycles per second	250	500	1000	2000
Sound-absorption . . .	55%	75%	85%	80%

PLIWEB (see page 107)

ROCKOUSTILE

A Johns-Manville System of Sound control

(Agents: Messrs. Douglas R. Smart and Son, Ltd.)

It is made from mica which has been expanded by the application of heat. It can be supplied either square-cut or bevel-edged, and in standard sizes 1″ thick and with a surface 12″ in one direction and 6″, 12″ or 24″ in the other. Application is ordinarily effected by means of nails and cement. The weight per square foot is 1·1 lbs. The following absorption coefficients will be of interest:

Frequency (c.p.s.) . .	125	250	500	1000	2000	4000
Absorption coefficients .	0·29	0·34	0·67	0·81	0·65	0·60

“SABINITE” ACOUSTIC PLASTER

(Licensees: May Acoustics, Ltd.)

This is applied in ½″ thickness on to a ⅜″ backing coat of gauged coarse stuff, the total thickness being ⅞″. It can be used on brick, breeze and wood or metal lathing. Its finish is hand floated; its weight is 40 lbs. per yard super. The average coefficient of absorption is 35%.

Incidentally it may be noticed, that this plaster received its name from the inventor, Dr. Paul Sabine.

SANACOUSTIC HOLORIB, PANELS AND TILES

Some Johns-Manville Systems of Sound-control

(Agents : Messrs. Douglas R. Smart and Son, Ltd.)

These products are made up of metal, mineral wool and asbestos. The tile consists of a perforated sheet-metal casing, finished with baked enamel, which contains a special rock wool pad, the sound-absorbing medium. The tile units lock into tee bars, which are mechanically fastened to the surface to be treated. The face of the rock wool pad is left exposed within the tile to assure the maximum absorption of sound, especially at the higher frequencies. The back and edges of the pad, however, are covered with asbestos paper, to prevent the infiltration of air. The standard sizes of the tiles are 12″ × 12″, 16″ × 16″ and 12″ × 24″.

Sanacoustic panels include, in addition to the above, a great flexibility of unit size, and are available in the following sizes in enamelled steel: In lengths of 96″, 120″, 144″ and 168″; in widths of 30″, 36″, 42″ and 48″. In aluminium the same sizes can be furnished up to 48″ × 120″. The rock wool blanket used as a sound-absorbent possesses the same qualities and characteristics as the pad used in Sanacoustic tiles. (Abstracted.)

Table A below refers to the tiles and Table B to Holorib.

A

The thickness is 1″, and the weight is 2·5 lbs. per foot super

Frequencies (cycles per sec.)	125	250	500	1000	2000	4000
Coefficients of absorption .	0·27	0·61	0·92	0·92	0·81	0·80

B

Thickness	Weight per foot super	Surface finish	Coefficients of Absorption at cycles per second					
			125	250	500	1000	2000	4000
2″	2·7	Perforated metal stove-baked enamel	0·5	0·79	0·87	0·79	0·77	0·75

SLAG WOOL SOUND-ABSORBENT SLABS

(Messrs. Frederick Jones and Co., Ltd.)

The following is for the most part abstracted from a Report issued by Dr. A. H. Davis (for the Director of the National Physical Laboratory) respecting the above. " The material supplied for the measurement of Sound-absorption coefficients by the reverberation method consisted of a layer of slag wool about 2″ thick packed between two layers of wire netting of about 1″ mesh. It was supplied in sheets measuring 3′ 4″ × 2′ 6″ and weighing approximately 2·5 lbs. per sq. ft.

The tests were conducted in a reverberation chamber of high acoustic isolation. The shape was irregular, with non-parallel walls, and a sloping ceiling. The volume of the chamber was about 9,700 cub. ft. The walls were mainly of rendered brickwork, and the floor and ceiling of rendered concrete, the various surfaces being painted. A recess about 10′ × 10′ × 5″ deep in one of the side walls provided accommodation for the test specimen. The recess was fitted with steel doors ¾″ thick which could be closed over the specimen. Twelve sheets were used for the tests, and were fixed to the back wall by means of 2″ × ¾″ horizontal battens on 3′ 4″ centres and 2″ × ¾″ vertical battens on 2′ 6″ centres. The area of the specimen was 100 sq. ft.

The following are the mean results obtained. In practice, however, it should be realised that, apart from difficulties in securing uniformity of manufacture, the acoustic absorption coefficient of a material is not an absolute physical constant, but is influenced by the size, position and distribution of the area treated."

Note.—Messrs. Jones and Co. kindly furnished the present writer with the above particulars, and they are given almost in extenso, as shewing the test method employed at the Laboratory. The Table below is also taken from the same Report:

Frequencies in cycles per sec.	125	250	500	1000	2000	4000	6000
Absorption coefficients (to nearest 0·05) . .	0·25	0·70	0·90	0·95	0·90	0·90	0·85

SLAGBESTOS and SLAGBESTOS BLANKET

(Messrs. F. McNeill and Co., Ltd.)

" Slagbestos is a pure mineral fibre manufactured from slag or a combination of rocks. It is made by converting this while in a molten condition (temperature between 2,000° and 3,000° Fahr.) by means of a blast of steam or air into a mass of exceedingly fine glass-like fibres which interlace and cross each other at every conceivable angle, thus forming innumerable air cells which receive and break up heat and sound-waves. In converting raw material into Slagbestos the bulk is increased twelve times, so that the resulting fibres enclose eleven times their bulk in air."

Slagbestos Blanket is a quilt prepared in rolls of any length up to three feet wide, and in thicknesses of ¼″, ½″, ¾″ and 1″.

Slagbestos (i.e. perfected slag wool), which is also known as Rock wool or Mineral wool, "through its combined inelasticity and want of solidity, completely breaks up sound-waves and thereby prevents the transmission of sound through the material. Tests undertaken by the Nat. Phys. Laboratory prove beyond doubt its efficiency."

SOUND-ISOLATION BLANKETS

A Johns-Manville System of Sound control

(Agents : Messrs. Douglas R. Smart and Son, Ltd.)

These are composed of Banroc wool (rock wool) $\frac{1}{2}''$, 1″ and 2″ thick, stitched between sheets of various materials, including flame-proofed Kraft paper both sides, flame-proofed Kraft paper one side and flame-proofed muslin the other, or flamed-proofed muslin both sides. It is furnished in rolls, either 22″ or 36″ wide. The length of rolls varies with the thickness, being 65′, 35′, and 18′, decreasing with increase of thickness. Other types are 50′ or 25′ long, according to thickness.

The following Table gives the results of tests upon 2″ Blanket finished both sides with flame-proofed muslin, the weight per sq. ft. being 6 lbs. :

Frequency in cycles per second . . .	125	250	500	1000	2000	4000	6000	8000
Absorption Coefficients per cent. . .	65	70	85	90	90	90	85	75

"The idea of the Johns-Manville System of Sound Isolation (formerly, the Stevens System) is to place a shock-absorbing construction between the light exposed surface of a room and the main structure, no solid through-connections being used. These light-weight units receive the vibration and transform it into mechanical energy and absorb it when transformed. Sound-isolation blanket, or fill, used in connection with the isolators, adds a sound-damping medium and prevents drum action. In this system cushioned isolators are installed at specified points to take up the shocks which the sound-waves generate. A means is provided for securing a finished surface to a wall, ceiling or floor which not only holds the various parts together, but also breaks the otherwise direct contact of solid material which would conduct vibrations. The shock-absorbing units (' chairs ' or ' isolators ') consist of a metal support or fastener to which studding, sleepers or joists can be fastened, and one or more layers of heavy cushioning felt, which comes between the structural member and the metal fastener. When these units are installed in a wall any sound-impulse uses itself up in compressing the resilient felt and is largely prevented from reaching the structure beyond."

