FLUORESCENT LIGHTING

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Dealing with the Principles and Practice of Fluorescent Lighting, for Electrical Engineers, Illuminating Engineers and Architects

By

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WITH 84 ILLUSTRATIONS

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FOREWORD

THE fluorescent lamp differs greatly in characteristics from the incandescent lamp and many will find this work of great value in understanding the lamp and in making its application effective.

Fluorescent lighting is already fulfilling an important role in industry, having made possible the solution of many difficult lighting problems, but the future will find fluorescent lighting used more widely and for many other purposes. While the author recognises that the future holds many developments in store, he has gathered together in concise form much of our present-day knowledge of the subject.

W. J. Jones

PREFACE

DURING the past few years fluorescent lighting has reached a high stage of perfection. The first fluorescent lamp was a natural development from the electric discharge lamp. Although highly efficient in converting electrical energy into light energy, the electric discharge lamp gave a spectrum very far removed from that of natural lighting. To improve this, the discharge tube was enclosed in an outer bulb, the inner surface of which was coated with fluorescent powder.

The latest type of fluorescent lamp has the fluorescent material on the inner surface of the tube in which the discharge occurs. Improvements in design, and ingenious switching arrangements have enabled the large lamp manufacturers to produce fluorescent tubes in standard lengths of five feet, capable of being operated direct from the ordinary A.C. mains without the need for any form of high voltage transformer such as was required with the cold cathode tube.

This achievement introduces a new era in lighting and illuminating engineering.

The aim of the writer has been to present in a form convenient for reference the latest available information and data relating to this subject, which has now become of first rate importance to electrical engineers.

In addition to the scientific and technical facts which have been published chiefly in the form of papers read before the various scientific and engineering societies (see Bibliography), special care has been taken to include a wide selection of examples showing how this new type of lighting has been applied both in this country and in the United States of America. The opportunity may here be taken to express the Author's indebtedness to the following authorities:—

The Institution of Electrical Engineers.
The Illuminating Engineering Society.
The Illuminating Engineering Society (of America).
The Electric Lamp Manufacturers Association.

The courtesy of E.L.M.A. members, and of the General Electric Co. (of America) in supplying photographs is gratefully acknowledged.

It is hoped that electrical engineers will find that the information given in the following pages will answer any questions which may arise in connection with the subject of fluorescent lighting.

Any suggestions for improvement in later editions will be appreciated.

A. D. S. ATKINSON

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FLUORESCENT LIGHTING

Chapter I

LIGHT AND FLUORESCENCE

IN a book of this nature, intended for the use of engineers and others who turn to practical use the theories and discoveries of scientists and physicists, it would be out of place to discuss the ultimate nature of light, but a proper understanding of much of what follows will be easier if it is remembered that light is an electro-magnetic radiation which is distinguished from other similar radiations by one important quality: it stimulates our organs of sight and enables us to see.

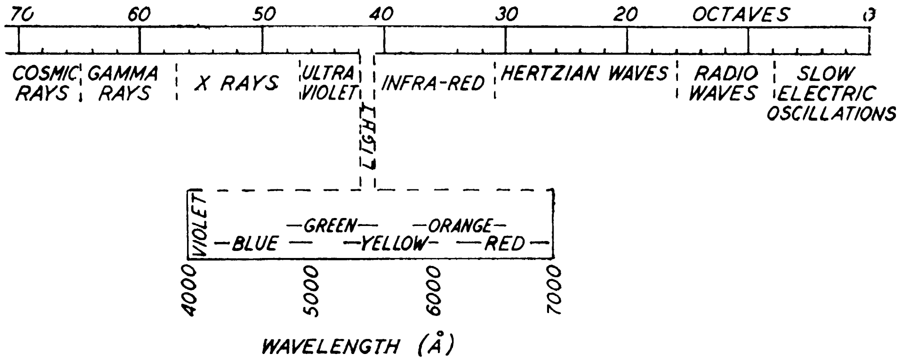


Fig. 1.—THE ELECTRO-MAGNETIC SPECTRUM, WITH THE VISIBLE RANGE ENLARGED TO SHOW THE APPROXIMATE WAVELENGTH BANDS OF COLOURED LIGHT.

(Note that the various sections of the electro-magnetic spectrum are not strictly divided as shown, but tend to merge into those on each side.)

There is a vast range of these electro-magnetic radiations, all of them travelling through space at the gigantic speed of nearly thirty thousand million centimetres (186,000 miles) per second. They need no material body such as air or water to carry them, but it is convenient to consider that they travel forward in the same way as ripples move over the surface of a pool. The ripples move outwards in widening circles from the point of disturbance, and though the crests and troughs move laterally the only movement of the water itself is vertically up and down.

As the ripples, or waves, always travel outwards at the same speed, it is apparent that when the crests are following one another very closely the vertical oscillation of any particular drop of water will be rapid; in other words, its speed of vibration, or frequency, will be high: but if the distance from crest to crest, i.e. the wavelength, is large, then the frequency is lower. In fact, the product of wavelength × frequency is a constant, and to speak of high frequency therefore automatically denotes also a short wavelength.

The varieties of electro-magnetic radiation are shown diagramatically in figure 1, and to illustrate the small proportion of their vast range with which we are directly concerned it is useful to think of them as being distributed over a piano keyboard, with treble and bass reversed, and

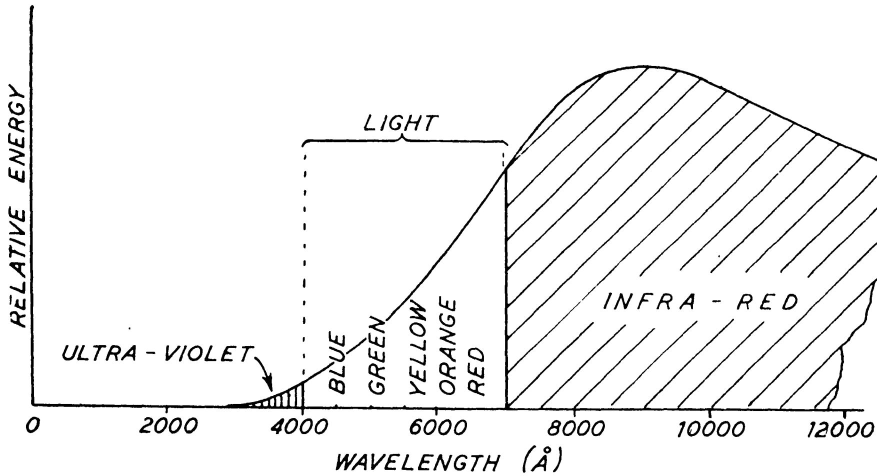


Fig. 2.—Energy Radiation from Incandescent Filament Lamp. (Far infra-red region not shown.)

expanded to cover about 70 octaves instead of the usual seven or so; as in a piano, the frequency of any note (or radiation, in this case) is double that of the corresponding note an octave lower. With about 70 octaves in the whole range, rather less than one octave represents light, all the other radiations being of too high or too low a frequency to have any useful effect on human eyes, which are only sensitive to radiations at wavelengths between about 4000Å and 7000Å.*

All the other varieties of electro-magnetic radiation, in the descending scale of wavelengths from ultra-violet to cosmic rays, and in the ascending scale from infra-red (heat) to the radiations emitted by electrical machines working on 50 cycle alternating current, are invisible; but nevertheless we are concerned with two of them. With our present knowledge we are unable to generate light without also generating considerable quantities of heat, and in fact the heating effect of lamps can be a limiting factor in

* Å = Angström unit (one hundred-millionth of a centimetre).

lighting schemes: further reference to this will be found in later sections. Ultra-violet rays, though invisible in themselves, can nevertheless be utilised in the production of light, and there seems to be no doubt whatever that to a large extent lighting of the future will be dependent upon the efficient generation of invisible ultra-violet rays and their subsequent conversion to visible light of the colour required.

The process may seem to be a roundabout and complicated one, but it results in lamp efficiencies considerably higher than 20 lumens per watt, which appears to be about the practical limit for incandescent lamps.

The Incandescent Filament Lamp

The manner in which energy is radiated from the incandescent filament of an ordinary electric lamp is shown in figure 2. It will be seen that the major part of the energy is emitted in the infra-red region, or in other words, as heat. A relatively small quantity of energy is emitted as light, at wavelengths between about 7000Å and 4000Å; and an extremely small proportion of ultra-violet is also emitted at wavelengths just below 4000Å. In the 100-watt size of lamp, for instance, about 12% of the input energy appears as light, while about 88% is converted into heat and removed from the lamp by radiation, by convection currents in the air, or by conduction through the lamp supports and leads. Thus the efficiency of an incandescent electric lamp is low, although it may be better in this respect and more convenient to use than some other light sources.

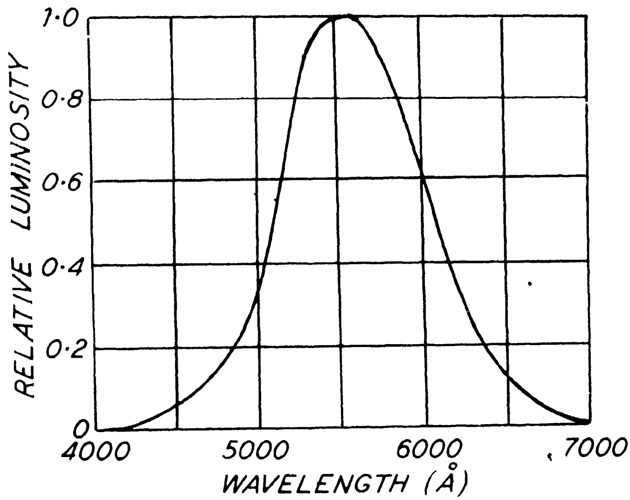


Fig. 3.—RELATIVE VISIBILITY OR LUMINOSITY OF RADIANT ENERGY. (For the average normal eye.)

"White" light is composed of a mixture of all colours of light, with approximately the same amount of energy in each colour; but the energy radiated as blue or green light from an incandescent lamp is a great deal less than that radiated as yellow and red. If the eye were equally sensitive to each colour of light, we should therefore see the colour of incandescent lamp light as predominantly red, but in fact the eye does not work in that fashion. It is much more sensitive to radiations near the middle of the visible range than at the extremes. Figure 3 illustrates the way in which the eye responds to radiations containing an equal amount of energy, and it will be seen that the greatest sensitivity is at about 5550A°, (yellow) whilst violet or blue and red light both have a relatively poor stimulating effect. It will be apparent that in order to judge the visibility of the light from any given source, such as an incandescent filament, it is necessary to take into account not only the energy radiated at various visible wavelengths, but also the ability of the eye to respond to each individual radiation; to multiply together the curves shown in figures 2 and 3, as it were. The result is shown in figure 4, and it will be seen that violet and blue have now become very weak, red only a little stronger, and yellow predominant. Hence the yellowish appearance of incandescent lamp light.

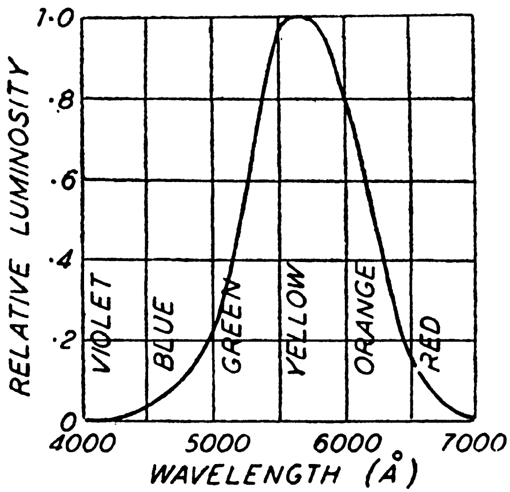


Fig. 4.—RELATIVE LUMINOSITY OF LIGHT FROM GAS-FILLED TUNGSTEN FILAMENT LAMP.

Coloured Light from Filament Lamps

Should a coloured light be desired from filament lamps it can only be obtained by transmitting the original light through, or reflecting it from, a material which absorbs the colours which are not required. If, for instance, a colour of light approximating to natural daylight is required, it is necessary to absorb the excess red and orange light emitted by the filament, and this can either be done by using a blue glass for the lamp bulb, as in the daylight blue lamp, or by reflecting the light of an ordinary lamp from a blue surface.

This process of absorption leads, of course, to a reduction of the total amount of light available for use, and it becomes necessary to increase the wattage of the lamps in order to compensate for this loss. In the case of daylight blue lamps at least twice the wattage, compared with ordinary lamps, is necessary to provide any given amount of light.

Approximate wattage multiplication factors for various colours are given in Table I.

TABLE I

Colour.	*Wattage Multiplication Factor.*
Daylight Blue	2–3
Orange	4
Red	17
Dark Blue	Over 40
Green	5
Yellow	1·5

Thus it will be seen that the incandescent filament lamp, which is a comparatively inefficient generator of its normal yellowish-white light, may become highly inefficient as a generator of strongly coloured light. The simplicity with which coloured light may be obtained from this lamp will often be more important to the user than mere efficiency, but it is worth noting that by using the principle of *fluorescence,* light of the required colour can be generated originally, no wasteful process of absorption being necessary.

Fluorescence

Fluorescence is one of the phenomena grouped under the general heading of *Luminescence,* by which is meant the emission of light other than the temperature radiation of a hot body such as a lamp filament or a gas mantle. Luminescence may be produced by living organisms (bio-luminescence), by chemical reactions (chemi-luminescence) or by the action of light itself or some similar radiation (photo-luminescence). It is with photo-luminescence only that we are concerned here.

If the light which is produced by a luminescent material is emitted only during stimulation by the exciting rays, the material is said to be *fluorescent;* but if, on the other hand, some of the exciting energy is stored up in the material during the period of exposure, this energy, or part of it, is gradually released subsequently, so that the material may continue to glow for an appreciable time after stimulation ceases; it is then said to be *phosphorescent.* Many luminescent substances in general use are both fluorescent and phosphorescent, and the after-glow caused by the latter property may be necessary or desirable for the purpose in view; but there are occasions when even a very small degree of phosphorescence would be fatal, e.g., any trace of after-glow in the fluorescent powder used in the cathode ray tube of a television receiver would make the picture completely incomprehensible.

Stokes' Law states that the wavelength of the emitted light is always greater than that of the exciting radiation; and while this law is not strictly true under all circumstances, it is generally borne out in practice.

In effect, the process of fluorescence can be likened to that of a voltage transformer, wavelengths being transformed instead of volts, and always in an upward direction. Thus it will be evident that if it is required to produce visible light of a certain colour, some radiation with a shorter wavelength must be used as an exciting agent. For some purposes it may be expedient to use radiations of very short wavelength: for radiography, for instance, rays may be required to pass through part of the human body before falling on a fluorescent screen, and it therefore becomes necessary to use X-rays which can penetrate human tissues. Generally, however, ultra-violet radiations with wavelengths more nearly approaching those of visible light are employed, as they are comparatively easy to produce in abundance.

It will be appreciated that two separate and distinct processes must be carried out with as little loss as possible if the production of fluorescent light is to be efficient.

Firstly, the exciting radiation must be generated as efficiently as possible, and secondly, the fluorescent powder, paint, or whatever it may be, must be a good converter of this primary radiation into visible light. This is true whether the fluorescent material is either at a distance from, or incorporated in, the lamp used to generate the ultra-violet radiations, though the lighting effects produced are entirely dissimilar.

Fluorescent Materials

In addition to Stokes' Law there are four other rules relating to fluorescent materials which are of importance to intending users.

1. The energy of the exciting radiation is absorbed by the fluorescent material over a wavelength band of definite width, and radiation outside this band cannot excite fluorescence.
2. Fluorescent light is emitted over another band of wavelengths nearer to the long-wave end of the spectrum.
3. The distribution of fluorescent light, i.e. the proportion of light emitted at each wavelength in the fluorescent band, is independent of the wavelength of the exciting radiation.
4. Over a wide range the intensity of the fluorescent light is proportional to the energy absorbed, provided the wavelength of the exciting radiation is constant, i.e. in general two similar ultra-violet lamps will produce twice the fluorescent effect of one lamp.

Most organic substances fluoresce to some extent. Finger nails and natural teeth, for example, glow white, while many other organic compounds fluoresce in colour; but those who intend to employ fluorescence will generally prefer to make use of the various preparations available which produce the required colour of light as effectively as possible when activated by any given source of ultra-violet. Much of an authoritative nature has already been written about fluorescent chemical compounds, and the subject scarcely comes within the scope of this book, but the following general observations will be of interest to users.

Fluorescent compounds can be conveniently divided into two main classes.

1. Those which are strongly excited by "near ultra-violet" radiation of approx. 3654Å, such as is emitted by "black" lamps.
2. Those which require a shorter wavelength of ultra-violet for their excitation.

Since over-exposure to short-wave ultra-violet may be harmful to animal tissues, such radiation as excites materials in class 2 must not be liberated freely in an ordinary room. In general, therefore, fluorescent compounds of this nature are used within the envelope of the lamp generating the ultra-violet, so that the potentially harmful radiation is absorbed before it can emerge from the lamp.

Where fluorescent materials are applied to surfaces outside the ultra-violet lamp itself, they generally belong to class 1 above. Many of them are strongly phosphorescent.

Much research work has been and is being carried out on activated inorganic "phosphors," i.e. compounds which fluoresce and also phosphoresce to some degree. The performance of these materials depends almost entirely on the presence of minute quantities of metallic impurities (activators), the control of the exact amount of these necessary impurities and the exclusion of accidental ones being a matter of great manufacturing difficulty.

Common activated inorganic materials in class 1 are the zinc sulphides, which with suitable activators will fluoresce in all colours from blue to red, e.g. with a manganese activator, zinc sulphide fluoresces yellow; with a copper activator, green; and with a silver activator, blue.

In class 2, among the activated inorganic materials most commonly used are zinc beryllium silicate and magnesium tungstate. The activating element is usually manganese. Though materials in this class are strongly excited by radiation at 2537Å they do not respond to an appreciable extent to the radiations of longer wavelength, such as are emitted by "black" lamps (page 18).

Chapter II

THE PRODUCTION OF ULTRA-VIOLET RADIATION

REFERENCE to figure 2, page 10 will show that the incandescent electric lamp generates a very small amount of ultra-violet immediately below the visible band, i.e. at wavelengths slightly shorter than 4000Å, and fluorescent materials which respond to stimulation at these wavelengths can therefore be made to produce visible light. It will be apparent, however, that since the total energy which an incandescent lamp emits as visible light is far greater than the energy emitted as ultra-violet, a fluorescent effect will be so completely swamped that it is practically unnoticeable when using incandescent lamps as ordinary sources of light.

If fluorescent effects only are desired it becomes necessary to suppress all the visible light, and this is done conveniently by means of a screen, or filter, of *Wood's Glass.* This glass, containing a percentage of nickel oxide, appears nearly black in ordinary light as it almost completely absorbs all wavelengths in the visible range, but transmits a high proportion of ultra-violet radiation, at wavelengths of the order of 3654Å. When an incandescent lamp is viewed through a piece of Wood's glass the filament may be seen as a dull mauve-red line; this effect is not due so much to transmission of visible light as to the fluorescence of parts of the eye itself which is irradiated by the ultra-violet light passing through the glass.

The proportion of ultra-violet generated in an incandescent lamp may be increased by running the filament at a higher temperature than normal, i.e. by applying an excess voltage to it, but this has a very serious effect on the life of the lamp, and is therefore a procedure seldom adopted except for temporary or experimental installations.

Except where very limited fluorescent effects are required, or where the first cost of the installation is of primary importance, it will generally be desirable to employ light sources which generate ultra-violet more efficiently and in larger quantity than is the case with incandescent filament lamps. Carbon-arc lamps come in this class, but their use will not be discussed here, as the well-known disadvantages of these sources of light for ordinary lighting schemes apply also, in large measure, to their use for generating ultra-violet rays. It is sufficient to state that Wood's glass filters can be used with arc lamps as with filament lamps, the effect being to absorb the visible light whilst allowing the useful ultra-violet to pass. Where ultra-violet irradiation of very large areas is required arc lamps are often employed because their high ultra-violet output obviates the use of numbers of other types of lamps, or merely because arc lamps are already installed and need only the addition of the required filters.

The mercury electric discharge lamp, on the other hand, is not only a prolific generator of ultra-violet rays, but is also compact, stable when used with the correct control equipment, and can be made in a variety of sizes suitable for most normal requirements. It is evident, therefore, that this type of lamp will be chiefly used in the future to produce the wide

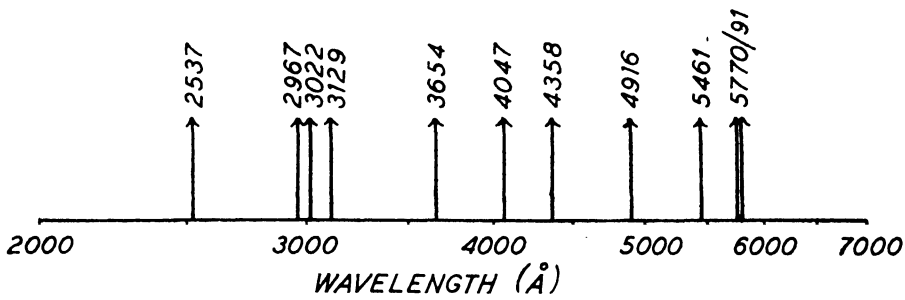


Fig. 5.—PRINCIPAL WAVELENGTHS OF MERCURY RESONANCE RADIATION BETWEEN 2,000Å AND 7,000Å.

range of fluorescent effects which will undoubtedly be demanded. Neon-filled tubes will also be used, especially for the production of warm colours of light.

The electrically excited gases or vapours used in discharge lamps have radiation characteristics quite different from those of an incandescent body such as a lamp filament. The radiation spectrum of a hot filament is continuous (figure 2, page 10), that is, within the limits of its spectrum there are no wavelengths at which radiation does not take place. Discharge lamps, however, radiate energy at certain fixed and definite wavelengths only; their spectrum is discontinuous (ignoring the small amount of continuous-spectrum heat radiation emitted by the hot parts of the lamp) and between the particular wavelengths at which radiations occur there are wide gaps in which no energy is emitted (see page 21).

Each electrically excited vapour or gas has its own family of *resonance lines*, i.e. wavelengths or frequencies at which energy is emitted. The wavelenths of these resonances are fixed by nature and cannot be altered by varying conditions of temperature or pressure, but the proportion of the total input energy which is emitted at any one resonance line depends on current density and vapour-pressure, which in turn depends on temperature. This fact is important not only to the lamp maker who may wish to increase emission at certain parts of the spectrum at the expense of other parts, but also to the lamp user who, by running the lamp under unsuitable conditions, may unwittingly change its operating temperature to such an extent that the lamp performance suffers.

A mercury arc resonates at a large number of wavelengths, but many of the resonance lines are of minor importance owing to the very small quantities of energy emitted. Figure 5 shows the principle radiations which give ultra-violet or light, the relative strengths of the lines not being indicated for the reason mentioned above.

The type of glass used for the inner and outer tubes of the 400 watt and 250 watt mercury lamps is semi-transparent to ultra-violet at 3654Å, as is also the outer bulb of the 125 watt and 80 watt lamp; but the transparency of the glass rapidly falls almost to zero as the wavelength is decreased. For this reason fluorescent materials responding chiefly to irradiation at wavelengths of the order of 2537Å must either be brought into direct contact with the discharge itself, i.e. must be contained within the lamp, or require stimulation by special lamps with the bulb made of a material such as quartz which is more transparent to ultra-violet radiations of this order of wavelength.

The "Black" Lamp

The visible light from ordinary mercury discharge lamps may of course be absorbed by any convenient medium such as Wood's glass, and fluorescent effects are therefore quite possible when using these lamps suitably screened. The proportion of the input energy which emerges as ultra-violet, however, is very small in the case of the 400 watt and 250 watt lamps (about 3%), the ultra-violet originally present in the discharge having to pass through the inner and outer lamp bulbs, a proportion being absorbed in each. In the case of the 125 watt and 80 watt lamps used in this manner, the proportion of input energy received as useful ultra-violet is greater (about 4·5%) partly because the inner tube, which is made of quartz in order to withstand the high temperature of the discharge, is more transparent to ultra-violet than the hard glass of which the inner tube of larger sizes of these lamps is made.

It is of course an advantage, when near ultra-violet* is required for stimulation of fluorescent materials outside the lamp itself, for the lamp to be as simple, efficient and compact as possible. The so-called "Black" lamp generally fulfils these requirements. It differs from the normal 125 watt and 80 watt high pressure mercury discharge lamps only in respect of the outer bulb, which is made of Wood's glass. Thus exterior filters are unnecessary and the ultra-violet may be directed where required by lighting fittings which are standard articles for use with 125 watt and 80 watt lamps used for ordinary lighting service.

* Near ultra-violet . . . this term is used to denote ultra-violet of wavelengths only slightly shorter than visible light, i.e. including ultra-violet at 3654Å.

Therapeutic Value of Ultra-Violet used for Fluorescent Effects

Many people may hesitate to make use of ultra-violet owing to a misapprehension; they are aware that over-exposure to ultra-violet of certain kinds may be extremely dangerous, but they are not aware that the term "ultra-violet" covers a wide range of radiations whose physiological effects are dependent on wavelength. Natural sunlight as received at the earth's surface, for instance, contains ultra-violet down to a wavelength of about 2800Å, and the healthy skin-tan is produced most effectively by radiations at about 2900Å. Too much exposure to rays of this order of wavelength is certainly harmful, and for that reason special sun-lamps, which generate radiations of this nature in large quantities, should not be used in a reckless manner. Moreover, it is not difficult to generate artificially ultra-violet at 2537Å, which strongly affects living tissues; for this reason germicidal lamps using this mercury resonance radiation can be used effectively for purification and sterilising purposes, provided that proper care is exercised.

Authoritative medical opinion, however, holds that ultra-violet radiation at wavelengths above about 3300Å are practically valueless for therapeutic purposes, and though the "black" lamp cannot truly be said to radiate no energy whatever at these comparatively short wavelengths, the energy so emitted is extremely small, necessitating only ordinary commonsense precautions Nearly all the ultra-violet energy is emitted at 3654Å, which is harmless, but nevertheless it is a good working rule, so far as screening from the eyes is concerned, to act as if the "black" lamp were, in fact, an ordinary high-pressure mercury lamp of the same wattage. High-pressure mercury lamps of 125 watts and 80 watts give approximately as much light as 300 watt and 200 watt gasfilled lamps respectively, and no-one with any regard for their eyes would use such lamps so poorly screened that they were unduly visible at normal angles of vision. In general, a suitable reflector to prevent prolonged direct view of the "black" lamp is all that is required.

There is, however, a slight fogging effect on vision which some people may find unpleasant, particularly at first. Certain parts of the eye are faintly fluorescent, and under the action of ultra-violet the eyeball itself becomes a weak source of light. This effect, which is particularly noticeable when looking directly at the lamp, makes it a little difficult to focus objects sharply; but those who in course of their employment spend much of their time under "black" light do not appear to suffer any ill effects.

Control of Ultra-Violet

Ultra-violet may be controlled and directed by the same reflecting equipment used for normal lighting purposes, though the loss of ultra-violet by absorption in the reflecting surfaces tends to be higher than with visible light. This is not generally of great importance when using "black" lamps, and vitreous enamel reflectors may be used successfully for providing a flood of ultra-violet in a general direction, or silvered glass reflectors for a more accurately controlled beam or fan distribution. Ultra-violet of short wavelength is reflected better from aluminium surfaces, but there are few occasions, except in laboratory work, when short-wave ultra-violet is permitted to travel through or beyond the lamp bulb.

How an Electric Discharge takes place

In any gas or vapour there are normally a very small number of electrons free to move from one atom to another. These ions, as they are termed, are formed by the action of cosmic radiation received from outer space, new ions being continually formed at the same rate as others recombine, so that a quantity of ions are always present at any instant.

The atoms of the gas consist of a central positively charged nucleus round which electrons, or negative charges, circulate. Normally the positive and negative charges balance each other so that the atom is electrically neutral, but if one of the electrons be removed from the atom, by cosmic radiation or other agency, then the atom is in an electrically unbalanced state, and if a voltage is applied to it the positively charged atom will move towards the negative electrode, and the negative electron or ion towards the positive electrode. Generally this flow of current will be so extremely small that it can be ignored in most electrical practice, e.g. the minute wasted current flowing through the air between the overhead lines of the grid is altogether negligible from the point of view of the efficiency of electrical distribution.

The speed of movement of the ions depends on the potential difference applied, and if this is comparatively low the speed of the moving ions will be such that when they collide with atoms in their path, as they are bound to do from time to time, they will merely rebound and continue on their way. If the voltage is raised, however, the speed (and therefore the energy) of the moving ions may be increased to such an extent that, on collision with an atom, the moving ion knocks one of the atom's electrons into an external orbit, the nature of the orbit depending upon the characteristics of the atom in question and on the energy transferred to it by the impact of the moving ion. The atom is now said to be *excited.*

If the voltage be increased still further beyond the critical value described above, collision will result in the complete expulsion of an electron from an atom. In this state the atom is said to be *ionised.*

It will be seen that an ionising collision results in the formation of two new ions, i.e. the positively charged atom and the free negative electron; both these new ions then move under the influence of the voltage, and collide with more atoms, making still more ions, and so on with cumulative snowball effect. Thus, once the ionising process is started, the current flowing in the gas will increase rapidly, and it becomes necessary in practice to limit it by some convenient device.

When a gas or vapour is electrically excited, the atoms with electrons in exterior orbits possess surplus energy which they have acquired from the moving ions. This excitation energy is generally very quickly given up as the electron returns to its normal orbit, and unless collision occurs with the walls of the container in which they are confined, or with other atoms, the energy so released appears in the form of radiations the wavelengths of which are characteristic of the gas or vapour in question.

This emission of energy may take place in a series of steps, each step from a highly excited state to some lower state of excitation being marked by radiation at a wavelength peculiar to that step. The many millions of excited atoms enclosed in a discharge tube thus return to normal by one or more stages; some will do it in one stage, some in two, others in three, and so on: but with any given conditions of pressure, current density, etc. in a particular gas or vapour the relative numbers of atoms returning to their normal state by any one of the alternative paths is fixed at a definite proportion of the whole. Each of the radiations characteristic of the gas or vapour are therefore emitted, but some are stronger than others; and by careful control of the current density and pressure it is possible to some extent to alter the relative strengths of these radiations. For instance, mercury vapour at about atmospheric pressure radiates strongly at various lines in the visible spectrum between 4047Å and 5791Å, whereas at the low pressure used in a fluorescent tube the visible radiations generated in the discharge itself are very subdued, while the ultra-violet radiation at 2537Å emits more than half the total energy supplied to the lamp.

It will be understood that a relatively high voltage is required to start the ionising process, but a lesser voltage will maintain the discharge as soon as ionisation has occurred. In the case of the well-known neon type of high-tension low-pressure discharge tube used for advertising purposes the high initial voltage is usually obtained from a leakage transformer in which the secondary voltage falls to the correct value for the running condition as soon as the tube current reaches its normal value. In the case of ordinary high-pressure mercury discharge lamps in the 400 watt to 80 watt range starting is effected by inserting a very small quantity of argon into the discharge tube with the mercury, and applying approximately full mains voltage between one main electrode and an auxiliary electrode very close to it. The high voltage gradient (voltage difference per inch) over this small gap is sufficient to ionise the argon at this point, whereupon the argon discharge strikes across the main electrodes at each end of the tube. The auxiliary electrode has a high resistance in series and can therefore be ignored after it has started the discharge.

Mains voltage in excess of the voltage required at the lamp electrodes must be absorbed by some convenient device. A variable resistance would be suitable were it not for the trouble of operation and the power loss which it entails. Automatic resistance regulation is found in the dual type of lamp, wherein a tungsten filament, part of which is short-circuited by a thermal switch late in the run-up period, is connected in series with the discharge, and in the same outer glass bulb.

As a general rule, however, mains voltage in excess of tube voltage is absorbed by a choke which, though adding considerably to the initial cost of each lamp circuit, absorbs very little power and thus does not reduce the lighting efficiency of the circuit to any considerable extent below that of the lamps themselves. In the mains-voltage type of fluorescent lamp the choke is also made to provide the voltage surge necessary for starting, as described on page 30.

Chapter III

APPLICATIONS OF FLUORESCENCE

"BLACK" lamps and other ultra-violet radiators may be used to obtain fluorescent effects which can be divided into two loosely-defined categories (*a*) Decorative and Artistic, (*b*) Industrial and Commercial.

For decorative and artistic purposes fluorescence can produce an apparent brilliance of colour usually unobtainable by other means. Only those surfaces which fluoresce naturally, or are specially treated, will glow and become self-luminous, all other surfaces remaining dark unless lighted by other means. The most striking effects are of course obtained when no extraneous lighting whatever is present, or is of a low order, as in cinema and theatre auditoria during a performance, and especially on a darkened stage when spectacular or trick lighting effects are desired.

The presence of a moderate amount of ordinary light does not preclude the possibility of obtaining fluorescent effects, provided that sufficient concentration of ultra-violet is obtainable. Artificial flowers, curtains, mural decorations and other features which fluoresce naturally or to which fluorescent pigments have been applied will glow with unusual vitality even though the interior may also be reasonably well lighted by ordinary means.

The full value of fluorescence as a decorative medium will not be appreciated until more experience has been gained in its use, but interior decorators will welcome the opportunity of introducing a new form of vitality and colour into their schemes, and can now do this in a particularly satisfying manner since the effect is produced without any apparent cause.

It must be borne in mind, however, that articles cannot fluoresce unless they are irradiated by ultra-violet. The source of ultra-violet must therefore be placed so that no person or object is likely to come between it and the surface it is irradiating, otherwise shadows will be produced, and an uncanny effect might result from such shadows appearing with no visible light source to cause them.

Commercial and Industrial Applications

Although there are some fluorescent paints, etc. prepared especially for exterior use, as a rule the fluorescent qualities of materials deteriorate with exposure to strong sunlight and general weathering, and it detracts from their effectiveness to protect them by glass, varnish or similar transparencies as these substances reduce the strength of the ultra-violet reaching the fluorescent surface underneath.

It is therefore chiefly indoors that fluorescence will be used in commercial premises, and then generally for decorative purposes. But there is also a wide field of application in display work, where the aim is always to catch the eye by one means or another.

It is evidently after darkness falls, or in interiors such as cinemas and theatres where a state of semi-darkness is usual, that fluorescent effects become most marked. It is possible, for instance, to arrange for two apparently different displays to be arranged in one shop window, one display being lighted by the normal means, and parts of it being treated with fluorescent pigments to become luminous when the normal lighting is switched off. (The normal illumination in the average shop window is sufficiently high for fluorescent effects to be completely swamped while it is switched on.) If desired, objects could be made to change colour by this means, and it would need little ingenuity to devise showcards, etc. which gave different messages according to whether the main window lighting was in use or not. Ideal for this purpose, of course, are fluorescent paints which are quite invisible when seen by daylight or normal artificial light.

When considering the use of ultra-violet for any such purposes as outlined above, it is necessary to remember that "black" lamps cannot be made to flash on and off as can incandescent lamps. Once they are switched off they will not re-strike until they have cooled down, and then need a further period of time, say four minutes, before they are again giving their full ultra-violet output. Flashing effects from "black" lamps can only be obtained by using some shutter device to obscure them when not required, and it is evidently far simpler to arrange, if possible, for the lamps giving visible light to be switched instead.

Fluorescent effects are used in such a large number of other occupations and industries that it would need a fair sized book to contain adequate mention of them all. The few examples given below are intended merely as an indication of the wide variety of purposes for which fluorescent effects are employed.

Laundries make good use of ultra-violet. It is now possible to dispense with the cryptic symbols which used to be written on or sewn into linen to enable it to be identified. Such disfiguring marks are often replaced nowadays by letters or numbers written in a fluorescent liquid which is quite invisible under ordinary forms of lighting, but shows up clearly when passed under a "black" lamp on its return to the laundry.

Many chemical substances fluoresce strongly, and fluorescence is therefore used to a considerable extent in analysis. Chemicals are also likely to leave fluorescent traces behind them, and ultra-violet is regularly used for the detection of erasures from documents. Since different inks may fluoresce differently in colour or degree, it may be possible to tell with certainty whether a suspected document was not all written with the same ink.

Philatelists find ultra-violet helpful in detecting forgeries and alterations by comparing the fluorescence of genuine stamps with suspected ones. Repairs to stamps may become evident, and faint watermarks and erased postmarks may also be detected.

A process has been developed by means of which fluorescence is used for *detection of fine cracks* in shafts, etc. ; fluorescent material penetrates the crack and remains there for ready identification under ultra-violet after the material has been removed from other parts of the shaft.

Oil or grease stains on cloth are readily apparent under ultra-violet whereas they may be very difficult to distinguish under ordinary light. For this reason textiles are sometimes passed under ultra-violet before dyeing, in order to discover whether machine stains appear.

The state or composition of various *food products* may be judged by their fluorescent appearance. For instance, fresh eggs fluoresce red, while stale eggs appear brown. Butter appears yellow, and margarine mauve. Ring rot can easily be detected in seed potatoes when cutting them for planting.

Ultra-violet is used also in *medical science* for the examination of different kinds of bacteria, which fluoresce in characteristic colours.

A number of uses have been found for fluorescence for A.R.P. purposes in the blackout. Police on point duty at some road junctions have been supplied with fluorescent cuffs or oversleeves, and also perhaps helmets, with an ultra-violet lamp overhead; their directions to traffic are then more readily understandable than when signals are given by waving a dimmed torch.

Blast damage to the roof of an important building such as a power station might make it necessary to extinguish all visible light in the interior. As a precautionary measure vital control levers, switches, gauges, etc. may be treated with fluorescent paint and constantly irradiated with ultra-violet so that in the event of an internal blackout becoming necessary the vital machinery can still be kept running under proper control.

Passes admitting the bearer into important buildings are frequently made fluorescent, as this adds to the difficulty of forgery. Exit signs and other direction indicators within the building may be treated with fluorescent, or preferably phosphorescent, paint with a long afterglow, so that the signs are readily visible for a considerable period after the failure or extinction of all normal lighting.

High Pressure Mercury Fluorescent Lamps

Numerous though the applications of ultra-violet may be for stimulating fluorescent materials at a distance from the lamp, fluorescence will be used in the future to a much greater extent within the lamp itself, sometimes to modify the light otherwise generated, but more usually for the generation of practically the entire light output of the lamp.

The 400 watt, 125 watt and 80 watt mercury lamps have been available for some time with special outer bulbs coated internally with a thin layer of fluorescent powder. When fitted with plain glass bulbs these lamps are very deficient in red light, with the result that the colour appearance of many coloured objects is badly distorted; most red objects, for instance, have a chocolate appearance under plain mercury discharge light, and though this colour distortion is not necessarily a handicap for a number of purposes it is generally preferable, other things being equal, that the light should not be of such an unnatural colour.

