COLD CATHODE FLUORESCENT LIGHTING

COLD CATHODE FLUORESCENT LIGHTING

BY

HENRY A. MILLER, A.M.I.E.E.

LONDON
THE TECHNICAL PRESS LTD.
LATE OF AVE MARIA LANE, LUDGATE HILL
GLOUCESTER ROAD, KINGSTON HILL, SURREY
1949

First Published 1949

Made and printed in Great Britain by
Stephen Austin & Sons, Ltd., Printers, Hertford.

PREFACE

This is really an attempt at pioneering, for, to the best of my knowledge, it is the first book entirely devoted to cold cathode fluorescent lighting.

Although cold cathode is a comparatively new departure in interior lighting technique, it is already well past the experimental stage. This is borne out by the recent practical applications which indicate that future possibilities are enormous. Cold cathode fluorescent lighting has undoubtedly come to stay.

In a scientific era, with widespread atomic energy round the corner, it is fitting that our houses, shops, offices, factories and buildings generally should be illuminated by electronic sources. It is not suggested that the new lighting medium will entirely replace the two, four or five feet long hot cathode fluorescent lamp. For, despite the fact that it *can* be mass-produced, it is not (in my opinion) merely as a straight tube of standard length that cold cathode will have its maximum demand ; it will, I feel, be more in the form of a decorative lighting unit specially adapted to individual situations and designed to harmonize with existing architectural features.

The object of this book is to describe the principles, manufacture, operation and installation of cold cathode fluorescent lighting.

It is intended to be of interest to the student, the electrical engineer, the practising architect and all distributors, users and potential users of fluorescent lighting. The chapter on manufacture and vacuum technique will, of course, concern only the first two.

With these brief preliminaries goes the hope that the work in some measure achieves its aim.

HENRY A. MILLER.

Liverpool.
1949.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of the following in supplying technical information and illustrations :

Acme Electric Corporation, British Thomson-Houston Co., Ltd., Colorescent Laboratories, W. Edwards and Co. (London), Ltd., Fluorescent Lighting Association, Franco-British Electrical Co., Ltd., General Electric Co., Ltd., General Luminescent Corporation, Illuminating Engineering Society, Lighting Service Bureau, Sola Electric Company, *Signs of the Times* Magazine, Swedish Iron and Steel Corporation, Westinghouse Electric and Manufacturing Co.

The photograph on the dust cover is reproduced by kind permission of The British Thomson-Houston Co., Ltd.

CONTENTS

CHAPTER I

GENERAL

Light

Light may be defined as radiant energy evaluated according to its capacity to produce visual sensation. In other words, it is a form of radiant energy that reacts on the optic nerve in order to make us see. Radiant energy consists of periodic disturbances. This band of disturbances covers an extremely wide frequency range, but light, or the visible portion, occupies only a narrow strip of the band (between 400 and 750 million vibrations per second). The colour of the visible light produced depends on the frequency of the vibrations. There are several scientific concepts of light, but it will be sufficient for our purpose if we conclude that it consists of rapid vibrations in the ether. For we are concerned here not so much with the cause as with the effect.

Natural light or daylight consists of all colours of the solar spectrum—violet, indigo, blue, green, yellow, orange, red—although this varies according to the time of day and the climatic conditions. Noon sunlight on a clear June day is often taken as the standard for comparison.

Some people take natural light for granted. They see, yet fail to observe, the infinite variations of daylight in the natural scene. They are content to visualize sunlight as yellowish-white in colour and unchanging in effect; they recognize quantity but not quality. To such people the incandescent lamp may seem as good an all-purpose light source as any.

Only in recent years has quality in lighting really been taken into account. Artificial lighting was formerly something of an afterthought in building schemes—a kind of necessary evil. But nowadays illumination has a technique all its own and the lighting engineer is a specialist. With the recognition that illumination is something more than making things visible has come the realization that it has a pronounced pyschological effect; that it can create atmosphere, promote moods; in short, that good lighting is both a salutary and a commercial proposition.