THERMACOUST

(Thermacoust Products, Ltd.)

Made up in slabs and tiles. Each slab measures 84" × 23⅛", holding 1½ sq. yds. The thicknesses are ½", ¾", 1", 1½", 2", 2½", 3" and 4", and the respective approximate weights per sq. ft. are 1·6 lbs., 2·1 lbs., 2·5 lbs., 3·2 lbs., 4·1 lbs., 4·8 lbs., 6·0 lbs. and 6·7 lbs., the average density is 25 lbs. per cubic foot.

It contains no magnesite or salts.

The following data obtained under tests are of interest:

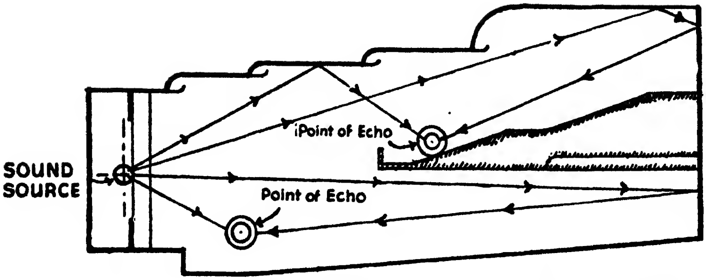
Transmission of Air-borne sound as found at the National Physical Laboratory.

Note.—The partitions tested were 5′ 2″ × 3′ 10″. The Thermacoust was insulated by felt from the wooden frame of the specimen.

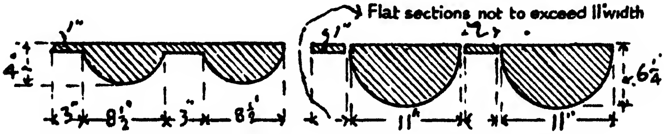
Measured over the Frequency range of 200–4000 cycles.

Description	Thickness in Inches	Approx. Weight in lbs. per sq. foot	Average Reduction in Decibels
Brick wall, 4½ inches plastered both faces	5½	47	52
Ditto with 2″ air space and 2″ Thermacoust and plastered as above	10	55	60
Ditto with 1″ Thermacoust fixed on 2″ × 2″ battens, 27″ o/c and plastered as above	9	53	60
1″ Thermacoust fixed to two faces of 4″ × 2″ studding at 19″ centres and plastered as above	7	16	58
2″ × 2″ studding at 19″ centres with 1″ Thermacoust to two faces and plastered as above	5	15	56
3″ × 2″ staggered studding at 16″ centres with 1″ Thermacoust over and plastering as above	9	22	59
2″ Thermacoust separated by 1″ air-space from 2½″ Thermacoust and plastering as above	6½	20	60
2½″ Thermacoust plastered on both faces	3½	14	46

The texture can be varied from fine open grain for acoustical correction to wide close grain for roof insulation. Slabs 2″ thick and over are self-supporting. Thinner sizes are nailed to timber, bolted to steel or



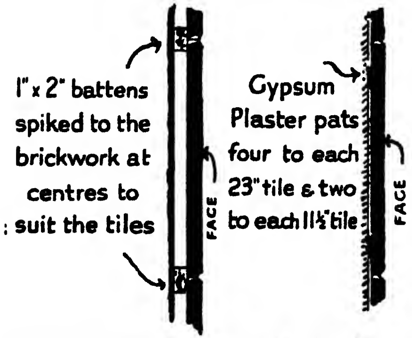
A TYPICAL SECTION ALONG AUDITORIUM SHEWING ECHO CAUSED BY SOUND REFLECTION FROM DISTANT SURFACES



SMALL SECTION PILLAR LARGE SECTION PILLAR

PLANS of MOULDED THERMACOUST

FOR PREVENTION of DIRECT REFLECTION AND ECHO.



METHODS OF FIXING THERMACOUST TILES

FREQUENCY IN CYCLES per SEC.	ABSORPTION PER CENT
250	30
500	60
1,000	80
2,000	60

SOUND ABSORPTION FOR 1" THERMACOUST

FIG. 14.—From data supplied by Thermacoust Products, Ltd.

keyed to concrete. When Thermacoust is nailed to timber, the joints may be either (1) left open and filled with gypsum plaster or (2) butted, and covered with scrim. The latter treatment is preferable, as it prevents all risk of pattern staining.

When Thermacoust is built up as a self-supporting partition, lime mixes, or cement or gypsum may be used. Cement and sand should not exceed 4 and 1 in strength.

The accompanying figure (Fig. 14) is abstracted from a Technical Data Sheet kindly forwarded by the Company, who, in a covering letter remark, the pillar type slabs illustrated " are used generally for the back wall correction of Cinemas; the flat acoustic slab and the acoustic tiles with bevelled edges are generally used in Schools and Halls and so on, and it is common practice to decorate them with spray painting."

See additional information on page 107.

TRANSITE ACOUSTICAL PANELS AND TILES

A Johns-Manville System of Sound-control

(Agents: Messrs. Douglas R. Smart and Son, Ltd.)

Transite is a perforated asbestos-cement product, made up as tiles and panels. The tiles, entirely of minerals, are fire resistant, and each one is 12" × 12" × $1\frac{1}{8}$" thick. The panels consist of large sheets of perforated Transite, backed by a rock wool (Banroc) Sound-absorbing element. Their advantage over the tiles may be taken to be the larger units obtained. The edges are slightly bevelled. The standard size panels are 12" × 12", 12" × 24", 24" × 24" and 24" × 48". In using continuous " panelling " the perforations are continuous, there being no unperforated border as for separate panels.

The following test data refer to the perforated tile. The weight is 2·25 lbs. per ft. super.

Frequency in cycles per sec.	125	250	500	1000	2000	4000
Absorption Coefficients .	0·47	0·62	0·71	0·75	0·72	0·70

TREETEX

(Treetex, Ltd.)

It is made from " the finest Swedish timber. The logs are reduced to fibres, which are graded and waterproofed, and are subjected to processes protecting them against dry-rot, etc., after which they are ready for felting into board-form. Throughout this process nothing is done that could in any way adversely affect the insulating properties. Thus no pressure is used which tends to destroy the air cells from which insulating efficiency is obtained. On the contrary, the felting process insures that countless dead-air cells are formed in addition to those already contained in each fibre. The felting machine consists of a large roller on to which the fibres are sucked, and the board leaves the roller on to a conveyor in a continuous sheet 12 ft. wide, and whilst actually moving is cut by a travelling cutter into suitable lengths. The ½" board has a density of 13·1 lbs. per cub. ft. Its Sound-reduction over a frequency range of 200 to 4,000 cycles per second averages 27 decibels, with a maximum reduction of 36 dbs. The acoustical sound-absorption at 512 cycles is ·30.

Treetex adheres direct to brickwork by means of neat cement (slurry) and can be applied to hollow tile construction by being cemented or nailed, the combination providing efficient protection against the passage of sound. The accompanying sketches are from the Company's pamphlet, from which, too, the foregoing particulars are abstracted. (Fig. 15.)