By means of the fluorescent powder some of the ultra-violet generated by the discharge is transformed into visible light which contains a relatively large proportion of red; this fluorescent light blends with the visible light from the discharge and results in a mixture which renders colours considerably more truly. If natural daylight be taken to contain 15% of red, fluorescent bulb mercury lamps give about 5% of red, compared with only about 0.5% of red from a plain mercury discharge lamp.

The fluorescent powder coating naturally obstructs and absorbs some of the light generated by the discharge tube, but in the case of the 125 watt and 80 watt lamps the quantity of light lost by absorption is approximately equal to the amount added by fluorescence; thus the efficiencies of the plain and fluorescent types are equal in these sizes. In the 400 watt size, however, it is necessary to add cadmium to the mercury in the discharge in order to compensate for the blue light absorbed by the yellow fluorescent powder, and this adulteration reduces the efficiency of the lamp by some 16%.

In order to prevent deterioration of the fluorescent powder due to excessive heating it is necessary to use an enlarged outer bulb. In the 400 watt size the "Isothermal" bulb shape usually employed ensures that the temperature over the greater part of the bulb surface is reasonably even.

Though there are a number of occasions on which the light of these lamps is a sufficient improvement on the light of plain mercury lamps to enable otherwise difficult or impossible tasks to be performed successfully, the fact remains that the fluorescent bulb type of lamp does no more than modify the original discharge light to a slight degree. The spectrum of the light is still predominantly discontinuous, and there is therefore bound to be considerable distortion of many colours. The principle of fluorescence, in fact, is used here to provide only a small proportion of the total light, whereas in the lamps discussed in the remaining pages fluorescent powders are used to provide the major part of the light, the colour of which is thus brought under almost complete manufacturing control.

It is to these lamps that we must look to provide the lighting of the future.

High Tension Cold Cathode Fluorescent Tubes

High tension fluorescent tubing has been developed from the simple discharge tubes originally used chiefly for signs; but instead of the rather crude colours emitted by the earlier types, it is now possible to obtain a variety of vivid colours or pastel shades, including practically white light, by making use of fluorescent material adhering to, or incorporated in, the glass wall of the tube. The use of neon-filled fluorescent tubes in conjunction with the mercury-filled tubes adds greatly to the range of colours for lighting purposes and to the decorative effects obtainable. This ability to utilise the rich, red light from neon is one of the main advantages of H.T. fluorescent lighting.

It should be borne in mind that in summarising the performance of these tubes it is not possible to take into account the characteristics of all the wide variety of tubes manufactured. The figures given in the following observations are therefore only to be taken as approximations, not as exact values.

The tubes are made in a number of diameters, usually between 10 and 25 mm., and the electrode at each end consists of a hollow cylinder usually of iron which may be coated with electron-emissive material. The ends of the tube are usually enlarged to contain the electrodes, and these may be bent back parallel to the axis of the tube to enable tubes to be placed end to end without any break in the line of light. The bent-back portion is usually hidden from view by fixing inside a special electrode box or behind a partition.

The voltage required to keep the tube alight may be divided into two parts (1) the voltage required in the immediate neighbourhood of each electrode; (2) the voltage needed over the remainder of the discharge path. For a given set of operating conditions the latter voltage drop is regular along the length of the tube, and is dependent upon that length. In a mercury tube of 20 mm. diameter, for instance, with a current of 60 milliamps., about 70 volts may be required for each foot length of tube.

The voltage drop at the unheated electrodes, however, is independent of the length of the tube. For the size of the tube quoted above, it may be of the order of 150 volts. Thus a 4 ft. 60 mm. tube would need a running voltage of $150+4\ (70)=430$ volts, while a 10 ft. tube would need $150+10\ (70)=850$ volts.

With a power factor of 0·93, the power consumption of the 4 ft. tube would be 24 watts, and of the 10 ft. tube 48 watts. But the 10 ft. tube, has a useful length about 2½ times as great as the 4 ft. while the power consumption is only doubled. Thus the greater the length of the individual tube, the greater the efficiency of the installation.

The voltage necessary to operate a given length of tubing increases as the diameter decreases. For a given current, therefore, a small diameter tube dissipates more watts and gives a greater light output than a tube of the same length but of greater diameter. It will be evident that for a given light output and length, larger diameter tubes (20–40 mm.) are less bright than tubes of smaller diameter and therefore more suitable for interior lighting. Small diameter tubes (up to 15 mm.) lend themselves to sign work because of the ease with which they can be bent into complicated shapes.

A number of tubes are normally connected in series with a high-voltage transformer, total lengths of 60 feet and more being quite feasible. A leakage transformer provides the extra high voltage necessary to start the discharge, the voltage being automatically regulated to a lower value to suit the running condition after the discharge has struck.

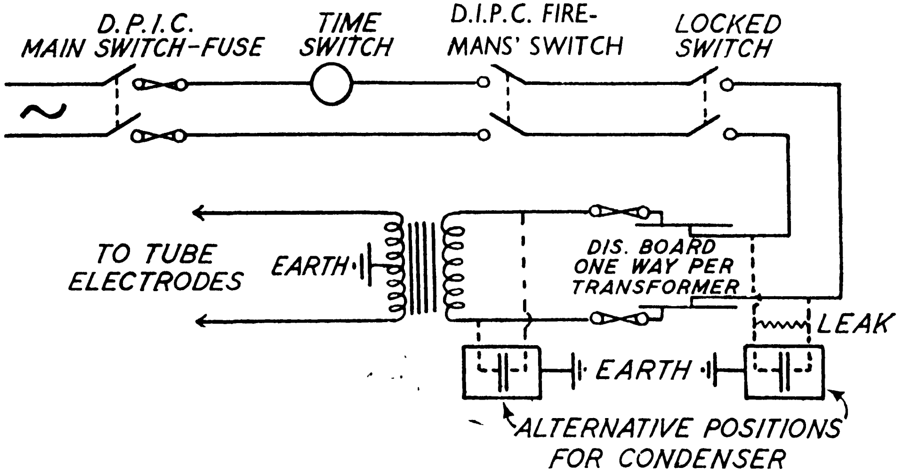


Fig. 6.—Circuit Arrangement for H.T. Cold Cathode Fluorescent Tubing used on the outside of Buildings.

(For interior use the time switch would not normally be fitted, and the fireman's switch can be omitted.)

With mercury filled H.T. tubes the end of useful life is not determined so much by actual failure of the tube as by the gradual deterioration of light output, which eventually makes it worth scrapping the tube although it still gives some light. Renewal of old mercury tubes may be delayed by increasing the current through them, the necessary adjustment being made by some device such as a variable reactance in the H.T. transformer primary circuit. Some thousands of hours use are to be expected in any event.

With neon tubes the light output remains practically constant throughout life, which is determined by the "clean-up" of the gas causing eventual failure to light.

Cold or Hot Cathodes?

From the engineering point of view, a long length of H.T. tubing is served by a single transformer with a dangerously high secondary voltage, against which adequate precautions have to be taken. The large transformer is replaced in the hot cathode circuit by a number of smaller chokes, and the starting voltage is obtained by automatic interruption of ordinary mains voltages instead of by high-voltage windings.

Though long individual lengths of H.T. tubing may have an efficiency equal to or even greater than that of hot-cathode lamps, as a general rule it is lower, so that the cost of current will be greater for equal light output. Against this disadvantage should be set the longer life of the H.T. tubes, and the curved shapes in which they can be obtained if desired.

The question whether H.T. cold-cathode tubing is to be preferred to the mains-voltage hot cathode tubing discussed in the following sections must be answered according to the economics of each case and the personal preference of the architect or user. The greater flexibility of the long lengths of H.T. tubing and the more extensive range of colours and decorative effects obtainable through the use of neon fluorescent colours will appeal to many. Nevertheless, it seems probable that the more highly standardised high-efficiency hot-cathode lamps operating at ordinary mains voltages will be the more popular choice.

Chapter IV

OPERATION OF MAINS-VOLTAGE TUBULAR FLUORESCENT LAMPS

THE mains-voltage tubular fluorescent lamp consists essentially of a glass tube whose inner surface is coated with fluorescent powder, a coiled filament electrode being fitted at each end of the tube, which is filled with mercury vapour and argon gas at very low pressure.

Figure 7 shows the schematic diagram of the British 80 watt lamp and associated circuit, which operates in the following manner:

When the circuit switch S_1 is closed, current flows through the choke, the automatic starting switch S_2 which is closed,* and the lamp electrodes, heating them to a suitable operating temperature. After a short period the automatic starting switch opens, interrupting the current in the entire circuit. This sudden interruption gives rise to a high induced voltage in the choke, and this voltage which, it will be seen, is applied across the ends of the lamp, is sufficient to start a discharge from end to end of the lamp. Once the discharge is started the normal mains voltage is more than sufficient to maintain it.

Characteristics of the lamp are as follows:—

Length	60 ins.
Diameter	$1\frac{1}{2}$ ins.
Power consumption	80 watts
Power loss in choke	9 watts (approx.)
Normal current	0·8 amps.
Initial efficiency	35 lumens per watt
Initial light output	2800 lumens
Normal life	2000 hours
Lamp voltage	115 volts
Supply voltage	200—250 volts

Whereas in the case of an ordinary incandescent filament lamp there is little that the user is likely to do which will seriously impair its efficiency or life, except of course to apply an incorrect voltage to it, the fluorescent lamp may be adversely affected by several factors, some of which are under the user's control. That is not meant to infer that these lamps are likely to give trouble; far from it: but a proper understanding of the various parts of the circuit will make it easier to recognise what is causing

* Except when the glow type of starter switch (p. 37) is used.

any trouble that may occur, with a consequent saving of time in remedying it. The various parts of the 80 watt lamp and lamp circuit are therefore considered in detail.

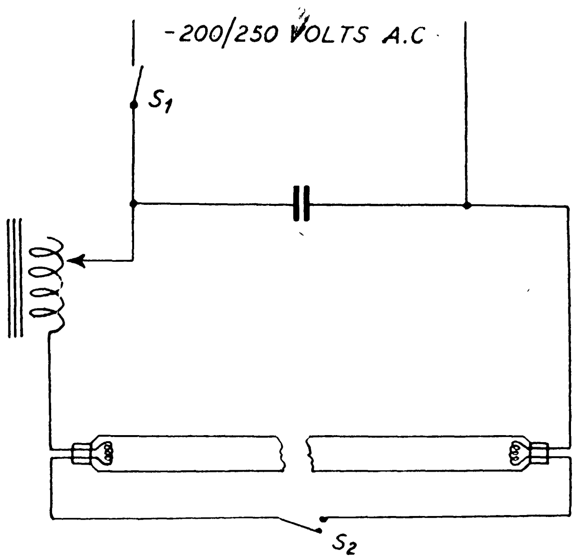


Fig. 7.—Schematic Diagram of Fluorescent Lamp Circuit.

The Lamp Electrodes

The electrodes are formed of a coil of fairly thick tungsten wire coated with material which emits electrons freely when heated. Pre-heating of the electrodes takes place for about two seconds after the lamp is switched on; a current of about 1·3 amps. flows through them during this period, raising them to a cherry red heat in which condition they are capable of handling without damage the discharge current of 0·8 amps. as soon as the main discharge is struck.

The starting current sets up a potential difference of about 10 volts across the ends of each electrode. This voltage, though low, is sufficient to cause ionisation in the immediate neighbourhood of the electrode, and a small amount of ultra-violet radiation is generated which is sufficient to cause the fluorescent powder near the ends of the tube to glow. The ionisation occurring in the region of the electrodes also assists in the striking of the main discharge and makes this striking more certain.

A flat metal collector plate is attached to each end of each electrode to serve as a collector during the A.C. half-cycle in which the electrode to which it is connected is acting as the anode, thus avoiding overheating which might cause the active material on the electrode to evaporate and disperse.

Heating of the activated electrodes also facilitates the operation of the tubes on ordinary mains voltages since the copious emission of electrons reduces the voltage required in the immediate neighbourhood of the electrons and thus obviates the necessity for a step-up transformer such as is required with cold cathode tubes.

It will be seen that two leads must be taken to each end of the lamp. The use of 2-contact B.C. caps enabled the British 80 watt lamp to be

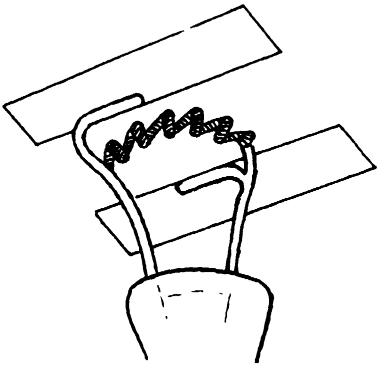


Fig. 8.—ARRANGEMENT OF 80 WATT LAMP ELECTRODE AND COLLECTOR PLATES.

made available early at a time of great need in 1940, but there is much to be said for the American type 2-prong cap; this enables the lamp be to slid into its holders, a quarter-turn of the lamp locking it in position. Whatever type of cap and holder is used, allowance has to be made for the expansion of the lamp as it becomes warm.

The Discharge Arc

The gaseous filling of the tube consists of Argon at a few millimetres pressure to start the discharge and mercury vapour at a few thousandths of a millimetre pressure to produce the ultra-violet radiation, principally of wavelength 2537Å, which excites the fluorescent coating to luminescence. Tube dimensions and operating conditions are designed to achieve the optimum production of light.

Abnormal operating conditions which result in a change of pressure in the tube will have the effect of varying the energy emitted at 2537Å, therefore altering the quantity of light, since the fluorescent powders are most strongly excited by this particular radiation.

Since the discharge takes place at low pressure it is not necessary to wait for any considerable time, while the mercury vapour cools down, before a lamp which has recently been switched off can re-start. Whether warm or cold, lamps strike almost immediately, there being only a slight delay while the automatic-starter switch (page 36) performs its allotted functions.

A very little argon is introduced into the tube to assist in starting the discharge, in particular by ionisation of the argon during the pre-heating of the electrodes. No light is received from the argon while the tube is operating normally.

The Fluorescent Coating

The fluorescent coating consists of a very fine mixture of powders each of which is strongly excited by the 2537Å resonance of the mercury discharge. Various powders are available which fluoresce with characteristic colours, e.g.

Cadmium Phosphate, Chlorophosphate or Borate	Red
Zinc Beryllium Silicate	Orange or Yellow
Zinc Silicate	Green
Magnesium Tungstate	Blue

If white light is required as in the British 80 watt colour "A" lamp, a selection is made of suitable powders, the proportions being adjusted so that light of the desired quality is obtained.

Colour "A" Light and Daylight

The colour quality of natural daylight varies from day to day and minute to minute, and it is therefore unwise to state that any particular

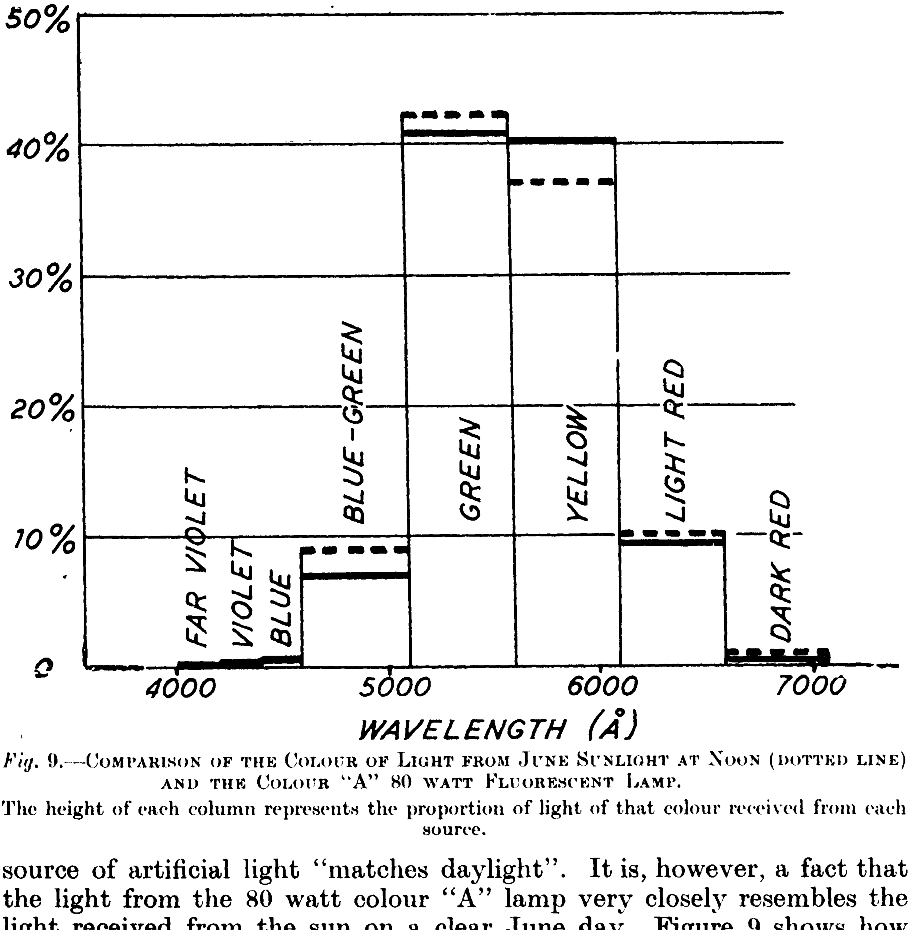


Fig. 9.—Comparison of the Colour of Light from June Sunlight at Noon (dotted line) and the Colour "A" 80 watt Fluorescent Lamp.

The height of each column represents the proportion of light of that colour received from each source.

source of artificial light "matches daylight". It is, however, a fact that the light from the 80 watt colour "A" lamp very closely resembles the light received from the sun on a clear June day. Figure 9 shows how nearly the constituent colours of each kind of light agree.

It might be argued that representation of the colour quality of a light source by means of a "block" diagram of this nature is not so simple to understand as the smooth curve which can be drawn to represent the light emission of ordinary "temperature radiators" such as the sun or a tungsten filament lamp. It is true that a smooth curve could be drawn to represent the light received from the fluorescent coating of the lamp, but it must be remembered that the mercury discharge within the tube generates radiations at a number of wavelengths, some of which are visible; and although these visible radiations are weak in the case of a discharge at very low pressure, they are nevertheless present, and are not entirely absorbed by the layer of powder. Thus the curve would have sharp peaks, or lines, of this raw discharge light superimposed on the smooth curve below. The energy contained in the peaks cannot be truly represented pictorially, and if attempts to do so are made by broaden-

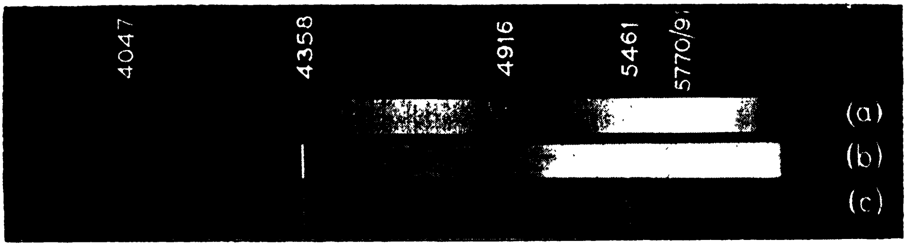


Fig. 10. — SPECTRUM OF:
(a) Noon sunlight.
(b) 80 watt colour "A" fluorescent lamp.
(c) Similar lamp without fluorescent coating.
Wavelengths in Angstrom units.

ing the peaks into the form of pillars whose area represents energy, the resultant picture is rather confusing and is liable to give the wrong impression. For this reason the "block" diagram is adopted.

It should be noted that about 90% of the total light emitted by the lamp is due to the fluorescence of the powder, only some 10% being contributed by the mercury discharge. This high proportion of fluorescent light is in contrast to the commonly used high pressure mercury lamp in which an inner tube of glass or quartz is surrounded by an outer envelope coated internally with fluorescent powder. For such lamps the main discharge produces the bulk of the light, colour modulation being achieved to some extent by the fluorescent powder. In the low pressure tube the direct contact between the powder and the 2537Å radiation results in a highly efficient conversion of the latter into visible light, losses due to absorption by glass or quartz surfaces being avoided.

The colour rendering properties of the lamp are very constant throughout its life.* A slight colour difference of lamps does not necessarily give rise to apparent colour difference of articles viewed by the light of the lamps. The aim of the lamp makers is to standardise the colour rendering

* The "blue" constituent of the fluorescent powder deteriorates at a slightly greater rate than the other constituents. Thus an old lamp tends to give a rather pinkish light; the colour change, however, is generally negligible.

of objects rather than the colour of the lamps themselves, and this is achieved to a satisfactorily high degree.

Careful observation may reveal faint bands of light of various colours at the edges of swiftly moving objects seen under white fluorescent lamps. This effect appears to be of no practical importance; it arises from the varying degrees of phosphorescence possessed by the individual "coloured" fluorescent powders which are mixed together to give the required white light.

Coloured Fluorescent Lamps

Since the colour of the fluorescent light is entirely dependent on the nature of the powder coating it is evident that coloured light can be produced in a variety of shades by using a suitable powder or mixture of powders. The coloured light is generated within the tube, and is not obtained by the wasteful absorption of unwanted colours, as in the case of coloured lighting by incandescent filament lamps (see page 12). This fact contributes largely to the comparatively high efficiency of coloured lighting by fluorescent tubes.

Though the demand for strongly coloured light is limited, it is probable that coloured fluorescent lamps will be available here in the future. Without knowing the hue or degree of saturation of the colours it is impossible to state exact figures of luminous efficiency, but American experience suggests that the efficiency compared with that of a similar lamp giving colour "A" (cold white) light will be approximately as shown in Table 2.

TABLE II

Colour of fluorescent lamp.	*Approximate efficiency (lumens per watt) as percentage of efficiency of Colour "A" lamp.*	*Approximate efficiency compared with that of equivalent incandescent lamps with suitable colour filter (per cent).*
Colour "A" (cold white)	100%	700%
Warm White	90%	250%
Light Blue	67%	3000%
Green	190%	2000%
Gold	80%	300%
Light Red	70%	1500%

Safe Nature of the Radiation

The 2537Å radiation so strongly generated within the tube is very active biologically and fear is often expressed that some harm may be caused by this radiation escaping from the lamp. The whole object of the fluorescent coating, however, is to absorb this radiation, which it does very effectively; any such rays which happen to penetrate the fluorescent coating then strike the glass wall of the tube which is opaque to radiation at this wavelength. Thus there is a double barrier to the passage of biologically active radiation, and the lamp is perfectly safe to use, the small quantity of harmless long-wave ultra-violet which escapes being approximately equal in amount to that of equivalent incandescent lamps. In other words, for most practical purposes it can be ignored.

The Starting Switch

As stated previously, the functions of the starting switch are two-fold—(*a*) to complete the circuit so that the lamp electrodes may be heated to operating temperature before the discharge strikes, (*b*) to interrupt the circuit after a predetermined time so that a voltage sufficiently high to start the discharge is induced in the choke.

Provided that the switch performs these two functions satisfactorily it may be constructed in any convenient way. An ordinary hand-operated tumbler switch, or one of the bell-push variety is quite effective in emergency, but for general purposes the necessity to operate by hand two switches (the circuit switch and the starting switch) for each lamp is obviously undesirable. For this reason starter switches are made automatic in action, and need no attention until the end of their useful life. The automatic switches used in this country are of two types—(*a*) thermal type, (*b*) glow type.

Thermal Type Starter

This consists essentially of two bi-metallic strips carrying the contacts, with a small heater coil near one of the strips, the whole being enclosed in a glass bulb. Four leads are taken to the starter, one to each side of the switch and one to each end of the heater; these four leads may either be in the form of coloured tails—green and yellow to the switch and black to the heater—or the bulb may be mounted on a plastic base with four stud contacts, the bulb and base being plugged into a spring holder to which the connections from the outside circuit are made. (Fig. 11).

One of the bi-metallic strips is arranged partly to enclose the heater coil, which warms it preferentially. When warmed, it bends away from the other strip, thus breaking contact. Normal variation of atmospheric temperature will not affect the working of the switch.

Figure 11 shows the circuit diagram for the thermal type of switch. Normally, the starter switch contacts are closed. When the circuit switch S_1 is closed, a current of about 1·3 amps. flows through the heater coil (*H*) both filament electrodes and the starter switch; after about two seconds, during which time the electrodes are pre-heating, the starter switch opens and the induced surge of about 1000 volts strikes the arc from end to end of the lamp. The discharge current of 0·8 amp. is sufficient to hold the starter switch contacts apart, since the heater coil is still in circuit. When the lamp is switched off the bi-metallic strips cool down and close the circuit ready for the next operation.

It may by chance happen that the starter switch opens at the moment when the A.C. current wave is very nearly at zero. When this occurs, the induced voltage may not be sufficiently high to start the discharge; the starter switch will then automatically re-close and repeat its cycle of operations.

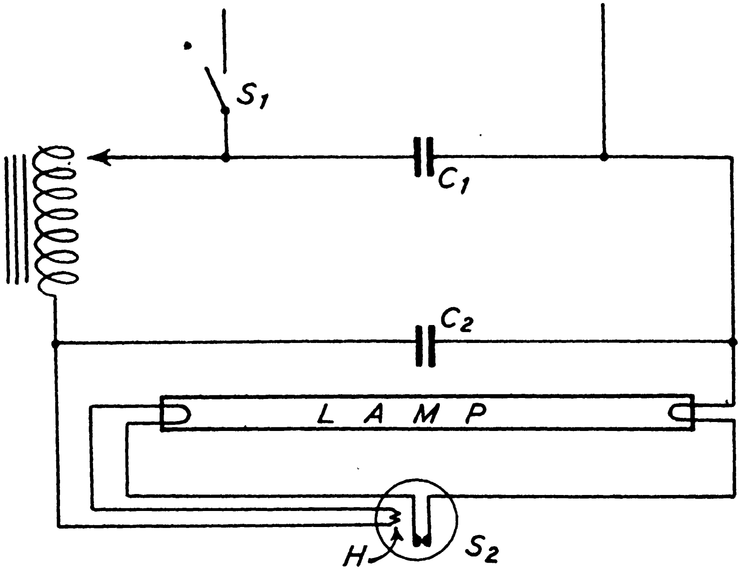


Fig. 11.—Circuit Diagram for Thermal Type Starter Switch.

The condenser C_2 of 0·05 mfd. capacity by-passes unwanted radiations generated within the lamp, which might otherwise cause radio interference. It should be noted that C_2 and the starter switch contacts are connected to opposite ends of the lamp electrodes, whose resistance thus checks surges from C_2 which might weld together the switch contacts.

Glow Type Starter

The glow type starter (Fig. 13) consists of two bi-metallic strips carrying the contacts and mounted in a glass bulb filled with helium at low pressure. A 2-contact S.B.C. cap is fitted.

This type of starter is connected as shown in figure 14, its operation being as follows:

On closing the circuit switch S_1 almost full mains voltage is applied across the starter switch which, in its normal position, is open. This voltage is sufficient to start a glow discharge in the helium between the bi-metallic strips, a current of about 100 milliamps. passing. The discharge warms the strips which bend towards each other, until finally the contacts touch and the lamp filaments are pre-heated as with the thermal switch (page 36).

As soon as the starter switch contacts close, the voltage between them falls to zero and the glow discharge is therefore extinguished. The bi-metallic strips cool down again, and the starter switch contacts open, breaking the circuit and thus providing the voltage surge which

Fig. 12.—THERMAL STARTING SWITCH.

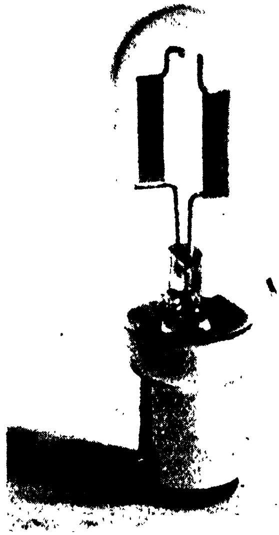


Fig. 13.—GLOW STARTING SWITCH.

strikes the discharge in the lamp. When the lamp is alight, the voltage difference across the ends of the lamp is insufficient to re-start the glow discharge in the starter switch, whose contacts remain open ready for the next restarting operation.

As in the thermal starter circuit, the condenser C_2 by-passes radio interference, and the resistance R (100 ohms) in series with it checks condenser surges so as to prevent the starter contacts welding together.

Choice of Starter Switches

There is very little to choose between the two types, both of which operate perfectly satisfactorily. Since the thermal type switch is already closed when the lamp is first switched on, it is rather the more rapid in action, but on the other hand the heater coil is always in circuit and is therefore a possible cause of failure. The heater consumes about 1 watt of energy.

The glow type switch is a little slower in action, but consumes no energy while the lamp is running normally. If desired, it may be removed from the circuit while a lamp is alight, in order to replace a faulty or missing starter of a similar type in another lamp circuit.

Both types should outlast several lamps.

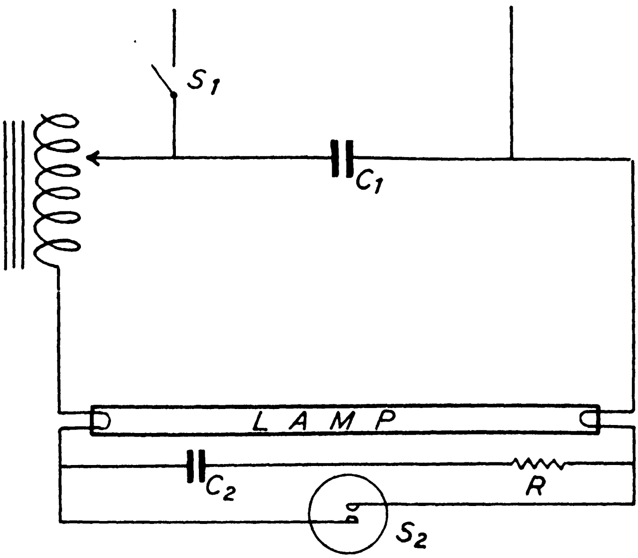


Fig. 14. Circuit Diagram or Glow Type Starter Switch.

The Choke

Since it is important that the voltage applied to the lamp shall be correct within close limits, the choke should be readily adjustable to suit the average mains voltage at the lighting point (unfortunately this is not always the same as the rated voltage of supply). Tapped windings, with steps not greater than 10 volts, are therefore desirable, at least for industrial and commercial installations.

The lamp electrodes and the starter switch heater (if the thermal type of starter is employed) are the parts of the fluorescent lamp circuit particularly liable to damage by excessive current. In order to protect them as much as possible it is essential to connect the choke in the *phase* lead of the supply, then if an accidental leak to earth occurs at any point on the lamp side of the choke, the faulty current will be limited by the choke to a value practically the same as the starting current of the lamp. Circuit components are designed to withstand this current safely for a period, and are therefore unlikely to suffer damage unless the fault remains uncorrected.

Though the lamp itself has a power factor of nearly unity, the series choke gives the circuit as a whole a power factor of about 0·5 lagging. For economy in running cost, it is usually expedient to correct the power factor to a value of about 0·9 lagging by connecting a condenser of 7½/8 mfd. capacity across the mains. If desired, a group of N lamps can be served by a single condenser of $8N$ mfd. capacity.

It should be specially noted that the condenser should be connected to the *mains* side, not the lamp side, of the choke.

Radio Interference

Though the radio suppression condenser is generally sufficient to avoid radio interference by radiations generated in the lamp, it may not

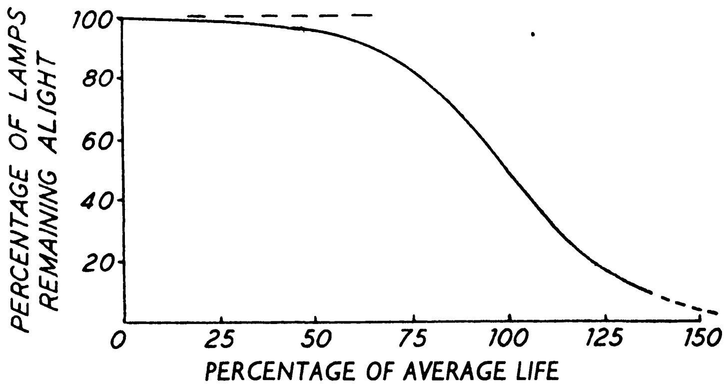


Fig. 15.—Mortality Curve for a group of 100 Fluorescent Lamps.

always completely eliminate the trouble. In such cases, a cure can often be effected by reversing the leads at each end of the lamp; proper earthing of any metal reflector used is, of course, helpful in reducing such radiation.

Should the interference be mains-borne, a high-frequency filter in the mains may be necessary.

Life of the Lamp

The average life to be expected of the 80 watt lamp is 2000 hours, but it must be recognised that the life of any single quantity-produced article which undergoes complicated manufacturing processes, and is afterwards used under conditions not under the manufacturers' control cannot be precisely stated.

Under normal conditions the mortality rate of lamps follows a curve similar to that shown in figure 15. Though the average life of a number of lamps will be approximately 100% of the rated life, there will inevitably be a few which fail early, and others which have longer lives than normal. Even if it were technically possible to achieve perfect life uniformity there would be serious disadvantages in practice if all the lamps in an installation failed simultaneously. There is however no risk of this at present and manufacturers are constantly aiming at the best life uniformity which is practically attainable.

It may well be economical to replace some of the lamps with abnormally long lives before they actually fail, since the normal reduction of light with age may reach a point such that the cost of a new lamp is less than the cost of the wasted current used by an old, inefficient lamp. Obviously the number of burning-hours after which it becomes desirable to discard old lamps must depend on local conditions, but generally it will be before 3000 hours is reached.

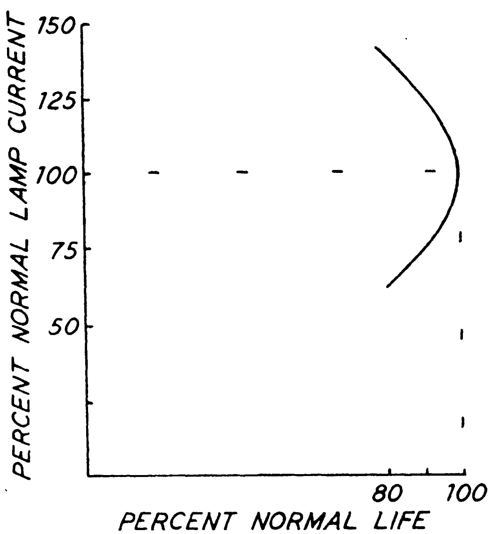


Fig. 16.—Effect of Variation of Lamp Current on Life—80 watt Lamp.

Apart from damage occasioned by mechanical breakage, the end of lamp life is generally due to failure of one or other of the electrodes, probably by exhaustion of the active material with which they are treated. Most of this material will normally be dissipated during the time that the lamp is alight, but the rate of dissipation depends on the lamp current. If the current is too high the electrodes will become overheated and loss will occur by evaporation; if the current is too low, there is loss by sputtering, i.e. a disintegration and dispersal of the active material due to ionic bombardment. Thus either over-running or under-running the lamp tends to shorten its life (figure 16).

Normal lamp life can be expected with about four starting operations per day, but excessive switching will reduce life considerably. Fluorescent lamps therefore should not generally be used for flashing signs, etc., even if the slight delay in starting, caused by the operation of the starter switch, is unobjectionable for this purpose.

Insufficient pre-heating of the electrodes will not only cause uncertain starting of the lamp, but also damages the electrodes by sputtering. When a lamp flashes or blinks in making several starting efforts before finally lighting in a normal manner, the matter should be investigated; if the unusual behaviour is due to a starter switch operating too rapidly the lamp will suffer damage, while if it is due to the lamp nearing the end of its useful life the starter switch may be damaged in repeated efforts to start the lamp.

Light Output

The light output of all types of mercury discharge lamp diminishes during life, and in the case of the fluorescent lamp the light output curve may be divided into two sections (figure 17). During the first 150 hours or so of life there is a sharp drop of output to about 85% of the initial value, while from this point onwards there is a fairly steady gradual fall until at the end of normal life the output is some 70% of the original.

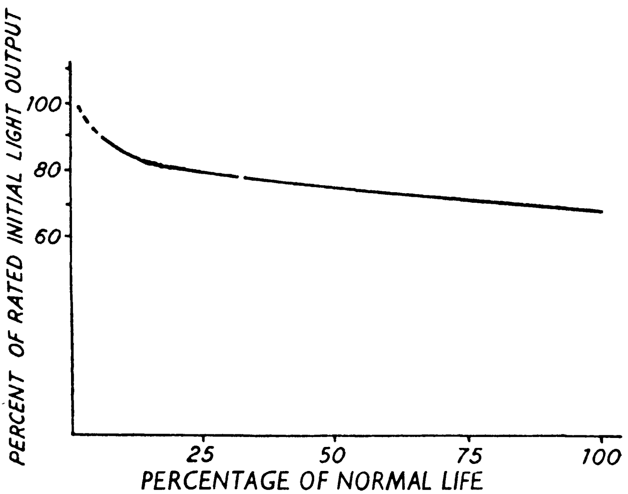


Fig. 17.—Light Output Maintenance Curve of 80 watt Colour "A" Lamp.
(The initial rating of light output, 2800 lumens, is a conservative one.)

The comparatively high loss of output occurring during the first part of lamp life is chiefly due to a reduction in effectiveness of the fluorescent powder, the surface of which appears to become contaminated by a film of metallic mercury. It may be found possible in the future to reduce or eliminate this initial drop, and if so a valuable increase of overall lighting efficiency would be obtained.

Lighting installations planned on the assumption that the 80 watt colour "A" lamp gives 35 lumens per watt (2800 lumens) would obviously give much less than the desired illumination during the major part of lamp life. It is therefore the practice of lighting engineers to base their calculations on the efficiency and light output after the initial drop (30 l.p.w. and 2400 lumens respectively). The loss of efficiency over the remainder of lamp life is then adequately catered for by applying the depreciation factor (usually 1·43) normally used for installations employing other types of lamps.

This reasonable method of procedure results, of course, in a correctly planned installation giving considerably more than the required service value of illumination when it is first put into commission. The excess footcandles, however, will disappear in a short while, and may be regarded as a kind of "bonus" which is received every time a lamp is renewed. In multi-lamp installations where lamps are replaced as and when they fail, it is unlikely that the majority of lamps serving any one area will fail at the same time, and the "bonus" will therefore not be so readily appreciated.