The Human Eye

The eye is the medium by means of which light is apparent. The human eye consists of a lens which throws an image of an object on the retina, and an iris or diaphragm for controlling the light through the lens to the retina. It is a most adaptable organ capable of functioning over a range of illumination levels as great as 100,000 to 1.

Rays of light are reflected from the object seen into the viewer's eye. They pass through the pupil, which is the opening in the centre of the iris, and the lens, controlled by tiny muscles, focuses the image on the retina. The retina is studded with ends of a multitude of nerves. These nerves are stimulated by light and convey to the brain the sensation of seeing.

Since seeing is both a physical and a mental process, bad lighting can adversely affect both body and mind.

Speed of Vision

Up to a certain limit providing a high level of good quality illumination increases the speed with which a seeing task can be performed. Also, the decreases in time required to carry out a specified seeing task diminish as the higher levels of lighting are approached. In cases of defective eyesight the advantages of higher levels of illumination are even more marked.

It is not generally realized that the process of seeing takes a certain amount of time. The time taken depends to some extent on the relative positions of the eye and the object. For instance, it is estimated that from 0·1 to 0·2 second according to the efficiency of the lighting is needed for the eye to transmit each message to the brain in reading a line of print.

Propagation of Light

Light travels in straight lines. If this fundamental law were not true we should not be able to "see" anything properly. In fact, no object would appear to our eyes to have any shape; we should be conscious only of a sensation of brightness or darkness.

The fact that light can be scattered leads us to believe that when it falls on an atom it sets the electrons in motion so that they re-emit light. The character of scattered light depends on the nature of the atom as well as on the incident light.

In the graphical representation of light propagation a line drawn in the direction of light travel is conventionally termed a ray; a number of rays, either parallel, divergent, or convergent being known as a beam.

Light, as everyone knows, casts shadows. If an opaque sheet with a narrow slit is placed between a light source and a screen, a bright strip surrounded by a shadow will be observed on the screen. If a sharp edge is interspersed in front of and parallel to the slit, then the edge of the shadow on the screen will be broken up into bands. This is due to diffraction of the light. In view of the wave theory of light, it might be asked, why did not the light spread out in all directions after passing through the slit? The reason is that the waves of light are extremely small compared with the distance between the slit and the source of light. Due to the different distances travelled by different rays of light, many of the light waves will neutralize one another's effects. This condition is more marked when the source is a bulb rather than tubular in shape.

Reflection

If what we know as a ray of light was made to pass through pure dry air, it would be invisible, although the source could be seen. Only when the ray reached a surface, such as a wall, would the light be apparent. Normally, however, this condition is not likely to be met with. The air we breathe contains minute particles of dust and moisture which deflect and scatter light. So an observer is able to see the passage of a ray in a darkened room because the light is reflected from the particles into his eyes. Obviously, reflection plays an important part in lighting technique. In fact, if there were no reflection there would be no lighting technique.

Since light is itself invisible, it follows that we are only able to see those objects that reflect at least some of the light falling upon them. Furthermore, those objects appear to our eyes to vary in shape and texture solely because they reflect certain qualities of light in a particular way. A red object appears red when it reflects only red rays. A polished object appears smooth because it reflects rays at the angle at which they strike it ; a surface is seen to be rough when it scatters the rays at various angles.

Diffusions

Light passes practically unchanged through a transparent medium such as clear glass or plastic. If the glass or plastic is frosted or shot-blasted (translucent), however, the rays are scattered as they pass through it. This effect, which is known as diffusion, is utilized in lighting units to obscure the light source and spread the light. Soft or diffused lighting is both restful and pleasing.

Colour

If a ray of light passes through a translucent object in the form of a glass prism, not only will the ray be split up, but each component colour of the spectrum will be separated. This is because, in passing through the prism, the velocity of each colour has been reduced by a different amount. White light, therefore, consists of vibrations of varying length (i.e. producing different colour sensations) all travelling at the same speed.

We saw that a red object illuminated by white light reflected only red rays. A coloured translucent medium does not colour or tint any white light that passes through it ; it merely obstructs all rays except those of its own particular colour. And when we are dealing with coloured light sources we must remember these points. The apparent colour of all objects is completely dependent on the colour of the lighting.