VIBRAFRAM TILES

(Originally, HEERWAGEN TILES)

(The Celotex Corporation)

In principle, Vibrafram departs radically from conventional acoustical materials of porous composition. It depends for its sound-absorption qualities on diaphragmatic vibration of the individual tile units, instead of on porosity. Acoustical material is needed for the correction of excessive reverberation where speech and music are carried on. Conventional sound-absorbing materials adequately absorb high-pitched sounds, but provide inadequate absorption for sounds in lower frequencies. This characteristic accounts for the 'dead' condition occasionally complained of by musicians in acoustically-treated rooms, and particularly affects the problem of correction in sound-picture theatres.

Vibrafram has a nearly-flat absorption-frequency characteristic with somewhat higher absorption at the low, than at the high, frequencies. The principle of absorption by diaphragmatic vibration is not a new discovery, but it was M. Paul Heerwagen (the inventor of Vibrafram) who first applied it practically. This is a tile made of felt of about the thickness used for billiard tables. It is sized and is formed into hollow tile shapes, which retain the vibratory quality. Its weight is about 3 oz. per foot super.

The tiles are applied with approved adhesive direct to plaster, &c.

Vibrafram is useful either alone or with other types of treatment for obtaining the desired reverberation times

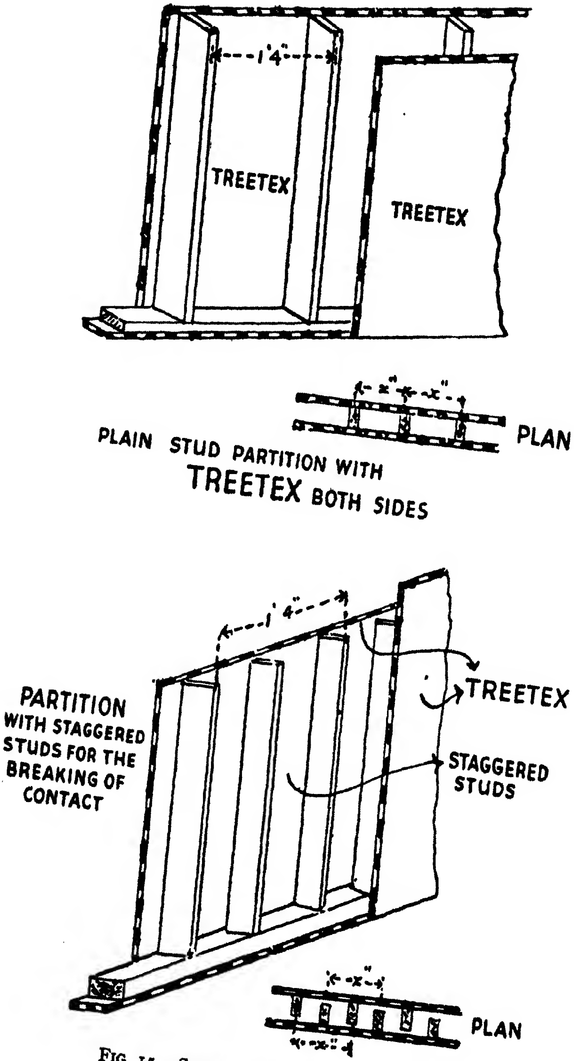


Fig. 15.—Some of the uses of Treetex.

over the entire frequency range. Amongst other uses it is recommended for Radio studios. (The above notes are abstracted from a Celotex booklet.)

VIBRODAMPERS (see page 108).

WELLINLITH LIGHT-WEIGHT SLABS

(Gliksten Doors, Ltd.)

The slabs are composed of intertwined wood fibres, chemically impregnated and concrete-bound (without magnesite or magnesium and chloride compounds) and are formed under high pressure. Owing to its characteristic structure Wellinlith is highly non-conductive of sound. The innumerable small cavities in its fibrous structure, coupled with the elasticity of the material, afford a high degree of sound-absorption.

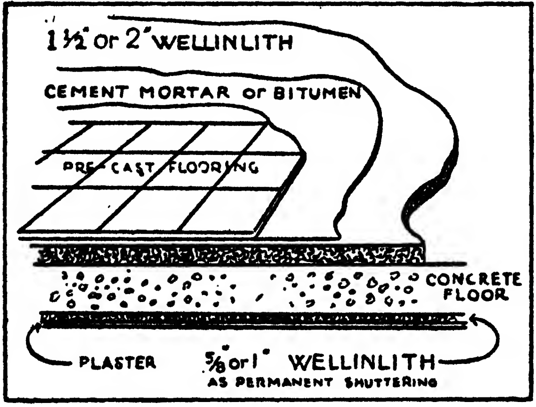


FIG. 16.—Wellinlith laid on concrete.

It is made in slabs ranging in thickness from ⅝" to 4", with a surface of 1½ sq. yds., and an average weight of 25 lbs. per cub. ft.

To construct floors, sound-insulated and draught-proof, Wellinlith is laid either on top of the concrete sub-floor, or alternatively is nailed over the joists. (See Figs. 16 and 17.)

The following tests information (National Physical Laboratory) is of value:

Material as tested: Specimen approximately 10 ft. × 10 ft.	Reverberation absorption coefficients (to nearest 0·05) for frequency bands in region (cycles per second)			
	250	500	1000	2000
" Wellinlith " Light-weight building slabs, 2″ thick, nailed on 3″ × ¾″ battens. Four vertical battens at 3′, 4′ and 3′ centres successively. Two horizontal battens at 10′ centres.	0·35	0·60	0·70	0·55

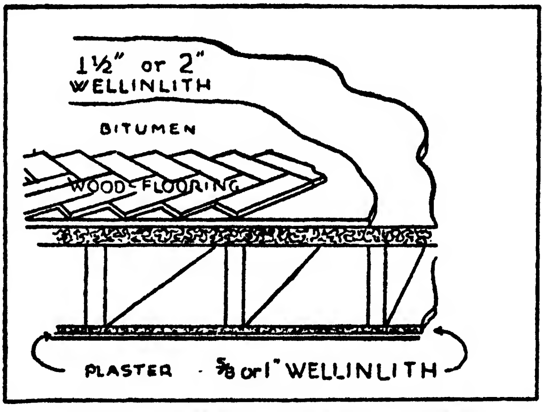


FIG. 17.—Wellinlith nailed over joists.

Measurements of the sound-intensity are expressed below in two different ways: The reduction factor, being the ratio which the sound-energy transmitting through the open aperture bears to the sound transmitted through the test partition, and (2) The reduction expressed in decibels; this is equal to 10 times the common logarithm of the reduction factor. Note, that the transmission factor is the reciprocal of the reduction factor:

Description	Frequency (cycles per second)	Acoustical Reduction factor (R)	Acoustical Reduction 10 decibels ($10 \log_{10} R$)
Double partition 5′ 2″ × 3′ 10″ × 9¾″ thick, formed of two leaves of the slabs, each 1½″ thick, on 3″ × 2″ staggered studs. Separation between the leaves 5½″, each leaf insulated from wood frame by ½″ felt. Outer faces plastered ¼″. Each set of studding on about 21″ centres. Weight: 20 lbs. per sq. ft. (Total—400lbs.)	200	4,000	36
	300	63,000	48
	500	100,000	50
	700	80,000	49
	1,000	100,000	50
	1,600	630,000	58
	2,000	1,000,000	60
	4,000	16,000,000	72

The above results refer only to air-borne sounds, and not to impact noises or similar structure-borne sounds. Since the conditions under which measurements of sound-transmission are made in various laboratories differ to some extent, the above results should not be used in conjunction with others obtained elsewhere.