Though the lamp gives approximately its normal light output as soon

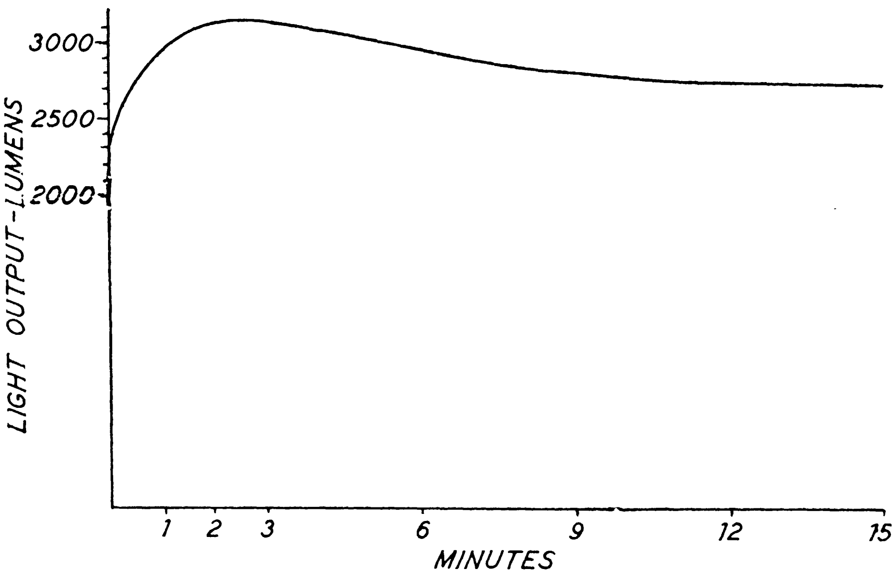


Fig. 18.—TYPICAL CURVE OF VARIATION OF LIGHT FROM 80 WATT LAMP DURING THE FIRST FIFTEEN MINUTES AFTER STARTING.

as it lights up, readings of illumination or brightness should not be taken until after about a quarter of an hour. Figure 18 shows that if the lamp is switched on at ordinary room temperature the initial light output is about 80% of the rated value. For the first two or three minutes it rises to a maximum, and then gradually falls again to its normal level, these variations being due to the changes in internal temperature and pressure before a state of equilibrium is reached.

Normally the variation of light output will pass unnoticed by an observer, but if the lamp is started at abnormally low temperature its initial light output will be considerably reduced, and the gain in output during the first few minutes will be very apparent.

Effect of Temperature Variation

The 80 watt colour "A" fluorescent lamp is designed to give its rated light output in free air at a temperature of 20°C (68°F), corresponding to a tube wall temperature of about 48°C (118°F) but it will also work satisfactorily at all temperatures likely to be encountered in normal interior lighting installations. Temperature does however have an appreciable effect on the light output of the lamp, as is shown in figure 19.

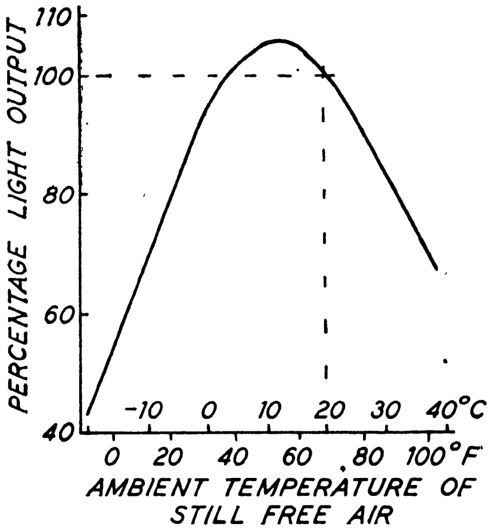


Fig. 19.—Variation of Light Output with Temperature.

With ordinary temperature variations the variation in light output is not due to any deterioration of the fluorescent powder, but to the fact that the pressure of the mercury vapour is changed with changes in temperature, and as explained on page 21 this change of pressure has the effect of reducing the proportion of energy emitted at 2537Å, which is the chief exciting agent of the fluorescent powder.

Excessive lamp temperature may be caused either by (1) over-running the lamp, i.e. allowing too much current to flow owing perhaps to wrong selection of choke tapping, or (2) by installing two or more lamps too close together, so that the heat radiated from one lamp strongly affects those on each side of it, or (3) by using a lamp or lamps in enclosures from which the lamp heat generated cannot escape sufficiently rapidly, or (4) by excessive ambient temperature.

Ambient temperatures which are unusually low for interior installations may adversely affect the ability of the lamp to start. It is difficult to give an exact figure, but it appears that at air temperatures below about 40°F there is a likelihood of there being some difficulty in starting, evidenced by the lamp flashing at each of the several complete starting operations performed by the starter switch. At still lower temperatures the lamp may entirely refuse to start, and therefore it is not recommended for general exterior use in its present form.

Stroboscopic Effect

When ordinary incandescent lamps are run on 50-cycle A.C. supplies the current through the filament rises to a maximum and falls again to zero one hundred times a second, and the filament tends to become hotter and cooler in accordance with the variation in current. The mass of metal forming the filament, though very small, is nevertheless far too great for its temperature to rise and fall in strict accordance with the heating effect of the current which varies so rapidly; in fact the temperature of the filament, and therefore the light output of the lamp, varies only very slightly from instant to instant, and this variation is both too rapid and too small to be generally noticeable.

With discharge lamps, however, the discharge arc is actually extinguished one hundred times a second, this occuring at those instants when the current wave passes through zero. Though some light may still be obtained from the incandescence of hot parts of the lamp, the total is only a small fraction of the light emitted from the discharge at instants when the current is a maximum, and the large periodic variations in light output, though usually unnoticeable when viewing stationary objects, may become evident where moving objects are concerned.

A moving object will only be seen at those instants during which light is emitted by the lamp, but will be invisible, or nearly so, during the dark periods. Thus the object will seem to move by a series of steps or jumps, the length of each step being the distance it travels between successive light periods. The persistence of the eye, which "remembers" something it has seen a moment before, may therefore account for an article such as a single spoke of a rotating wheel appearing to be a series of spokes each being separated from its neighbour by a regular angular displacement.

This phenomenon may be the cause of some unusual effects. In the case of a multi-spoked wheel, for instance, it may happen that the angular distance moved by a "real" spoke between lighted periods coincides exactly with the angular distance between the "apparent" spokes produced as described above. At certain definite wheel speeds the images of the real and apparent spokes will coincide, and the spokes will appear to be stationary, while at speeds slightly above or below this synchronous speed the wheel and spokes will appear to rotate slowly in a forward or backward direction. Much the same effect may often be seen on a cinema screen, when the wheels of moving cars, carts, etc. may appear to be stationary or even to move against their real direction of rotation.

It is evident that this stroboscopic effect, as it is called, could under certain circumstances be so confusing as to render some discharge types of light source quite unsuitable for the purpose in view, unless adequate steps are taken to reduce the effect to such a degree that it becomes innocuous. In large installations the method usually employed is to connect adjacent lighting points to different phases of supply so that although a lamp immediately overhead may be giving practically no light at one particular instant, the nearest lamps will be giving light, thus to a large extent reducing the effective variation of light of any one lamp. Another method sometimes employed is to "blend" the light of mercury lamps with that from incandescent filament lamps which, for most practical purposes, can be considered to give a steady light; this steady component of the total light from the mixed system results, of course, in the proportional variation of light being less than it would be with a mercury discharge system alone.

In fluorescent lamps the powder is slightly phosphorescent, and the after-glow from the powder persists over the period while the discharge arc is extinguished, so that the variation of light is reduced, and stroboscopic effects are not so noticeable as with other types of discharge lamps.

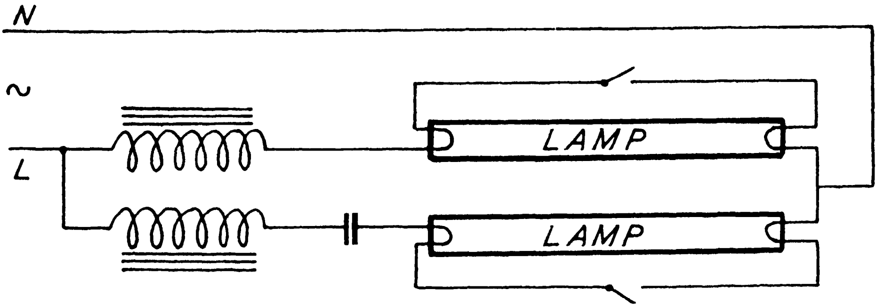


Fig. 20.—SCHEMATIC DIAGRAM OF BALANCED INDUCTIVE-CAPACITATIVE CIRCUIT FOR TWO LAMPS.

Balanced Two-Lamp Circuit

Should it be necessary or desirable to employ a single phase of supply for the lighting installation, stroboscopic effects may be reduced by connecting pairs of lamps as shown in figure 20. The power-factor correction condenser usually connected across the mains is omitted, but another of suitable capacity (6/8 mfd. for 80 watt lamps) is inserted in series with one of the lamps. A voltage of approximately 370 volts is generated across this condenser, which should of course be of suitable voltage rating to withstand this pressure. The choke windings in the two circuits are dissimilar.

The current in the lamp with the series condenser leads the voltage wave, whilst the current in the other lamp lags behind it. Thus the current, and therefore the light output, of the two lamps differs in phase by about 120°. In other words, the effect is very similar to that obtained by connecting alternate lamps to two phases of a 3-phase supply; either method very materially reduces stroboscopic effect.

A balanced two-lamp circuit as described above is evidently most effective in reducing stroboscopic effect when two, or multiples of two, lamps are mounted in the same fitting. With single lamps widely spaced but connected in pairs as described, the major part of the light received at any point of reference is likely to be given by the nearest lamp, the complementary light from the distant lamp of the pair not being strong enough to be very effective as a balancing agent.

The leading power factor of the condenser-fed lamp circuit balances the lagging power factor of the other lamp circuit, so that the power factor of the two-lamp circuit as a whole is very nearly unity.

Electrical Characteristics of the Lamp

An excess voltage applied to a lamp circuit will result in greater current flowing through the lamp and choke. The greater lamp current has the effect of producing more ions in the discharge, reducing the resistance and thus reducing the voltage drop across the lamp. Thus the power in watts consumed by the lamp increases, but to a less extent than the lamp current (lamp watts are equal to about 90% of the product lamp current × lamp volts, the current wave-form not being truly sinusoidal).

The increased current generates more light, but due to the change of pressure and temperature conditions (see page 21) the increase of light is smaller in proportion than the increase of current.

The approximate variation in normal operating values which result from a 5% variation in supply voltage are shown in Table 3.

TABLE III

APPROXIMATE VARIATION OF ELECTRICAL CHARACTERISTICS AND LIGHT OUTPUT OF LAMP WITH 5% VARIATION OF SUPPLY VOLTAGE.

Supply Voltage Increases by 5%	Lamp current increases by ..	12%	Normal value	0·8 amp.
	Lamp watts increase by ..	8%	,, ,,	80 watts.
	Lamp volts *decrease* by	4%	,, ,,	115 volts.
	Light output increases by ..	5%	,, ,,	2800 lumens (initial).
	Lamp efficiency (lumens per watt) *decreases* by	3%	,, ,,	35 lumens per watt (initial).

Note.—Within normal limits of supply voltage variation, the figures shown above may be adjusted in proportion to that variation, e.g., an increase of supply voltage of 2½% will result in halving the above figures.

Decreases of supply voltage have the opposite effect to that shown in the Table.

From the above Table it will be seen that increased lamp current results in a relatively small increase in light output. Either increase or decrease of lamp current shortens lamp life (see page 41).

It will also be seen that the light output is much less affected by voltage variations than is the case with incandescent filament lamps, where 1% change of voltage results in about 4% change of light output.

Direct Current Working

Fluorescent tubular lamps may be run on direct current if desired, but this practice is not to be recommended except as a temporary measure, or unless some very special reason exists for wishing to use this particular type of lamp where a D.C. Supply only is available.

On direct current the choke loses its value as a current-limiting device, but is still necessary to provide the voltage surge necessary to start the lamp. A stabilising resistance has to be inserted in series with the choke in order to absorb the difference between the mains voltage and the correct lamp voltage. This resistance (of about 140 ohms for 230 volt supplies) wastes rather more power than is consumed by the lamp; the circuit as a whole consumes about 185 watts on D.C. compared with about 89 watts on A.C. (80 watts in the lamp, 9 watts loss in the choke.) Thus, even if equal light output is received, the efficiency is approximately halved when working on D.C.

It will be found that after the lamp has been operating on D.C. for a short time there is an obvious reduction of light output from one end of the tube. This is caused by migration of the mercury from the positive end of the tube to the negative end, and may become noticeable after half-an hour's burning. The process will continue until the light output of the positive half of the tube is very seriously reduced. Reversing the polarity of the lamp will effect a temporary cure, but the process starts again in the opposite direction. For D.C. working there should therefore be a convenient means provided for reversing polarity frequently.

The power-factor correction condenser should of course be omitted from the circuit. The automatic starter switch does not operate with the same certainty on D.C. as on A.C. and it may even be necessary to dispense with it and use a hand-operated switch instead.

Series Working of Lamps

It has been found impracticable so far to run two fluorescent or other discharge lamps in parallel controlled by a single choke winding, though in theory it should be possible to do so if the lamps were perfectly matched. In practice this perfect matching cannot be obtained, with the result that one lamp of the pair is over-run while the other is under-run or may even fail altogether to start.

There is, however, no reason why fluorescent tubular lamps should not be run in series with a single choke winding, provided that sufficient voltage is available. Each 80 watt lamp requires about 115 volts to be applied to it, and a further voltage drop is required for the choke. Thus two 80 watt lamps may be connected in series to 400 volt mains with very satisfactory results.

The schematic circuit diagram is shown in figure 21, details of the starter switches and suppression condensers being omitted for the sake of clarity (see pages 36 to 39 for details). With such a circuit the starter switches operate in sequence, the lamps striking up one after the other and functioning in a perfectly normal manner. It will be evident that the choke must have different electrical characteristics from that for single-lamp working on the 200/250 volt range.

The great disadvantage of series working with filament lamps—that when one fails both are extinguished and there is often doubt as to which is the faulty one—is not nearly so serious with fluorescent lamps. Generally, a lamp which fails does not do so suddenly or without adequate warning. A lamp about to fail will usually advertise the fact by flashing several times before starting, by a snaking or shimmering effect in the tube, or by very dark deposits near each lamp cap. Any lamp which

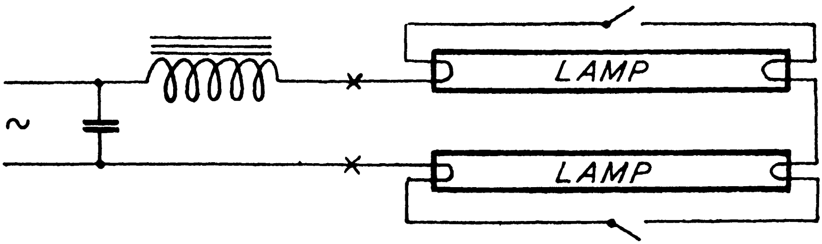


Fig. 21. SCHEMATIC DIAGRAM OF TWO-LAMP SERIES CIRCUIT.
(Note.—Heaters of thermal type starting switches connected at points X.)

shows these symptoms, or which actually fails, should certainly be replaced immediately in order to save possible damage to the other lamp of the pair; but even though the lamps may not be alight it will usually be quite obvious which is the faulty one.

Since on a 400 volt (approx.) 3-phase A.C. network there is only 230 volts to earth, on the score of danger there seems to be little objection to the use of series circuits on these power mains where they are available. Series working would be of particular value in situations where two, four or six lamps were grouped in a single fitting, since the wiring to each pair of lamps would be simplified. Some saving in weight and cost of the steel and copper used for chokes might be obtained, and the overall efficiency of the lighting would probably be increased, since the number of chokes would be halved, and power losses in the chokes reduced in consequence.

In American industries where A.C. supplies at voltages of the order of 270 volts are common, a 4-lamp series-parallel circuit is often used. This is essentially a combination of the circuits shown on pages 46 and 49, the four lamps being controlled by a single split-phase choke.

Burning Position

Tubular fluorescent lamps are normally burned in the horizontal position, but there appears to be no objection to using them upright if desired. No data are available of the effect on light output or life, but experience suggests that if there is, in fact, any deleterious effect it is so small as to be negligible.

Servicing Fluorescent Lamp Installations

Unlike a filament lamp, which either lights or does not light according to whether it is sound or not, a fluorescent lamp may work erratically for a number of different reasons; and although there is little reason to expect a lamp to work in other than a normal manner, much time and trouble (and also possible damage to components) may be saved if the cause of erratic behaviour can easily be diagnosed. The following section, while not intended to be comprehensive, is therefore provided as a general guide in tracing the troubles most likely to be encountered in ordinary lighting practice.

Abnormal behaviour on the part of the lamp will probably fall under one of the headings A to E below:—

A. LAMP MAKES NO EFFORT TO START

If the lamp fails to flash within three or four seconds of closing the circuit switch, inspect the lamp electrodes, which may be easily seen through the clear glass rim next to each lamp cap.

1. *If both electrodes are glowing*, the elements of the starter switch are probably stuck together. A flick with the finger may temporarily free the contacts and enable them to open, but the only permanent cure is a new starter. In the case of the glow starter, the probable cause of welded contacts is a failure of the 100 ohm resistance incorporated in the suppressor unit. If so, this should be replaced.

2. *If only one electrode glows* there is an earth in the wiring of the starter or suppressor. (Note:—The choke should always be connected in the phase lead of the supply, in order to limit the current flowing on account of such earth faults, thus preventing damage to otherwise sound components).

3. *If neither electrode glows* there is an interruption somewhere in the circuit. Likely places are the lamp electrodes, lampholder plungers and the heater of a thermal starter. A similar effect is caused by a thermal starter whose contacts do not close when the lamp is switched off, or by glow starter contacts which fail to close when the lamp is first switched on; in this event replacement of the faulty starter is the only cure.

B. Frequent Flashing When Starting

An occasional flash when starting is quite normal, but frequent flashing may be due to one of the following causes:—

1. *Low ambient temperature or cold draughts.* The voltage necessary to start the lamp begins to rise as the ambient temperature falls below about 50°F. but this is unlikely seriously to affect starting until temperatures much nearer freezing point are reached. It may be possible to shield or screen lamps to prevent any trouble of this nature.
2. *Wrong choke tapping or low mains voltage.*
3. *End of lamp life.*
4. *Starter switch operation too rapid,* giving the lamp electrodes too little time in which to heat up properly. Replace starter.

C. Flashing While Running

This is most probably caused by:—

1. *Starter faulty or elements displaced* so that they do not hold in the normal running positions (open in thermal type, open and no glow in glow type).
2. *Normal end of lamp life.* In this case the flashing or blinking will probably be accompanied by a shimmering effect, and the ends of the lamp will have become blackened.

D. Low Light Output

Light output will suffer if the lamps are either too hot or too cold. In ordinary trough fittings they burn quite satisfactorily, but if enclosed or used in unusually high or low temperatures attention to ventilation or screening may be profitable. Losses of light output due to such causes should not be confused with the normal drop of about 15% during the first 150 hours or so.

E. Colour Difference

Before assuming that different lamps are not of the same colour, make sure that the apparent difference is not due to the colour of adjacent surfaces or light sources of another type, or to the fact that one lamp is older and dimmer than another with which it is compared.

General

Lamps which are suspected of being faulty can be safely tested in a circuit known to be satisfactory, but a good lamp should never be put into service until its circuit is thought to be correct. A bad lamp, if left in circuit, may ruin a good starter, and a bad starter may spoil a good lamp; therefore a lamp circuit behaving abnormally should be disconnected or otherwise put out of action until the fault can be traced.

A faulty electrode in the lamp may cause the heater of a thermal starter to burn out. Therefore, if a faulty heater is found, look also at the lamp electrodes, and *vice versa*.

The average user either does not realise or will not admit that his lamps and fittings may be dirty, but about half the complaints concerning low light output are due simply to a layer of dust and dirt which a thorough wash would remove; and most of the other half are due to the choke tapping not being selected to suit the *actual* mains voltage at the lighting point.

Chapter V

FLUORESCENT LIGHTING FITTINGS AND THEIR PERFORMANCE

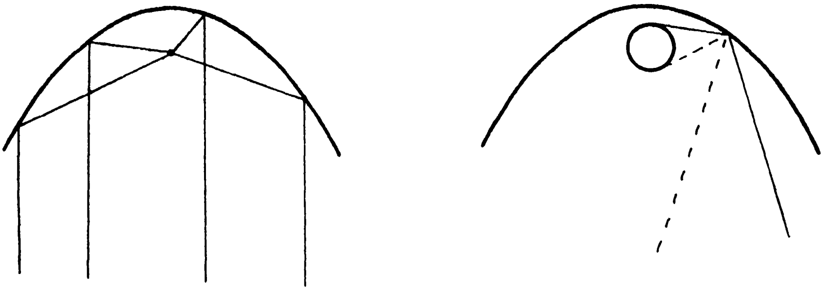
THE low brightness of fluorescent lamps compared with other types is likely to lead to the supposition that they will be quite satisfactory when used bare, provided that no particular control of the light is required. This supposition may lead to a good deal of disappointment. If it were merely a matter of obtaining twice as much light for a given consumption of electricity, then substitution of bare fluorescent lamps for incandescent lamps in enclosed glass fittings might be justified: but the added light will be obtained with added discomfort, since the brightness of the apparent source will, in general, be greater also, and therefore glare and glitter will increase. For commercial and domestic interiors at least, fluorescent lamps are not objects which automatically give greatly improved lighting conditions; but they are entirely new sources of light, good enough to merit some thought being given to the manner in which they are used.

Light sources in general may be required to provide an unrestricted flow of light in all directions, as for instance, totally enclosed opal glass diffusing fittings for incandescent lamps; or they may be required to provide a flood of light in a general direction, as in "direct" lighting systems; or to control and confine the light within a specified narrow angle, as in spotlights and floodlights.

Narrow-angle concentrated beams of light are not normally required for general lighting schemes, but for display purposes they may be essential. A light distribution of this type can only be obtained when the original light source is compact and of small dimensions, and the large size of fluorescent lamps therefore limits their possibilities in this respect.

Parabolic Reflectors

A parabolic mirrored surface will reflect parallel beams of light from a point source placed at its focus (fig. 22) but a source such as a fluorescent lamp which has a considerable diameter must give a spreading beam. The degree of spread will be reduced as the focal distance of the parabola is increased, but this entails either the use of a large cumbersome fitting or a decrease in the proportion of light which is re-directed by the reflecting surface. In practice, therefore, a high degree of light control should not be expected from commercial fluorescent fittings.



(a) *Fig.* 22. (b)

(a) Point Source of Light at the Focus of a Parabolic Polished Reflector gives a Parallel Beam of Light.

(b) Spread Beam from Cylindrical Lamp in Parabolic Trough Reflector.

Unless there is a special reason for using specular reflecting surfaces in any part of a fitting normally visible, it is preferable to choose a finish with reflecting properties of a more diffusing nature so that, whatever the viewing angle, the reflecting surface will appear fairly bright. With specular surfaces the reflector will only appear bright when the light is being thrown directly towards the eye; at other times it appears dark, and there is likely to be an unpleasantly high contrast between the lamp and the dark background against which it is seen.

The designer of fluorescent lighting fittings must effect a compromise between the ideal and the commercially practicable. For instance, a reflector designed to control the light within a fairly narrow angle may be built up of a series of plane surfaces each inclined at about the same angle as the part of the parabola it is intended to replace; manufacture may thus be simplified, and the resulting control of light is little inferior to that of the true parabolic section, while the positioning of the lamp within the reflector is not so critical (figure 23).

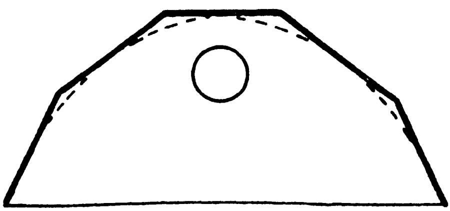


Fig. 23.—Built-up or Pressed Reflector with Flat Enamelled Surfaces arranged to follow approximately the General Contour of a Parabola.

Prismatic lens plates with the prisms in line with the major axis of the lamp may be used for sideways control of the light. For this purpose it has been found effective to mount the lamp at one focus of a reflector of elliptical section, the lens plate being at the other focus. The extent to which light is refracted sideways is decided by the shape of the prisms.

Incandescent lamp fittings for most general lighting purposes are not usually expected or required to exert a very strict control over the distribution of light. Abrupt changes in candle-power at different angles, in fact, are deliberately avoided by using reflecting surfaces which to a greater or lesser extent diffuse the light striking them, and also by using diffusing glass or plastics. There seems to be no valid reason for changing this practice.

Enamelled Reflectors

Enamelled surfaces, which are so widely used in lighting fittings, should not be expected to reflect light in the same specular manner as mirrors or polished metal surfaces. From the point of view of light control, a coating of enamel behaves much as if it were blotting paper covered by a sheet of glass. A very small percentage of the incident light will be reflected specularly by the glass face, but the major part of the light which penetrates the glass is reflected in all directions according to the "cosine law", the distribution of the reflected light being quite independent of the direction of the incident light. Thus it will be evident that the shape of an enamelled reflector will only control the distribution of reflected light to a minor degree; but this statement should not be taken to infer that the shape of an enamelled reflector is immaterial. That is not so, by any means. Other considerations have to be taken into account, among them being avoidance of multiple cross-reflection, which leads to a loss by absorption each time the light strikes a reflecting surface.

The fact that fluorescent lamps are more efficient generators of light than incandescent lamps does not justify the use of fittings which are unnecessarily inefficient. The more the raw light is controlled, either by reflection or transmission, the greater the proportion which is lost. Complicated fittings may be essential for certain specialised applications, but for ordinary everyday lighting purposes they are wasteful and expensive. "The simpler the better" is a good general rule which designers and users alike would do well to bear in mind.

Choice of Lighting Fittings

The selection of type of lighting fitting to be employed depends upon the answers to the following questions:—

Where is the light wanted, and from which direction must it come?

Should it be directional or diffused, or of some intermediate character?

Will the light be comfortable, and free from direct glare or glitter?

Will it be reasonably efficient and easily maintained so?

Will its appearance be in keeping with the nature of the interior?

Will the initial cost of the necessary number of fittings, and the running cost of the installation as a whole, be reasonable, bearing in mind the effects the lighting is expected to produce?

The relative importance of the above considerations will of course depend on the nature of the interior.

INDUSTRIAL

As a general rule, the light is required chiefly on the horizontal plane, with some sideways light to illuminate vertical surfaces; the brightness of the light source should be sufficiently low to avoid glare and glitter from the materials being worked; shadows should be soft; and light must be provided as efficiently as possible from durable, hard-wearing fittings whose decorative value is of minor importance.

These requirements automatically indicate the general advisibility of using an overhead, direct lighting installation of inverted open-mouthed (for efficiency) trough-shaped (for directing the light) fittings with a reflecting surface of vitreous enamel (diffusing and hard-wearing) or some other material with similar qualities. A wide variety of such fittings are available, and it remains for the intending user to make his choice.

Open-top Fittings

In order to make a trough fitting as compact as possible the lamp is fixed in a position well inside the trough, where it naturally obstructs some of the light being reflected from the surface above it. The loss is not of great importance, since only about one quarter of the light intercepted by the lamp is absorbed. Many industrial trough reflectors are available with a partly open top, i.e. a long open slot, perhaps an inch wide, is cut in the reflector immediately above the lamp, so that the light previously reflected and trapped is allowed free exit in an upward direction. The appearance of the room is thus improved, since the ceiling becomes lighter, while the downward illumination is reduced very slightly if at all, as the small amount of light now escaping upwards may be compensated for by the better ventilation of the fitting, reducing lamp temperature and increasing the efficiency of light generation (page 44).

Continuous Lines of Light

In situations where the illumination level is to be of a high order, it is preferable, if possible, to employ continuous lines of light running from end to end or from side to side of the interior, rather than to use large numbers of individual fittings. Not only is the whole installation much neater, but the number of suspensory chains, tubes or brackets may be greatly reduced, since considerable lengths of continuous troughing can be installed with only one support at each end. In certain designs of continuous troughing, wiring may also be simplified.

The illumination over an area served by a number of lamps will generally be reasonably even* if the fittings are spaced at a distance

* Minimum illumination not less than 70% of the maximum.

apart not greater than 1½ times the mounting height above the plane of work (see page 65). This spacing applies to both the longitudinal and transverse directions. In most cases, however, this maximum spacing will not be used, a lesser one being either more convenient for installation work, or necessary in order to provide sufficient illumination on the work; a lesser spacing of course improves the uniformity of illumination.

Multi-lamp Fittings

Fittings housing two or three lamps may be used either to provide extra high illumination levels at low mounting heights, or (provided the available height is sufficient) to reduce the number of fittings it is necessary to use to provide moderate illumination. The necessity to avoid such fittings being unduly large, the obstruction which each lamp offers to the light from the other lamps, and the extra heat developed in a multi-lamp fitting all tend to reduce the efficiency compared with an equivalent number of single-lamp fittings. The degree of loss naturally depends on the design of the reflectors, particularly as regards the spacing of the lamps, their distance from the reflector surfaces, and the angle of "cut-off" from the lip of the reflector to the lowest point of the farthest lamp. Individual makes of multi-lamp reflectors therefore vary in efficiency according to the value the manufacturers attach to angle of cut-off, compactness, etc. It is quite possible to make a 3-lamp fitting almost equally as efficient as a well-designed single-lamp fitting, but the relatively high efficiency will probably be obtained only with a fitting which is unduly large or has the cut-off angle (usually about 20° below the horizontal for a single-lamp fitting) reduced so that the lamps become more visible at normal angles of view. If the cut-off angle of a 3-lamp fitting is retained at 20° the efficiency of a compact 3-lamp fitting of good design will fall by about 15%, and that of a 2-lamp fitting by about 10%. Greater losses are to be expected in fittings which are made too small, or where the lamps are crowded together too closely.

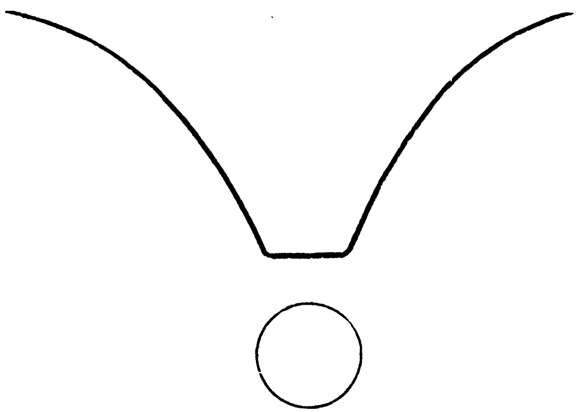


Fig. 24.—Section through Distributing Type Reflector.

In interiors with low ceilings the *distributing* type of fitting may be preferred (figure 24). This type will not give so much downward light as the inverted trough, but a proportion of the light goes in an upward direction and, with the help of the reflector, is spread over the adjacent ceiling. For efficient utilisation the ceiling must, of course, be white or off-white, in order to reflect the light downwards again and to ensure that the lamp is not seen against too dark a background.

COMMERCIAL

It is too early yet to base any comments on the comparatively small selection of British fluorescent fittings designed for commercial use, but it is reasonable to assume that when circumstances permit the extensive use of such fittings in this country British practice will have much in common with American.

Almost without exception, commercial interiors require the walls and ceiling to be well lighted, and therefore pendant fittings generally allow some of the light to go sideways and upwards. In order to avoid the fittings being seen as dark objects against the lighted ceiling and walls, they must be luminous themselves, so that they will inevitably be constructed of metal-framed glassware or translucent plastics.

Lamp Spacing Behind Luminous Panels

Such fittings are likely to be chosen more for their appearance than for their efficiency, and one of the faults which can ruin an otherwise good appearance is a spotty or streaky effect in luminous panels which are intended to be uniformly bright. Commercial fittings will be constructed to house several lamps which, unless they are spaced correctly with respect to their distance behind the diffusing panel they are lighting, will certainly exhibit this fault. Unfortunately the required depth behind the panel cannot always be provided without making the fitting too large and cumbersome, but if this is so it may be possible to arrange for a narrow metal grille or other device to cover the areas of least brightness, as when a surface is divided into a number of sections in this manner differences of brightness are not so readily apparent.

A panel of flashed opal glass is evenly lighted by opal filament lamps symmetrically spaced at a distance apart equal to the distance of the filament from the glass, while with frosted glass the distance behind the glass should be at least 1½ times as great as the spacing, and perhaps more, depending on the degree of frosting. With fluorescent tubular lamps, so far as crossways spacing is concerned, it is safe to follow the same rule; in fact a spacing wider by some 50% than that indicated above is unlikely to give rise to any noticeable brightness differences. But when lamps are required to be placed end to end adjacent lampholders make a wide break in the line of light, and at least an additional five inches should be added to the distance behind the glass if this dark spot is not to be apparent. It is better, if possible, to arrange for adjacent lamp ends to overlap very slightly, and lie side by side, so that the break in the line of light is made very small.

The above suggestions are made on the assumption that the lamps are enclosed in a white-lined recess with a diffusing surface on three sides. Where no matt white surface exists behind the lamps, spacing will have to be considerably reduced.

Louvres

In most commercial interiors the actual source of light is of no interest. In a shop, for instance, customers are unlikely to notice first-class lighting. In fact, the better the lighting the less does it draw attention to itself, and the more emphasis is laid on the goods for sale. But bad lighting will not escape notice, although the customer, if asked, could probably not explain where the fault lay.

In an industrial interior, where one expects to find an efficient workmanlike atmosphere and where the normal line of sight is distinctly in a downward direction, it is usually considered unnecessary completely to screen fluorescent lamps on account of their low surface brightness; to do so would automatically reduce the illumination without gaining any compensating advantage.

But in shops and other interiors where prestige is important it is an entirely different matter. A high-class shopkeeper is willing to spend a great deal on his furnishings and general shop fitments in order to impress customers, to show that he is up-to-date, and to indicate that the service he can give is the best in the district. To him, the right atmosphere is more than half the battle, and he is unwise to begrudge any slight extra cost incurred in making the lighting as fit as possible for its purpose.

Fluorescent lamps are not so ornamental that they should be made prominent features of an interior; nor are they of sufficiently low brightness to avoid giving rise to a feeling of irritation if their presence is too obvious, as it may easily be in a shop where the normal line of sight is somewhere near the horizontal. Their job is to provide light, not to draw attention to themselves, and they should therefore be screened from normal view by some convenient means.

Most fluorescent fittings will be square or rectangular, and a form of screening particularly suitable for this shape of fitting is a straight system of louvres. These consist of a series of thin plates of metal, obscured glass, plastic or other suitable material placed on edge along or across the length of the fitting, or perhaps lying both ways and being joined together to form a kind of open egg-box underneath the lamps so as to cut off all direct view of them unless the observer stands almost immediately below and deliberately looks upwards. There is some loss by absorption as the light strikes the louvre surfaces, but this is usually of minor importance where the surfaces are white; in some cases, however, particularly with a large fitting giving a great amount of light, it may be advisable to finish the louvres light grey or some other suitable colour which will not appear too bright, and in such instances, the loss of light by absorption will of course be higher.

To prevent direct view of the lamp at any given angle of view, the size of each "egg-box" depends upon its depth. If the louvre is shallow, the "egg-boxes" must be small, and *vice versa*. As much depth as possible is generally to be preferred, as the smaller the individual compartments the more difficult they are to keep clean, and the more "fussy" their appearance.

From the point of view of maintenance an open-top fitting with a louvred bottom is better than one with the underneath closed by a translucent panel, since much of the collection of dust and dead flies which would collect on the latter falls straight through the louvres whose vertical surfaces remain reasonably clean for long periods.

Troffers

New building work or reconstruction gives the opportunity to dispense with the usual pendant fittings altogether, and to substitute lighting built in to the ceiling. Americans have coined the word "troffer" to describe the recess in which the lamp lies, and these troffers generally run the entire length or width of the room. They may be open or closed by a diffusing panel; in the former case the troffer must be deep enough to prevent direct view of the lamps at normal viewing angles from the side, while transverse louvres are spaced down the length of the trough in order to prevent lengthwise view of the lamps. Troffer width is usually about 12 inches; if made much narrower than this they become relatively inefficient due to the absorption of light on the troffer sides.

Architects will welcome the fluorescent lamp as it enables them to put forward schemes using continuous lines of light in this and other ways, without having to consider so much the ability of the client to meet the running cost. Architectural lighting—that is, lighting which is built-in to become part of the structure—if carried out with filament lamps was generally much more costly than a less ambitious scheme using pendant fittings; large numbers of small lamps had to be employed, and they had to be screened either by using their light indirectly, and therefore inefficiently, or by means of panels which unfortunately scarcely ever appeared evenly bright all over; the comparatively large amount of heat generated had to be dissipated somehow; and current consumption was relatively high.

These disadvantages are very greatly reduced when fluorescent lamps are employed. The lamps do not need such elaborate screening, and a smaller number need to be installed; they give only one third or less of the heat, and the current consumption is, by comparison, very moderate. They are what architects have been demanding for years.

Group Replacement

Fluorescent lamps, for the present at any rate, are not likely to be made in sizes larger than about 100 watts. Probably the present 5 ft. 80 watt lamp will remain the largest in this country, its light output being equivalent to a 200/150 watt incandescent lamp. A fitting about 6 ft. long may not be desirable in many moderate sized or small commercial interiors particularly where the ceiling is low; therefore smaller sizes of lamps will be used, with consequently less individual light output, and to obtain the volume of light required per fitting it may be necessary to use multi-lamp fittings.

The uncared-for appearance of such a fitting when a single lamp fails may be more important to the user than the temporary local reduction of illumination; in particular this is so where the lighting system is decorative rather than utilitarian. Though the dead lamp is an eyesore, it probably has to remain in place at least until the end of the day, and perhaps until the end of the week, since its replacement during working hours might well cause an undesirable interruption of business.

Most commercial lighting installations are switched on as a whole for a definite and regular number of hours per week, and it might benefit many commercial lamp users to adopt a system of *group replacement* whereby the number of lamps failing in service may be greatly reduced. A careful record will show when the whole installation has been in service for a period approaching that of the expected lamp life, and under the group replacement scheme *all* the lamps, whether still serviceable or not, are replaced at about this time.

Reference to figure 15, page 40 shows that while very few lamp failures can be expected to occur before about 50% of nominal life, from this point onwards failures become more and more common. The curve shows that about 20% of lamps will have failed by the time the installation has been in use for 80% of the nominal lamp life, and these early failures must of course be replaced as soon as convenient. But suppose now that the entire installation is relamped at this point. Obviously some lamps which are discarded would have failed very soon in any case; but equally obviously some other lamps could have been kept in service for a considerably longer time, though they would have become dimmer and dimmer as time progressed.

Group replacement means, on the debit side, that more lamp replacements have to be bought per year; but there is also a credit side. Firstly, only a few lamp failures occur during business hours, and therefore the installation has a better appearance and there is less frequent interruption of normal routine when the maintenance man gets out his ladders. Secondly the brightness of all lamps will remain more nearly equal than would be the case if some were allowed to burn for hundreds of hours longer than they should; thus there is further improvement in appearance.

Thirdly, and perhaps this is the most important item, the cost of maintenance may be very drastically reduced.

Consider the cost of a lamp failure. Either it stays where it is, giving no light and spoiling the look of what may have been a decorative lighting scheme; or the maintenance man is called. He spends some time locating the faulty lamp, fetching a new one, rigging his ladders, replacing the lamp and "giving the fitting a dust over while he is about it"; and meanwhile the people down below are inconvenienced. Certainly the cost of a lamp failure is in some cases far greater than merely the cost of a new lamp.