The mixing of coloured light does not follow the same rules as those governing paints or pigments. From our early school lessons in art we may remember that all colours could be made up of three primary colours—blue, yellow, and red—and that a mixture of each two of these produced the three secondary colours orange, violet, and green, which were said to be complementary. In the case of light the primary colours are red, green, and a particular blue which, when mixed together, result in white. This mixing of coloured light to produce white would, if it were required, present many difficulties in practice.

Colours, in so far as lighting is concerned, are associated with some emotional quality. To some extent this quality may be comparable with the state of the sky—a " warm-orange " simulating sunlight and a " cold grey " imitating an overcast sky. In display work red or orange may be used to indicate warmth and blue lighting to convey the impression of coolness.

For most purposes, daylight is taken as the ideal in spectral composition, although there are certain cases where this is not so. In some industrial applications, particularly ore-sorting operations, a deficiency in red in the spectrum of the lighting is an advantage. Other cases occur in which an excess of red light is required.

However, it is important to remember that seeing depends a great deal upon recognition of colour contrasts. For general purposes, distortion of colour rendering makes certain contrasts very difficult to recognize since, as we saw earlier on, the colour of an object as seen by the eye is dependent upon the property the object has of reflecting only certain wavelengths of light. If those certain wavelengths of light are not provided by the source of light, the object will have a false appearance of colour.

The retina of the eye is now known to consist of two components called rods and cones. For normal light intensities it is the cones that are most concerned in conveying visual sensation (the rods being utilized only for very low intensities). There are three types of cones which produce sensations of red, green, and blue respectively.

The subjective valuation of things viewed by the eye and loosely interpreted by the individual may be roughly classified into (*a*) brilliance, (*b*) hue, and (*c*) purity. Let us analyse these three classes. Class (*a*) presupposes the relative placing of an object somewhere in a scale which has white at one end and black at the other ; in other words, assessing a surface as or equivalent to one of a series of greys. The second class attributes the quality by which the object differs from grey (e.g. reddish, greenish, bluish). In class (*c*) we are concerned with degree of purity or vividness. Two surfaces or portions of surface may have the same brilliance and hue, yet one may appear more vivid than the other. This way of specifying colour attributes is identified by the term "spectroradiometric function".

Although different colours may reach the eye with equal intensity, they do not appear of equal brightness. This is because the eye is more sensitive to some colours than to others. Sensitivity tests have ascertained that yellow-green light having a wavelength of 5,550 Angstrom units has the greatest apparent brightness.

Illumination Terms

The design of artificial lighting is based on certain standard definitions. Chief amongst these is that of illumination itself, which may be defined as the amount of light falling on a surface as measured by the amount reflected from each unit area of the surface.

Until quite recently illumination values were expressed as so many foot-candles. In the new I.E.S. Code (issued by the Illuminating Engineering Society, London), however, the unit is called 1 lumen per square foot. This does not involve any numerical change in conversion, as 1 foot-candle is a measure of the degree to which a surface is illuminated when 1 lumen of light flux (see below) is distributed evenly over 1 square foot of the surface.

The term "illumination" may be used to denote quality as well as quantity. Other important terms are :—

Luminous Intensity.—The intensity of light emitted by a source in a stated direction is expressed in candle-power, one candle-power being the lighting power of a standard candle of specified construction. Although the candle-power of a source in various directions may be used in illumination calculations, it is not a direct measurement of the quantity of light emitted. A "polar-curve" is used to show graphically the candle-power distribution of a lighting unit in any particular plane.

The average candle-power of a source measured in all directions is called the "mean spherical candle-power".

Light Flux.—The unit of light flux is the lumen which is the direct light flux intercepted by or falling upon a surface of 1 square foot, every part of which is at a distance of 1 foot from a uniform point source of 1 candle-power (i.e. lumen per square foot).

A uniform point source of 1 lumen per square foot emits 4π (12·57) lumens.

Brightness.—The average brightness of any projected surface emitting or reflecting one lumen per square foot is called 1 equivalent foot-candle.