(Note.—The above particulars are abstracted from literature kindly furnished by the Company.)

ZONO ACOUSTIC PLASTER

(Messrs. Honeywill and Stein, Ltd.)

This is a micaceous product which can be applied to any decorated surface in plaster form to a thickness of ½″. In appearance it is a golden rough-textured material and its tint is permanent and will not fade with the passing of time. But decoration must not be applied to the surface.

It is specially recommended for use in cinema auditoria correction as it is economical and speedily applied, and the plaster may be laid on brickwork without the usual basecoat plaster being applied first.

The coefficients of absorption for this material are:

Frequency (cycles per second) .	250	500	1000	2000
Coefficients of absorption .	0·3	0·306	0·294	0·3

(NOTE.—The above particulars are quoted from a very informative letter from the Company regarding their products.)

ADDENDA

NOTE.—The following additional information was supplied just in time for inclusion herein.

THERMACOUST

Sound-Absorption Memoranda

Frequency in cycles per second .	200	500	1000	2000
Coefficients	0·30	0·60	0·80	0·60

The above values were obtained at the National Physical Laboratory by the Reverberation Chamber method. (See pp. 94–95.)

VIBRO-INSULATIONS, LTD.

(See also page 78.)

Cocosquilt is a coir fibre manufactured in quilt form in various thicknesses, and is used for insulation of roofs and partitions.

Pliweb is specially designed for insulating steel structures and steelwork carrying machinery.

Vibrodampers are metal boxes housing helical springs and insulating materials, and are used for preventing transmission of vibration and noise from machinery. They can be specially designed for all machinery, big and small. For certain types of machinery installations spring vibrodampers might not be considered advisable, and in such cases there are available solid materials, such as

Corbase (Standard and Expanded) and *Cormat*, which are all pure corkwood manufactures for machinery isolation.

APPENDIX A

The following is extracted, by his kind permission, from Professor Floyd R. Watson's "Acoustics of Buildings," for use as an Appendix to the current work.

Acceptable Time of Reverberation for Auditoriums of Different Volumes

An important factor, and one that must be known when correcting or designing the acoustics of an auditorium, is the time of reverberation that will give the best results. This information is obtained by tabulating the acoustic data of auditoriums that are pronounced good by public opinion. Kreuger published a table that is instructive regarding acceptable time (t) for good acoustics.*

If t is greater than 5 seconds, acoustics very bad.
,, lies between 5 and 3 seconds, acoustics bad.
,, ,, ,, 3 and 2 ,, ,, fairly good.
,, ,, ,, 2 and $1\frac{1}{2}$,, ,, good.
,, ,, ,, $1\frac{1}{2}$ and $\frac{1}{2}$,, ,, very good.

The question of acceptable time has been considered by a number of investigators, with a general agreement that the preferred time lies between 1 and 2 seconds depending on the volume of the hall.† Some years

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* H. Kreuger, "Research into Acoustical Problems in Buildings," *Ingeniors Vetenskaps Akademien*, Stockholm, 1924.

† P. E. Sabine, *Amer. Archt.*, June, 18, 1924. S. Lifshitz, *Phys. Rev.*, Vol. 25, p. 391, 1925; Vol. 27, p. 618, 1926. F. R. Watson, *Architecture*, May, 1927. S. Beljajew, *Akustik grosser Räume, Deutsch. Bautzig.*, No. 7, 1926.

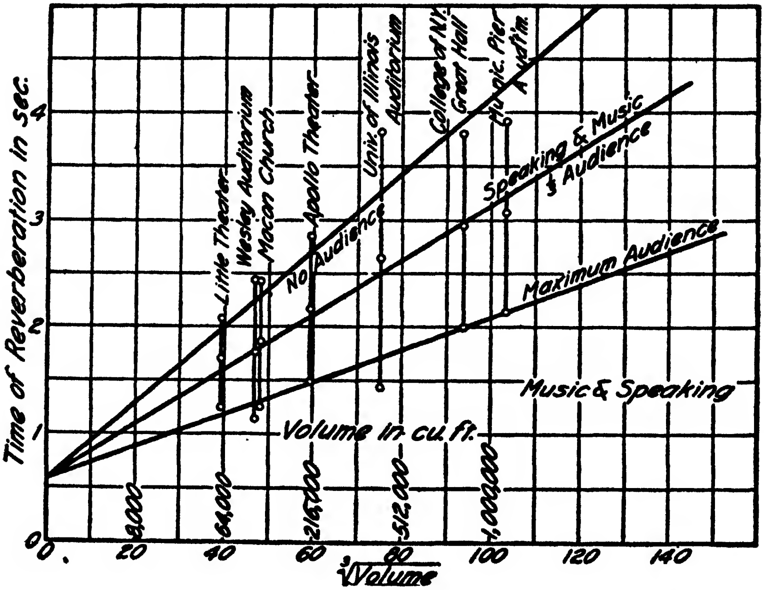

FIG. 18.—Acceptable time of reverberation for auditoria of different capacities.
(*By kind permission of Prof. F. R. Watson.*)

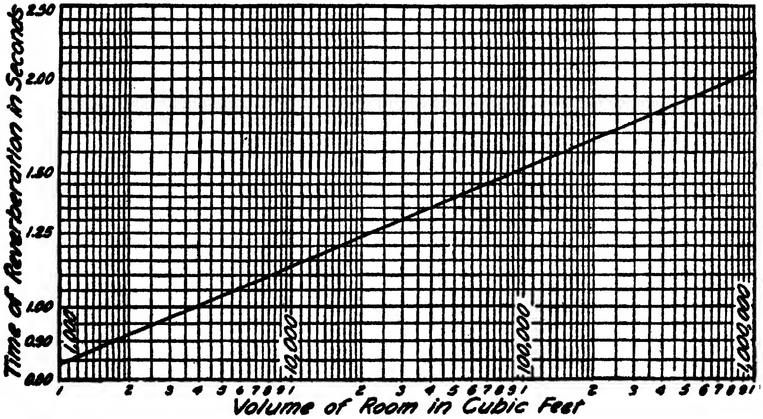

FIG. 19.—Optimum time of reverberation for different auditoria.
(*By kind permission of Prof. F. R. Watson.*)

ago, the author published the curves shown in Fig. 18, and used them extensively in the correction of acoustics. Experience indicates, however, that shorter times of reverberation than given in the figure produce better results, and a later graph of "optimum" times was advocated, as shown in Fig. 19. It is to be noted that the optimum time increases with the volume, varying from 0·84 second for a room of 1,000 cu. ft. to 2.05 seconds for a volume of 1,000,000. According to these optima, "perfect" acoustics would be expected. Practical installations have not always borne out this expectation because no systematic provision was made for the performer whereby he could adjust his speech or music for best effect. To secure these optimum times of reverberation, it is necessary to install absorbing materials in sufficient amounts, which are indicated in Fig. 20.