It is for the user to decide. Will he replace lamps as and when they fail, with a consequent high cost (in time and trouble) of replacement? Or will he sacrifice some of the lamp life and accept a higher total lamp cost, improving the appearance of his lighting and increasing the service it gives? If the latter, it may be found that since lamp replacement is carried out in bulk, the total maintenance costs are reduced by an amount which more than balances the extra lamp cost.

Accessibility

A particular type of fitting is usually chosen for its appearance, or for its efficiency; seldom, if ever, for its accessibility, yet this is a most important item. It might perhaps be thought that if fluorescent lamps have longer lives than filament lamps, attention to the fitting would need to be less frequent, and therefore accessibility would be less important.

But that is not so, by any means. Even one thousand hours, the nominal life of a filament lamp, is far too long to leave a fitting uncleaned. One which was left for two thousand hours or longer—nine months of ordinary use—would be in a deplorable state of filth, and certainly no credit to its owner, besides being of very little practical use as a source of light.

Much more attention should be given by buyers and users to this question of accessibility. Human nature being what it is, a fitting which is difficult to open up for cleaning is just "forgotten" until its appearance or inefficiency can be tolerated no longer. One which is easy to clean has at least a reasonable chance of being maintained in a creditable and useful condition.

Chapter VI

ILLUMINATION DESIGN DATA

THE familiar Inverse Square Law which states that the illumination received is inversely proportional to the square of the distance from the (point) source of light does not operate with fluorescent lamps, which are by no means point sources of light; and there is no simple easily worked formula by which illumination at various distances and in various directions from an extended source of this kind can be found. Accurate formulae exist, but the average lighting engineer will find it much more convenient to use tabular or graphical results of tests taken on representative lamps and equipment. Less mathematics are involved and calculations are easier to check.

At the present time the type of fitting most commonly used is the inverted enamelled trough housing a single 80 watt colour "A" lamp, and mounted not more than about 7 ft. above the working plane. Illumination values received at 1 foot intervals measured longitudinally and transversely from beneath the centre of the lamp are shown in figure 25, and though the curves are approximately correct for standard fittings of this type, and for lamps with an efficiency of 30 lumens per watt (allowing for the fall in light output during the first 150 hours) they must not be taken as indicating exact values, which must to some extent be dependent on the shape of the trough and the quality of the reflecting surface.

Iso-footcandle diagrams such as those shown in figure 26 are of greater value when dealing with installations comprising a number of lamps, since they show the illumination in all horizontal directions from the point immediately below the centre of the lamp or fitting, and a clearer picture is gained of the distribution of illumination. It will be noted that at low mounting heights the diagram is elongated in the direction of the major axis of the lamp, while at a mounting height of about 5 ft. it becomes approximately circular. At heights greater than are likely to be encountered in practice, for the present at any rate, the diagram actually becomes slightly elongated at right angles to the major lamp axis; but for mounting heights above about 4 ft. 6 ins. very little error is occasioned by assuming the diagram to be circular. Thus established installation practice for the symmetrical reflectors used with other types of lamps can also be followed with fluorescent lamps, their transverse spacing being made equal to their longitudinal spacing between centres.

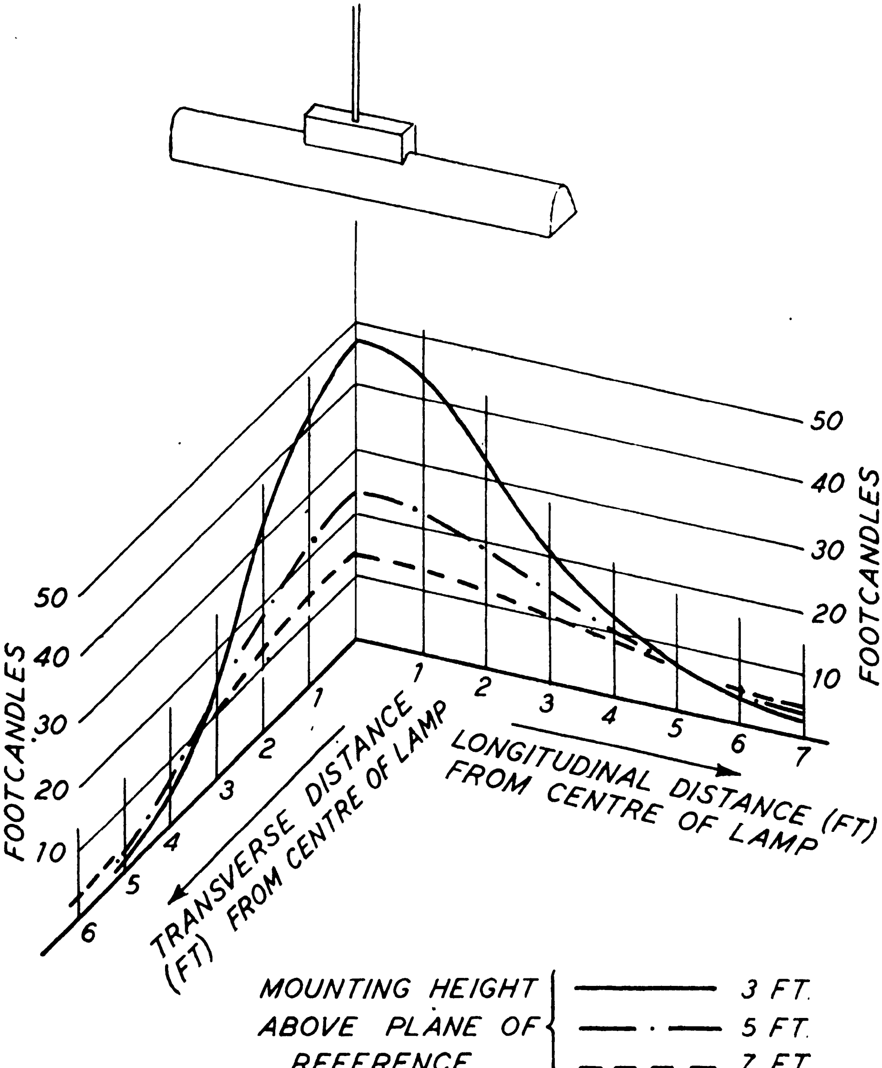


Fig. 25.—APPROXIMATE ILLUMINATION VALUES AT POINTS UNDER THE MAJOR AXIS, AND TRANSVERSELY TO THE MAJOR AXIS, OF A SINGLE 80 WATT LAMP IN TYPICAL ENAMELLED TROUGH REFLECTOR.

(Note.—No allowance for depreciation has been made. Illumination values in service will average about 70% of the figures indicated.)

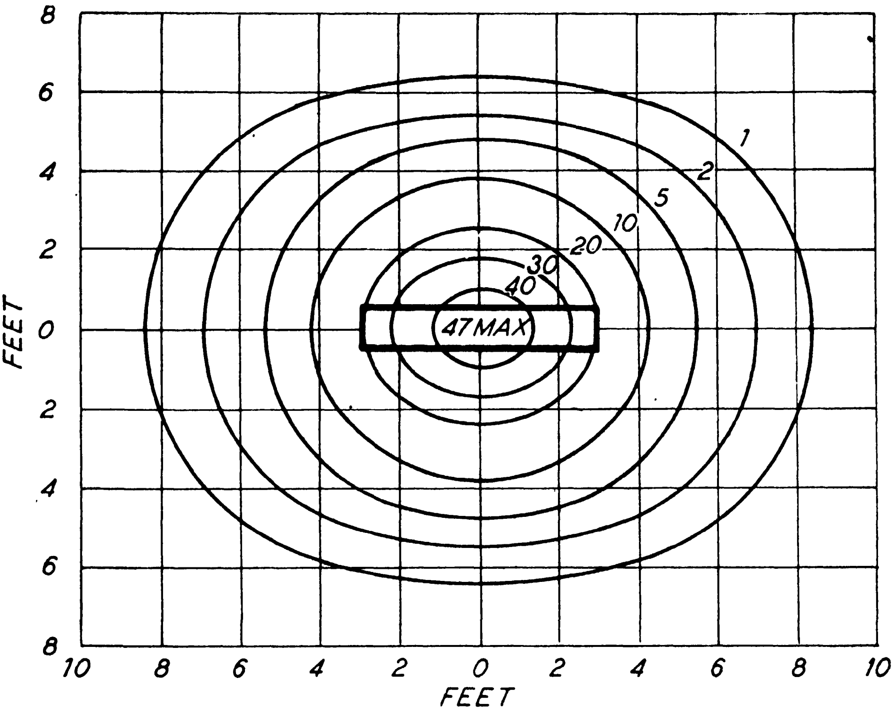


Fig. 26 (a).—Iso-Footcandle Diagrams showing the Illumination received at points on a Horizontal Plane marked in 2-foot Squares. 80 watt Colour "A" Lamp in Enamelled Trough Reflector mounted at a height of 3 feet above the Working Plane on which the Illumination is Measured.

Note.—Due to depreciation in service the illumination received will be about 70% of that indicated by the above curves.

Spacing of Fittings

The maximum distance apart at which fittings can be spaced depends on the mounting height of fittings above the plane of work, or, in the case of semi-indirect and indirect fittings, on the ceiling height above the plane of work. As a general working rule, the distance between fittings used in a general overhead installation should not be greater than one-and-a-half times their height above the working plane. A greater spacing than this will usually result in too great a variation of illumination throughout the room. This general rule of course does not apply to fittings with strong directional characteristics.

General Lighting with Trough Fittings

Since the polar curve of light distribution of a trough fitting becomes approximately circular at the mounting heights at which it is likely to be employed in a general overhead lighting scheme, and since the

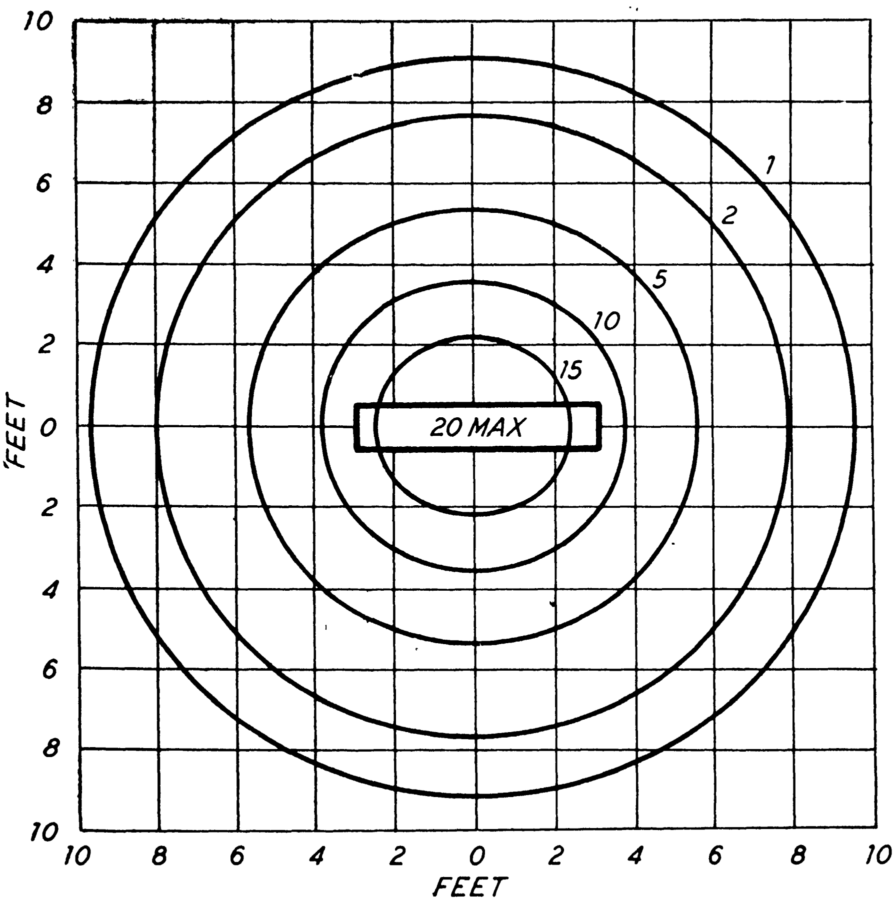


Fig. 26 (b).—Iso-Footcandle Diagram showing the Illumination received at points on a Horizontal Plane marked in 2-foot Squares. 80-watt Colour "A" Lamp in Enamelled Trough Reflector mounted at a height of 5 feet above the Working Plane.

efficiency of a trough fitting is very similar to that of a dispersive type of industrial reflector for incandescent lamps, the same coefficient of utilisation may be employed in design calculations.

In order to make allowance for the effect of room proportions, the Room Index must first be found from Table IV page 68.

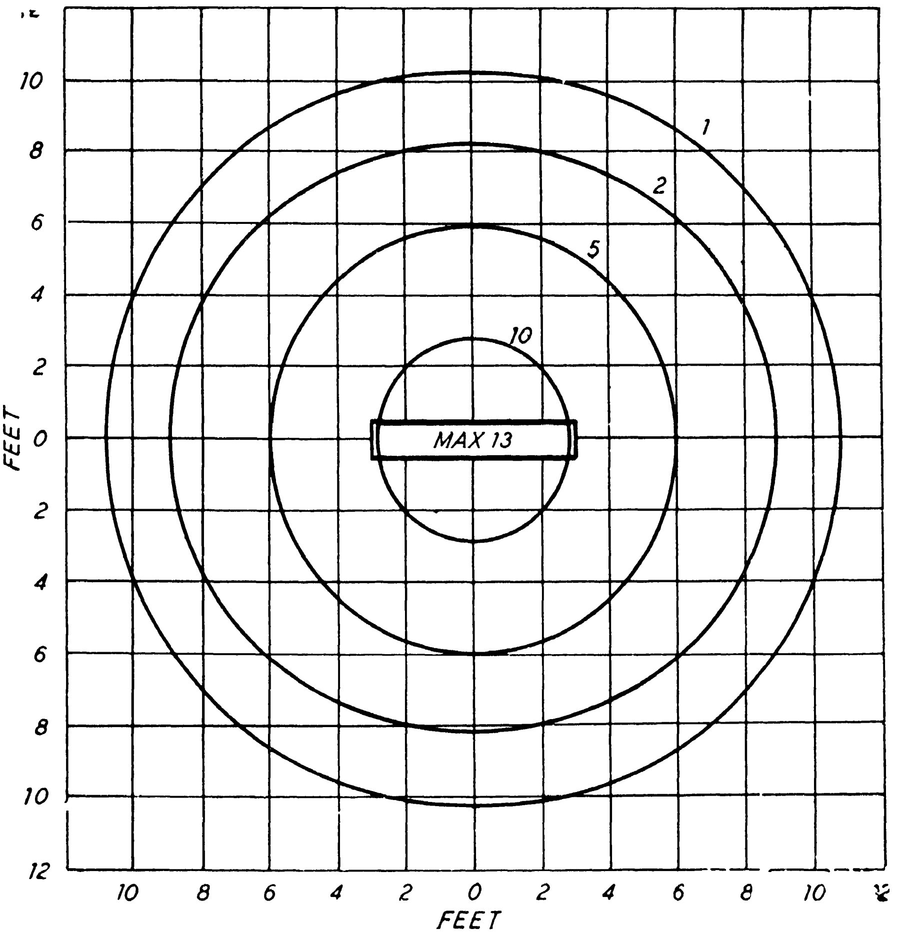


Fig. 26 (c).—Iso-Footcandle Diagram showing the Illumination received at points on a Horizontal Plane marked in 2-foot Squares. 80-watt Colour "A" Lamp in Enamelled Trough Reflector mounted at a height of 7 feet above the Working Plane.

It will be noticed that in this diagram, and the preceding one, the illumination curves are very nearly circular. When the mounting height exceeds about 7 feet above the working plane, the illumination curves may become slightly elliptical with the major axis of the ellipse at right-angles to the axis of the trough reflector.

These conditions, however, are seldom encountered in actual practice and it may be assumed that, where the mounting height is 5 feet or more above the working plane, the illumination curves would be approximately circular, as already pointed out on page 63.

Table IV ROOM INDEX

Room Width. Feet.	*Room Length. Feet.*	*DIRECT LIGHTING FITTINGS Height of Fitting above Working Plane—Feet.* 5	10	14	18	22	26	30
8	10	A*	—	—	—	—	—	—
	12	A*	—	—	—	—	—	—
	16	B	—	—	—	—	—	—
	24	B	—	—	—	—	—	—
	35	B	—	—	—	—	—	—
	50	C	A	—	—	—	—	—
10	10	B*	—	—	—	—	—	—
	14	B*	—	—	—	—	—	—
	20	B	—	—	—	—	—	—
	30	C	—	—	—	—	—	—
	40	C	A	—	—	—	—	—
	70	C	B	A	—	—	—	—
12	12	B*	—	—	—	—	—	—
	18	B*	—	—	—	—	—	—
	24	C	A	—	—	—	—	—
	35	C	A	—	—	—	—	—
	50	D	B	—	—	—	—	—
	90	D	B	A	—	—	—	—
16	16	C*	A*	—	—	—	—	—
	30	D	B	—	—	—	—	—
	50	D	B	A	—	—	—	—
	80	D	C	B	—	—	—	—
	120	D	C	B	A	—	—	—
20	20	D	B	A	—	—	—	—
	40	D	B	A	—	—	—	—
	60	D	C	B	A	—	—	—
	100	D	C	B	B	—	—	—
	140	D	C	B	B	A	—	—
30	30	E	C	B	A	—	—	—
	60	E	D	B	B	A	—	—
	100	E	D	C	B	A	—	—
	140	E	D	D	B	B	A	A
40	40	E	D	C	B	A	—	—
	80	E	D	D	B	B	—	—
	140	E	D	D	C	B	B	B
60	60	F	E	D	C	B	B	B
	100	F	E	D	C	C	B	B
	200	F	E	E	D	D	C	C
80	80	F	E	E	D	C	C	B
	140	F	E	E	D	D	D	C
100	100	F	F	E	D	D	C	C
	200	F	F	E	E	D	D	D
120	120	F	F	E	E	D	D	D
	200	F	F	F	E	E	D	D

* *The Room Indices marked with an asterisk should be advanced two steps when only a single lighting fitting is employed; for example: "A" will be altered to "C".*

Note:—It is the *proportions* of the room which affect the Room Index, not its *size*. If therefore the dimensions of any given room do not correspond with those shown somewhere in the Table, divide each dimension by an equal amount, e.g. a room 30 ft. × 90 ft. with fittings mounted 15 ft. above the working plane has the same Room Index (C) as a room 20 ft. × 60 ft. with a 10 ft. mounting height.

The Coefficient of Utilisation may then be found from Table V.

TABLE V

COEFFICIENT OF UTILISATION

(for single-lamp trough fittings—direct lighting only)

Ceiling.	*Fairly light* (40 % *R.F.*)		*Very light* (70 % *R.F.*)	
Walls.	*Fairly dark.* 25 % *R.F.*	*Light.* 50 % *R.F.*	*Fairly dark.* 25% *R.F.*	*Light* 50 % *R.F.*
Room Index.	*Coefficient of Utilisation.*			
A	·39	·43	·39	·44
B	·43	·46	·43	·47
C	·50	·53	·50	·54
D	·55	·58	·56	·59
E	·60	·64	·61	·65
F	·65	·68	·66	·70

Area Served by Each Fitting

The area to be served by each fitting may then be found from the following formula:—

$$A = \frac{L \times C.U.}{FC \times D}$$

where A = area per fitting in sq. ft.
L = lumen output of lamp (assumed to be 2400 lumens in the case of the 80 watt colour "A" lamp, see page 42).
CU = Coefficient of Utilisation found from Table IV.
FC = Footcandle illumination required in service.
D = Depreciation factor (usually taken as 1·43).

Fittings should then be spaced so that each serves the area found from the above formula, e.g. if A = 80 sq. ft. then fittings could be spaced 8 ft. × 10 ft. or approximately 9 ft. each way, according to the facilities on site, provided that such spacing is not greater than 1½ times the lamp height above the working plane. Should the spacing thus indicated be unreasonably close, it will be necessary to use multi-lamp fittings and to follow the manufacturers' advice in making allowance for any loss of efficiency such grouping of lamps may entail.

Local Lighting by Trough Fittings

As large numbers of fluorescent lamps in trough fittings are being used to an increasing extent for local or localised lighting purposes, it will be useful to give Table 6 showing the approximate illumination values etc. to be expected from typical installations of this nature. It should be borne in mind that the figures should not be treated as exact values, since they must depend to a slight extent on the characteristics of the particular make of reflector(s) in question; but they are based on the average results from typical good-quality products and may be taken as approximately correct for single-lamp trough reflectors of any reputable make.

It should further be noted that the illumination values given are *service* values, i.e. allowance has been made both for the initial drop in efficiency of the lamp, and also for the 30% loss of efficiency of the fitting as a whole on account of further lamp depreciation, and because of the dust and dirt which collects in the interval between regular and reasonably frequent cleaning by the maintenance staff. The illumination obtained from a brand-new installation will of course be considerably higher than the values shown.

TABLE VI LOCAL ILLUMINATION VALUES

Single Fitting

Lamp height above working plane.	*Approximate area over which diversity of illumination does not exceed 2 : 1.*	*Footcandles illumination.*		
		Max.	*Min.*	*Mean.*
2 ft.	Ellipse 5 × 3 ft.	60	30	45
3 ft.	Ellipse 6 × 5 ft.	30	15	25
4 ft.	Circle 6 ft. dia.	20	10	15
5 ft.	Circle 7 ft. dia.	15	7	10

Single line of Fittings—illumination values on a bench 4ft. wide.

Lamp height above working plane.	*Spacing*	*Footcandles illumination.*			*Distance between lines.**
		Max.	*Min.*	*Mean.*	
3 ft.	6 ft.	34	18	26	10 ft.
4 ft.	6 ft.	24	16	20	12 ft.
4 ft.	8 ft.	20	12	16	11 ft.
5 ft.	6 ft.	18	14	16	13 ft.
5 ft.	8 ft.	14	10	12	12 ft.
5 ft.	10 ft.	14	7	10	11 ft.

**This column shows the maximum distance apart at which lines of fittings should be spaced if the illumination is nowhere to fall below the statutory minimum of 6 footcandles (Factories [Standards of Lighting] Regulations, 1941).*

A continuous line of fittings mounted centrally 2 ft. above a bench 2 ft. wide will give an average illumination of the order of 50 footcandles.

Performance of Decorative Fittings

The performance of fittings of a more decorative nature, such as are suitable for shops, offices, restaurants, hotels and domestic interiors must vary widely with the style of fitting and the materials used. Until such time as a variety of fittings become available it is impossible to do more than indicate what results are likely to be obtained from various types.

From time to time the General Electric Co. (of America) have published installation data showing the number of fittings, and lamps per fitting, required to provide a given illumination in rooms of varying proportions. For this purpose different styles of fitting have been grouped together when they have approximately equal performance. It would serve no useful purpose to give American installation figures here, since our lamp ratings may differ from theirs; but the lumen output of their lamps has been used as a basis for constructing Table VII.

American type fittings are grouped as follows:—

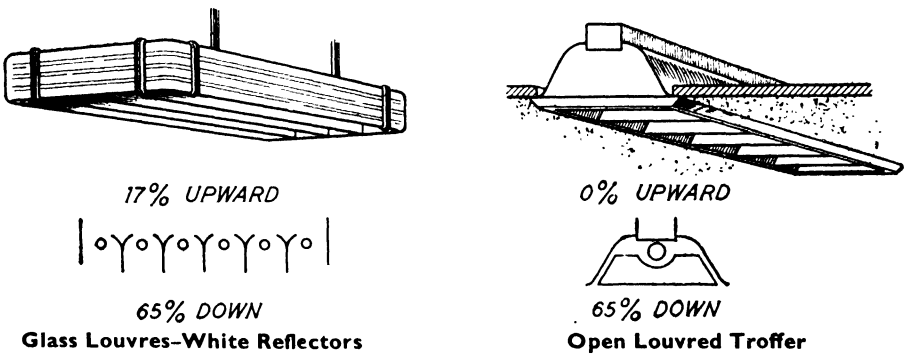


Fig. 27 (a).—FITTINGS CLASSIFICATION—*Group* "*A*".

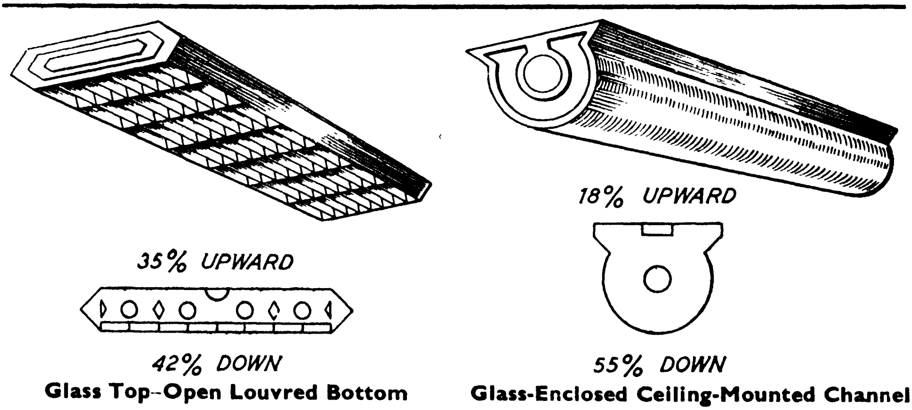


Fig. 27 (b).—FITTINGS CLASSIFICATION—*Group* "*B*".

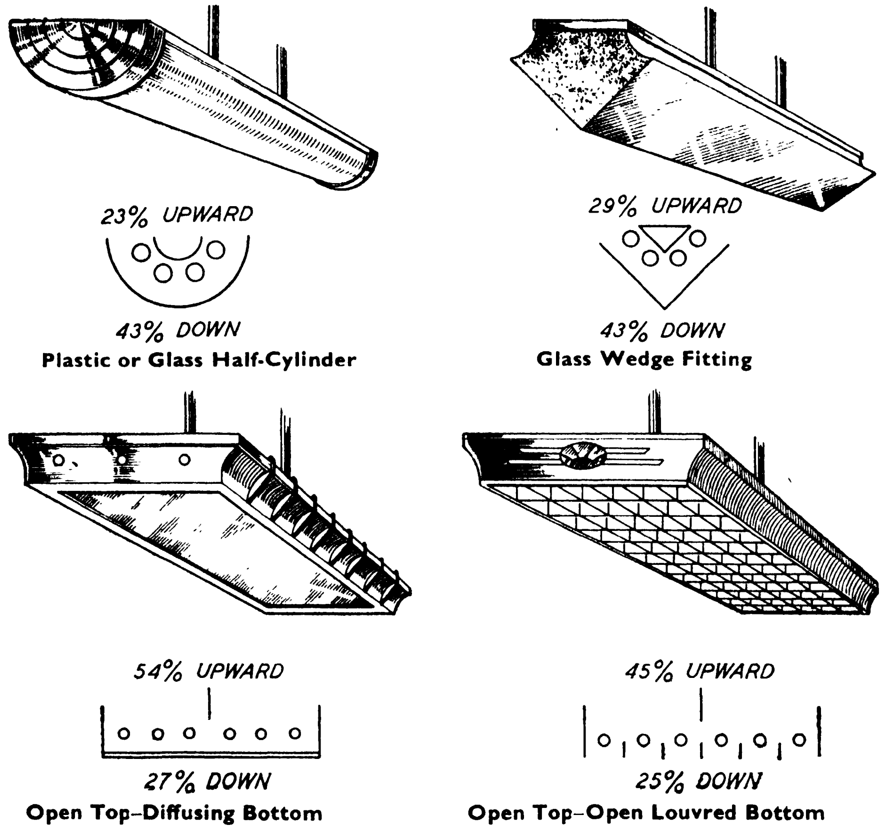


Fig. 27 (c).—FITTINGS CLASSIFICATION *Group* "*C*."

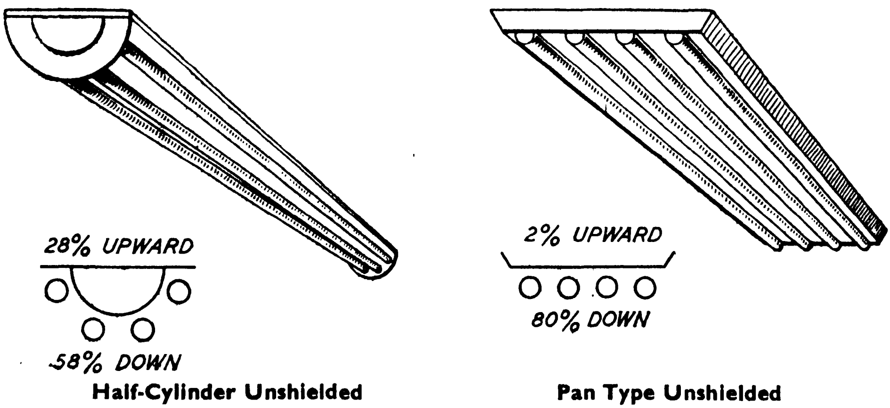


Fig. 27 (d).—FITTINGS CLASSIFICATION—*Group* "*D*."

Room proportions are classified as follows:—

LARGE	MEDIUM	SMALL
Room width 4 times room height	Room width twice room height	Room width equal to room height

Decorations are classified broadly as:—

Light finish:—Reflection factor of ceiling 75% and wall 50%
Medium finish:— ,, ,, ,, ,, 50% ,, ,, 30%

TABLE VII

GENERAL ILLUMINATION DATA FOR FLUORESCENT LIGHTING FITTINGS

(1) *Group of Fitting* (*see figures 27* (a-d)).	(2) *Proportions of Room* (*see above*).	(3) *Watts* per 1,000 sq. ft. Floor Area, per one footcandle illumination.*		(4) *No. of Lamps* per 1,000 sq. ft. Floor Area for 20 footcandles illumination.*	
		Light Finish.	*Dark Finish.*	*Light Finish.*	*Dark Finish.*
A	Large ..	72	76	18	19
	Medium ..	88	92	22	23
	Small ..	108	112	27	28
B	Large ..	84	100	21	25
	Medium ..	100	120	25	30
	Small ..	132	156	33	39
C	Large ..	100	124	25	31
	Medium ..	120	152	30	38
	Small ..	156	200	39	50
D	Large ..	68	80	17	20
	Medium ..	80	100	20	25
	Small ..	105	135	26	34

* *Based on the 80 watt Colour "A" lamp running at 30 lumens per watt efficiency. For other lamps, multiply in inverse proportion to their efficiency, e.g., at 20 lumens per watt, multiply by* $\frac{30}{20} = 1{\cdot}5$.

Figures in columns (3) and (4) may be adjusted in proportion to the footcandles desired.

Table VII above does no more than enable one to calculate the total wattage or number of lamps required to produce a given number of footcandles over a given area, and it is then necessary to arrange the lamps so that all parts of the area shall be illuminated to approximately the same level. Though there may be a few exceptions, with the great majority of fittings the uniformity of lighting will be sufficiently good to make variation of illumination unnoticeable if the fittings are mounted at a distance apart (in each direction) not greater than 1½ times their height above the "working plane"—usually 2½ feet above the floor for tables and desks, and 3 feet above the floor for shop counters and show-cases, and for workbenches.

The mere fact that a fitting houses fluorescent instead of incandescent lamps does not alter the principles of illumination design. If the manufacturer's polar curves show that a fluorescent fitting has a light distribution identical with that of a typical incandescent fitting, then its

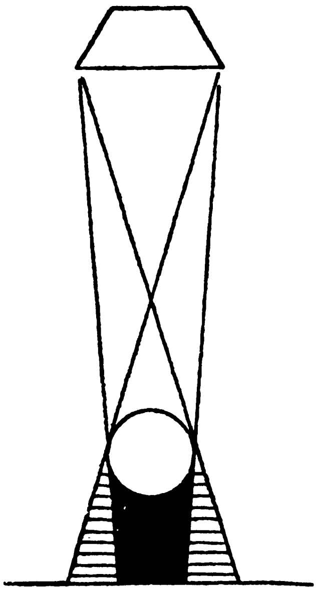


Fig. 28.—Umbral and Penumbral Shadows cast by an Object.

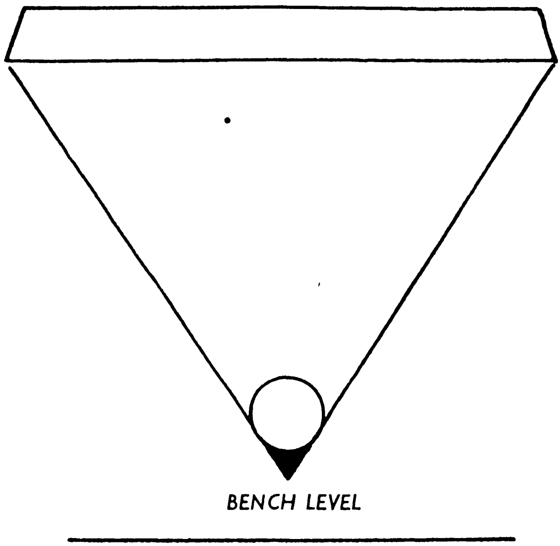


Fig. 29.—A small or medium sized object casts very little shadow provided that its length lies across the line of the lamp.

(Diagram shows end view of shadow-casting cylinder.)

coefficient of utilisation will also be the same, and the well-known "Lumen method" of design may be employed. But until the trend of fluorescent fittings in this country becomes clear, and until complete data about each type is published, Table VII may be a useful indication of the results to be expected from various general classes of fittings.

One important point about fluorescent lighting design should perhaps be emphasised, and that is that the designer of a fluorescent lighting scheme may have only one chance of planning correctly. In the case of lighting by incandescent lamps, should the result not come up to expectations the designer can sometimes put the matter right merely by substituting lamps one size larger or smaller than his faulty calculations indicated were necessary; but such a simple escape from trouble will seldom be possible with fluorescent lamps since different wattages of lamps will probably be of different length, and fluorescent fittings are hardly likely to be made adjustable to compensate for carelessness or ignorance on the part of the installation designer.

Shadows

The 80 watt fluorescent lamp is sometimes referred to as a shadowless source of light, but this may not be even approximately true if the lamp is not orientated correctly with regard to the workpiece or obstructions likely to cast shadows.

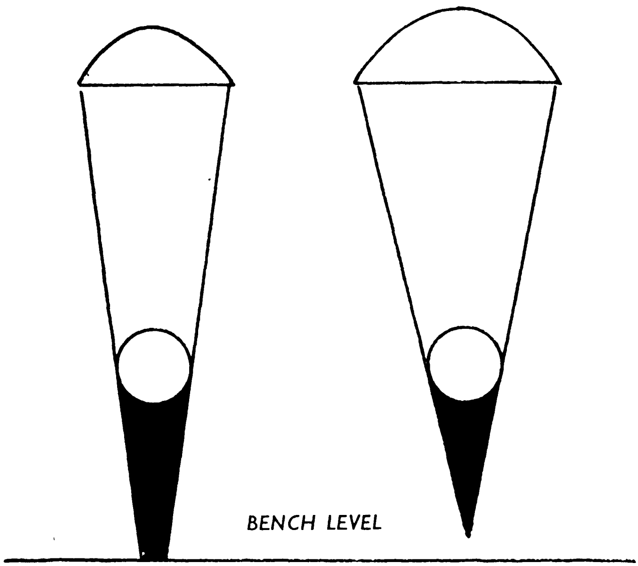


Fig. 30.—SHOWING HOW A WIDE FITTING CASTS LESS SHADOW THAN A NARROW ONE.

When any opaque object obstructs light there must necessarily be a certain amount of shadow varying in depth between complete darkness (umbra), through intermediate stages (penumbra) until positions of no shadow are reached (Figure 28). It is usually the business of the illuminating engineer to arrange the lighting in such a way that any shadow cast is faint, amounting to no more than a slight reduction of illumination.

The length of an 80 watt lamp and its associated reflector is so great in relation to the smaller dimension of such objects as a man's hand and arm, or of anything of such a size as to be held in a bench vice, that any such object *lying across the line of the lamp* will generally cast no appreciable shadow (figure 29). But if such objects lie parallel to the line of the lamp they may sometimes cast shadows quite dense enough to interfere with the work.

At Mounting heights less than 3 ft. above the bench a wide reflector may be preferable as the area of complete shadow cast by a parallel obstruction will be less than with a narrow one (figure 30). At these mounting

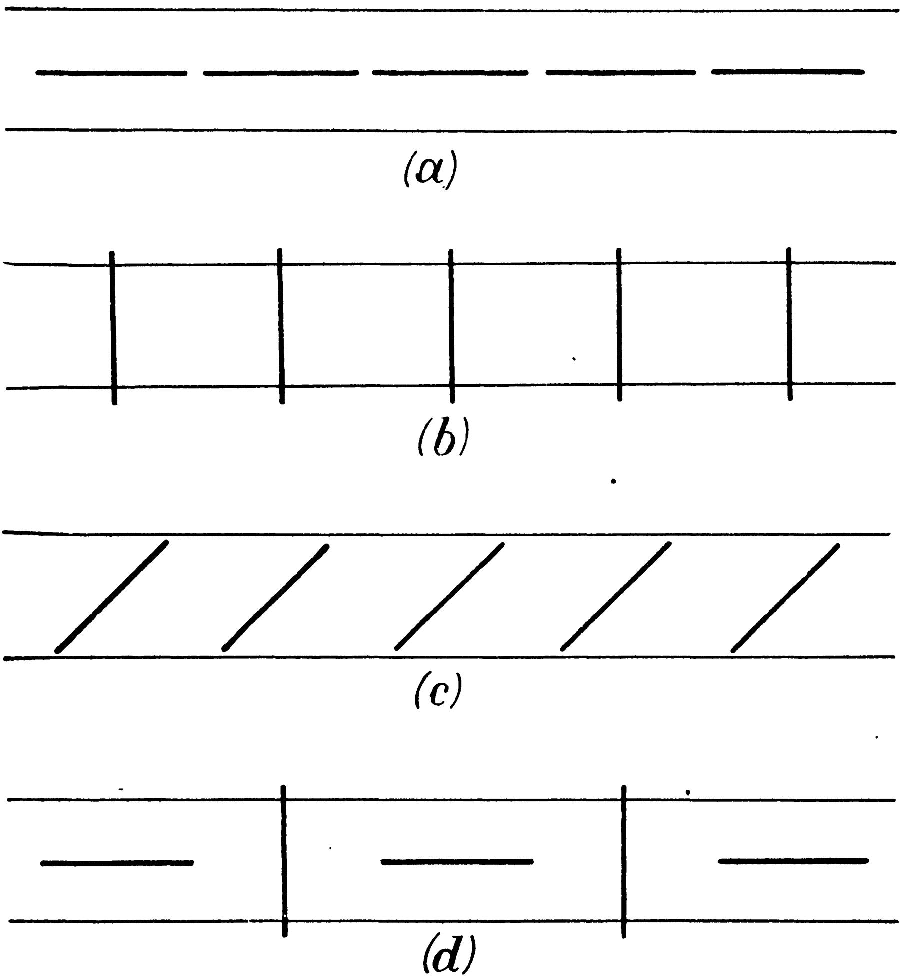


Fig. 31.—Four Methods of Mounting Fluorescent Lamps in Trough Fittings above a Bench 4 ft. wide. (Lamps only are shown.)