The low surface brightness of fluorescent tubing is one of its advantages over other light sources. This is obvious when it is considered that the total light output of a source is proportional to its average brightness multiplied by its superficial luminous area.

Any source capable of producing the sensation of brilliance possesses the property of brightness. The generally accepted standard, by international agreement, is the brightness of the black body radiator. It is, strictly speaking, the brightness of a source that specifies the ability of an element of the source to produce luminous effects.

The average brightness of a source may be approximately determined by the ratio of the illumination upon a surface normal to the source at its centre to the solid angle subtended by the source. This relationship is particularly useful in assessing the brightness of a gaseous discharge column.

For a perfectly diffusing luminous surface, having constant brightness from any angle of observation, the brightness in any direction at a point on that surface is commercially equal to the luminosity at that point divided by π.

In estimating brightness the only possible course is to base the estimate on brightnesses that appear equal to the average observer. The popular unit of brightness is the "equivalent foot-candle" which is the brightness of a white diffusing surface of 100 per cent reflection factor having an illumination of one lumen per square foot. Obviously, for a coloured surface of the same illumination the brightness will be proportionally less. The particular surface adopted as a standard is magnesium oxide, the source of illumination being a tungsten filament vacuum lamp.

If a coloured surface appears to the average observer to be neither darker nor lighter than a white surface of brightness 0·05 equivalent foot-candle, then he is justified in saying that the "apparent" brightness of the coloured surface is 0·05 equivalent foot-candle.

To be strictly correct in estimates of brightness, three factors related to the human eye should be taken into account. They are (1) the Purkinje effect, which causes displacement of eye sensitivity values at very low intensities ; (2) the amount of dilation of the pupils, which are assumed to be at maximum diameter as they are in the dark ; and (3) the angle of the observer's eye subtended by the surface viewed—in other words, the surface must not be so small as to cause an image on the fovea only.

Area-Brightness.—In problems of light distribution and control both the brightness and area of the source are important. The lower the brightness the larger will be the reflector required to project a given amount of illumination.

Whilst it is true that greater control is possible with a small source of light, the element of glare is also much greater. Therefore, this possible advantage of filament lamps over luminous tubing is cancelled out in all cases where general illumination over a large area is required. This is particularly true where reflected glare is likely to be experienced. In addition, large area sources such as fluorescent tubing, produce soft almost shadowless lighting, whereas filament lamps or other small-area sources are liable to cast heavy shadows.

Glare.—Glare, or dazzle, is mainly caused by excessive contrasts. Although direct glare is less likely to occur with fluorescent lighting than with other lighting owing to the long length and low surface brightness of the tubes, it can be caused when the lighting unit is viewed against a dark background. Polished surfaces or other specular materials in the field of vision may be indirect sources of glare.

In planning a lighting installation it is advisable to ensure that where local lighting is used the general interior lighting should not be less than 6 lumens per square foot ; also that with horizontal illumination of about 6 lumens per square foot the brightness of parts of lighting fittings or other objects that would be visible within an angle at the eye of 110 degrees from the perpendicular to the floor would not exceed 2·5 candles per square inch for a fitting mounted at or less than 8 feet above the floor. The latter stipulation is based on the assumption that the brightness of the lighting units used, in candles per square inch, should roughly be made numerically equal to the square root of the number of lumens per square foot required on the horizontal working plane. These arbitrary values, however, are only used as a guide.

The effect of glare—either direct or reflected—in the eyes of a viewer is to cause discomfort and fatigue and hence to reduce the efficiency with which a given task can be carried out. In general, direct lighting units should always be mounted at sufficient height to keep them well above the normal line of vision.

Factors

In planning a lighting installation it is advisable to take the following factors into account :—

Maintenance Factor.—This is applied to allow for the deterioration of a lighting scheme due to the accumulation of dust or dirt both on the lighting units themselves and on ceilings, walls, and other surroundings. Periodical cleaning would, of course, keep this factor high, but even then a factor of 0·8 is found in practice to be appropriate. Under particularly dirty conditions the factor to be applied may be as low as 0·4.