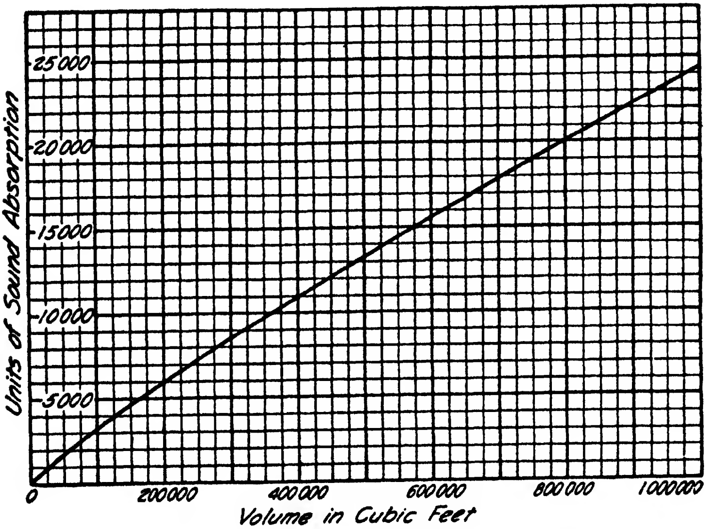

FIG. 20.—Amount of Sound absorption needed to give the optimum time. (*By kind permission of Prof. F. R. Watson.*)

A very important question arises, in the adjustment of acoustics, about the size of audience for which the optimum should be applied.

Audiences absorb much sound because of the clothing worn, and this must always be considered in adjusting a room. Almost any hall filled with a capacity audience will have good acoustics, but when empty, or with a small audience, there will be too much reverberation. It is desirable to make the room as independent of the audience as possible, and this is done by installing materials that reduce the reverberation for the empty room so that the audience has less effect.

It is common practice now to use values similar to those in Fig. 18 for the correction of acoustics, but experience is showing that the data of Figs. 19 and 20 give better results if applied to the size of audience for which perfect acoustics are desired. For instance, in broadcasting rooms, which have no audience for consideration, the optimum should apply for the empty room.

APPENDIX B

Note.—The department of Scientific and Industrial Research has very kindly sanctioned the reproduction below of information obtained by the Department. Work on acoustics of buildings is carried out jointly by the National Physical Laboratory and the Building Research Station of the Department working at Garston. The Note is printed in extenso.*

THE DESIGN OF CONCRETE FLOORS TO REDUCE THE TRANSMISSION OF SOUND

The following note is a summary of available knowledge —the treatment is not exhaustive. It is presented in the hope that it may be found useful as a convenient résumé of existing information.

1. Preliminary

In considering the design of concrete floors to reduce the transmission of sound it will perhaps be useful to recall that in their Final Report issued in 1936 the Ministry of Health Departmental Committee on "The Construction of Flats for the Working Classes" stated that an insulation against impact noises of some 15–20 phons was a desirable standard for flats. The phon, it may be noted, is a measure of loudness as heard by the human ear, and need not be defined for the purposes of this note beyond stating that for sounds of medium

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pitch and loudness a reduction of 10 phons gives an impression to the listener of the noise being halved.

2. THE PROBLEM DEFINED

The problem under consideration has mainly to do with noises arising from impacts upon the floor such as footsteps, or from machinery resting on the floor, rather than with air-borne sound such as that of conversation, the gramophone or wireless. The reduction of air-borne sound is governed largely by the mass of the construction and concrete floors are usually so heavy that they are at least moderately satisfactory in this respect. But when impacts occur upon it *the floor itself acts as a source*, and the sound permeates the building structure to such an extent that it is common for the occupants of neighbouring rooms to suffer, whether rooms by the side and above or those beneath.

Many instances to illustrate this come to the notice of the Building Research Station. Perhaps one of the most interesting of recent cases was that of a squash racquets court in a luxury block of flats, which was built in contact with an old house. The occupants, both of the house and the flats, complained that they could hear the impact of the ball in play in the court. The court was in the basement of the building and separated from the house by a corridor, as well as a brick wall totalling 32″ in thickness. The sounds of the impacts were clearly audible both in the house and flats, however, and it was discovered ultimately that a most remote and unexpected path was being taken by the vibrations. The cure was a matter of some considerable expense, but the possibility of trouble could have been eliminated during construction at a small cost.

The cure for such problems as these lies in the localisation of the noise in any way practicable. If the vibrations can be confined to the surface on which they start, no nuisance or difficulty need be anticipated. This can be done by isolating the floor surface from the rest of the structure, but in building construction it has been the practice to require that all parts of the structure shall be firmly bonded together. The introduction of the discontinuities necessary to afford the desired localisation of the noise is a marked departure from traditional practice and it is with the methods of doing this, as regards floor construction, that the present note deals. It should be noted as well, however, that any construction to improve the reduction of impact sounds can normally be expected to reduce the transmission of other sounds also.

3. METHODS OF CONSTRUCTION

In the investigations on the subject which are being conducted jointly by the National Physical Laboratory and the Station, the National Physical Laboratory being responsible for the physical measurements, four particularly successful and useful treatments of the concrete structural floor to localise noise have been developed. These are all of what may be termed the " floating floor " type, where the wearing surface is carried upon a resilient material which serves to insulate the main structure from the vibrations. The various types are illustrated in Fig. 21, and of these, types 1 and 3 are very simple and cheap, while types 2 and 4 give slightly better results at somewhat greater cost and are more certain to give satisfaction. Types 1 and 2 are suitable for finishing with screed and lino, cork, rubber or woodblocks and similar materials while 3 and 4 are of the timber-on-batten type, having a wood finish in the usual manner.

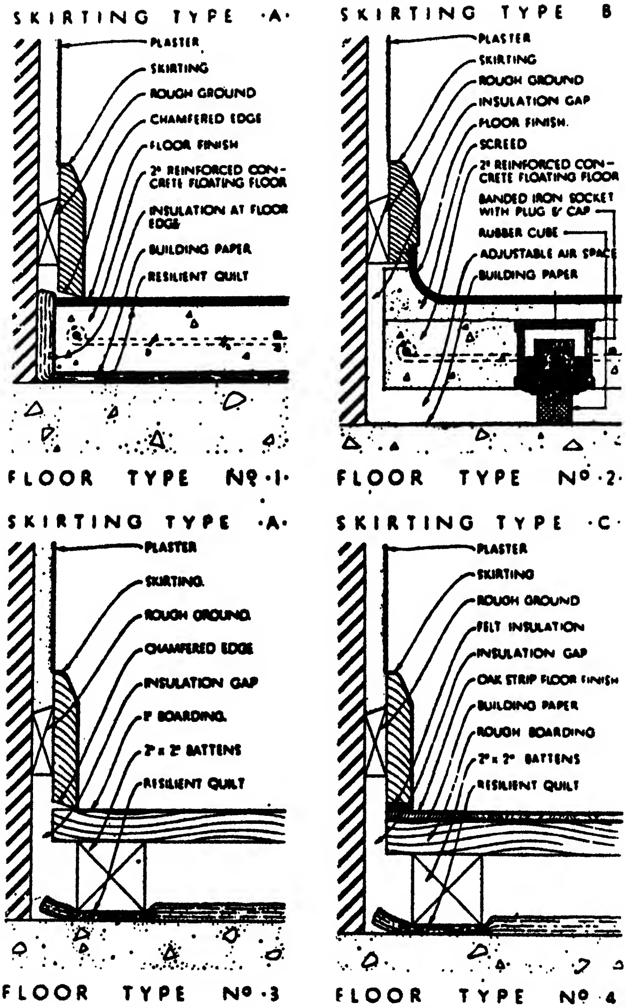

FIG. 21.—Types of Floating Floors.
By kind permission.

The characteristics and details of construction of these floors are as follows:

TYPE 1

Construction.—Nominal ½ in. thick quilting of glass silk, eel grass or slag wool is laid upon the bare structural concrete, the joints of the quilting being lapped, and the whole covered with a waterproof building paper. A screed from 1½–2 in. thick, slightly reinforced in mid-section, is poured directly upon the prepared quilting. The surface is then prepared to receive the wearing finish.