(a) Continuous trough over C/L. of bench. This method wastes least light at very low mounting heights.
(b) Equally as effective as (a) at mounting heights of about 4 ft. and more above the bench. Gives less shadow than (a) from objects lying parallel with bench.
(c) Diagonal scheme giving most light from the left front of workers on either side of bench.
(d) Combination of (a) and (b). Gives very little shadow whatever the orientation of obstructions.

heights the polar curve of light distribution from the fitting is elliptical, being elongated in the direction of the major lamp axis; if used for illuminating a narrow bench the reflectors will therefore usually be mounted in a continuous line parallel with the bench, in order not to waste too much light beyond its confines. With this arrangement there will be no appreciable shadow cast by operatives' arms reaching towards the centre of the bench, but if the arrangement of the work necessitates objects lying parallel to the lamps, wide reflectors are advised.

At mounting heights between 3 ft. and 5 ft. above the bench the polar curve of light distribution has become approximately circular and it is therefore immaterial, from the standpoint of waste light, whether fittings are mounted parallel with the bench, or across it, or diagonally (figure 31). The same rule, however, still applies: the major axis of the lamp should be placed at right angles to the line of probable obstructions. Where these are likely to lie in a variety of directions it may be wise to employ the mixed arrangement (d), while if most of the light is required from the left a diagonal arrangement such as (c) may be desirable.

It should be noted that arrangement (a) does not permit of closer lamp spacing than about 6 ft. from centre to centre, while the effective spacing in (d) may be reduced to slightly over 3 ft. With arrangements (b) and (c) the lamps may be spaced as closely as may be desired to obtain unusually high values of illumination.

At mounting heights greater than 5 ft. above the bench the orientation of lamps becomes of less importance with increasing height, since any given point on the working plane is receiving light from an ever greater number of fittings each of which will tend to illuminate a shadow cast by another, and since the ratio of lamp length to mounting height becomes less. Though some slight advantage may be gained by careful orientation of the lamps, fittings more than, say, 7 ft. above bench level are usually installed either in the most convenient way from the point of view of suspension, or with special regard being paid to the appearance of the finished installation.

Chapter VII

APPLICATIONS OF FLUORESCENT LAMPS

1—FACTORIES

ADEQUATE lighting is part of the machinery of production, and unless the method of lighting is selected to suit the specific needs of the particular process being carried out in any one shop, in just the same way as machine tools are selected, it will not be possible for either the workpeople or the machines and tools they operate to work at their optimum efficiency. Choice of one method of lighting as against another should of course be based on expected results; but quality, quantity and costs of production depend on the physiological and psychological influence of lighting on the operatives, and the reason for one type of light being better than another will not be clear unless the nature of the seeing task is understood.

In general, from the physiological standpoint, lighting in a factory has to enable an operative to see detail—sometimes in motion and sometimes of a minute order of magnitude—so that his brain receives guidance and can then direct the necessary movements of his limbs in order to carry out the operation. Clearly, the act of seeing is an essential prerequisite in the performance of almost all industrial work, and unless seeing is both rapid and accurate, the performance of the operative is bound to suffer. Lighting of a nature that causes difficulty in seeing will also cause fatigue, still further reducing the efficiency of the human machine.

From the psychological standpoint, lighting should be of such a nature that it avoids mental irritation of any kind, for it is acknowledged that depression and worry, even though caused only by trifles, are adverse factors of major importance in industry.

For a lighting installation to be adequate for its purpose it must provide sufficient light of the right quality, with the required depth of shadow, and at an economic cost. These, and allied factors, are discussed in the following pages.

Quantity of Light Required

If the cost of lighting be considered in its true relation to other costs, and if there be no artificial restrictions to the level of illumination, such as may be required in wartime in the interests of economy or conservation of materials, then the limit to which illumination can be usefully raised

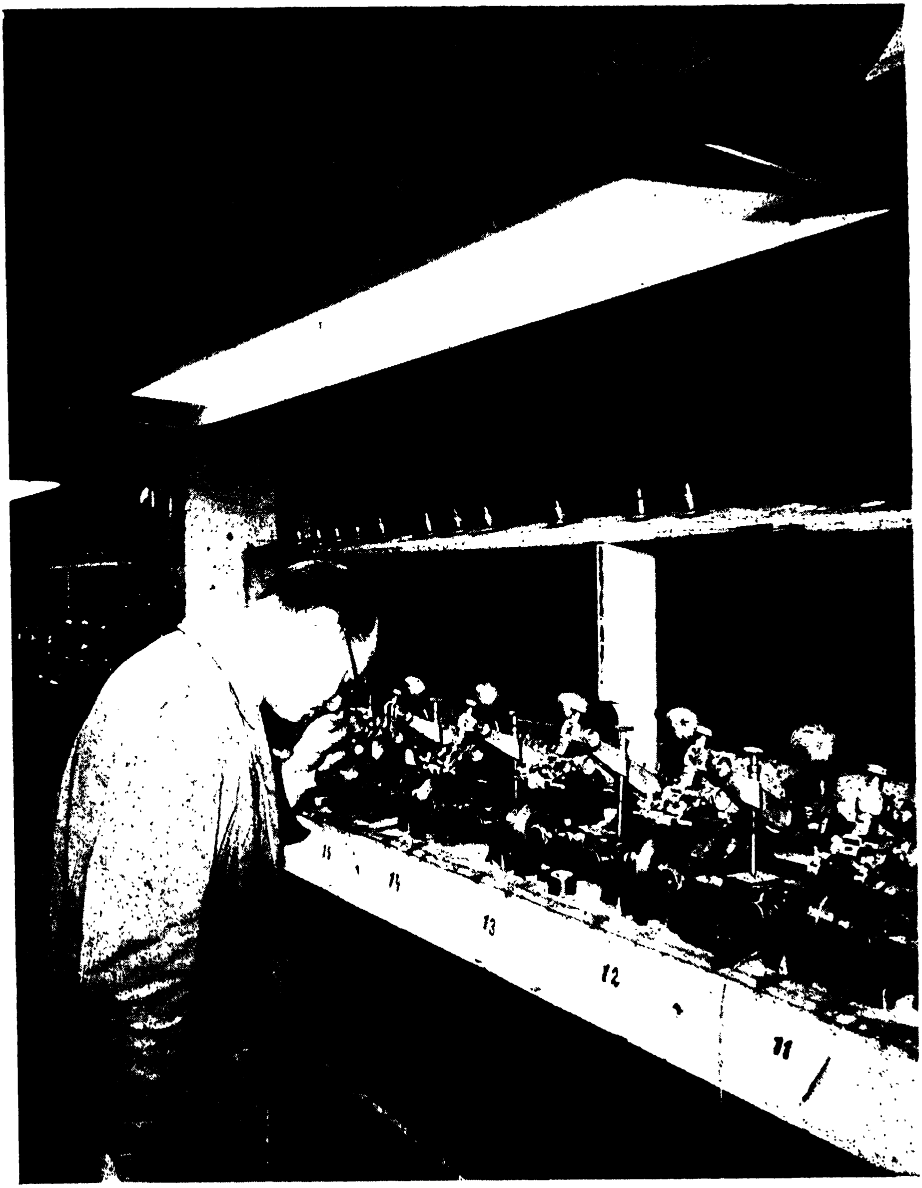


Fig. 32.—DIAMOND SAWS.

Errors here could be very expensive, and even with the best lighting, magnifying glasses may be necessary for very fine work such as this.

lies a long way above that found in normal industrial interiors today.

The ideal at which to aim is probably a brightness* of the objects within view approximately equal to their brightness under unobstructed light from a north sky, i.e. out-of-doors on a clear day and shaded from the sun. Under these conditions there may be an illumination of anything between a few hundred and a thousand footcandles, and these are the natural lighting conditions to which human eyes have become attuned by many centuries of development; therefore they may reasonably be expected to work at their best under such conditions, and scientific investigation† shows that, in general, that is so.

Reduction of illumination to a level very materially below the optimum for the eyes must inevitably impair their efficiency to some extent, though not in linear proportion since the relation between illumination and visual acuity appears to be a logarithmic one, at least over a very wide range of illumination levels, i.e. reduction from 100 to 10 footcandles illumination reduces the ability to discriminate detail to about the same extent as a reduction from 10 to 1 footcandle. Or, to put it another way, an increase of a few footcandles from a low level of illumination effects a greater improvement in seeing than the same increase at a higher illumination level; an equal *proportionate* increase will, in general, be required to affect seeing to the same extent.

Where the object which has to be seen is in motion, speed of vision generally becomes at least as important as ability to discriminate detail. Seeing is not an instantaneous process: it takes a definite interval of time for the eye to perceive an object and to pass a suitable message to the brain. The time interval is shortened by a high level of illumination and vice versa, in the same way as the shutter speed of a camera may be varied according to the lighting conditions. Given suitable conditions "the quickness of the hand deceives the eye"; but under factory conditions the quickness of the eye may be the deciding factor, controlling the success or failure of some important process.

In any process, whether operated by hand or machine, the psychology of the worker plays an important part. Figures are not needed to prove that a worker in bright and cheerful surroundings feels more fit and more on top of his job than one in a dark, gloomy shop. Probably it is true that a man working under conditions which he thinks are bad for his health will actually suffer in health, although in fact for no other reason than his depressed frame of mind.

The above considerations clearly indicate that the quantity of light strictly necessary for the proper performance of any process must depend largely on the fineness and intricacy of the work. There must be some

* *Brightness* . . . The brightness of an object should not be confused with the *illumination* it receives. Brightness is a measure of the light the object reflects, and is equal to Illumination × Reflection Factor.

† R. J. Lythgoe . . . The Measurement of Visual Acuity (Special Report No. 173, Medical Research Council, 1932).

Fig. 33.—Good Examples of Fluorescent Lighting in an Engraving Works, for which High Intensity and Freedom from Shadow is always desirable.

minimum level of illumination for even the roughest and simplest operation since accidents, so often caused directly or indirectly by bad lighting, have to be avoided, and the morale of the workers has to be maintained. Six footcandles in working areas, measured on a horizontal plane three feet above the floor, is the minimum requirement of the Factories (Standards of Lighting) Regulations 1941; and although this particular requirement was introduced in wartime it is equally justifiable in peace, representing as it does the lowest level of illumination which is tolerable for any length of time under factory conditions.

For work of other than the roughest grade, however, more light is justified. Work cannot be done to fine limits unless fine detail can be accurately seen and gauged, and the level of illumination generally accepted as adequate is that indicated in the Code of Recommended Values of Illumination sponsored by the Illuminating Engineering Society, the Code being based partly on theoretical study of the illumination required for specific tasks, and partly on representative good modern practice which, of course, takes account also of the economics of the case.

Provided that sufficient wattage is employed, any kind of lamp can be used, if desired, to provide a given level of illumination, and generally the choice of lamp type should be settled by consideration of how the *quality* of the light each can provide will suit the process it is intended to serve. Economics must, however, be considered, though too often a particular system is chosen merely because it happens to be the cheapest, without due regard being given to the poor effect it may have on factory output.

There are instances where fluorescent lighting may be justified on account of its high efficiency alone. Occasions arise in which it is necessary to convert the whole or part of a factory to produce a finer grade of article, for which the existing filament lighting would be insufficient. Should the existing installation be already loaded to capacity, any increase in load would entail the installation of another system parallel with the existing one, or else complete rewiring; in both cases a good deal of work and material is involved. Replacement of existing filament lighting by self-contained fluorescent lamp fittings wired to the same outlets would entail no alteration whatever to the installation, and approximately twice the illumination would be received, total wattage remaining no higher than before.

Quality of Light

Light of the highest quality may be described as a light which is no handicap whatever to the operative in the performance of his job. Perfection being unattainable, the best the lighting industry can do is to aim at the provision of an installation which hinders as little as possible, and this involves the avoidance of objectionable features which may be

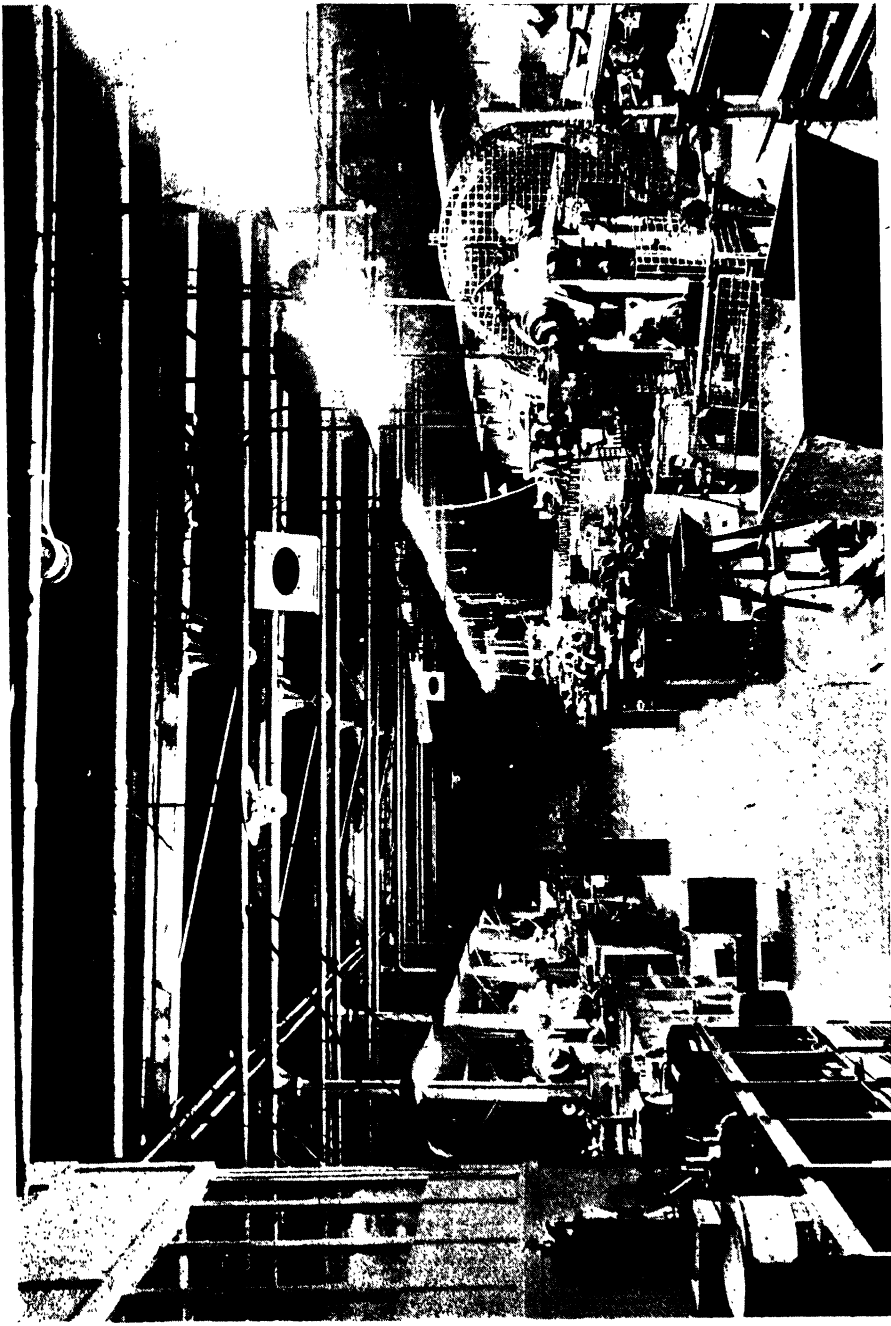


Fig. 34.—Typical Machine-shop Lighted to an Average of 15 Footcandles. Mounting Height 8 ft. 6 in. from Floor.

recognised by the operatives, or may not. In other words, factors of which the worker is unaware, though in fact they may greatly affect his working efficiency, must be avoided, as well as those factors which have an obvious and direct effect on ability to see the work in hand, and therefore on ability to get the work done.

Physiological Effects of Lighting Faults

Direct Glare

Improvements in electric lamp performance during the last forty years or so have not generally been accompanied by recognition by users of the need to modify old-fashioned lighting practice. The shallow conical enamelled shade (Chinaman's hat) may have been of some use above a carbon lamp since, if clean, it did at least re-direct some of the light which would otherwise have passed upwards. So limited was the light output of carbon lamps that some arrangement of this kind was obviously desirable.

The introduction of gasfilled lamps, however, should have made it quite evident that the function of a shade or reflector is not only to re-direct the light where it is required, but also to prevent direct view of the brilliant light source or of its reflection in glossy work surfaces. Unfortunately it has not done so. The most obvious fault in present-day industrial lighting, apart from insufficiency, is the direct glare of inadequately shaded or completely unshaded lamps hung near the normal line of sight, where their paralysing effect on vision makes it impossible for the eye to use all the illumination available.

In factories normally working more than 48 hours a week, or in shifts, regulations* now require, in effect, that fittings hung less than 16 ft. from the floor shall either cut off the direct light from the lamp at an angle at least 20° below the horizontal, or shall have a brightness of less than 10 candles per square inch. Installations of filament or discharge lamps complying with this requirement are reasonably free from direct glare, provided that operatives do not look upward at an angle greater than 20° above the horizontal. This, however, they are certain to do occasionally whatever their job; whilst those employed on work at or about eye level, and those operating on the under-side or edges of horizontal surfaces such as aeroplane wings, must spend a considerable part of their time looking upward, and may thus be unable to avoid frequently looking at a brilliant light source, with all the well-known harmful after-effects.

The 80 watt colour "A" fluorescent lamp has a surface brightness of only about 3 candles per sq. in., and may therefore, according to the regulations, be used where and how it is desired (with the possible exception of local lighting, to which a further regulation applies, see

*Factories (Standards of Lighting) Regulations, 1941.

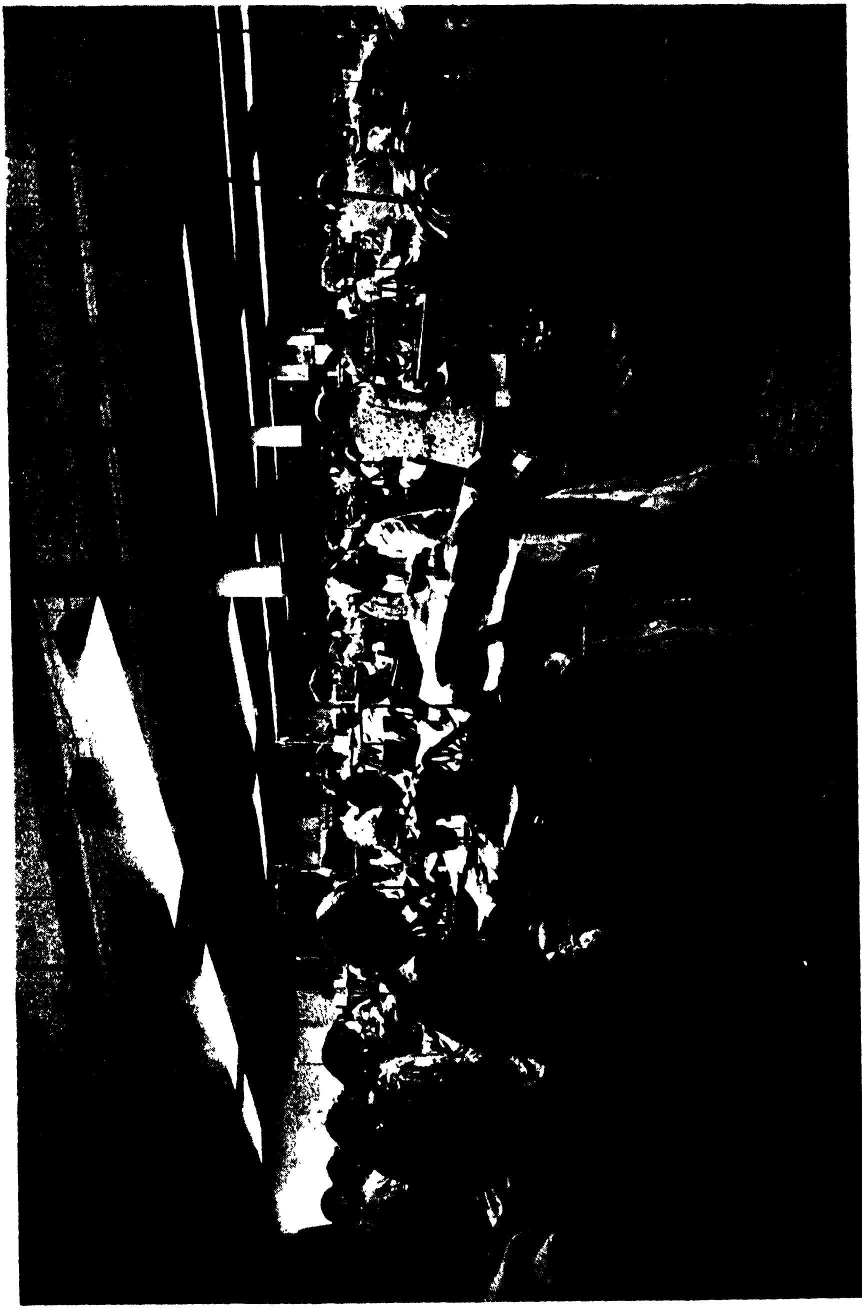


Fig. 35.—The Body of the Sewing-machine casts no shadow, and there is no Glitter from the Needles or Needle Plate.

page 92). The lamp brightness is, in fact, only slightly greater than that of a north sky, and is unlikely to give rise to any complaints of direct glare unless it is seen against a dark background.

Indirect Glare

This is the glitter caused by the reflection from glossy, smooth or wet surfaces of the brilliant light sources overhead, and in some instances the effect is so severe that the operative can only see to do his work with the greatest difficulty.

Chromium plate, tin plate, glass and enamel ware, and many other highly finished machined or polished surfaces are particularly troublesome in this respect, and the darker the colour of the material concerned the more disabling are the reflections. A worker faced with this difficulty will make an effort to overcome it by so placing himself on his work-piece that the reflection of a particular light source is not visible; but there are usually a number of other similar sources nearby, any of which will cause the same trouble. At best, therefore, reflected glare slows down production or interferes with vision to the detriment of the quality of product; at worst, it can cause an almost complete stoppage.

It is well known that the most effective cure for the trouble is to employ light sources which are of such low intrinsic brightness that they are incapable of producing dazzle or glitter either when viewed directly or when seen by reflection in mirror-like surfaces. With filament lamps or some sizes of ordinary discharge lamps a reduction of brightness may in some cases be secured by using standard fittings of the diffusing type, but considerations of mechanical strength and cost limit the size of the fittings, which must therefore still be moderately bright, so that they effect only a partial cure. Tubular fluorescent lamps, owing to the large surface area from which light is emitted, are less bright than the usual sizes of industrial diffusing fittings, and therefore give rise to less glitter on the work.

Glitter from Curved Surfaces

Glitter is likely to be especially evident where shiny convex surfaces are concerned, since they tend to have the effect of concentrating the reflection of light sources into a small intensely bright pin-point or, in the case of a cylindrical surface, a streak. Metal bottle-caps and ball bearings, for instance, tend to show pin-points of light. Numberless cylindrical rods, bars, collars, etc. are used or manufactured in every machine shop. Very frequently the curved surface of the cylinder is marked in a scale of degrees or numbers, as, for instance, a micrometer barrel. Figure 36 (a) shows how a general overhead system of dispersive type reflectors with filament lamps may cause a streak of light right across the scale, making it

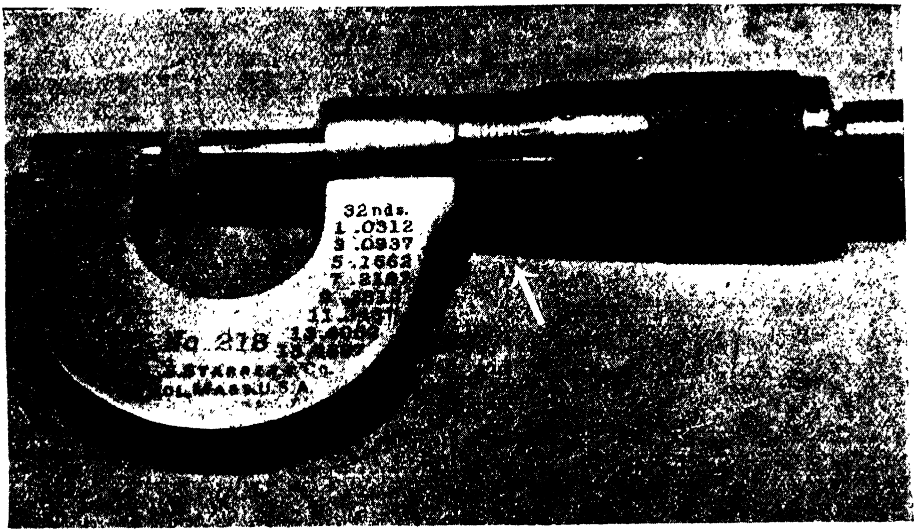


FIG. 36 (a).—MICROMETER SCALE LIGHTED BY GENERAL OVERHEAD SYSTEM OF GAS-FILLED LAMPS IN DISPERSIVE REFLECTORS.

(Note the streak of light making accurate and rapid reading of the scale very difficult.)

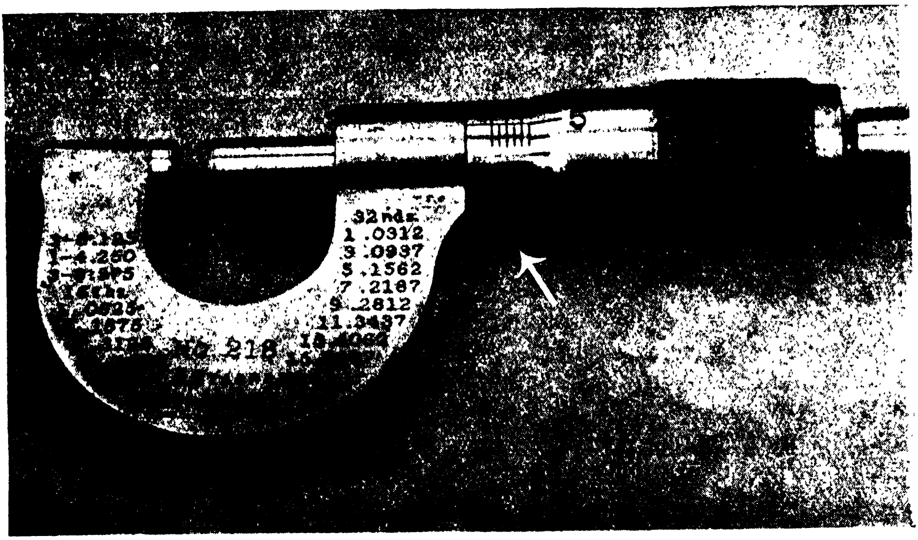


FIG. 36 (b).—VERY HIGHLY DIFFUSED LIGHTING MAKES THE SCALE CLEARLY VISIBLE.

(The quantity of illumination is the same as in the above illustration, but in this case indirect lighting has been used. See also Figs. 37 (a) and 37 (b).)

very difficult to read and therefore being a likely cause of very expensive errors.

Owing to the physical size and comparatively low brightness of the tubular fluorescent lamp, convex surfaces which reflect a pin-point of brilliant light from filament lamps now tend to reflect a streak of low brightness, i.e. the severity of the reflection, and with it the disability suffered by the operative, is reduced; and in the case of cylindrical surfaces it may even be possible, by careful arrangement of the lamp or work-piece, to eliminate the streak altogether.

Figure 36 (b) shows how the micrometer can appear when the length of the fluorescent tube is placed at right angles to the major axis of the cylinder. The very high degree of visibility of the scale has nothing to do with the *quantity* of light in this case, since the photographs (a) and (b) were taken at the same illumination level; but the high *quality* of light obviously enables accurate measurement to be made more quickly and with less risk of error.

It should be noted that totally indirect lighting, whereby the light from the lamps first strikes a white ceiling and is then reflected downwards to the work, is an almost certain cure for reflected glare or glitter: but very often the structure or type of ceiling precludes this method of lighting. Even if it is feasible, the wattage necessary will generally be about double that required by a direct lighting system giving equal illumination. Since the fluorescent lamp gives about double the light of a filament lamp of equal wattage, a direct fluorescent installation which may give light of a sufficiently high quality to replace an indirect filament lamp installation will save about 75% of the current used by the latter, whilst making it strictly unnecessary (though still desirable) to maintain the ceiling in such a state of light-coloured cleanliness.

Shadows

The formation of shadows from fluorescent tubular lamps is discussed generally on pages 75-77 but the subject is of particular importance to industry, especially if the present tendency towards the use of local lighting persists. With installations employing large numbers of lamps mounted more than, say, fourteen feet above the floor there is unlikely to be any seriously disabling shadow effect except where seeing conditions are specially severe, as in a drawing office. But when local lamps are mounted low over the work, with a supplementary general overhead scheme which only provides a very modest illumination, the local lights can cause very dense shadows if the area from which light is emitted is small, as is generally the case with filament lamps in local reflectors. Extension of the source of light to a length of several feet, as occurs in the fluorescent lamp, will evidently reduce the depth of shadow; if the lamp is carefully placed with relation to the work or machine it has to serve, it can usually practically eliminate shadow from important areas.

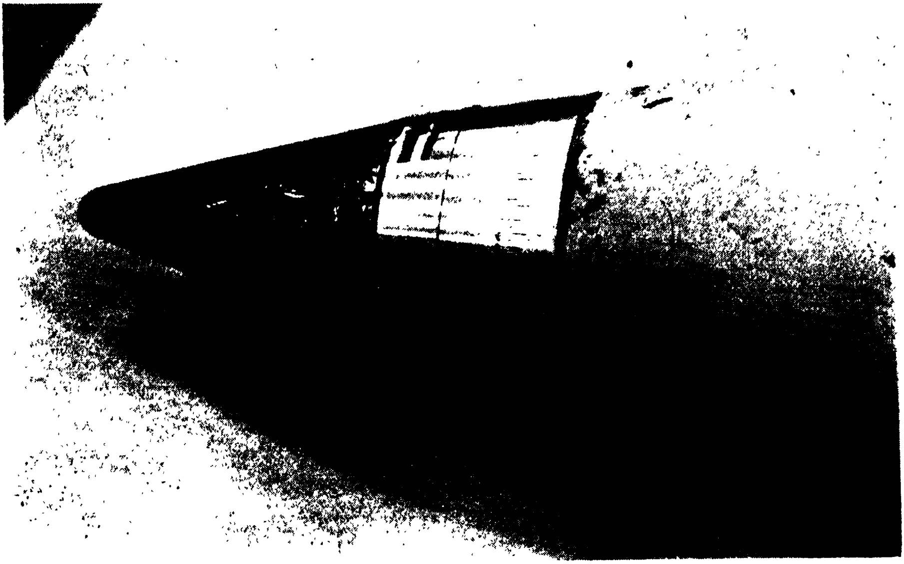


Fig. 37 (a).—GLITTER FROM UNPOLISHED BRASS.
(Each bright streak is caused by one gas-filled lamp in an open-type reflector.)

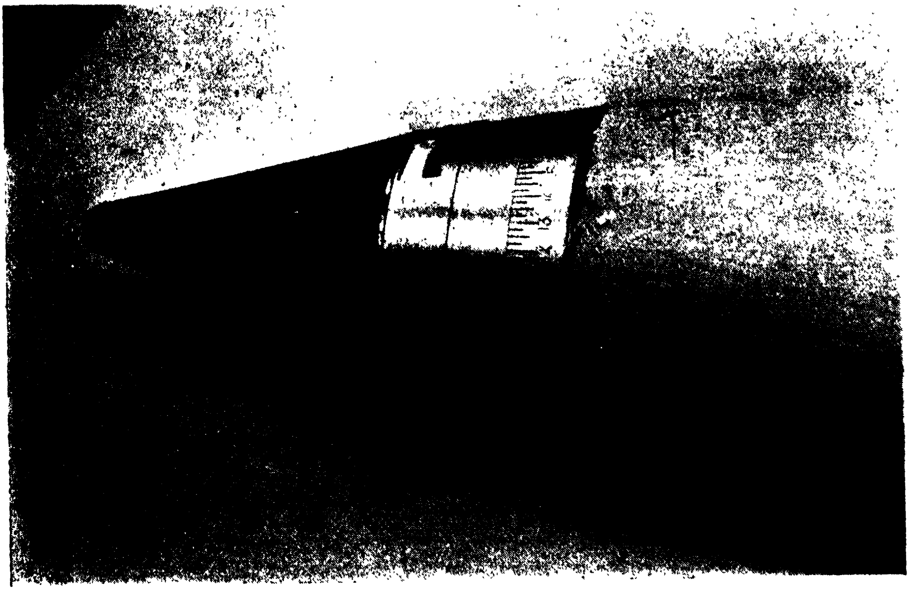


Fig. 37 (b).—GLITTER-FREE FLUORESCENT LIGHTING.
(The shell lies at right-angles to the major axis of the lamps. Note also the comparatively soft shadows.)

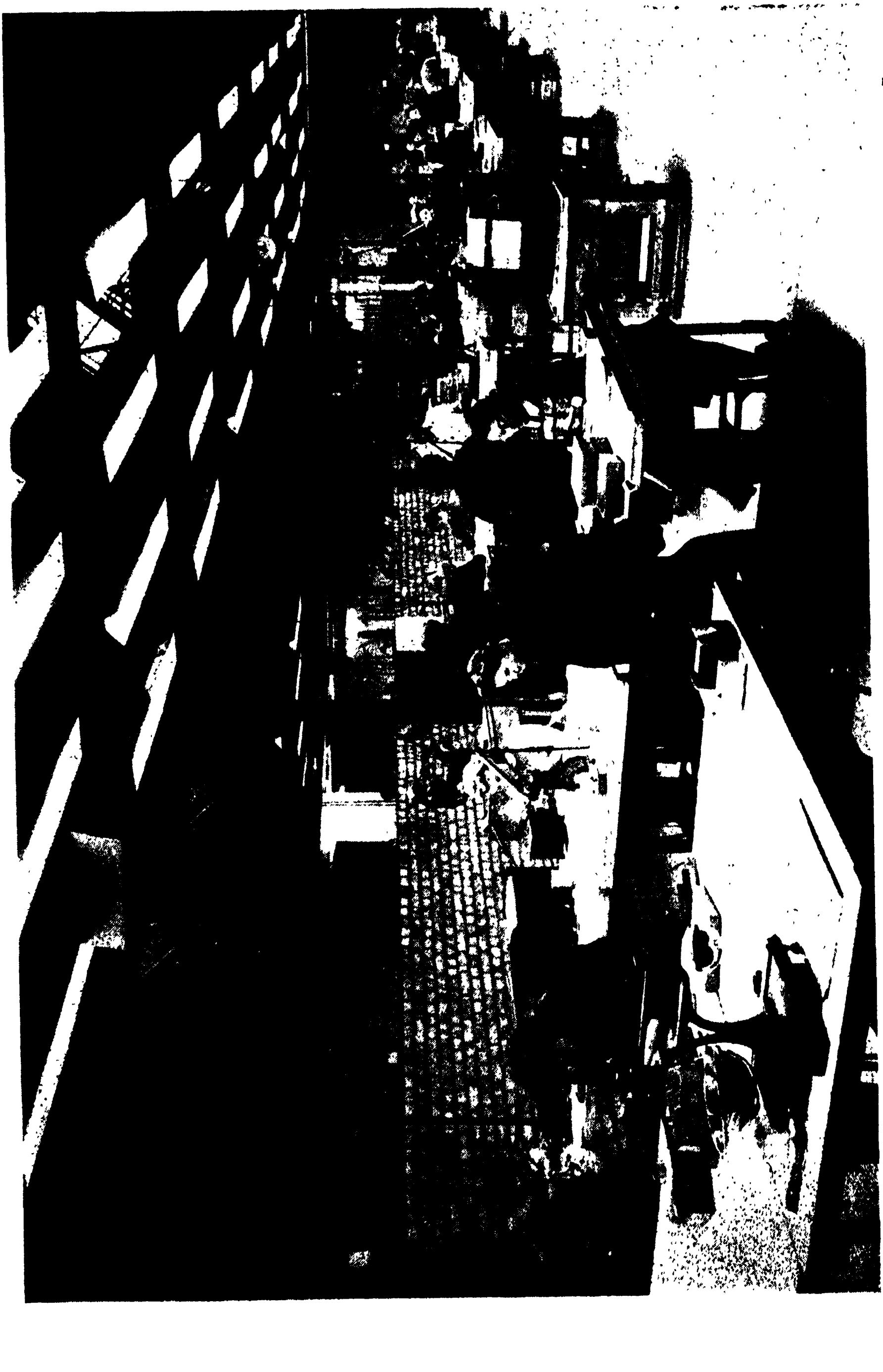


Fig. 38.—Radio Valve Assembly. Both the Glass and Bright Metal Parts would Glitter with Unsuitable Lighting

Fig. 39.—Drawing Office Lighting.
(Reflectors placed mutually at right-angles help to reduce shadow, especially in a small installation.)

The length of the fluorescent lamp is also an important factor in illuminating recesses. While there are, of course, numerous cases where a compact, adjustable local light is required for seeing into the interior of moulds, or into other places where the point of work is sunk below the general level of the work-piece or otherwise obscured, there are also many other situations where the high degree of diffusion from the long tube allows the light to penetrate inside the recess to such an extent as to render additional means of lighting unnecessary.

In drawing offices in particular, where faint pencil lines have to be distinguished and glossy papers may be used, every effort should be made to provide seeing conditions that are as easy and comfortable as possible. Shadows cast by draughtsmen's instruments, though faint, are liable to be particularly troublesome, and constant adjustment of small local fittings hung over or attached to the boards is a nuisance. A localised system employing a fluorescent lamp and reflector for each individual board is unlikely to be entirely satisfactory for all draughtsmen in an office, as they do not generally agree among themselves as to the best placing of the lamps, and any change of staff might entail rearrangement of the lighting.

American practice tends more and more towards the use of continuous lines of fluorescent lamps from end to end, or from side to side, of an office interior; but where drawing office boards are nearly horizontal it is found that more satisfactory results are obtained by the lines of light being run at 45° from the front left to the right rear of the draughtsmen. By this means practically all shadow is eliminated in moderate-sized or large interiors.

Local Lighting

It is not within the scope of this book to discuss the relative merits of general overhead, or general overhead plus local lighting, but it should be recognised that local lighting by filament lamps in small reflectors is a frequent source of direct glare or glitter. Also, by this means a relatively high illumination is confined to a small area, and the tool point or other object of immediate interest is seen against a general background of very much lower brightness.