Absorption Factor.—This is applied in situations where some of the light will be absorbed before reaching the working plane. In a foundry, laundry, or other locality in which there is a smoky or steam-laden atmosphere, a reasonable absorption factor would be 0·5.

Reflection Factor.—This refers to the proportion of light reflected from walls and ceilings in normal condition, and depends to a great extent on the colour of room decoration, etc. If the walls are obscured by fixtures such as cupboards or shelves of a dark colour, these must be taken into account in assessing the reflector factor ; this also applies to dark window coverings. A cream ceiling should have a factor of about 70 per cent.

Coefficient of Utilization.—This is dependent on the type of lighting equipment, the dimensions of the room, and the reflection factors of the ceilings and walls. For convenience in planning lighting installations, coefficients of utilization are usually tabulated in handbooks of illumination.

Sources of Artificial Light

Artificial light can be produced electrically in two ways : (1) by incandescence, and (2) by an electric discharge.

Incandescent lighting is obtained by temperature radiation, that is by raising the temperature of a body above that of its surroundings.

Imagine a small piece of metal to be suspended in a darkened room so that it is invisible. If sufficient heat is applied to the piece of metal it will begin to glow, first dull red, and then yellowish-white. At the latter stage the metal will be luminous ; i.e. it will become incandescent.

Incandescent light sources have been used since time immemorial. Oil lamps were known at Ur of the Chaldees 3500 B.C. Homer (1000 B.C.) described a splinter of pine which acted as a torch. Later, through the ages, we had candles introduced by the Phœnicians, flame lanterns used in the time of King Alfred the Great, and the coal gas lighting of Clayton, 1691.

A present-day example of incandescent lighting is the electric filament lamp in which light is produced by molecular activity in the filament caused by the heating action of the electric current. These lamps have been developed from the platinum wire lamps of Grove and de Moleyns via the carbon filament lamp of Edison and Swan, the Nernst rare earth lamp and the tantalum lamp, to the coiled-coil gas-filled device that we have to-day.

An incandescent electric lamp is simply a filament or wire enclosed in an evacuated glass bulb. A small quantity of gas—argon or nitrogen—is inserted into a gas-filled filament lamp solely in order to provide an internal pressure ; it takes no part in the production of light. This gas filling necessitates a filament of special design. It may be noticed that the filament in a vacuum lamp is in the form of a long thin wire, whereas in a gas-filled lamp the filament is closely coiled up. This is to reduce the undesirable cooling effect which the gas has on the filament.

Electric lamps are usually rated in watts, which, in the case of filament lamps, is the product of the current passing through the filament in amperes and the voltage of the supply. A 100-watt filament lamp on a 230-volt supply will therefore have a current of $\frac{100}{230}$ or 0·43 ampere.

Although great advances have been made towards the improvement of incandescent electric lamp efficiencies, the modern gas-filled tungsten filament lamp has an efficiency of only about 2 per cent ; most of the energy is utilized in the production of unwanted heat. Incidentally, 65 per cent of this heat is in radiant form which reacts directly on the occupants of a room without influencing a thermometer.

Of recent years, however, electric discharge lamps have been developed considerably and are rapidly replacing filament lamps for many applications. This form of lighting gives efficiencies very much greater than that obtained from incandescent lamps. The high-pressure mercury-vapour lamp, for instance, operates with an efficiency more than twice that of the gas-filled filament lamp.

The luminosity of a discharge lamp does not depend on the heating of a filament. The flow of electric current is rather akin to an elongated spark ; the gases or vapours contained in the lamp are themselves the conductors of electricity. Therefore, the amount of heat generated is small and the efficiency of the light source is correspondingly higher than that obtained by incandescence. And, what is probably more important still the quality of the lighting can be improved.

All electric discharge lamps, as will be described more fully in the next chapter, consist essentially of a glass or quartz tube fitted with metal electrodes (or cathodes) and containing a gas or metal vapour or both. One of the more fundamental types of discharge lamp contains a quantity of argon and mercury vapour. This gives a blue-green light. In another type of discharge lamp sodium vapour is used, which emits a monochromatic yellow light of extremely high intensity. Both of these lamps are used extensively for road lighting.