Comment.—In general, the thicker the quilting and the thicker the screed the better the insulation, although the minima suggested are quite effective.

The waterproof paper is intended simply as a precaution against concrete leakages through the quilting, for these can establish rigid bridges which short-circuit the insulation.

The cost of this treatment is little in excess of an ordinary screed and lino.

There is no doubt that this floor merits popularity. Its effectiveness and economy together are probably unequalled as far as present knowledge goes, and it can be adapted to suit almost any type of building.

Insulation value.—This type of floor would be classified as "fairly quiet" to "quiet" (ranging from 15–20 phons insulation), depending on the type of quilting (preferably of an inorganic type) and the thickness of the slab (preferably 2 in.). The nature of the wearing surface affects the overall insulation only slightly, but most floor coverings produce a further slight improvement.

Type 2

This floor, which is one developed at the Building Research Station * consists essentially of a slab which is cast in situ, and later lifted on to rubber cubes, which themselves rest on the structural floor.

Construction.—Paper is first laid on the structural floor to prevent the adhesion of the concrete screed. Upon the paper, at the proper spacing (usually about 2 ft.) are placed banded sockets of a dimension to suit the desired thickness of the screed, which is preferably about 2 in. The concrete is placed, with light reinforcement about mid-section. When the concrete has thoroughly set, wooden blocks are dropped into a *limited* number of sockets, and plugs are screwed down upon them. In this way the independent slab is gradually lifted, and when it has been raised slightly more than 1″, plugs with rubber cubes attached are inserted in the empty sockets. The wood blocks are next removed and similar plugs inserted in these sockets, and the screws adjusted until the whole floor is evenly supported on the rubber blocks. The thickness of the air-space should be about 1″ when the floor is complete. Covers can be fitted to the sockets, and a finish screed to receive the wearing surface can be placed.

Comment.—In making this floor no great skill is required, but care should be taken to ensure by plugging, or other means, that concrete is not allowed to get into the grooves of the sockets. A very slight greasing of the inside of the sockets seems advisable as well. The spacing of the sockets is determined by the strength of the slab rather than by the load which is placed on the individual cubes.

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* British Patent No. 466044. Inquiries regarding the use of the patent should be addressed to the Secretary, Department of Scientific and Industrial Research, 16, Old Queen Street, S.W.1.

The cost should be moderate, but is, of course, in excess of Type 1.

Insulation value.—With this floor the insulation value is high, and it would be termed a very quiet floor. Moreover, the process of lifting ensures that no rigid contacts will take place, and the insulation is therefore practically guaranteed. Insulation tests have shown values ranging from 20 to 25 phons.

TYPE 3

Construction.—The usual 1″ tongued and grooved or plain edge boarding is nailed to battens, recommended to be 2″ square in section at least, which in turn rest upon the resilient element. The latter may consist of rubber cubes (countersunk to permit of nailing them to the battens without forming rigid contacts) or strips of quilting, or an entire blanket over the structural floor.

Comment.—Whether the quilting is of eel grass, glass silk or slag wool appears to make no difference whatever to the insulation, and the choice as between these depends therefore upon other factors. Double thicknesses of quilting are usually more effective, but seem to be rather too springy. Slag wool is perhaps an exception. Rubber cubes are very efficient.

The cost of this floor, over and above an ordinary method of holding the battens appears to be negligible.

Insulation value.—These floors are about the equal of Type 1 (say 15–20 phons).

TYPE 4

This type differs from type 3 only in the finish and is simply an alternative. In this case, the 1″ tongued and grooved boarding can be replaced by the cheapest of rough boarding, overlaid with a stout, soft building paper and a thin strip hardwood wearing surface.

Comment.—The rough under-boarding is probably best laid diagonally, and the wearing surface related to the walls of the room in the normal manner. This ensures that each board in each layer can cross the supporting battens. The building paper provides a certain amount of damping, and frequent secret nailing of the wearing surface to the under-boarding should not affect the insulation adversely. The cost of this floor is not excessive, and depends principally on the finish.

Insulation value.—This floor appears to be slightly better than Type 3 and can, in general, be considered a quiet floor.

4. MATERIALS FOR INSULATION

All these floors depend for their insulation value upon the nature of the resilients used (i.e. rubber cubes, quilting, etc.) as well as the method of construction. In general it may be said the materials should be such as " give " under impact. No test data are as yet available on the life of these materials, under load, but the indication seems to be that inorganic materials are the more satisfactory, and are probably less inclined to change with time than the organic types.

Rubber requires special comment. If protected from light, oils or grease, and other deteriorating elements, it can probably be depended upon to act efficiently for from 20–40 years.

It should be mentioned that in addition to rubber, glass silk, eel-grass and slag wool quilting, many other materials have been tried including felt, clinker, cork granules, fibre board and asbestos, none of which however appear to be as desirable.

5. SKIRTINGS

The effect of a floating floor can largely be defeated if a skirting rigid with the structure is adopted. Skirtings have been devised, therefore, which avoid any rigid edge effect, and which incidentally do not allow access of vermin.

Where the floating floors are of concrete, such as Types 1 and 2, the skirtings will depend partly upon the chosen finish. Supposing this to be of lino, rubber or cork blocks, for instance, the edge of the floating portion can be treated either in the normal manner, with a skirting resting on the finish, or else can be designed to incorporate a cove skirting forming, as it were, a tray. These are represented by skirtings " A " and " B " respectively in Fig. 21. In the former, the finish itself will provide the insulation, although it is to be noted that the bottom edge of the skirting board is chamfered to a point in order to reduce the area of contact, which is itself a factor. The second type, " B," is more complicated. The cove of the skirting is incorporated with the floating screed and the upper portion of the skirting is of wood, applied to the wall. The lino or rubber is continued up the cove, and is made to adhere above and below the gap between the two parts. A similar and simpler, but less satisfactory, method is to construct the entire cove skirting on the floating screed, avoiding any contact with the wall, and providing an adhesive strip to cover the resulting open joint between the two.

With floating floors constructed of timber, such as Types 3 and 4, a strip of felt or similar insulation material should be inserted between skirting board and floor finish. The skirting should then be pressed down to provide a clamp at the floor edge. This is illustrated in skirting " C " of Fig. 21.

Skirting " A " should also be effective with timber floating floors, according to experiments made on the continent, and it is shown in connection with floor Type

3 as well as floor Type 1 in Fig. 21. No experiments with this skirting have been tried in this country, but the effect is probably dependent in this instance solely on the reduction of area of contact. The floating floors themselves should on no account make rigid contact with the walls. An air gap or insulation should be left between floating floor and wall.

6. OTHER SOUND REDUCTION TREATMENTS FOR FLOORS

Wearing surfaces.—Ordinary lino, wood blocks, cork or rubber placed directly upon the structural floor give a maximum of probably 5 phons reduction. The more expensive forms involving sponge rubber and under felts may give 10 phons. In no case do they approach the minimum insulation obtainable by a floating floor, although they are often more expensive than the latter.

Suspended floors.—Suspended floors, in which design the structural floor is itself mounted upon insulation, have been suggested at various times. These have, however, an immediately discernible fault, in that the floor is still the source of sound, and although some degree of localisation occurs, the occupants of the room below often suffer to a greater degree than before.