R. J. Lythgoe* has found that visual acuity at a given level of illumination is at a maximum when the background brightness is approximately one quarter that of the object being viewed, while acuity is improved continuously by illumination levels up to well over 1000 footcandles. Such levels are not practicable for industrial use but 100 footcandles are easily produced locally by either filament or fluorescent lamps. The latter have the great advantage of spreading the light over a less restricted area, reducing excessive contrast between the brightness of

* The Measurement of Visual Acuity (Medical Research Council).

Fig. 40. A Drawing Office lit by Fluorescent Lamps in Continuous Trough Reflectors.

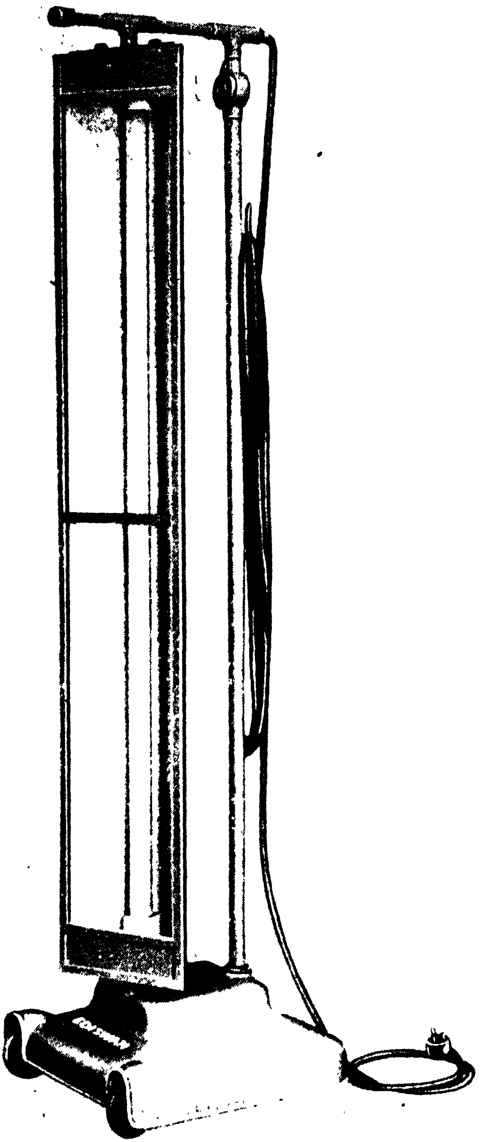


Fig. 41.—A Self-contained Mobile Fluorescent Lighting Unit which can be brought right up to the work, and may be used to give light sideways or upwards.

the object and its background and thus increasing acuity of vision; while at the same time the low brightness of the lamp reduces the possibility of direct glare from the lighting fitting or glitter from working surfaces.

The factory regulations* require, that "any local light shall be completely screened from the eyes of every person employed at a normal working place, or shall be so placed that no such person shall be exposed to glare therefrom".

"Glare" is not precisely defined, but the evident intention is to prevent the use of inadequately shaded incandescent lamps; and therefore one is reasonably safe in assuming that if a light source of sufficiently low brightness is used it will be unnecessary for screening to be complete. The various styles of fitting in which fluorescent lamps are being used for local lighting appear to meet with the approval of H.M. Inspectors of Factories so far as glare is concerned, while glitter is very markedly reduced.

Though many times larger than the caged incandescent lamp customarily used as a portable local light, it is by no means unusual for fluorescent lamps to be used for this purpose also. Self-contained mobile fittings are available which can be used either upright to illuminate

* Factories (Standards of Lighting) Regulations, 1941.

Fig. 42.—Single Reflectors butted to form Continuous Lines. For finer work lamps are sometimes used at a height of only 1 ft. above the bench.

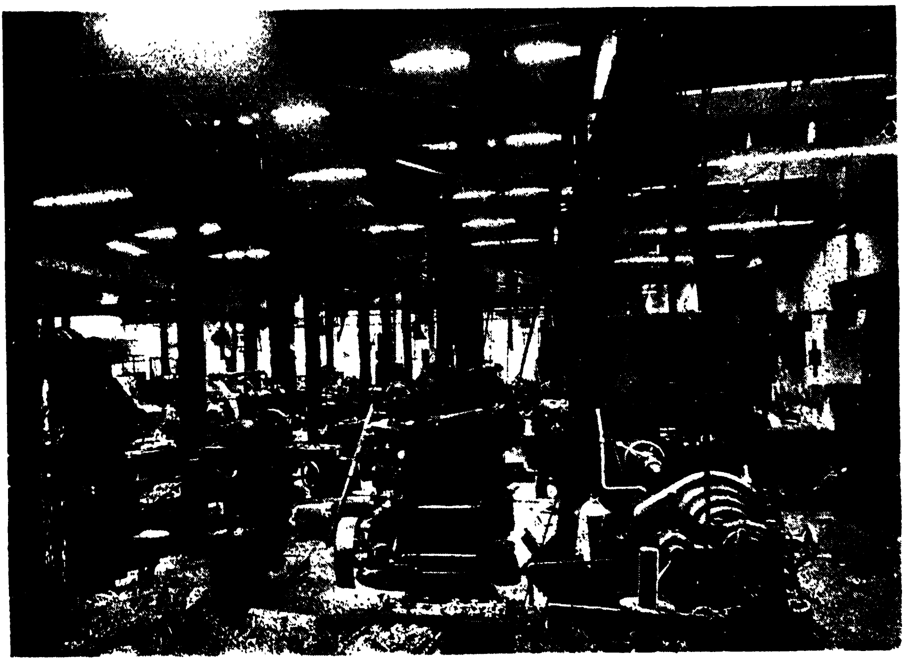


Fig. 43.—The Length of the 80 watt Fluorescent Lamp greatly reduces shadows cast by Shafts, Belts, and other Overhead Gear.

vertical surfaces, or laid on their backs to illuminate the under-side of bus chassis, aeroplane wings, etc.; and by this means the equivalent of about 150 watts of incandescent lamp light may be brought right up to the work with no harmful effects from glare, glitter or excessive heat.

The approximate performance of fluorescent lamps in trough fittings when mounted low over work benches is shown on page 70.

In those factories lit by incandescent lamps where machines are driven by belting from overhead shafts it is often a difficult matter to provide reasonably shadow-free lighting without using an uneconomically large number of small fittings. Fluorescent lamps and fittings can usually be arranged to fit easily between the shafts or belts, and the extended source of light will to a large extent eliminate shadows.

Temperature

It has long been recognised that too high or too low room temperatures both prevent attainment of full human working efficiency, and much attention is given to temperature control in modern factories (though the efficacy of any normal arrangements may of course be entirely ruined by blackout screening and other wartime necessities).

About 70% of the energy supplied to a clean incandescent lamp is radiated as heat; and allowing for absorption of some of this radiated heat by dirt on the lamp and reflector it is probable that each 200 watt lamp is responsible for radiating about 100 watts of heat downwards towards the operatives.

This additional heating may have some slight effect on the bodily comfort of the operatives even when the lamps are mounted high in a general lighting scheme; but with low mounting heights, such as are often encountered at inspection benches and other places where a high level of illumination is provided, a very considerable degree of discomfort can be experienced due to the heat beating down from overhead.

The temperature of the tube of a fluorescent lamp is comparatively low (about 120° F. in normal industrial reflectors) and therefore a large proportion of the heat generated by the lamp is dissipated by convection currents in the surrounding air, a lower proportion being radiated with the light. With an equal wattage of incandescent and fluorescent lamps, the latter radiate only about one half as much heat as the former: and when it is borne in mind that the efficiency of fluorescent lamps is approximately double that of incandescent lamps, it is evident that, for equal light output, the heat radiated is only about one quarter or one fifth as much. A distinct increase in the comfort of working conditions may thus be realised.

In certain industries, notably in food production and in gauge rooms, temperature control of the product is of great importance. The necessary control may be made very much easier by using fluorescent lamps and thus reducing a moderate but intermittent flow of heat from the lighting system.

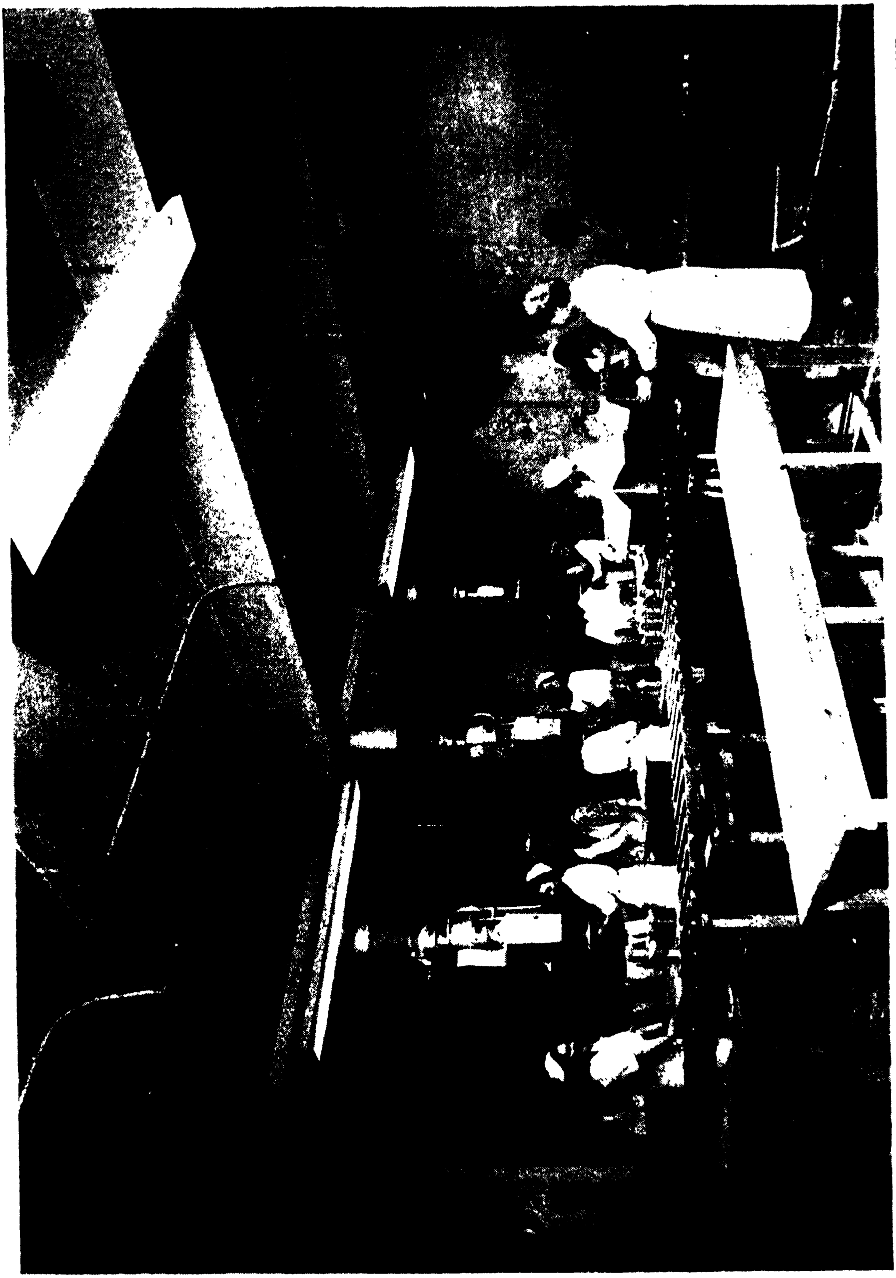


Fig. 44.—CLEANLINESS IS VITALLY IMPORTANT IN A FOOD FACTORY. A WELL-LIGHTED INTERIOR IS USUALLY ALSO A CLEAN ONE.

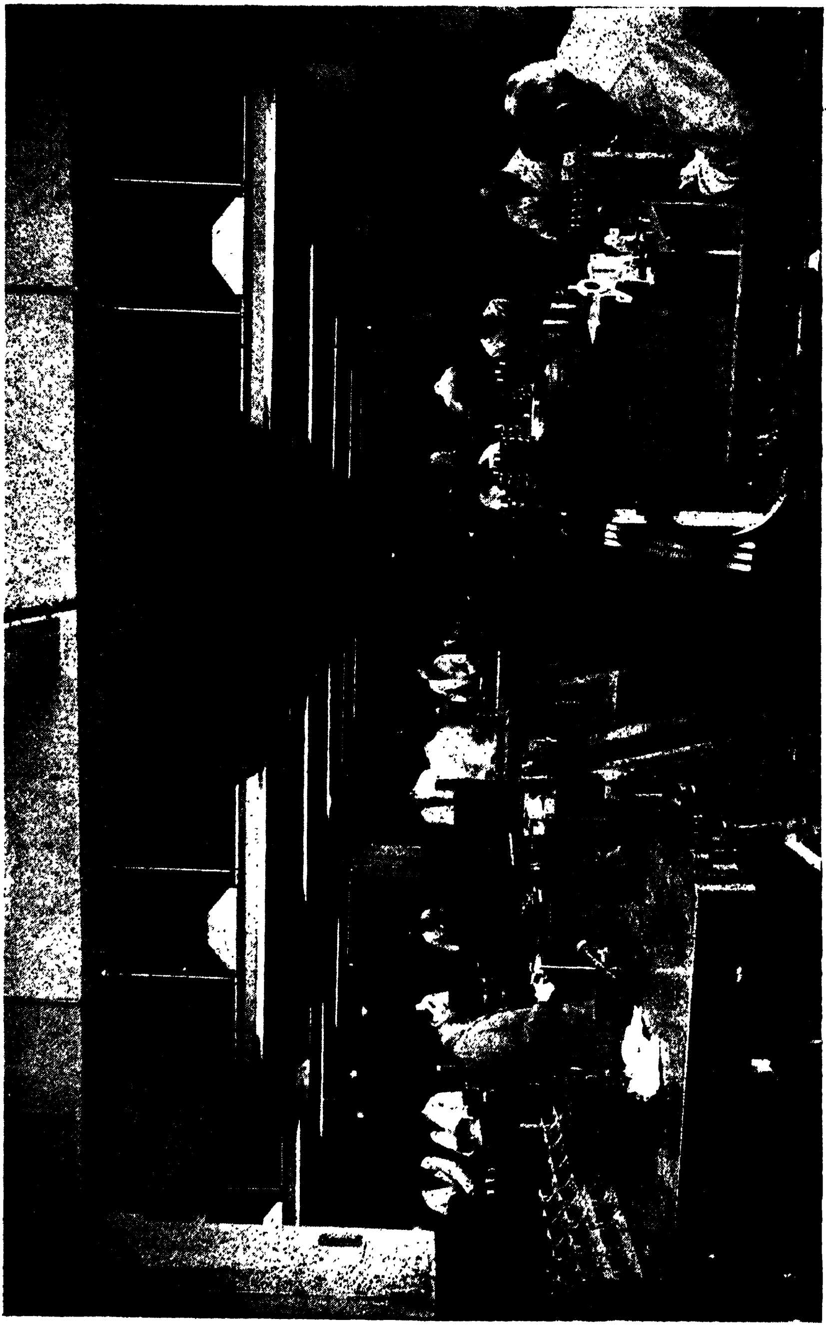


Fig. 45.—Gauge and View Room in which a Sufficiency of Light free from Glare, Glitter and Shadows is essential.
Fluorescent Lighting also facilitates temperature control owing to the small amount of heat radiated.

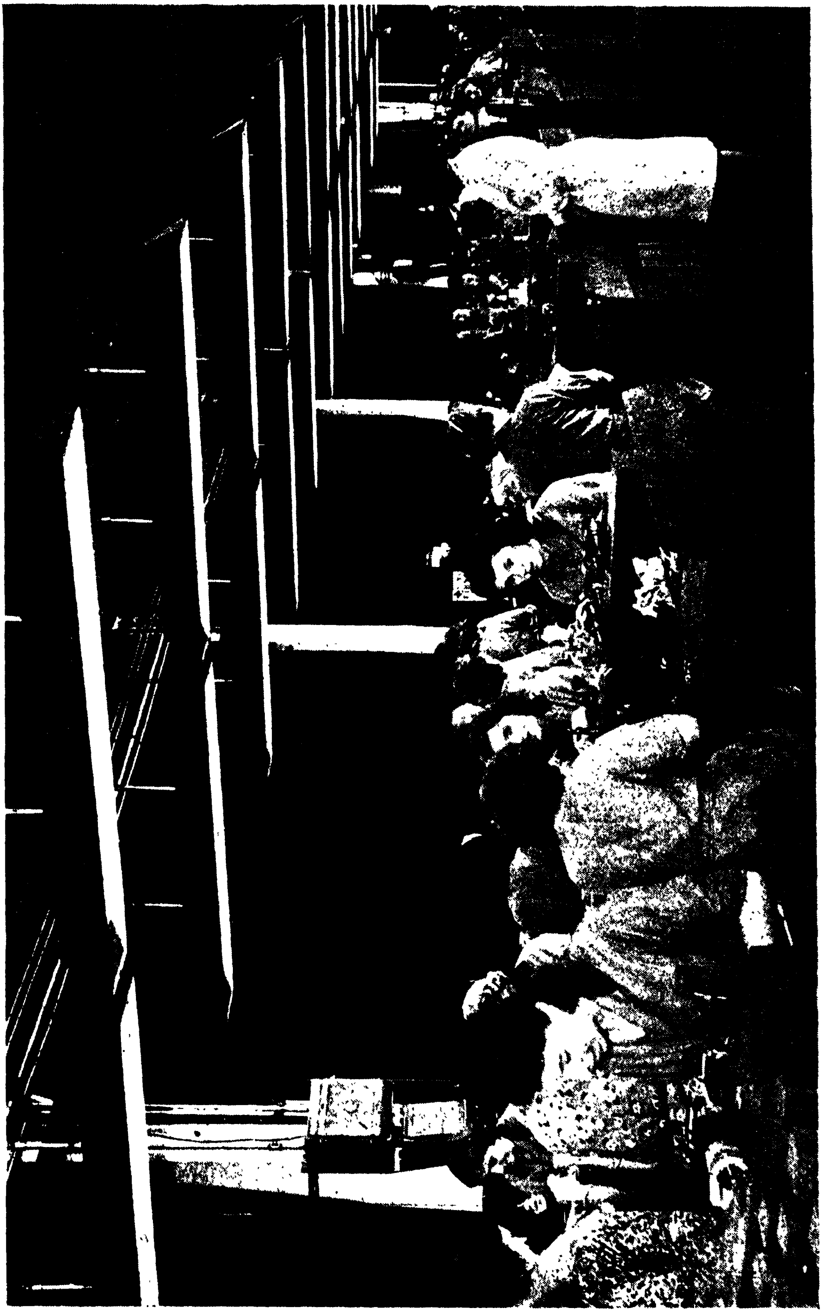


Fig. 46.—Fractional H.P. Motor Armature Winding.

Those working near the windows would benefit from the black-out curtains being light-coloured on the inside.

Psychological Effects of Lighting

It has been stated earlier that high quality lighting is of such a nature that it does not interfere with the worker in carrying out his job. Interference, however, may be due to the physical characteristics of the lighting being unsuitable (e.g. glare, shadows, etc.), or it may result from a feeling of dissatisfaction or discomfort the origin of which may not be immediately apparent.

Fig. 47.—NOTE HOW THE WHITEWASHED WALL IS RE-DIRECTING LIGHT WHICH WOULD BE ABSORBED AND LOST WERE THE WALL TO BE DARK OR DIRTY.

Wartime experience in blacked-out factories indicates clearly that workers do not appreciate artificial lighting conditions which differ too radically from those of natural daylight. It is therefore a wise plan as far as possible to disguise the artificiality of a lighting system—to provide an installation which does not constantly remind workers that it is only a second-class substitute for natural daylight. Artificial lighting is not necessarily either second-class or a substitute: it can actually be of greater utility and value than daylight, but only if attention is given to details of the lighting installation which may at first sight appear to be unimportant.

First there is the question of colour of light. Apart altogether from the obviously vital importance of the correct colour of light for some industries experience suggests that there is some value in providing the same colour of light by night as by day, particularly during the winter months when early morning or late afternoon daylight has to be supplemented by artificial light. We are used to daylight; we like it, and "a little of what you fancy does you good"; or in other words, colour "A" fluorescent lamps satisfy us in this respect, at least for industrial use.

The method of application of the lighting is also of much greater importance than was generally realised before the war. It is now recognised that an effective industrial lighting installation is not merely one which punches sufficient light downwards towards the work. Brightness of walls and ceiling, obtained by making them light-coloured and allowing some light to strike them, is not merely a refinement; it is a factor which may go a long way towards making the difference between a confined, prison-like atmosphere and one in which work can be performed in reasonable cheerfulness, with a consequent improvement in morale, and therefore also of work. Light which is directed towards the surroundings is by no means always wasted.

Reproducing Daylight Conditions

With a view to reproducing natural lighting conditions in factories with rooflights, fluorescent lamps have been mounted in the ridge, thus illuminating the sloping roof opposite the windows, and the effect has been to dispel the overhead gloom, or tunnel effect, which is such a depressing feature of many industrial installations where downward light only has been considered. An elaboration of this idea in blacked-out factories has been the provision of artificial laylights, that is, diffusing glass panels measuring several feet in each direction, with a few fluorescent lamps behind the glass to make it appear equally bright all over. The whole structure, in box shape, is mounted at or near the positions of blacked-out rooflights so that the colour, diffusion, and direction from which the light is coming are as nearly as possible the same as in peace-time daylight working. It could not be truly claimed that such an installation is highly *efficient* in the engineering sense, since a greater volume of light would be delivered to the working plane by other more orthodox methods; but nevertheless it has been proved to be *effective* in providing that quality of lighting which not only enables operatives to work better, but also puts them into a suitable frame of mind to do so.

It may be that we in this country are a trifle slow in adopting new ideas, or even in admitting the value of them. The majority of factory executives here would need much persuasion to install lighting giving an illumination of 40-50 footcandles, which the high-speed rearmament drive has made fairly common in the U.S.A., but the time will come when such installations will not be uncommon over here. Large numbers of lamps will be needed, but not, it is to be hoped, each in a separate fitting. Continuous troughs which can be built up to any desired length are available, and they make a far more workmanlike job than individual

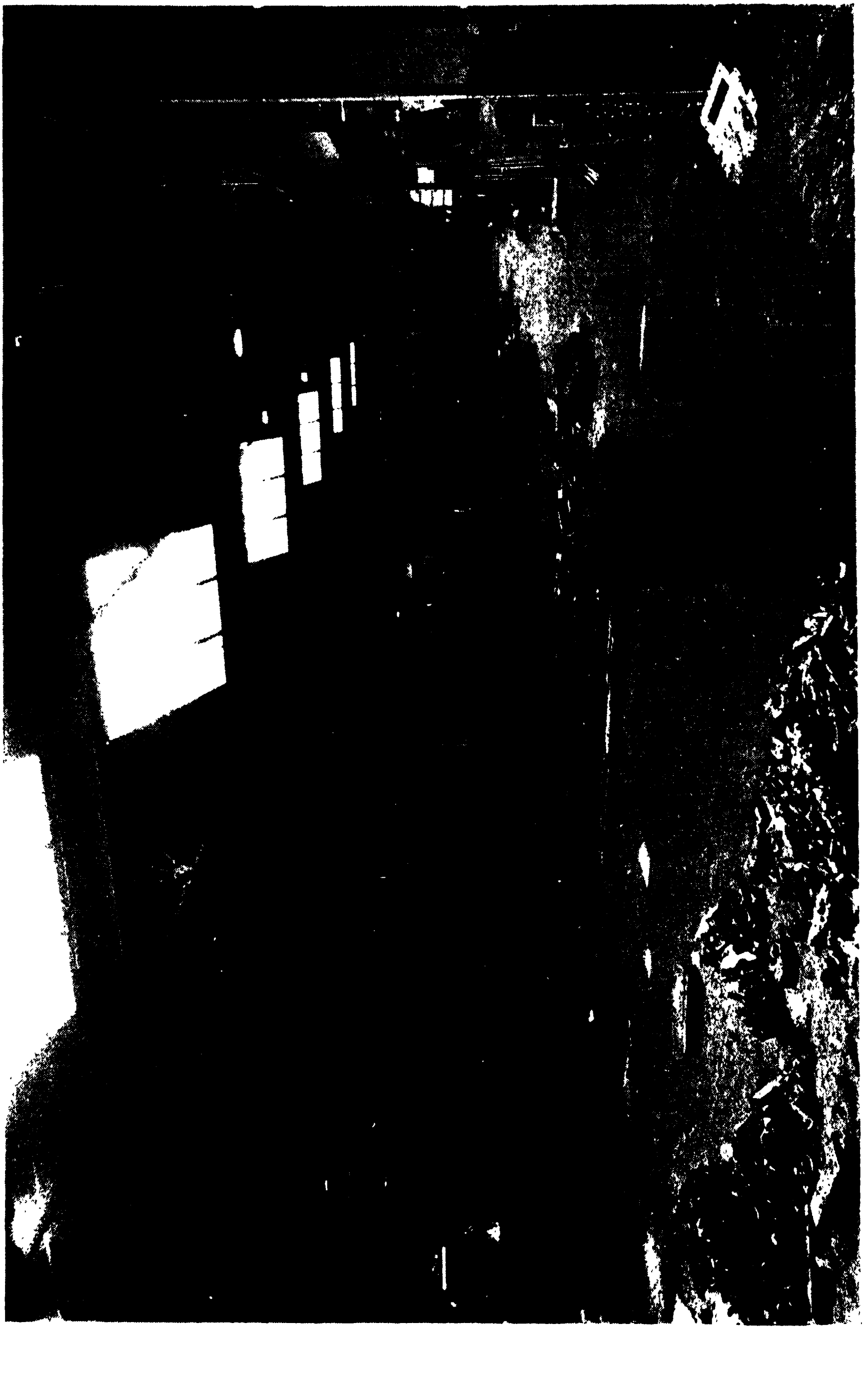


Fig. 48.—LARGE, LOW BRIGHTNESS LAYLIGHTS (ARTIFICIAL SKYLIGHTS), EQUIPPED WITH FLUORESCENT LAMPS GIVE HIGH QUALITY LIGHTING VERY SIMILAR TO THAT FROM NATURAL NORTH LIGHT WINDOWS.

reflectors, some of which probably hang crooked and out of line Continuous lines of light are not an eyesore, and can be made to appear almost as part of the structure.

The Inspection Department—and Others

It is so obviously important to have high quality lighting in the final inspection department of a works that few would deny it. Yet thousands of executives will not agree to provide lighting for previous manufacturing operations which gives the workers an equal chance of seeing what they are doing. It is not fair to blame a man for making mistakes for which he can hardly be held responsible if he cannot see clearly where the error lies; it is not fair to the inspectors constantly to have to reject faulty material (which may be difficult to obtain); it is unfair to make a man work with a poor light, and judge his work with a better.

And it is certainly not common sense to do so.

War-time Restrictions

In view of the special conditions prevailing in wartime, especially as regards the use of materials for chokes and reflectors, fluorescent lamps should only be installed in situations where the high quality of their light is strictly necessary for the proper performance of the work. It is impracticable to give a list of the various operations or buildings concerned, but as a general guide fluorescent lighting may be justified

(a) Where important work is carried out in underground or permanently blacked-out factories or parts of factories.

(b) In parts of factories engaged on important war production where

  (1) artificial light is required for accurate measurement, fine inspection and fine work generally.

  (2) The necessity for colour correction of the light would otherwise entail the use of colour screens with incandescent lamps.

  (3) The use of other systems of lighting would result in difficult shadows or serious reflected glare (glitter).

  (4) Difficulties such as heat radiation and direct glare would cause discomfort to the workers, owing to low mounting height of the fittings, were other systems of lighting to be used.

Fluorescent lighting may also be justified where additional illumination is required in a factory already lighted by incandescent lamps, if such additional illumination could be provided by fluorescent lamps without the necessity of increasing mains, switchgear etc., whereas additional incandescent lighting would necessitate such alterations.

Fig. 49.—LIGHTING AND THE DECORATIVE SCHEME ARE PARTNERS IN PROVIDING THE CORRECT ATMOSPHERE FOR APPRAISAL AND SELLING.

Here the wall is a mottled tan; the partially mirrored columns greenish-yellow; the furniture green and tan; and the carpet tan. Lighting by 200 watt indirect fittings spaced 13 ft. by 13 ft. and 200 watt flush fluorescent fittings on 13 ft. by 8 ft. centres.

2--SHOPS

There can be no doubt whatever that a shopkeeper's primary appeal must be to the eyes. The fact is demonstrated well enough by the employment of men specially trained in display work, by the attractive bottles, cartons and other containers used to please the eye, and by the relatively high illumination levels which are provided to assist vision in parts of many shops. The whole art of advertising and selling is intimately connected with the business of catching the eye of the prospective customer.

In normal times the average shopper enters a shop with the intention of buying one or more articles already pictured in his or her mind's eye. But a shopkeeper is not content with this; it is his business to make the customer realise that there are plenty of other things he needs too; to bring to his notice articles which might be termed "impulse" goods which the customer never knew he wanted until he saw them. Most people object to high-pressure sales talk, and therefore the sales suggestion is best made in an impersonal but forcible way, and light, suitably used, can make it.

Since the lighting requirements of the shop window and the interior are different in many respects they will be discussed separately.

The Shop Window

It can be taken as an established fact that, other things being equal, more people will stop and look at a window which is well lighted than one which is not. ("Well lighted", of course, means that the goods displayed are shown to the best advantage so that they create a desire for purchase or, at least, further investigation.) With comparatively few exceptions, chiefly among the best class of shops, the window lighting has been carried out almost entirely by means of a battery of silvered glass or prismatic reflectors housing incandescent lamps and giving an apparently even flood of light over the whole display: but it is very doubtful whether uniform lighting of this nature, by itself, is actually the most suitable for the average shop window, particularly if it happens to be in a main street.

Certainly it will give confirmed shop-gazers every chance to see everything the window contains, and for them it is ideal. But there has never been a very large proportion of people with unlimited time on their hands, and the proportion is likely to be extremely low in the future. The other and larger class of people are in a hurry. Whether they be in cars, on buses or on foot, they have an appointment to keep, and they are moving fast. It takes them very little time indeed to pass a 12 ft. window, and the display is in view for not more than two or three seconds.

How, in that brief moment, can it have a reasonable chance of giving the traveller at least *one* favourable impression which may lead to a subsequent sale?

There is reason to suppose that the solution can be found in a modified version of ordinary stage lighting practice. When the chorus fills the stage, it is flooded with light; but when the star also appears, he or she is spotlighted and the eyes of the audience are automatically drawn in that direction, charming and delightful though the chorus may be.

It may therefore be to the shopkeeper's advantage to select from stock some suitable article to be dramatised in this way. It should preferably be white or light coloured in order to stand out as clearly as possible, and it should have a matt or semi-matt surface which will not glitter. Selection is largely a display man's job, of course, but no-one can expect to obtain good results from his shop window unless he knows at least something about the art of display.

It is to be hoped that post-war windows will be constructed in such a manner that lighting is given a fair chance to be effective. It is practically impossible to illuminate a lofty shallow window effectively, since the light strikes the near-vertical surfaces of the goods at such an acute angle that their brightness is very low indeed; sufficient depth of window must be allowed so that glancing angles of light are avoided as far as possible.

Fluorescent lamps will certainly be used for the general lighting of shop windows for a number of reasons:—

1.—*Cost*

The first cost of a specially efficient lighting system is paid back more rapidly the more it is used and the higher the price per unit of electricity. Shop window lighting in general fulfils both these conditions. It was no uncommon thing in pre-war days to find the shop window lights in use for 12 hours per day, since the value of after-hour lighting was slowly becoming generally recognised. There was a 6-day week, and the cost of electricity per unit for this purpose was seldom less than 4d. per unit.

In order to compare the cost of fluorescent and incandescent lighting, we will consider a single lamp of an installation in a window lighted 10 hours per day, 6 days per week, with current at 4d. per unit. It is assumed that the price of the 80 watt lamp will remain at 30/-, and that the necessary control gear, excluding reflector, will cost about 45/-.

Taking the incandescent lamp first, and flattering a 150 watt lamp by crediting it with a light output equal to the 80 watt fluorescent lamp, we have:—

Total burning hours over 2 years	6240 hours.
$\therefore$ Units consumed $= \frac{6240 \times 150}{1000} = 936$ @ 4*d.*/unit	= 312/-
6 lamps will be used, @ (say) 3/6 each	= 21/-
	333/-

Each fluorescent lamp circuit consumes about 89 watts, allowing for the slight power loss in the choke.

$\therefore$ Units consumed $= \frac{6240 \times 89}{1000} = 555$ @ 4*d*./unit	= 185/-
3 lamps will be used @ (say) 30/- each	= 90/-
Control gear (say)	= 45/-
	320/-

According to these figures the difference, after two years, in favour of the fluorescent lamp is 13/-, which may be reduced by the difference in cost between the reflector for the 150 watt and the 80 watt lamp. Even in the unlikely event of the fluorescent reflector being 13/- more costly than the silvered glass incandescent reflector there is still a large long-term advantage lying with the fluorescent lamp, for the whole cost of the control gear has been included in the first two years working; thereafter, and as long as the control gear lasts—five years is a reasonable estimate—there will be a saving of 58/- every two years, that is 17·5% of the cost of the incandescent lighting.

The above example is, of course, only an indication of the comparative cost of installing fluorescent lighting. Different tariffs and hours of use will lead to a different result which may be more in favour of fluorescent lighting or may be less; but no calculation worked on these lines can really supply the answer to the question whether or not to use this or that type of lighting. The financial result that the lighting achieves, measured in terms of better or worse business, is of far greater importance than the mere cost of the lighting.

2.—*Heating Effect*

There have been numerous occasions in the past when the amount of light used in a shop window has had to be strictly limited on account of the heating effect of the lamps. Flowers, fruit and confectionery are three classes of goods which suffer from excessive heat, and there are many more.

If fluorescent lamps are used, the total heat generated is only about one third as much as would be generated by incandescent lamps giving an equal amount of light; and since a greater proportion of the heat of a fluorescent lamp is dissipated by convection, the radiant heat is only a quarter or a fifth as great.

Convected heat from the lighting installation is not usually of very great practical importance, since the heated air tends to remain at the top of the window and is removed by simple ventilating arrangements. Radiant heat, however, travels with the light and raises the temperature of the articles on display. The reduction of this heating effect is always welcome, and may in some cases be of very great importance indeed. The steaming of the interior surfaces of lighted windows in cold weather is largely caused by the heat of the lighting system, and though various devices have been tried to overcome it, none appear to have been completely successful; the lower heat output of fluorescent lamps will naturally make the problem easier of solution.

3.—*Colour Lighting*

Though there are very few, if any, occasions on which it is desirable to use strongly tinted light for the general illumination of a window, a slight departure from "white" is often held to be justified in order to enhance the appearance of the display, while at the same time care is taken not to mislead the public to an inexcusable degree. Furniture, for instance, particularly if it is antique, looks more mellow under a light faintly tinted with amber; butchers generally prefer a pink light, while fruiterers, florists and fishmongers (wet fish) find their goods much better displayed under a cold, natural daylight tint.

As explained on page 12 these variations of colour can be obtained by using colour filters with incandescent lamps, but only by wasting a proportion of the original light, so that a relatively large consumption of current is necessary; but with fluorescent lamps, in some cases at least, the required colour of light can be generated originally, with no loss by absorption, and the efficiency of light production by this means is very considerably higher (about 7 times as great for a daylight colour). (Page 35.)

Shopkeepers in general will wish to make full use of the natural attractive effect of a splash of vivid colour. Though strongly coloured light, if used for general illumination of the window, will usually ruin the appearance of a display, it can often be arranged to fall on the back or sides of the window enclosure, where it can be used in a decorative scheme without appreciably affecting the colour of the light falling on the goods displayed nearer the window glass.

For this purpose it may be found convenient to use a display stand placed a short distance from the back of the window, with fluorescent lamp holders and control gear ready fixed in position on the rear face of the stand. It would probably be an advantage, from the point of view of the lighting, if the upper rear corners of the window enclosure were to be rounded off so as to pick up the coloured light as effectively as possible. Plug points will be available at the back of any reasonably well designed window.

4.—*Absence of Shadow*

In any window where the dressing line is close to the glass it is most unlikely that overhead lighting can be satisfactory by itself, since it is almost certain that shelves or some of the goods on display will cast shadows on others. This type of display should be avoided if possible, but where it is unavoidable it will probably be necessary to instal supplementary lighting down the sides of the window. Fluorescent lamps will be very suitable for this purpose, as they occupy the minimum of space, and the extended area from which light is emitted will ensure that light softens any shadows cast by the overhead lighting.

It is to be presumed that skeleton fittings, consisting of little more than lampholders for fluorescent lamps, will be supplied with spring clips or some other simple attachment, so that they can be fixed beneath the front edge of shelves to illuminate the shelf below. In a well lighted window it might well be unnecessary to screen the fluorescent lamp so used, as the merchandise would be sufficiently bright to prevent the lamp from being dazzling, except perhaps where dark materials are displayed.

5.—*Absence of Glitter*

Many articles of hardware and grocery are of such a nature that unless they are very carefully placed, they reflect into the eyes of onlookers the images of the lamps in the lighting installation. Fluorescent lamps are of sufficiently low brightness to prevent this reflection from being disabling or distressing.

It should be noted, however, that certain articles such as diamonds are appreciated partly for the way in which they "catch the light". They do this best under light from a brilliant source, such as the filament of a clear gasfilled lamp, and it is at least doubtful whether fluorescent lamps are desirable for displays of this nature.

Shop Window Lighting Equipment

If it is desirable to make the shop window a dual-purpose one, as described above, it follows that there must be some provision for lamps and reflectors giving a concentrated beam of light which may be thrown in any desired direction. The necessary concentration cannot be obtained with fluorescent tubular lamps owing to their relatively great physical size (page 53) and incandescent lamps and equipment will be needed.

Since the general illumination in a moderately well lighted window will be of the order of 100 footcandles, and since the illumination on the specially displayed article should be at least four times as high as on the remainder of the display, it is not to be expected that a lamp size smaller than 200 watts will be effective. About 400 footcandles illumination is obtained over a small area from a 200 watt parabolic shop window floodlight at a distance of 5 ft., though this depends, of course, on the degree of beam spread for which the reflector is designed.

For the general lighting of windows it was usual to instal a row of silvered or prismatic glass reflectors behind the top of the glass, about 100 watts per foot of frontage being considered adequate for a high-class shop at the centre of a medium sized town. A much greater wattage per foot was often employed in the shopping centres of large towns and cities, while less was usually found sufficient for other and less important shopping areas. It was largely a matter of not being outshone by one's neighbours.