A more recent development in discharge lighting is the tubular fluorescent lamp. In this type of light source the interior of the glass tube is coated with luminescent powder that converts the invisible ultra-violet radiation of the low pressure mercury vapour discharge (which represents roughly one-half of the total energy) into visible light.

Mention has already been made of the fact that daylight is variable ; for instance, daylight under a western sunset sky is pinker or " warmer " than that under a north sky. The luminescent powders of fluorescent lamps are therefore arranged to give either of two alternative qualities of white light—" daylight " and " warm white ".

By replacing a small source of light (the filament lamp) by a comparatively large one (the fluorescent discharge tube) the possibility of shadow is reduced enormously. Also, by employing fluorescent discharge tubing giving a light approximating to daylight, coloured objects can be observed under more natural conditions. In addition, since in the case of the fluorescent tube the light is emitted from a larger source, the surface brightness of the tube is low enough to view directly without straining the eyes.

There are two main types of fluorescent lamps : (1) hot cathode, and (2) cold cathode.

(a) (b)

Fig. 1.—(*a*) Hot Cathode, (*b*) Cold Cathode.

The most familiar hot cathode lamps are the straight 5 feet long of 80 watts and the straight 4 feet long of 40 watts. These lamps operate from mains voltages but must contain cathodes (connections which lead the current into the gas and vapour) incorporating heating elements for starting the discharge. They have a guaranteed life of 2,000 hours.

In common with the high-pressure mercury and sodium lamps, the hot-cathode fluorescent lamp needs to be connected to some form of current limiting device, such as a choke, to prevent the discharge from " building up " and ultimately destroying the lamp. It is usual to have a separate choke for each lamp. In addition to the choke a special automatic starter is required. This has the double function of switching on the filament heaters momentarily and providing a high-voltage starting pulse across the lamp. An "instant start" circuit has been devised for hot-cathode fluorescent lamps but, owing to its high cost and technical difficulties, this has not been generally adopted.

Hot cathode fluorescent lamps radiate comparatively little heat. They have an overall efficiency of about 60 per cent, of which 40 per cent is in the infra-red and 20 per cent visible light. When we compare this with the 85 per cent infra red of a tungsten filament lamp, which consumes about double the energy for the same light output, we see that the heat from the fluorescent lamp is only about one-quarter of that from the filament lamp.

Cold cathode fluorescent tubing is a still more recent development in interior lighting technique. It has become extremely popular in the United States and is rapidly gaining favour in this country. Its main advantages over hot cathode tubing are its much longer life, its instantaneous starting, and its greater flexibility for decorative effects.

Cold cathode lamps or tubes may be theoretically of any length and in any one of a number of alternative colours, including daylight and warm white. They normally require a high voltage electric supply. The cold cathode discharge strikes up immediately the current is switched on and no filament heating or auxiliary starting apparatus is necessary. Being of fairly small diameter, the tubes can be bent into almost any contour. Their guaranteed life is from 5,000 to 10,000 hours.

The high voltage necessary to start and maintain the discharge is provided by a step-up transformer which, incidentally, dispenses with the need for a choke. Special precautions are necessary in isolating the high-voltage wiring and connections.

The electrodes or cathodes in a cold cathode tube operate at about 300° F. as compared with a filament temperature of 1,652° F. in the hot cathode lamp; hence the name. This does not necessarily mean that the cold cathode tube generates less heat than the hot cathode tube. The amount of heat produced depends on the wattage of the lamps.

Typical average efficiency of both types of fluorescent lamp is 24 lumens per watt (hot cathode 5 ft. 80 watts and cold cathode 9 ft. 6 in. 83 watts).

Chapter II

DISCHARGE PHENOMENA

The Electric Discharge

To some extent air is considered an insulator, but the fact that it can conduct electricity under certain conditions will be apparent to anyone who has watched an electric spark. The spark or flash that jumps across from one conductor to another or from a conductor to earth is called a discharge. Lightning, known as static discharge, is a familiar form of this.