Ceilings.—To give any useful insulation effect, ceilings must be either suspended or entirely isolated. Neither suspended nor isolated ceilings can take the place of floating floors however, due to the fact that the latter localise the sound, and the former merely impede one source of entry to any one room. As a protection in addition to floating floors they are of some use, the insulations being approximately additive, and they are also a protection, to some degree, against air-borne sound.

Suspended ceilings can be constructed either of battens held in clips close to the structural floor, or suspended from hangers. In either case felt should be introduced in some convenient way between the battens and the hangers at the point of contact. Patented devices of this nature are available. The insulation that can be achieved by these constructions is usually of the order of 5–10 phons.

Isolated ceilings of plaster carried by lathing on joists which themselves rest on corbels at the wall are usually more effective than suspended ceilings by some 5 phons, but a considerable loss of room height will probably be entailed.

A small loss of insulation occurs when the wall and ceiling plaster are continuous. This is probably not serious, but can be avoided if so desired by leaving a gap between the two, and covering it over with a papier-maché cornice of some kind.

An American development consisting of a suspended floor and a suspended ceiling combined, utilises light steel joists carrying a 2–3″ reinforced slab as a structural floor. Between the concrete slab and the steel joists is ½″ of emulsified asphalt. A ceiling is suspended from the steel joists and the whole design is said to be quite effective, although no opportunity has arisen as yet to test it in England. Illustrations of the above design are given in Fig. 22.

The use of sound absorbents on ceilings will have no effect upon the actual transmission, but will, of course, contribute in a normal way to the comfort of the room.

7. General

As a result of the investigations made, it can be said that there are practical and reasonably economical methods of preventing undue transmission of sound through concrete floors. In many instances the use of a floating floor will be cheaper than a good wearing surface alone, which, at best, can only give about half the sound reduction obtainable by the former. It may be added that timber joist floors, which in the bare condition are some 10–15 phons noisier than concrete, have not so far been given adequate attention, but work

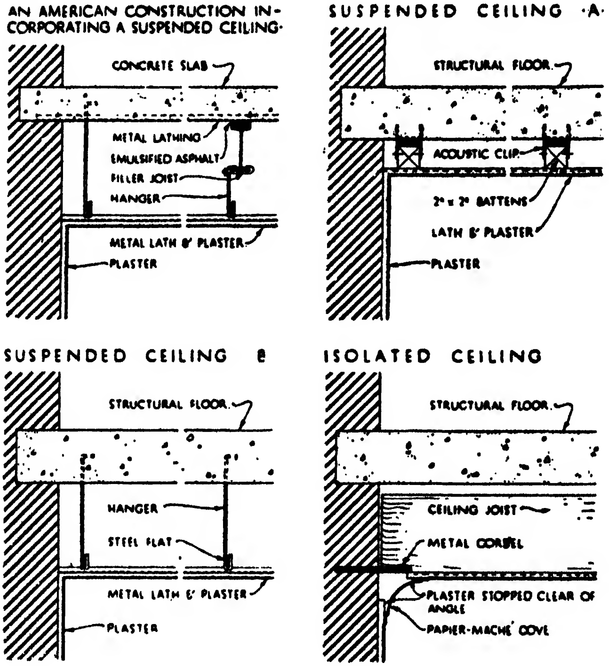

FIG. 22.—Suspended and Isolated Ceilings.
(*By kind permission.*)

on them is now in progress, and it is hoped that a great deal more knowledge concerning them will be available in the near future.

With regard to differences in the structural concrete floors themselves, it may safely be said that ordinary hollow block floors, solid concrete, and concrete combined with hollow clay tiles will all display equal qualities in respect of the transmission of impact sounds.

APPENDIX C

FLATS FOR THE MASSES CONSIDERED ACOUSTICALLY

The Ministry of Health issued some brief period ago a Report upon the above subject under the selected heading " Final Report of Departmental Committee on the Construction of Flats for the Working Classes." With the general tenour of that Report this book is in no wise concerned, but a few brief remarks dealing with the subject, prefaced by some general criticisms upon present-day procedure, will not be amiss. And, naturally, respecting the Report itself it is only the subject of Acoustics which may be appropriately reviewed in these pages. The first document issued took the form of an Interim Report, presented in 1935, the Final Report appearing in 1937. The Committee consisted of several well-known architects and engineers, who, by their co-operation, gave a cachet of considerable value, and with their labours there must be general sympathy; the criticisms that follow are more concerned with the whole system pursued.

In these days it is not a matter of " Each for himself and the devil take the hindmost," but much more is the slogan which is advanced " All for the masses (otherwise called, the Working Classes) and the devil take the others." It might have been not unreasonably thought, that those who find the bulk of the funds for building and maintaining the " Working Class " Flats and Cottages and such like, would deserve consideration on the part of those who administer the funds. And anything in the nature of luxury or unnecessary decorative treatment and of specialisation should be avoided in these days of superlative taxation. As things are, Peter pays heavily for Paul as well as for himself.

Any measures taken for securing resistance to fire, to the spread of disease, and the reasonable amelioration of the condition of the masses deserve full support, and at that point expenditure of public funds should abide, awaiting better days for the exploiting of the so-called " Classes "—an entire misnomer to-day.

The Report on its second page, under the heading " Acoustics " notes : " We laid particular stress in our Interim Report on the problem of noise transmission in buildings and on the special need for providing sound-insulation in working-class flats. We are more than ever convinced that the acoustic problem requires careful attention if the flats are to provide an appropriate degree of comfort." A mere member of the General Public might ask why *special* provision should be made in such Flats ? Assuredly, the materials employed should be of good quality and preferably sound-resisting, but not more so than for the innumerable houses built for John Citizen. The expense of erecting " floating floors " is admittedly higher than for fixed floors, and is not to be justified under existing conditions.

The Report is excellent and highly instructive, and is equally valuable, *as* a Report, for an ideal Republic ; but we are not living in such a Republic, and, therefore, some merely abstracted approvable items will be now dealt with.

Assuredly it is well to isolate noise at the source as far as possible, and noises due to water services should be reduced to a minimum by suitable choice and location of fittings, and by suitable positioning and fixing of pipes. And attention is drawn to the following: "It seems that a cavity partition consisting of two 2″ clinker slabs (insulated at the margins with cork) costs about one-third more than a $4\frac{1}{2}''$ brick wall whilst giving the standard sound-insulation of an $8\frac{1}{2}''$ brick wall. Apart from the intrinsic savings in cost, there is also the possibility of incidental economy in planning." Again, it is pointed out, that "A suspended ceiling can only protect the room in which it is placed. A 'floating floor' has the advantage that by cutting off near its source the sound transmitted to the main structure, it affords protection to all parts of the building."

In the detailed consideration regarding Dividing walls between dwellings, the subject of their differing effect as to acoustic conditions is well considered.

Appendix III of the Final Report was prepared by the National Physical Laboratory and the Building Research Station for the information of the Committee, and it deals specifically with the subject of Noise in Working Class Flats. It might seem to a casual member of the body politic, that "an attempt is made to meet the problem by imposing very strict regulations on the tenants" is a statement worthy of approval. Dealing with Outside noise, the Committee arrived at the conclusion, that its exclusion "is sometimes difficult to achieve by constructional methods, even when expense is not restricted," and the Report adds that "the problem then becomes essentially one of planning." The latter is certainly a method highly to be approved; where disposition admits of locating the noise-sources suitably, such planning should undoubtedly be adopted, and the remarks upon this are valuable.