There may be some shopkeepers who will be content to have as much light as in pre-war days, but there will be many others who will wish to take advantage of the high efficiency of fluorescent lamps by using them to provide more light than before. The owner of a shop with a 12 ft. frontage which previously had a window lighting installation totalling 1200 watts could, if he wished, replace it by a fluorescent installation totalling, say, 600 watts, and he would receive approximately the same amount of light at half the previous current cost; but alternatively he could install, say, 900 watts of fluorescent lighting which would give him about 50% more light with a reduction of 25% in his current cost. The better-class shops are almost certain to choose increased light, rather than reduced current consumption; many will even increase their lighting load and thus make the utmost use of the new source of light.

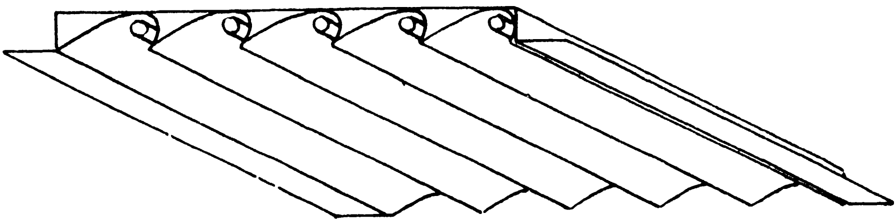


Fig. 50. MULTIPLE REFLECTOR FOR SHOP-WINDOW LIGHTING.

A single continuous line of fluorescent lamps placed in the position formerly occupied by the reflectors for incandescent lamps would not give a comparable quantity of light. An 80 watt fluorescent lamp, for instance, is loaded to only 16 watts per foot of length, whereas a loading of about 75 watts per foot of frontage may be required. Space will therefore have to be found for multiple lines of these lamps, and this consideration requires that fluorescent lighting fittings for shop windows must be as neat and compact as possible. There would seem to be little point, in any case, in attempting to obtain highly accurate control of the light by the use of specular reflecting surfaces with carefully designed contours. Light from a fluorescent lamp is bound to spread to some extent, whatever the shape or material of the reflector (page 54), and one can therefore make use of any convenient reflecting medium.

Windows which are small in depth (from front to back) would be adequately served by lamps mounted in a series of deep corrugations formed in a sheet of metal or plastic arranged somewhat as shown in figure 50. The reflecting surface might be polished or anodised aluminium, for maximum efficiency, or of stainless steel or chromium plate; vitreous or synthetic white enamel would also be satisfactory from the lighting standpoint, though its appearance might be condemned. The arrangement has the advantage of simplicity and need not be expensive; the lamps are well shielded from normal view, and if likely to be viewed from the side, could be fitted with transverse louvres without much added complication; and though some stray light will not strike the display, by far the greater part of it will.

For windows of greater depth a similar arrangement would generally be satisfactory, but the parts of the display farthest from the glass would be better lighted by applying the same principle to the whole ceiling, or by mounting lamps flush on the rear parts of the ceiling, with "egg-box" louvres beneath. Some ventilation should be provided in each case in order to prevent the lamps from running inefficiently due to overheating (page 44).

The completely equipped shop window will thus have a lighting installation consisting of:—

1. Fluorescent general lighting of the desired colour; a warm white is suggested as being most suitable for shops in general.
2. Ceiling plug point(s) to which may be connected one or more shop-window floodlights housing gasfilled lamps of at least 200 watts.
3. Side fluorescent lighting for shallow windows, by means of compact reflectors, perhaps of right-angle section, fixed vertically at the corners of the window.
4. At least one plug point at each corner of the floor, to serve shelf lights, luminous features, or colour lighting of backgrounds. It may also be desired to use fluorescent footlights to heighten a dramatic effect, or as is usually found with hardware shop windows, to enliven the appearance of the display.

Fading of Coloured Materials

Investigations* which have been carried out in America show that the fading of dyed materials is generally influenced by various factors, but it is impossible to assert that any factor will necessarily have the same fading effect on one particular dye as it does on a number of other dyes. The following observations should therefore only be taken as a general guide.

Experiment shows that the amount of fading depends on the duration of exposure and on the illumination, e.g. an illumination of 100 footcandles for 10 hours will fade materials as much as 1000 footcandles would do in one hour.

Very little fading occurs due to radiation at wavelengths below

* "Fading of Coloured Goods in Show Windows"—M. Luckiesh and A. H. Taylor, *Magazine of Light* (America).

3300Å, but from that point up to about 5500Å fading will occur depending roughly upon the energy emitted in that range; over 5500Å the fading effect appears to decrease. It thus appears impracticable to use filters to suppress the principal radiations which cause fading, as one would only be left with orange and red light, which would be almost useless from the standpoint of illumination.

Temperature appears to have little effect on fading provided 120°F. is not exceeded.

With an equal level of illumination, the fading effect of sky light (excluding sunlight) is about three times as great as that of incandescent lamps. Since the natural daylight illumination in shop windows is often greater than the artificial illumination, and is present for the whole period of daylight whereas the artificial lighting may only be used for a portion of each 24 hours, it is concluded that in typical windows lighted by incandescent lamps the artificial lighting is responsible for between 2% and 5% of the fading, though when articles are spotlighted the proportion may rise as high as 33%.

The authors state:—"While it cannot be denied that artificial light will fade coloured materials under some conditions encountered in practice, the same goods would generally fade much more quickly outdoors in daylight. Hence, goods which fade under ordinary exposure to tungsten filament lamps may be of questionable value to the consumer".

The same general conclusion can also be reached regarding the fading effect of fluorescent lamps. If materials are exposed for equal periods to equal illumination by incandescent lamps and fluorescent lamps giving a light approximating to daylight, fading of blue, violet and purple materials is a little faster under incandescent lamps, and fading of pink, yellow, orange and red specimens is slightly faster under fluorescent lamps. The distinction appears to be of academic rather than practical importance, since the effect in any case is usually small compared with the effect of natural daylight.

The Shop Interior

It has already been indicated that the average shopkeeper hopes to sell to a customer other goods besides those for which he entered the shop, and that lighting can help him very considerably. To do so, however, the lighting must be carefully planned with this end in view, for an installation which merely provides a moderate degree of "utility" lighting can do little more than enable a business to carry on; it can hardly expand it.

Examine the actions of an average shopper in an average shop. He or she enters, say, a medium sized shop to buy some socks or a pair of gloves. He makes his way by a fairly direct route to the appropriate counter, makes his purchase and leaves the shop by much the same route as he entered—an entirely satisfactory proceeding for the shopper, perhaps, but an opportunity sadly missed by the shopkeeper. In the first place the customer finds nothing particular to attract his eyes while he is awaiting his turn to be served or while his change is being counted; and secondly he could and should have been encouraged to make a tour of discovery of at least a part of the sales area, instead of taking the most direct route from and to the doorway. If a customer is shown nothing but what he knows he wants to see, sales will not be as large as they might.

General Lighting

It has been found by experience that a daylight colour of light is not generally the best for shop interiors. There are exceptions of course, but usually it is considered too cold, a warmer "white" being preferable as it apparently has the effect of encouraging people to spend money. If and when lamps giving a suitable colour of light become available, it would be economical to use such lamps rather than to use colour "A" lamps in yellow-tinted fittings which would absorb some of the light in modifying its colour. The unlighted appearance of a tinted fitting might perhaps be superior, but a shopkeeper having installed fluorescent lighting is unlikely to rely only on natural daylight even when it is plentifully available, because its colour does not generally suit his

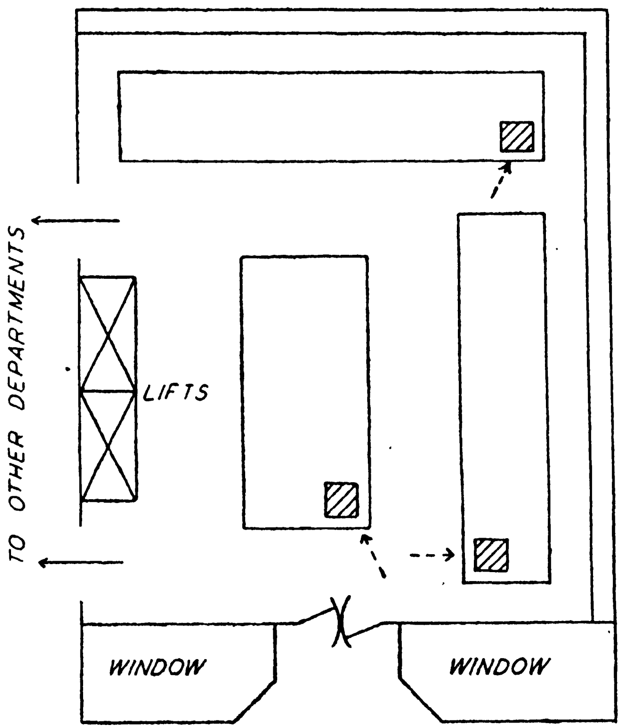


Fig. 51.—ILLUSTRATING HOW "TRAFFIC" MAY BE CONTROLLED BY HIGH-LIGHTED FEATURES.

(This men's department of a store was poorly patronised, customers entering usually turning left to other departments. High-lighted features placed to the right of the entrance, with the main direction of the supplementary lighting as shown by the dotted arrows, increased the number of customers turning right, by 63%.)

Fig. 52.—Dual Purpose Skylight.

(Daylight can be admitted through louvres 2 ft. wide by 15 in. deep. 6–8 kw. of fluorescent lighting is installed in closed top, open bottom louvred fittings recessed in the ceiling. Wall and ceiling brightness is obtained by a staggered double row of fluorescent lamps in coves along the walls.)

purpose; his fittings are therefore likely to be kept alight continuously throughout business hours.

A few trades, of course, do require daylight colour because it appears cool, or because the goods must appear as white as possible, or because it is important to show coloured merchandise as it will appear in ordinary daylight use. Examples are milk bars in summer, florists and fruiterers, vendors of white enamelled or glazed goods such as refrigerators and

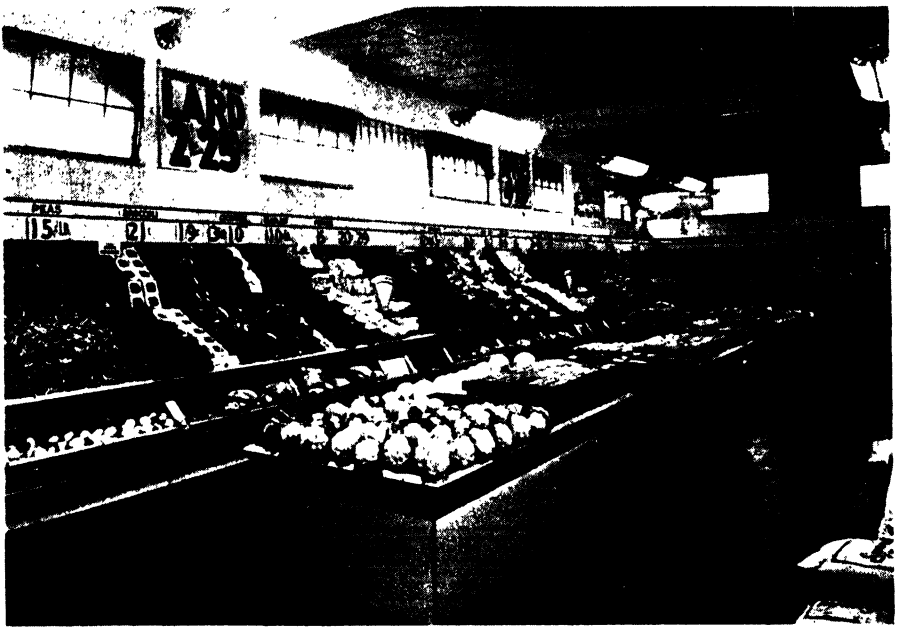


Fig. 53.—The Row of Semi-cylindrical Fittings concentrates attention on the Merchandise by Lighting Them to a Higher Brightness than their Surroundings. Goods of this nature benefit from the comparative coolness of fluorescent lighting.

sanitary ware, and parts of stores devoted to outdoor garments; for these the colour "A" fluorescent lamp will be quite suitable, though it will take some time for members of the public who wish to match the colour of a piece of ribbon or wool to realise that they can do so under artificial light.

Though some shops, especially those with new or reconstructed premises, will decide to install completely built-in lighting, the majority would probably prefer more conventional schemes if they could be sure that the desired effects would be achieved. Pendant fittings can certainly provide "amenity lighting" for sales areas, but it should be borne in mind that much of the stock-in-trade of some shops is viewed with the line of sight nearly horizontal; in other words one sees the vertical rather than

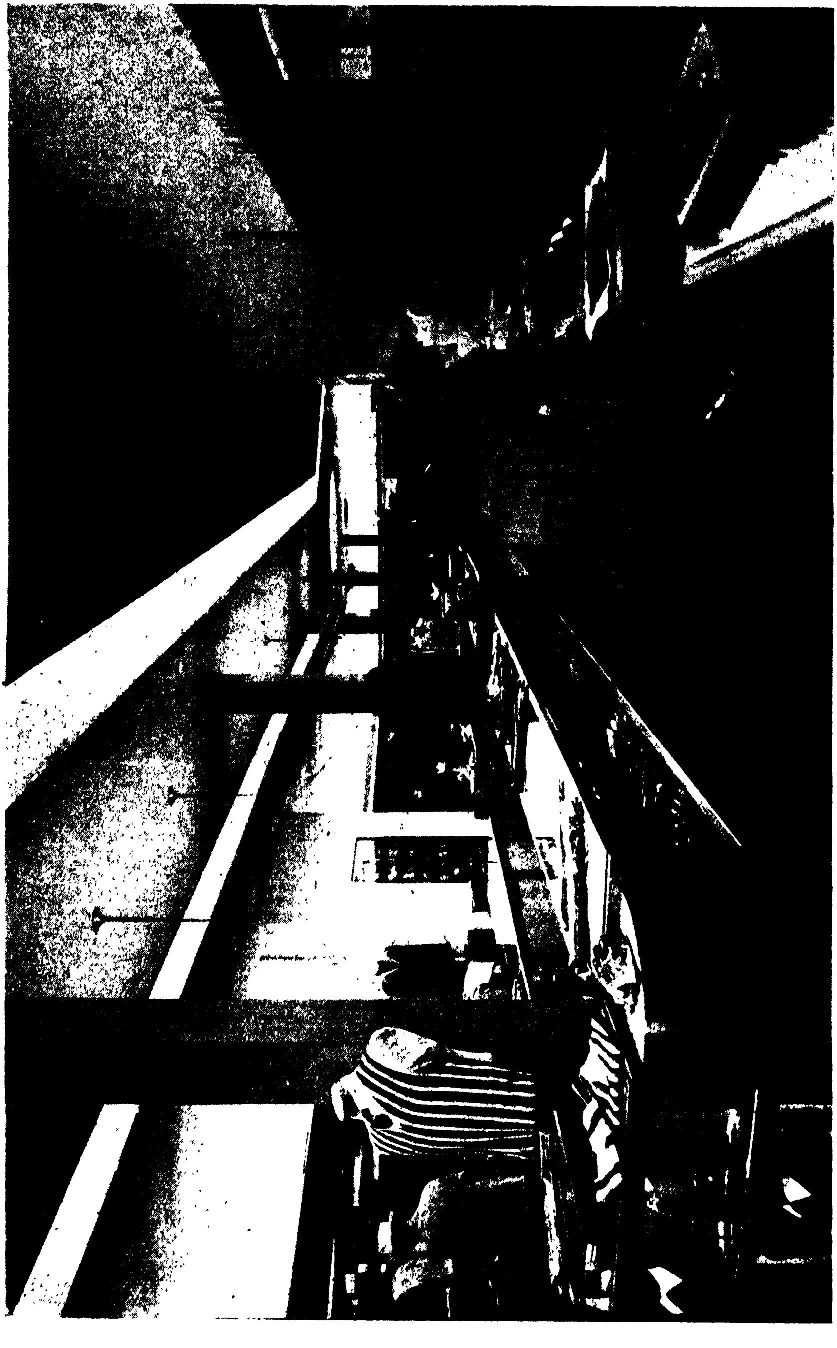


Fig. 54.—120 FOOTCANDLES ILLUMINATION—ALMOST DAYLIGHT EASE OF SEEING.
(Note the supplementary indirect lighting by suspended trough fittings, the silhouetted sign over the wall case, and the almost complete absence of shadow.)

the horizontal surfaces of the goods, and rapid vision is not obtained unless the lighting on these vertical surfaces is adequate.

Lighting of Vertical Surfaces

Provision of sufficient light in a sideways direction from a pendant fitting entails the use of rather deeper fittings than may be considered aesthetically desirable; the fitting, when seen from the side, might appear too bright for comfort were a relatively large amount of light to be emitted from a shallow side panel. It may, therefore, be advisable to consider one or other, or both, of the following general methods of lighting which not only improve the illumination of vertical surfaces, but also have some merit from the decorative or architectural point of view.

First, there might be continuous troughs sunk in the ceiling; these would contain one or more continuous lines of fluorescent lamps, the mouth of each trough being closed by prismatic glass with the prisms running parallel with its length. The prismatic control would secure the desired distribution of light, while the brightness of the glassware could be sufficiently low to avoid discomfort. In general, the lines of light should be arranged in the same direction as the greater dimension of the floor, for two reasons: firstly, because the more distant panels, which lie nearest to the normal line of sight, will usually be seen nearly end-on, when their brightness is likely to be less than the sideways brightness; and secondly because this arrangement will usually appear to the customer as lines of light leading from the area near the entrance to the further end of the shop—a small matter, perhaps, but nevertheless definitely influencing him to follow the lines of light and thus pass all the merchandise displayed along his route.

It should be noted that any system of lighting installed flush with the ceiling cannot directly illuminate it; pendant fittings giving upward light, or lighting from the walls should therefore be provided in addition.

The second main method of obtaining illumination on vertical surfaces, especially in narrow shops, is by means of lighting on or near the walls. This could usually be arranged at the top of the stock shelves or display stands behind the serving counters, and might well combine the main function of lighting with the subsidiary function of identifying the parts of the shop where different goods or services are to be found, e.g. gloves, hosiery, cashier, etc. (Figure 54). The parts of the ceiling near the walls would also be lighted, of course, by an installation of this nature, which enlivens the appearance of the interior by providing comfortable brightness within the field of normal view.

In newly relighted American shops the general fluorescent installation is sometimes supplemented by a row or rows of highly concentrating reflectors recessed into the ceiling and equipped with incandescent lamps. These reflectors are installed in lines immediately over the

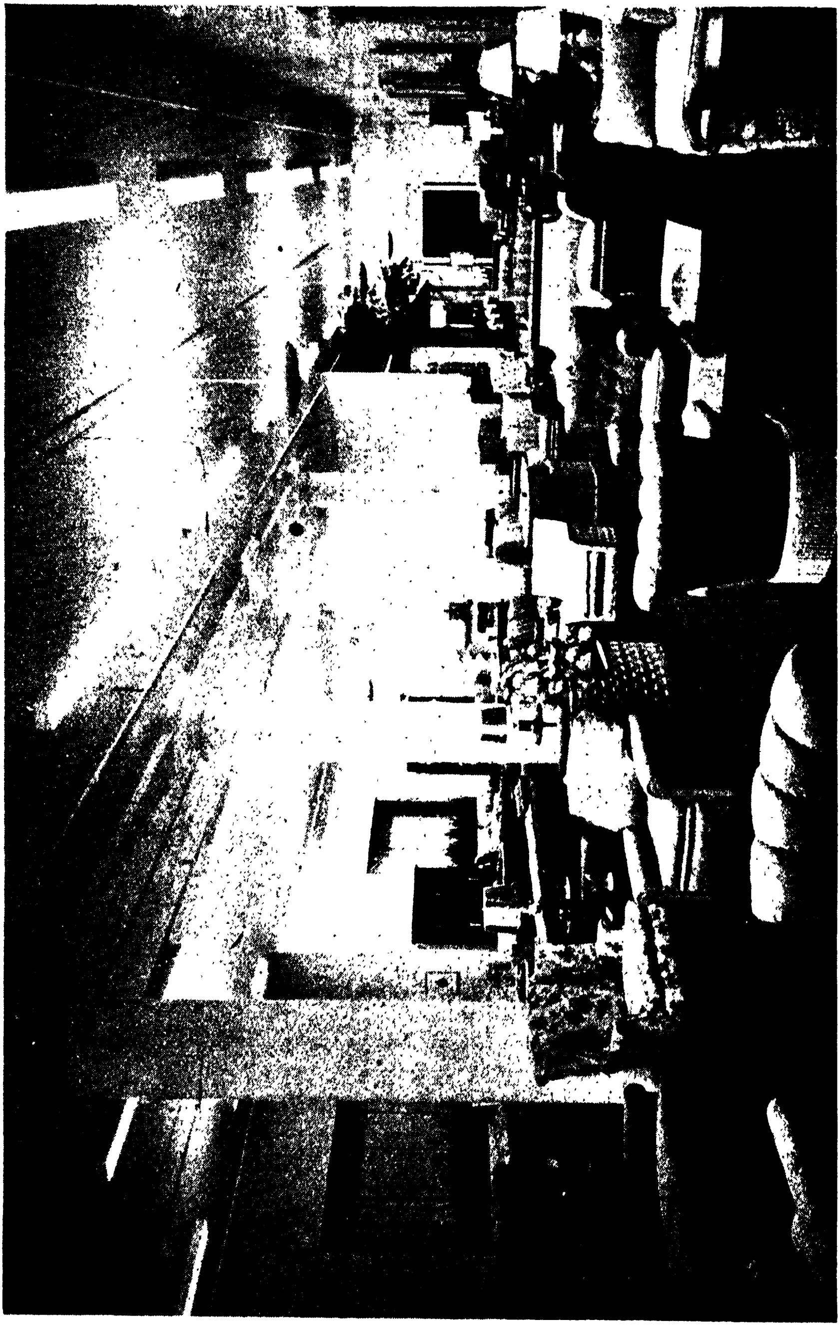


Fig. 55.—PROSPECTIVE PURCHASERS OF EXPENSIVE ARTICLES SHOULD HAVE EVERY OPPORTUNITY OF COMPARING STYLE, COLOUR, TEXTURE AND GENERAL WORKMANSHIP.

(Applied ceiling fittings—160 watt fluorescent. Pendant indirect fittings—200 watt gas-filled.)

principal selling areas—usually the counters—with the object of drawing particular attention to these important parts of the shop.

It is doubtful whether such a scheme would meet with very much approval here, perhaps because we may prefer a sales appeal to be rather more subtle. It has the advantage of course, of giving plenty of light at those places where it is particularly required for critical examination of merchandise, but the concentrated nature of the light is likely to give rise to severe glitter from horizontal polished surfaces beneath, and either the customer or the assistant may suffer unless counter tops are finished with a matt surface; and combined counter-showcases without clear glass tops lose much of their sales value.

Highlighting

The fact that eyes are automatically attracted towards high brightnesses can often be put to good use in medium or large shop interiors for encouraging the desired circulation of customers throughout the sales areas. A few display stands extra brightly lighted, and placed so that they lead the way towards those parts of the shop which are not doing sufficient business may result in sales from those parts increasing. In any case a more general movement of customers in that direction takes them past other counters and showcases on one of which they may find an "impulse" item; the value of this is already well recognised by shops which place the pay desk or their best selling articles in a position as far from the entrance door as possible.

The type of lighting required by interior displays of this nature must of course depend on the nature of the goods shown. The most dramatic presentation is achieved by skilful use of light and shade in sharp contrast, and is generally suitable for goods normally seen out of doors, such as flowers, sports gear and outdoor wear. For this class of display lighting there is nothing better than an incandescent lamp in a suitable reflector to concentrate the light within the confines of the display stand.

Various other articles of merchandise, however, are normally seen in use under comparatively low levels of artificial illumination, and it might entirely destroy their appeal if they were displayed under a light which was too revealing. Evening gowns are perhaps the best example. A light casting only very soft shadows is required, and since the illumination should not be very high it will be advisable to increase the eye-catching properties of the display by contrasting white goods against a dark background, and black goods against a lighted white background. For such a stand fluorescent lamps are ideal, for they can give nearly shadowless lighting of the merchandise from the front, and lighted back grounds free from the spotty effect often accidentally obtained with lighting from incandescent lamps.

It is surprising that so little use has been made in the past of well-designed and well-lighted displays immediately facing the entrances to

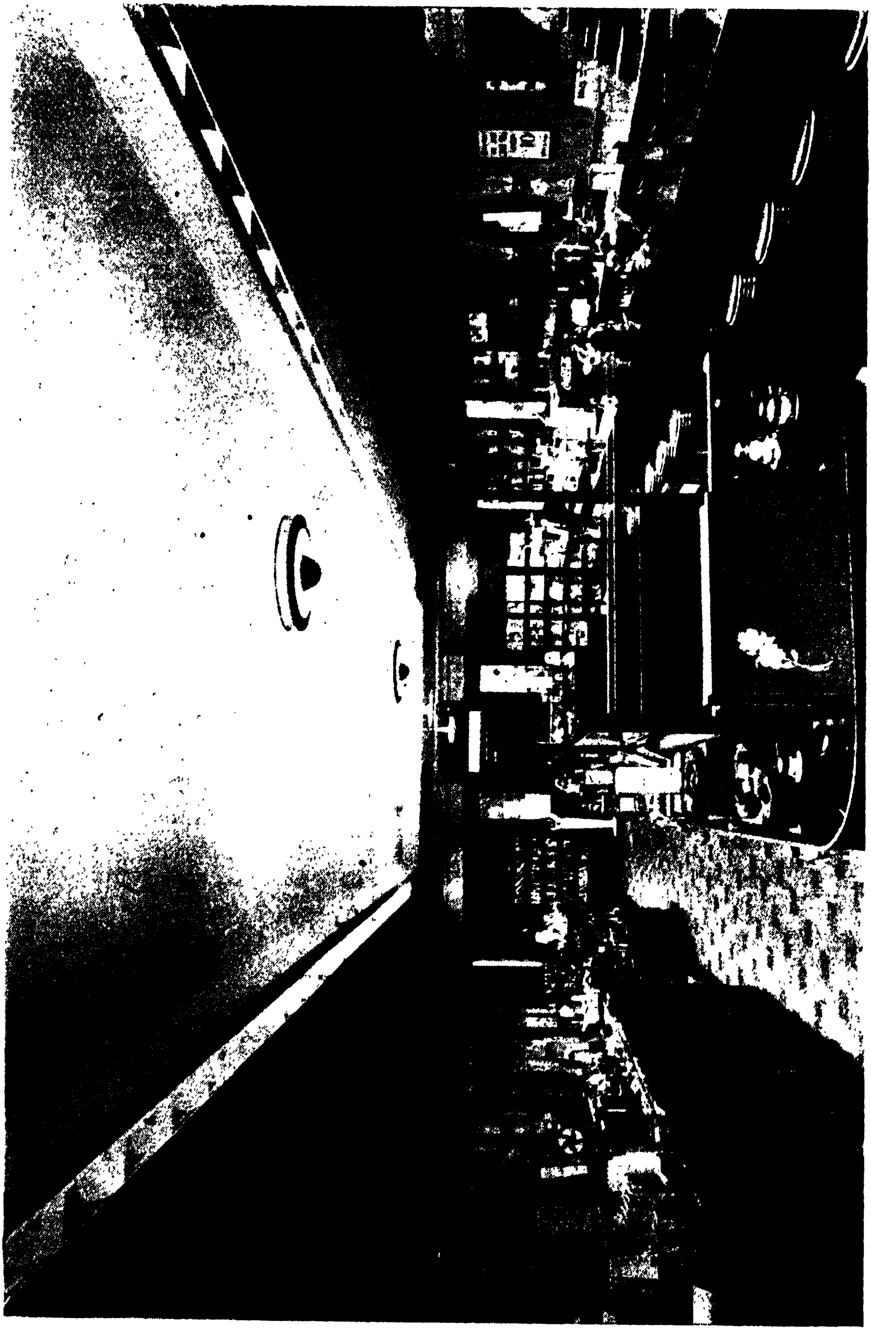


Fig. 56.—High-lighting of Selling Areas.
(30–65 footcandles on counters and wall cases. "Traffic" areas are lighted mainly by the pendant fittings using gasfilled lamps.)

lifts in multi-storey shops. The natural curiosity of human beings who see such displays through lift doors would surely result in increased business which would rapidly repay the expense incurred.

Showcases

It can be accepted as a general rule that a showcase will not attract a great deal of attention unless it is internally lighted to a level at least twice as high as its surroundings, and that up to a point the more brightly it is lighted the more useful it becomes as an aid to sales.

Showcase lighting by gasfilled incandescent lamps is not usually very impressive, for the lamps themselves are often too prominent a feature of the display, and the lighting they give is apt to be unevenly distributed. Vacuum tubular lamps can be easily fitted out of sight, and give more even lighting with less shadow; but their efficiency is comparatively low, and they develop a relatively large amount of heat, and consume more current for a given amount of light. A natural reluctance to incur a large bill for electricity, and the fear of damaging articles by excessive heating both tended to keep showcase lighting down to a low standard.

Fluorescent lamps, however, should enable shopkeepers to use as much light as they wish, with very little heat and without incurring heavy bills. The results obtained* in two identical showcases, one lighted by a fluorescent lamp and the other by tubular vacuum lamps are impressive.

Each showcase measures 6 ft. × 2 ft. × 3 ft. high, a false bottom beneath which control gear for the fluorescent lamp is concealed being fitted about 6 ins. above the floor. The top, the front and one end is glazed, and the interior is painted cream. The showcases are unventilated.

It is found that an average illumination of the order of 100 footcandles is provided by (a) one 80 watt colour "A" fluorescent lamp in a simple right-angled reflector fitted behind the top front beading, or (b) by four 60 watt vacuum tubular lamps in a small continuous trough reflector placed behind the top front beading, and two 30 watt lamps of similar type in the same kind of reflector placed behind each vertical beading at the front. Total consumption is therefore 89† watts for the fluorescent lamp and 360 watts for the vacuum lamps.

In each instance a steady interior temperature is reached after about one hour's running, but whereas the temperature rise with vacuum lamps is 24°F, it is only 7°F with the fluorescent lamp. The importance of this reduction in temperature when dealing with articles liable to be damaged by excessive heat is obvious; for instance, unwrapped chocolate appears to suffer no deterioration other than that normally attributable to age.

In the example quoted above the colour "A" fluorescent lamp gives a much fresher appearance to the showcase than the vacuum lamps, and glitter from cellophane-covered packets and other shiny objects is notice-

*E.L.M.A. Lighting Service Bureau. †Approximately 9 watts lost in the choke.

ably reduced. On the other hand, it is probable that a "warmer" light than the colour "A" will be desirable for certain classes of goods, and it is reasonably certain that fluorescent lamps giving such light will be available.

It is interesting to compare the lighting costs of the two showcases mentioned above. In the area concerned, current for lighting is supplied at a flat rate of 4½d. per unit, or at a business rate of £11 per annum per kilowatt installed, plus ¾d. per unit; and it is reasonable to assume that the lighting would be used for 10 hours per full working day, for 280 days per year. Owing to wartime variations, costs of individual reflectors, lamps, etc. cannot in all cases be quoted exactly, but are given as close approximations. It is reasonable to credit control gear and reflecting equipment with a life of 5 years.

(1) ANNUAL COST—Tubular Vacuum Lamps

		Flat rate.	*Business rate.*
Cost of lamps ..	Four 30 watt @ 4/- × $\frac{280 \times 10}{1000}$ ..	44/9	44/9
	Four 60 watt @ 4/9 × $\frac{280 \times 10}{1000}$ ..	53/2	53/2
Cost of current ..	$\frac{360 \times 280 \times 10}{1000}$ × rate	378/-	63/-
kW charge	£11 × $\frac{360}{1000}$	—	79/2
Cost of reflectors ..	£2 10 0 (five years)	10/-	10/-
	Total ..	485/11	250/1
	Cost per day (approx.) ..	1/9*d.*	10¾*d.*

(2) ANNUAL COST—Fluorescent Lamp

		Flat rate.	*Business rate.*
Cost of lamp	$\frac{280 \times 10}{2000}$ × 30/-	42/-	42/-
Cost of current ..	$\frac{89 \times 280 \times 10}{1000}$ × rate	93/5½	15/7
kW charge	£11 × $\frac{89}{1000}$	—	19/7
Cost of reflector ..	approx. 38/6 (five years)	7/8	7/8
Cost of control gear*	approx. 55/- (five years)	11/-	11/-
	Total ..	154/1½	95/10
	Cost per day (approx.) ..	6½*d.*	4*d.*

* *Excluding cost of periodical renewal of the starting switch. This would amount to perhaps 2/- per annum.*

These figures show that with the electricity tariff as stated above, fluorescent lighting is less than half as costly as filament lighting giving comparable results; and if the cost of using four 40 watt gasfilled lamps in shell type reflectors be calculated, it will be found to be within ½d. per day of the cost of fluorescent lighting on the business rate, though the appearance of the showcase and its contents will generally be markedly inferior.

Incandescent lamps are desirable for illuminating showcases containing goods required to glint and glitter, as certain varieties of precious stones; but as a general rule fluorescent lighting will minimise deterioration of the merchandise, will give it the best possible appearance, and will be almost as cheap or cheaper than other methods of lighting.

3—SCHOOLS

The artificial lighting of schools is a matter which is vitally important to the health and well-being of future generations. It must not and cannot be left to improve itself by gradual change, each improvement being twenty years behind the times. Whatever educational control there may be after the war, it should be the responsibility of some competent authority with compulsory powers to ensure that the lighting of *all* schools of whatever size or kind should reach and maintain at least a certain minimum of adequacy and suitability. Children's sight is too valuable an asset to be risked by permitting or causing them to work under the miserable lighting conditions far too commonly found in schools to-day. To argue that good lighting is expensive is merely to deny, by inference, that the preservation of good sight is important; and the argument is fallacious in any case, since the total installation cost of a good lighting scheme is almost certain to be less than 5% of the capital cost of the buildings, while the running cost will often be in even lower proportion to the running cost of the whole school.

It is often considered that adequate *day* lighting is provided by large windows along one wall of a classroom, but tests do not bear this out. Figure 57* shows how daylight illumination falls to very low levels as the distance from the window is increased, so that pupils on the far side of the room are working under a handicap all day. Either the natural lighting should be improved so that there is sufficient daylight illumination everywhere in the room, or artificial light should be used to supplement daylight in those areas where the latter is insufficient.

Quantity of Light

What is "sufficient illumination" for ordinary classrooms? An average of 12 footcandles can hardly be considered excessive, bearing in

* From "School Buildings" (National Union of Teachers) by John Sargent, M.A. and A. H. Seymour, B.Sc.

mind that young eyes are more liable than older ones to be adversely affected by conditions of strain, and that small print, and other fine detail will have to be carefully observed from time to time. Reading a book in English under good conditions may not be a very difficult matter for an adult, who recognises printed words by their general shape; but if each letter has to be scanned separately, as when learning to read, or when studying a text-book with strange technical terms or frequent mathematical symbols, reading becomes a really difficult job

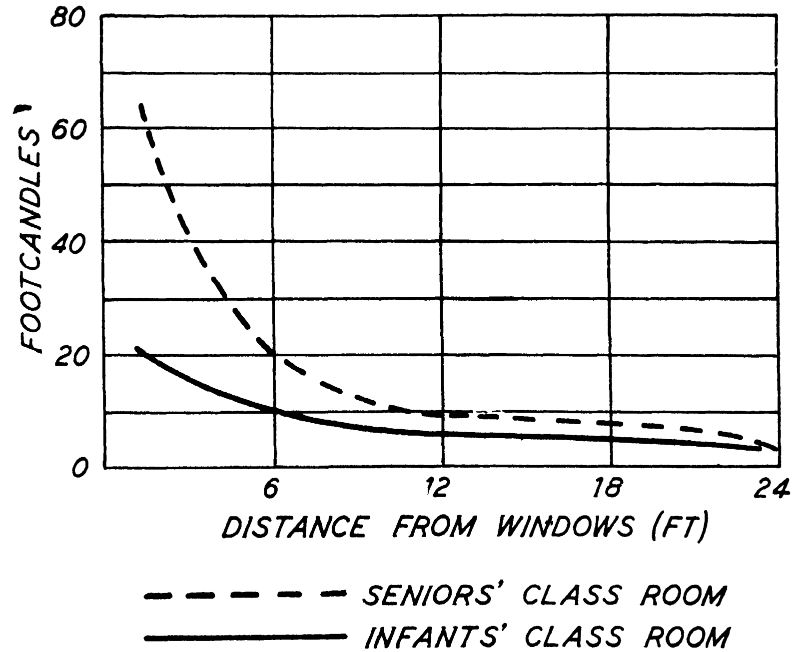


Fig. 57.—Daylight Illumination at a Distance from the Windows in Classrooms of a Quadrangular School.

even with the best lighting conditions, and the cause of severe strain and fatigue when the lighting is inadequate or unsuitable. Further, it must be remembered that technical schools are much used for evening classes after the normal day's work is done, when eyes are already a little tired and need all the help they can be given. If twelve footcandles illumination is recommended for medium classes of work in a factory, surely at least as much should be provided for ordinary classrooms where the seeing task is of equal or greater difficulty; and if there is a special room set apart for the use of myopic students the illumination there should be more of the order of 20 footcandles.

Prevention of Glare

In a classroom the lighting should be of such a nature that it is comfortable for both teacher and pupils when engaged on their normal school work, but the comparatively low ceilings of the classrooms in many modern schools have not made it easy to achieve this aim.

It is very desirable to allow ample light to pass in an upward direction to illuminate the ceiling, and unless completely luminous ceilings are employed it follows that supplementary fittings (perhaps in the form of wall-mounted reflectors) will be desirable if the basic lighting gives downward light only. Even with short suspension, the bottom of a pendant fitting when hung from a 10 ft. high ceiling is only slightly above the eye level of the teacher standing on his platform, and its brightness should therefore be severely limited for the benefit of the teacher who cannot avoid looking towards it. Even totally enclosed opal glass fittings housing incandescent lamps have been criticised by teachers on account of their brightness, which is only of the order of 1½ candles per sq. in.; the remedy adopted, unfortunately, has sometimes been to discard the enclosed fitting in favour of a deep conical opal glass shade which is less bright as seen by the teacher, but gives rise to serious reflected glare from students' desks and papers. Raising enclosed fittings nearer to the ceiling will not usually improve matters, as the ceiling brightness then becomes very uneven, and the teacher sees the bright fitting against a part of the ceiling which is comparatively dark, thus adding contrast glare to his troubles. An increase in the physical size of the fitting may also be impracticable, as, though it would reduce the brightness it would also, in most cases, be open to objection on mechanical or aesthetic grounds; and though a ceiling height of not less than 13 ft. would be preferable from the standpoint of lighting, other considerations may dictate that ceilings of future or re-constructed schools be kept at a lower height.

Desirable Characteristics of Lighting Fittings

When we glance up from our work we do not normally raise our eyes to a greater angle of elevation than, say, 20° above the horizontal. (Factory lighting regulations aimed at eliminating direct glare appear to be based on the same assumption.) It would be reasonable, therefore, to specify fittings which have a very low brightness, of the order of 1 candle per sq. in., or less, at angles between the horizontal and 20° below, while permitting a higher brightness at other downward angles; this relaxation is justified since the bright parts of the fitting would not be seen unless one deliberately looked upwards.