With air at its normal or atmospheric pressure there must be considerable potential difference between two conductors before a spark occurs and current can pass ; this means that a high voltage must be applied to the conductors. The value of the necessary voltage depends upon the distance apart of the conductors and to a lesser extent upon their shape.

Cold cathode lighting tubes are low-pressure discharge devices. The pressure inside the tubes is very much less than atmospheric. This, as we shall see, has considerable effect on the conditions necessary for an electric discharge to take place.

If we have a glass tube with its ends sealed up but with a metallic connection passing through each end so as to leave the tube airtight and we apply sufficient voltage across the metallic conductors a violet glow will be seen to extend along the tube and a faint hissing noise will be heard. This is a brush discharge.

Further increases in the potential difference will result in a succession of spark discharges in the form of luminous streaks resembling small-scale lightning. At this stage the applied voltage will be extremely high.

If the tube were connected to a vacuum pump and the pressure inside the tube gradually reduced we should see that the character of the electric discharge would undergo many changes.

At between one-half and one-third of atmospheric pressure the hissing or crackling would cease and the discharge would assume the form of a pink streamer. As the pressure was reduced still further the discharge would spread out and would become highly luminous. The necessary difference of potential between the conductors at the ends of the tube under these conditions would be very much less than that required at atmospheric pressure.

Close inspection of the tube would show a dark space near one of the conductors (the cathode). This is called the Faraday dark space. Extending from the dark space right to the other conductor (the anode) would be the luminous glow or positive column.

As the pressure was further reduced, thin bluish streamers would appear. These streamers would be seen to be constantly changing their discharge path.

When the pressure was down to about one four-hundredth of atmospheric the bluish streamers would change to a pink discharge practically filling the whole of the tube with the exception of the Faraday dark space and a bluish glow adjacent to the cathode which is known as the negative glow.

Still further reduction in pressure would cause the Faraday dark space to enlarge and move towards the anode and the negative glow to detach itself from the cathode and leave a second dark space. This second dark space would be the Crookes' dark space.

The Crookes' dark space would continue to extend as the pressure was reduced until finally there would be no luminous column. The actual walls of the glass would become luminous at this stage, the colour depending on the kind of glass of which the tube was made ; soda glass would glow a bright green, lead glass a bluish tint.

Supposing, after as much air as possible had been extracted from the tube, a small amount of rare inert gas such as neon or argon was admitted to the tube. The necessary voltage for the current to pass would then be much less, and the characteristics of the tube would be altered. Provided that the correct amount of gas had been introduced, the luminous column would consist of coloured striations due to the passage of the electrons from the cathode to anode.

Again, supposing that an alternating source of potential instead of a constant potential difference had been applied to the metallic connections at each end of the tube. Each connection would then have rapidly become cathode and anode in turn. Instead of striations, the luminous column would have become a uniform glow. This, of course, is the condition we need for purposes of illumination, and is a rudimentary form of cold cathode lighting tube.

The Rare Gases

The gases used in cold cathode tubes are constituents of air. Apart from traces of water, a considerable amount of carbon dioxide (2·5 to 4 parts in 10,000) and dust, air, or the atmosphere, contains seven gases, they are :—

Nitrogen . .	1 part in	1·261	by volume.
Oxygen . . .	1 ,, ,,	4·760	,,
Argon . . .	1 ,, ,,	106·8	,,
Neon . . .	1 ,, ,,	80,800	,,
Helium . . .	1 ,, ,,	245,300	,,
Krypton . . .	1 ,, ,,	20,000,000	,,
Xenon . . .	1 ,, ,,	70,000,000	,,

It can be seen that the last five are present in extremely small quantities. They are therefore known as the " rare " gases. All of these rare gases are chemically inert, which means that they do not combine with other elements. This is a useful property in so far as their employment in discharge tubes is concerned.

Attempts to use carbon dioxide and nitrogen in discharge tubes were unsuccessful on account of the chemical activity of these gases. Although they can be made to produce light, the continual combination of these gases with materials inside the tube, gives them a comparatively short useful life. Even Moore's idea of constantly replenishing the gas by means of an automatic valve was found to be commercially impractical.