And further, the remarks made about Equipment noise deserve every attention, and are probably adoptable without undue expense.

To the recommendation, again, that "insulation against air-borne sound equivalent to that given by an 8½" brick wall plastered on both sides should be provided between flats" full effect should be given.

Indeed, were the Report to be regarded as practical provision in all cases where individuals would pay for their own acoustical comfort, warm approval could be accorded. The above remarks are but a brief consideration of a long and most engaging document.

APPENDIX D

FLAT GROUP by Frederick Gibberd

The particulars contained in the following Appendix are extracted from an Article which appeared in "The Architects' Journal" for May 19, 1938, written by Mr. Frederick Gibberd, the well-known architect and technical writer. The inclusion herein as an Appendix is by the ready consent of the writer and the journal, and hearty thanks are accorded for the permission. The great bulk of the original article, together with one of the diagrams, is given here.

The client required absolutely sound-proof flats to let at "middle rent" rentals. The number of flats allowed by the Town Planning authorities, was fifty-four. The flats are split up into nine blocks of six flats. Each block is three storeys high with flats on either side of a central staircase. The external walls are 13½″ and 9″ brickwork, and the reinforced-concrete hollow tile floors span from these walls to a central reinforced-concrete spine. The high land cost and the comparatively low rents precluded expensive constructional systems, services and equipment. An absolutely sound-proof flat was not, therefore, possible. Nevertheless, in the planning and in the selection of equipment the question of noise was carefully studied. These notes show how the problem was tackled, and the amount of precaution against noise that may be reasonably taken in a flat without making the rent excessive. Prevention rather than cure was the approach to the problem of sound-proofing.

The sources of noise that cause the most inconvenience to tenants were classified under the following headings:

1. Street: Air-borne traffic noise.
2. Access: (*a*) Air-borne noise from tenants' tradesmen, dust carts, etc.
   (*b*) Impact noises on hall, stairs and landings.
3. Tenant: (*a*) Air-borne noises from talking, wireless, etc.
   (*b*) Impact noises from footfalls.
4. Services and equipment: Service pipes, w.c.'s, tanks, etc. Air-borne and impact noises from equipment, such as door catches.

STREET NOISES

The low building cost desired ruled out any question of sealing the flats against street noises by equipping them with double windows and artificial ventilation. Even had there been the money, it is doubtful whether artificial ventilation would have been adopted, as there is no question that tenants would have insisted on opening their windows, thus upsetting the balance of the air circulation through the plant.

Trees, particularly when in leaf, form a blanket against street noises. A survey of the exact position of all the trees on the site was made and the buildings arranged between them, so that they were practically all retained. The trees round the site were reinforced where necessary by new shrubs and trees so that the whole of the site is surrounded by a thick belt of trees screening the buildings from the roads.

The buildings were arranged to look inwards—towards the interior of the site rather than towards the roads—and in front of each an area of ground was laid out as a lawn or garden as a " quiet zone." The large windows to the principal rooms look on to these gardens. No windows look on to the roads.

SITE ACCESS

Access to the individual buildings is by paths which pass behind them. Small windows only face these paths. The multiplicity of entrance and access paths thins the traffic out on the site and avoids any large volume of noise that may occur through concentration of vehicles and people on the large drive.

No cars pass in front of the principal habitable rooms, and none can be seen from the gardens in front of each block. Dust is conveyed from the flats to the (collecting) store by small trolleys.

FLAT ACCESS OR STAIRCASE HALL

The type of access used for the individual buildings—the flat on either side of a central staircase—is quieter than the gallery plan where some windows are bound to look immediately on to the means of access, or the corridor plan where the corridor itself often forms a sound-box.

For the central staircase walls solid 9″ brickwork was chosen rather than a double partition, as it could be made to support the reinforced-concrete flights and landings, and a mass of material is an effective deterrent to air-borne noise.

Impact noises arising from footfalls on the stair and landings were muffled by the carpet finish. Acoustic plaster to the soffits of the stairs and landings to absorb air-borne noises could not be afforded.

The entrance and garden doors are fitted with double-action shoe springs so that the door does not come into contact with the frame, thus avoiding any possibility of impact noise.

TENANT AIR-BORNE NOISE

In the planning of individual flats against the transmission of air-borne noise laterally from one flat to another, it is usual to plan quiet rooms against quiet rooms and noisy against noisy. For example, in adjacent flats the party wall should be between bedroom and bedroom, never between bedroom and living-room. In this particular case the flats are entirely separated from each other by the staircase hall and the entrance lobby or the flat store. The principal habitable rooms look on to the garden, and the hall, kitchen, bathroom and spare bedroom on the access path, the small compartments thus isolating the main rooms from the noise of occasional callers and tradesmen.

TENANTS' IMPACT NOISE

Most complaints from tenants of flats are about the transmission of noise through floors. The Building Research Station was consulted and the following notes made: " Impact noise from footfalls is the chief consideration. A solid reinforced-concrete floor—or for that matter, a hollow tile floor—offers little resistance to impact noise, the sound below the slab being practically equal to that above. Treatment in the form of a suspended ceiling below the slab or an independent floor above the slab is necessary. A completely isolated ' floating ' floor was recommended, as this cuts off the impact vibrations from the main structure of the building. With regard to air-borne noise, the heavier the floor the better is the insulation. A normal slab gives insulation about equal to a $4\frac{1}{2}''$ brick wall. As it is not a practical proposition to make exceptionally thick floor slabs, insulation must be provided by discontinuity of surface. Thus any precaution that may be taken against impact noises is likely to improve insulation against air-borne."

It was felt that the provision of a completely separate floor resting on resilient pads would be very expensive, and that in all probability some simpler and cheaper method of construction, such as separating the screed from the floor slab by cork or felt, would give satisfactory results.

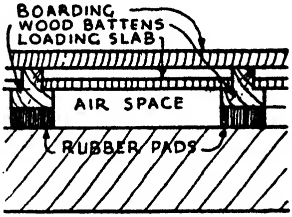

FIG. 23.—Air-spaced type of floor used.
(By kind permission.)

In order to come to a decision it was decided to carry out tests on different floor types.

(NOTE.—After testing various types, it was found, that air-spaced floors gave infinitely better results than the others, and eventually the following system was adopted):

A patent soundproof floor, consisting of wood battens laid at 14″ centres on to 2″ long by $\frac{7}{8}$ in. high rubber isolators. The battens are rebated to carry 12″ square loading slabs which stiffen the floor and prevent the battens from twisting. Tongued and grooved boarding was nailed to the battens. (See Fig. 23.)

The floors were tested by a tapping machine and the noise level of the room underneath was measured with a noise meter.

SERVICES AND EQUIPMENT

The Local Council required that soil and vent pipes should be outside the building.

The tank room was planned over the store so that no portion of it came over the actual flats.

Several w.c.'s were inspected and a " low down " model with an easily operated handle and quiet flush selected.

Extra heavy bronze lever handles, and stout locks were chosen for the room doors to avoid rattle. As catches such as the " ball " type give a sharp ring, cupboard doors were fitted with latches which must be pressed by the thumb to operate, thus preventing them from being snatched open or slammed to.

Electric light switches are of the silent " hospital " type in which the switch action strikes against small rubber pads.

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N.B.—An * following a page number and before the punctuation mark indicates two or more references on the page. "etc.," refers to a succession of pages. Mere link words are not indicated by a —— Upper-case clauses are to be read successively from the right. Lower-case clauses are to be read after the final upper-case clause.

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