A fitting having this characteristic will not be glaring when directly viewed at normal angles of view by either the teacher or students, but it can give rise to very bad reflected glare from polished or glossy surfaces of desks and papers, unless the brightness of the fitting as seen from

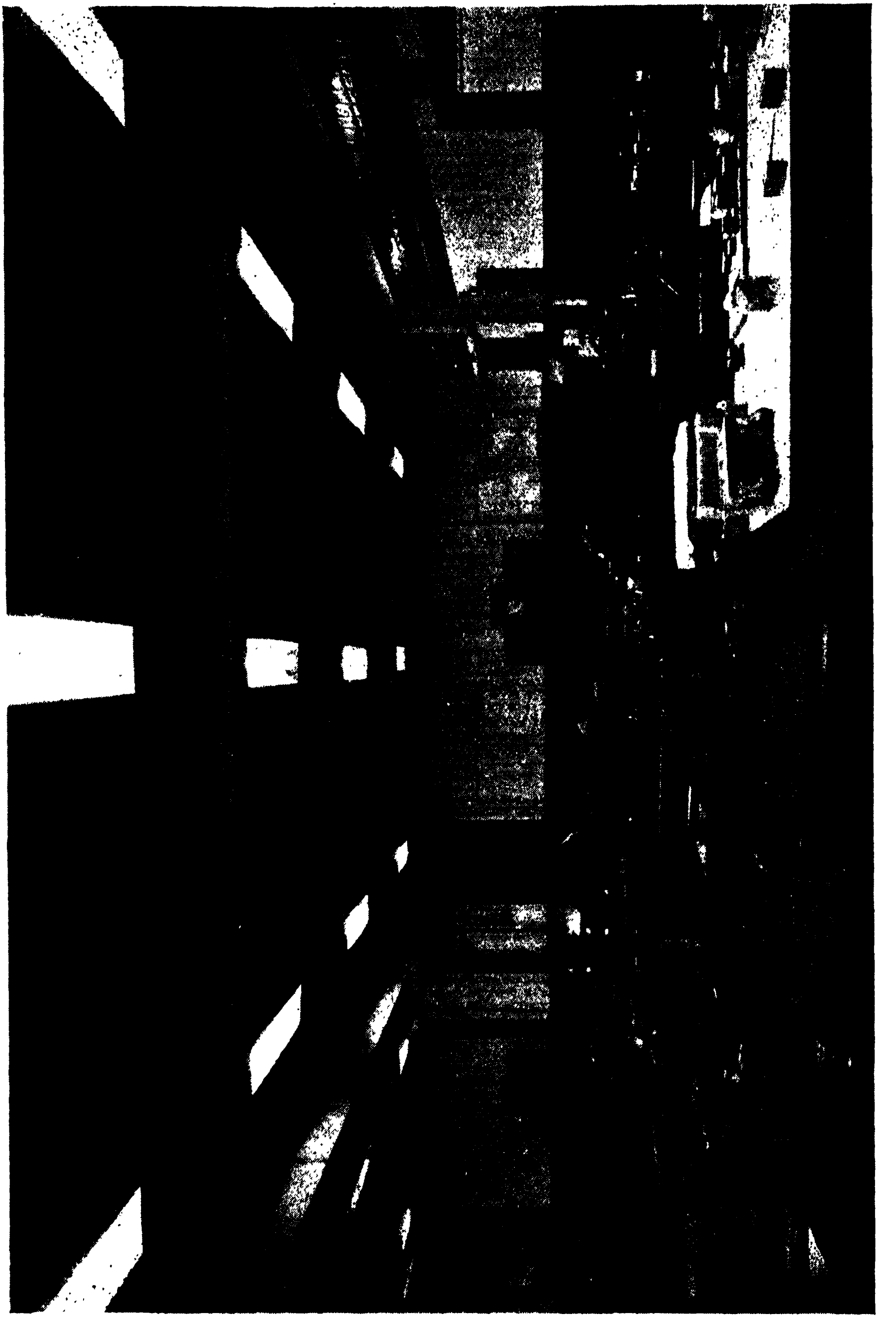


Fig. 58.—The Workshop of a Technical College. The standard of lighting here should be at least equal to that found in up-to-date Industrial Plants.

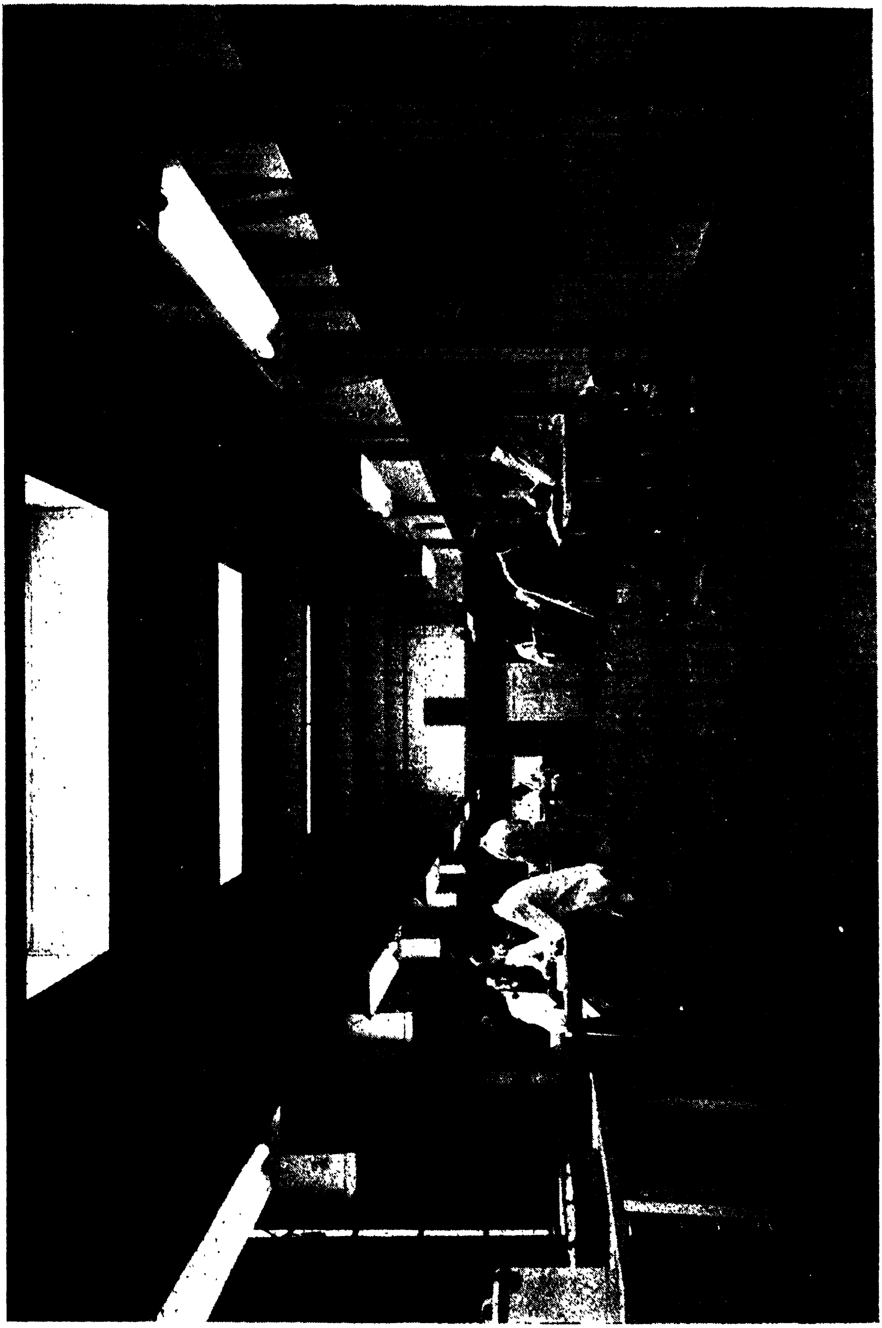


Fig. 59.—Fluorescent Lighting in the Dissecting Room of a Hospital Medical School.

below is also limited. A value of brightness less than 5 candles per sq. in. within angles of 70° to the downward vertical is desirable, and is in fact obtainable from unshielded fluorescent lamps, whereas with incandescent lamps the efficiency of the fitting is reduced by the necessary inclusion of some diffusing medium such as opal glass.

Indirect lighting is ideal for classrooms, as it gives rise to neither of the troubles mentioned above, but there are few if any installations of indirect lighting in classrooms in this country, chiefly on account of the additional running cost involved. Fluorescent lamps, however, have about double the efficiency of incandescent lamps and can provide indirect lighting at approximately the same current cost as is needed for direct lighting by incandescent lamps. Indirect fittings should be moderately self-luminous in order that they do not appear as dark patches against the lighted ceiling.

Arrangement of Fittings

The standard classroom of about 480 sq. ft. floor area would need eight 80 watt fluorescent lamps, or their equivalent, in "direct" type fittings to provide an average illumination of 12-14 footcandles in service. (It is assumed that the fittings employed would be of rather better appearance and slightly less efficient than the trough reflectors at present used for industrial lighting and would have a "cut-off" 20° or more below the horizontal.) Four two-lamp fittings symmetrically spaced would generally cater adequately for the lighting of all desk and table tops, but additional lighting will be required for the area of the blackboard—or chalkboard, as it should be named, for it is to be hoped that in the future this necessary piece of apparatus will have a reflection factor comparable with that of its general surroundings, though it need not necessarily be of the same colour. The illumination on this board should be of at least as high a value as the illumination on the desks since some of the writing on it will, to the students, be about the same apparent size as the printing in their books, and also because the contrast on the chalkboard (e.g. using blue chalk on a yellow ground) will not be so high as the contrast of black print on a white page.

Reference to figure 57, page 124 indicates that it is advisable to arrange a classroom lighting installation so that the row(s) of lamps farthest from the window can be switched on separately in order to compensate for insufficiency of daylight on dull days or towards evening. One might reasonably go much farther and take the responsibility of turning on lights as and when required out of the hands of teachers, some of whom do not realise the harm they can cause by undue economy in this matter, and all of whom are from time to time forgetful. A number of American schools have had classroom lighting controlled for some time past by means of one or more photo-electric cells placed at suitable positions; these cells operate relays which switch on the lights as soon as the daylight

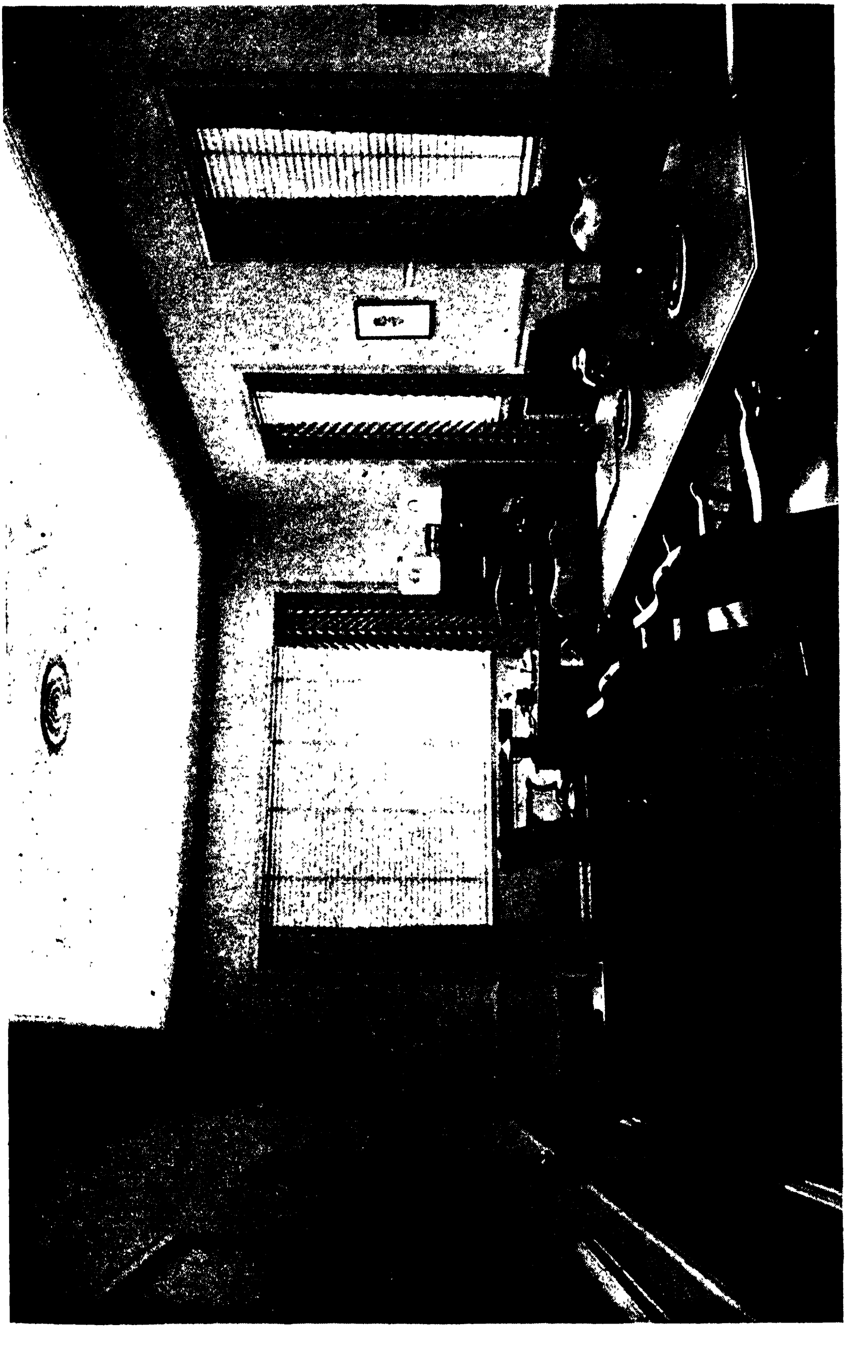


Fig. 60.—Fluorescent Lighting from an Indirect Cove.

(Loading about 20 watts per foot run. In some such cases it might be desirable to fit additional wall brackets to introduce a measure of brightness contrast into the field of view.)

Fig. 61.—FLUORESCENT LAMP FITTINGS EACH OF 320 WATTS REPLACE FORMER GASFILLED LAMP FITTINGS EACH OF 300 WATTS. ILLUMINATION RAISED FROM 15 TO 45 FOOTCANDLES.

illumination falls to a predetermined level, and switch them off again when it rises to a level at which artificial lighting can safely be dispensed with.

The colour of the light for ordinary classrooms is not a matter of great importance provided that it is as near to "white" as ordinary incandescent lamp light. There might perhaps be some advantage in using colour "A" fluorescent lamps on account of the close similarity of their light to daylight, but many will consider a warmer shade of "white" more restful. If one may judge by the prolonged controversy over the pleasantness or otherwise of the light from the "daylight blue" incandescent lamp, the question is merely one of personal preference which may indeed be strong, but for which it is usually difficult to give adequate reasons.

Workshops

School workshops should reproduce as nearly as possible the conditions which prevail in the best equipped modern factories, partly because it is naturally desirable for students to be given the best chance of doing good work and partly because early familiarity with good working conditions will enable them to detect, and perhaps cause to be corrected, deficiencies they are likely to find in any factory in which they may subsequently be employed.

The lighting installation should be no exception to this rule; and it need scarcely be said that any system, other than a fluorescent one, which purports to represent good industrial lighting practice, will rapidly become out of date.

4—OFFICES

Though there may be a few offices in which all the furnishings and fittings are on a lavish scale merely in order to impress customers and clients, an office is usually a place where work vital to the business is done, and where inefficiency, slowness and mistakes may have very far-reaching consequences.

Office work in general tends to become more intricate, and many processes are mechanised to simplify and speed up the work of employees. But the employees are not machines; unless they are given suitable conditions their work is bound to suffer, but the fault will not be theirs.

Lighting Requirements

It is reasonable to suppose that the level of illumination which can best be justified will lie above that of lighting inadequate enough to give rise to complaints, but below that chosen by the average office worker given entirely free choice in the matter. Two tests show where these limits lie.

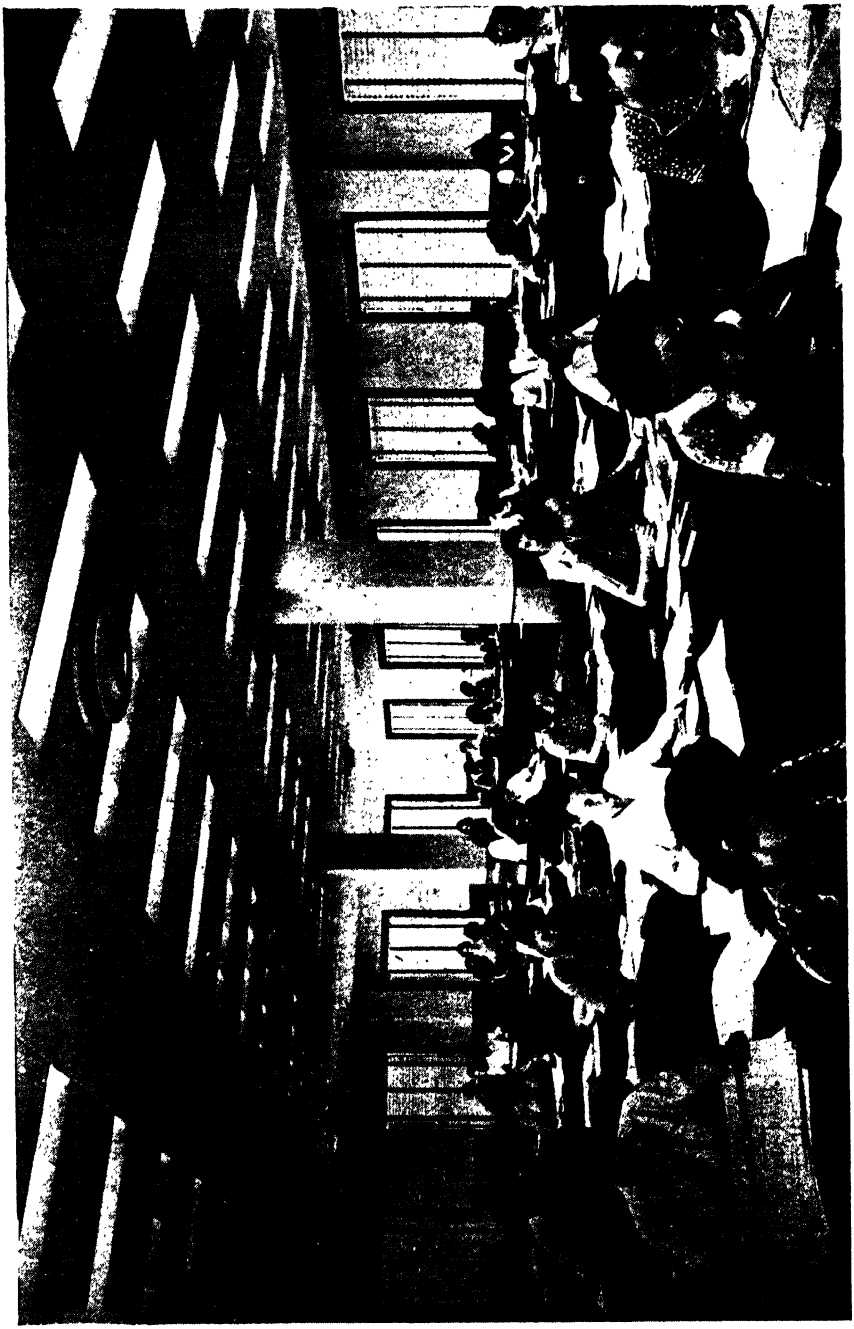


Fig. 62.—DISTANT FITTINGS CAN BECOME COMPLETELY INCONSPICUOUS.

Modified parabolic troffers, with semi-matt aluminium reflecting surfaces and transverse louvres.

In the first test* it was established that the average office worker will switch on artificial lighting as soon as the natural daylight illumination available falls to 5 footcandles.

Five footcandles can therefore be termed the "grumble-point". Not only is it the illumination level below which complaints are bound to arise, but it is the level at which the worker is quite conscious of being handicapped in her work. At considerably higher levels of illumination she will still be handicapped, though she may be unaware of the fact and would not think her speed and efficiency were being reduced.

The other test concerns a group of office workers entirely free to select the illumination they preferred for transcribing shorthand notes and typing. Without counting the cost, they could have anything from 2 to 500 footcandles; and though, as one would expect, there was a considerable variation in the choice made by individuals, the average choice was for 95 footcandles.

Though economics may make it impractical at present to erect office lighting installations giving a general illumination of this order, it is apparent that in normal times we should get as close to it as we reasonably can. At the same time we must ensure that the lighting is as comfortable as it can be made, and it is in this particular that fluorescent lighting has great advantages. Elaborate diffusing devices are not necessary to reduce the brightness of the lamps to comfortable limits, and comparatively high illumination levels can be produced with none of the glitter one usually associates with them. Also, one might well hesitate to instal a system of incandescent lamps giving 50 footcandles, as if its appearance were in keeping with modern office standards it would generate an amount of heat which would raise problems of its own; fluorescent lighting, of comparably good appearance, on the other hand, would have a relatively small effect on the temperature of the room or its occupants.

Daylight lighting in an office may well be as unevenly distributed as in Schools; if artificial lights in offices are not automatically controlled (p. 128) the circuits should at least be arranged so that those farthest from the windows may independently switch on the lights in that part of the room as soon as daylight becomes insufficient.

Decorations and Equipment

The illustrations show a number of examples of offices in which the lighting has been planned to give comfortable and rapid vision, but it should be recognised that the most perfect lighting installation cannot be fully effective unless other factors affecting seeing are also doing their part.

Chief among these is contrast. Under twenty-five, thirty, fifty and more footcandles of illumination, white paper has a brightness far higher

* "Daylight Illumination Necessary for Clerical Work," Technical Paper No. 19, Department of Scientific and Industrial Research.

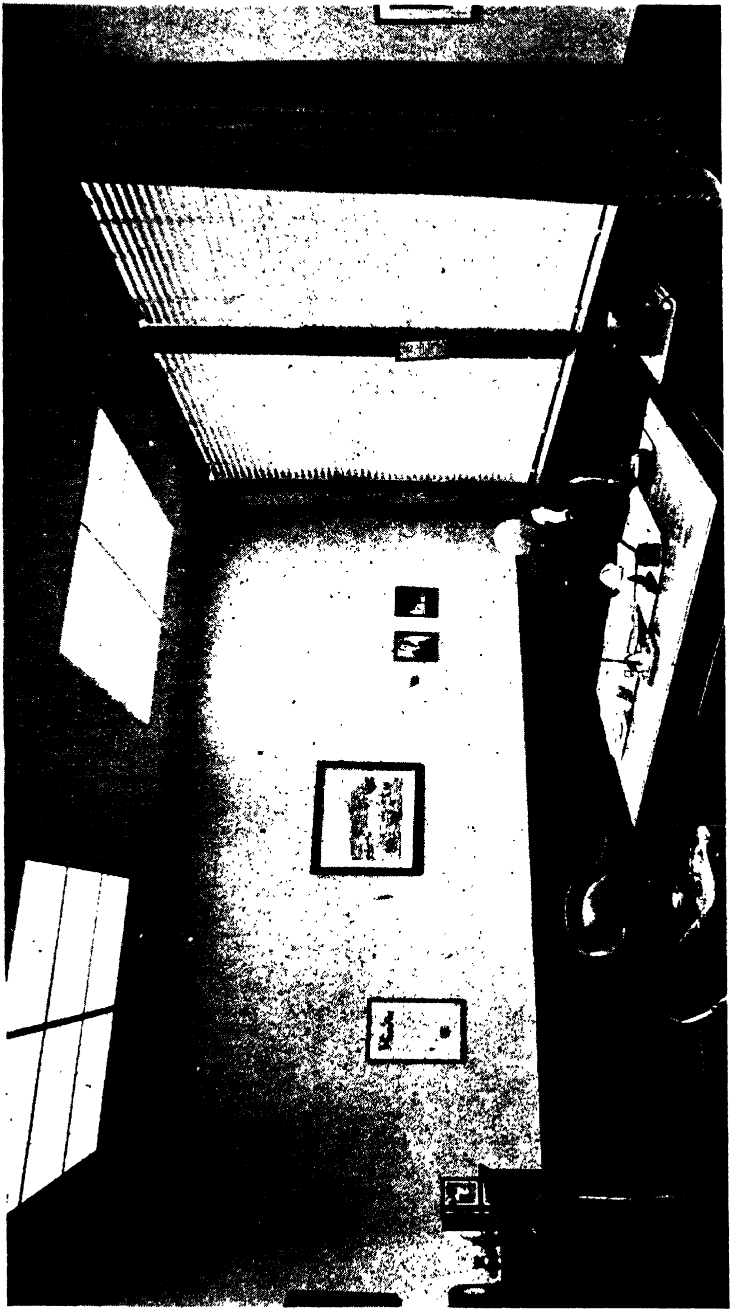


Fig. 63.—THE ILLUMINATION IN THIS 16 FT. BY 15 FT. OFFICE IS ALMOST 100 FOOTCANDLES, PROVIDED BY FOUR RECESSED COFFERS CLOSED BY DIFFUSING GLASS. EACH COFFER CONTAINS A TOTAL OF 400 WATTS OF FLUORESCENT LAMPS.

Relatively high artificial lighting values of this order are still only a fraction of those obtaining out-of-doors from a north sky.

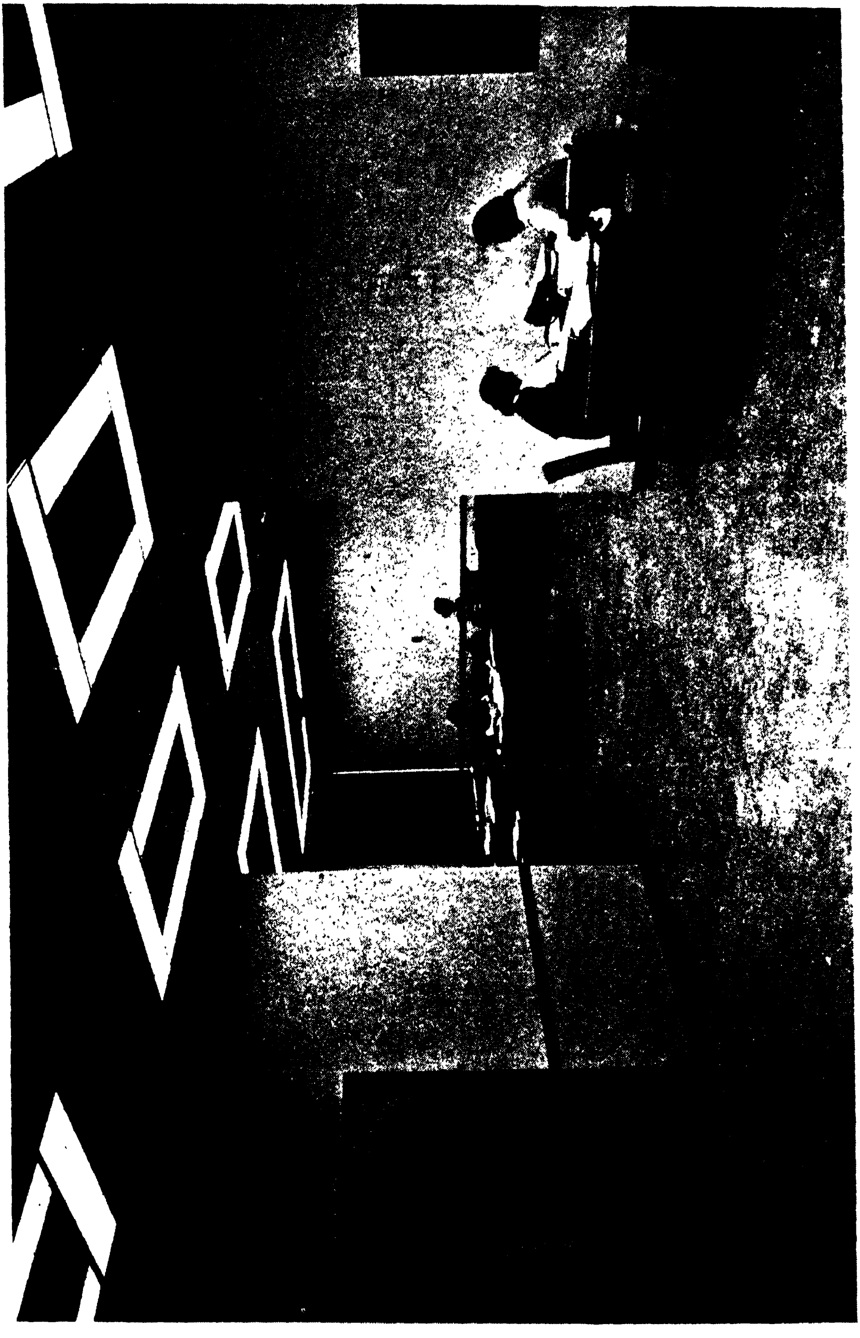


Fig. 64.—50–55 FOOTCANDLES IN SERVICE FROM RECESSED TROFFERS.
(Top surface of glass panels is frosted, lower surface fluted. Panels are hinged for easy access.)

Fig. 65.—Troffers specially designed to present Low-brightness Surfaces at Normal Angles of View.
(Louvred aluminium reflectors of modified parabolic section. Spacing, 4 ft. Note short sections at left hand end of each third main troffer; these compensate for light lost through windows.)

than that of a dark coloured desk top. The contrast between the two should be reduced by finishing desks, and indeed all office furniture, in reasonably light colours. The finish of office equipment should also be matt, so far as the requirements of maintenance allow, in order to reduce high-lights reflected in polished surfaces; light-coloured semi-matt linoleum has been used, for instance, as a very satisfactory cover for desk tops.

Dark panelled walls may be impressive for a board-room, where one does not expect the visual tasks to be severe, but the "dignity" of dark surroundings should be reserved for such places; light coloured walls and ceiling are necessary components in the plan for better seeing, both for the sake of economy and for the comfort without which no commercial lighting installation can be a complete success.

5—DOMESTIC LIGHTING

It is not to be expected that fluorescent lamps will be in general use in homes for some considerable time, partly on account of conservatism and partly because the public as a whole will not become aware that new and suitable light sources are available until they are widely used in such places as shops, restaurants and cinemas.

It is an uphill task trying to tell the average householder what kind of lighting he should have. He makes his own choice for his own reasons, though the result is not often all that might be desired either as regards quantity, quality or decorative value. In point of fact, the greater part of the "utility" lighting of the ordinary home can be done quite effectively and pleasantly by incandescent gasfilled lamps in suitable fittings, and for most domestic purposes there is little to justify fluorescent lighting unless its overall cost over a period of time is below that of equivalent incandescent lighting.

Before the war, however, an increasing number of householders were beginning to realise that lighting need not necessarily be carried out only by pendant fittings or wall brackets. Cornice lighting installations were becoming more popular; lighting behind curtain pelmets and similar decorative schemes were being tried; luminous panels were being fitted in addition to, or instead of, the ceiling lights in various parts of the house: and for all such applications, which may be broadly classed as "built-in" lighting, there is no doubt that fluorescent lamps will be especially suitable, both on account of the reduced running cost and of the greater ease of avoiding patchiness or spottiness of the lighting, which can so often mar its appearance.

There is one room in particular for which fluorescent lamps can certainly be justified. It has often been said that the lighting of the kitchen should be the best in the house, since it is the home workshop in which the housewife spends a large part of her time, and in which she requires to

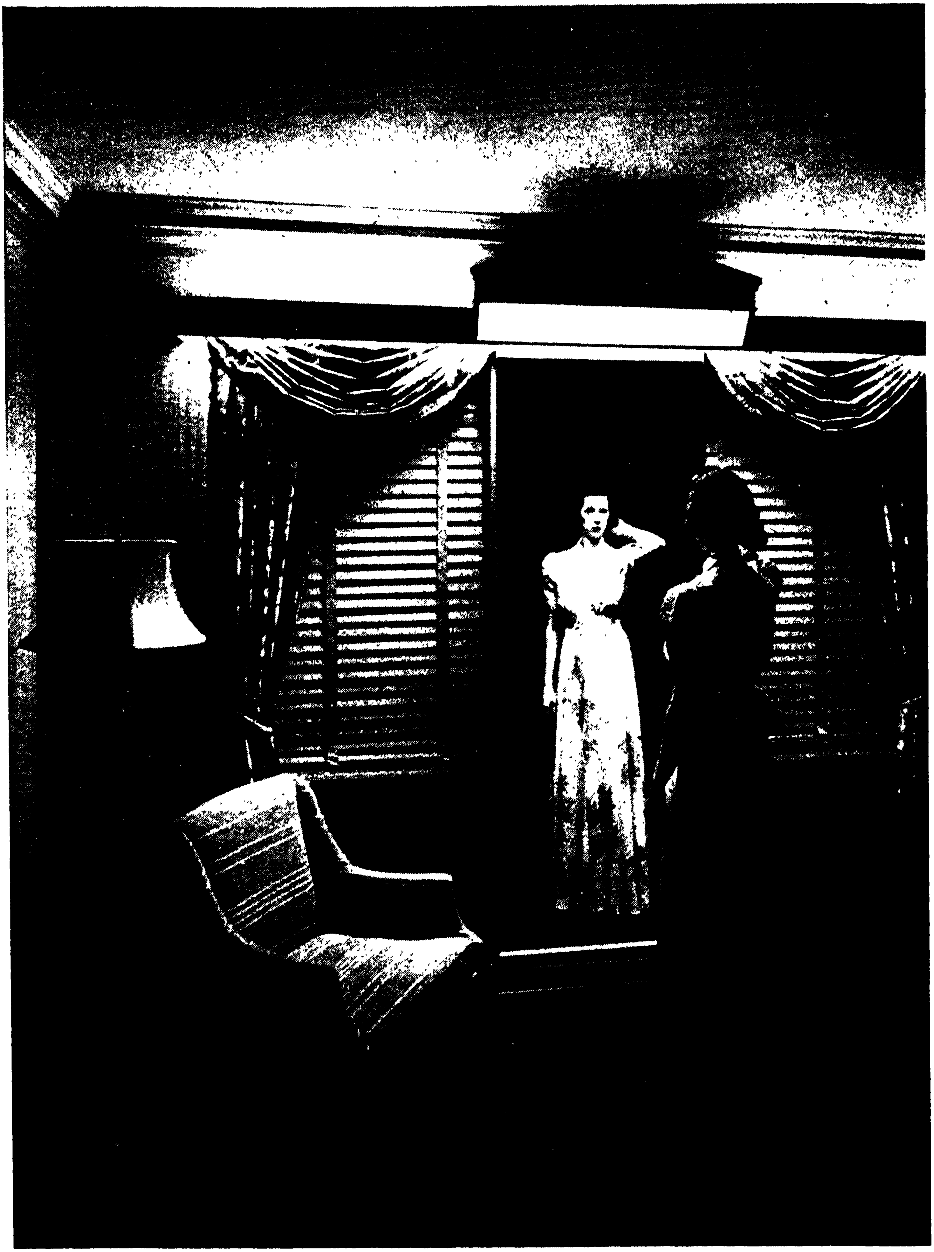


Fig. 66.—A FULL-LENGTH MIRROR WITH FLUORESCENT LIGHTING PROVIDING 20–25 FOOTCANDLES ILLUMINATION OVER THE ENTIRE FIGURE 30 INCHES FROM THE GLASS.

Note also the decorative curtain lighting from behind each pelmet.

see things as they really are. But except on special occasions it is out of the question to use a portable lamp to get the light where it is specially required, as can be done in other rooms; the lighting is fixed to the wall or ceiling and must do its job adequately from there.

Generally the sink and cooker are arranged against adjacent walls, and for the lighting to be effective a person standing in front of either

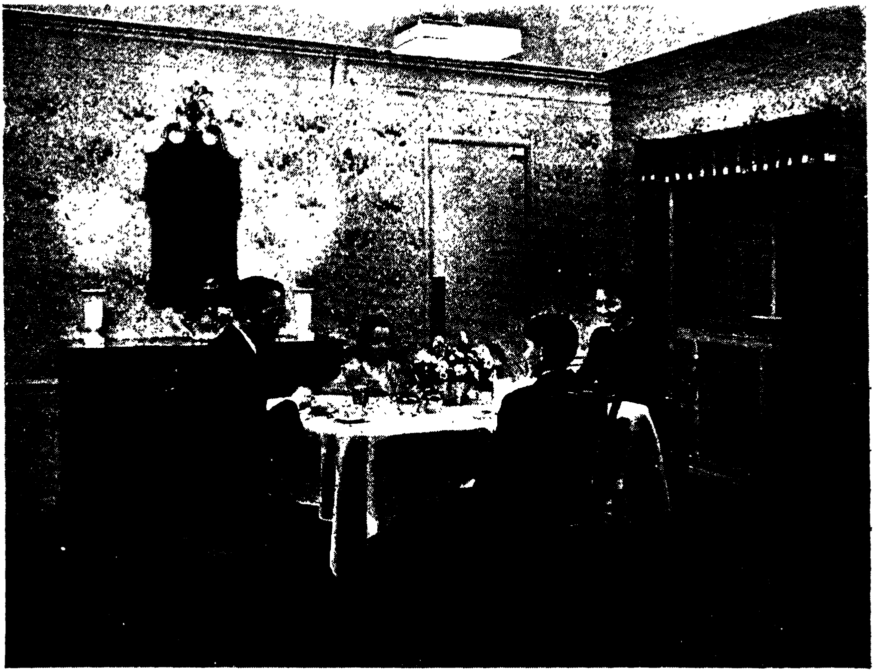


Fig. 67.—About 15 footcandles Illumination is provided on and around the table area by a total of 60 watts of Fluorescent Lighting.

must cast practically no shadow. It is impossible to arrange shadowless lighting in a kitchen from a single lamp, but two fluorescent lamps, if properly arranged, can be very satisfactory in this respect. One should be mounted on the ceiling over the sink, or perhaps on the wall above the window, if the sink stands in front of this; the other should be on the ceiling in a position nearly over the front edge of the cooker. The two lamps are thus arranged in the form of a broken "L" and shadows all over the room are soft, while at the sink and cooker they scarcely exist.

Since many of the articles used in the kitchen, such as knives and spoons, catch the light and are apt to emphasize stroboscopic flicker, it is advisable to balance the two-lamp circuit as described on page 46 in order to reduce this effect to the minimum; it is not strictly necessary to do so, however, as the housewife rapidly becomes accustomed to the flicker occasionally noticeable with straightforward inductive circuits.

Fluorescent lamps can also be used with advantage in situations where tubular incandescent lamps were formerly employed, as for instance for dressing table and shaving mirrors; an equal quantity of light will be obtained with a very greatly reduced current consumption. This matter is not of great importance, of course, since the period of use of such lamps is very limited, and the cost of current for them is usually insignificant.

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