Of the rare gases, which are extracted from the atmosphere by fractional distillation, only argon, neon, and helium have until recently been used to any great extent due to the very high cost of separating the minute traces of krypton and xenon.

Argon is used on a large scale in gas-filled filament lamps. It is never used alone in cold cathode tubes owing to its poor light efficiency, but it is a useful carrier gas in luminous tubes containing mercury.

Neon, the gas employed extensively in neon signs, gives a bright orange-red light when used alone in luminous discharge tubes. Neon-filled discharge tubes are not very efficient illuminants but are efficient producers of the brilliant glow used for its attractive colour rather than its illumination propensities. Such tubes can, however, be used successfully in combination with luminous tubing of another colour.

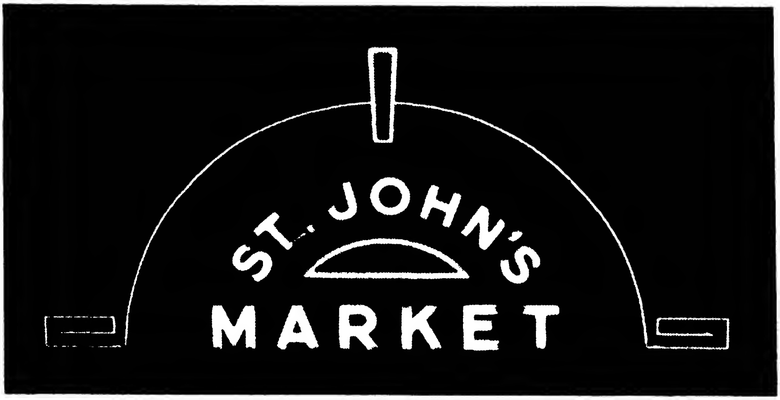


FIG. 2.—Neon Sign. (Miller Electric Co., Ltd.)

Helium produces a pale yellow glow when used in discharge tubes. It is used occasionally in the luminous tube industry for gold-coloured tubes. These tubes have a lower efficiency than neon-filled tubes and have shorter life.

Mercury

Most cold cathode fluorescent tubes for interior lighting contain liquid mercury. Mercury is really a metal in liquid form. Mercury molecules are therefore not fixed as in a solid, but are free to move about. Even at normal temperatures mercury is volatile, and some of the molecules move into the atmosphere as vapours. This is obvious when we consider the low melting point of mercury ($-39 \cdot 5^\circ$ C.).

Suppose a small quantity of mercury to be admitted into our sealed glass tube with a conductor (an electrode) at each end. If the tube is connected to a vacuum pump and exhausted of air, we shall not get the extent of vacuum we should have had if the mercury had not been present. The reason, of course, is that some of the mercury will have vaporized. Mercury vapour, however small in amount, will have completely filled the tube ; the density of the vapour depending on the temperature inside the tube.

If, in addition to the mercury, a small amount of argon gas is allowed to enter the tube this can act as a carrier, that is to say, it can be used to assist in conducting an electric current. The current, which must be of high voltage in order to strike up the discharge, is applied by connecting each secondary terminal of a step-up transformer to one electrode. The transformer, having had its primary winding connected to the alternating current electricity mains (usually 230 volts), steps up the voltage to a high value. Provided that the voltage is high enough, a pale blue discharge will strike across the tube through the argon. As the discharge continues the temperature inside the tube will rise and more mercury will be vaporized. Our tube will now be a low-pressure cold cathode tube. The term "low-pressure" relates to the gas pressure inside the tube which is very low in comparison with the atmospheric pressure outside.

When current flows through the mercury vapour and argon some of the electrons are liberated from the atoms and, as we shall see later, the gas and vapour have become ionized. At this stage it is sufficient for our explanation if we say that under the influence of the electric current electrons and atoms collide inside the tube and release energy in the form of radiation, in this case blue light.

The Atom

To gain some idea of the reasons for the processes that occur inside our discharge tube, we must first consider the structure of the atom.

By his investigations in connection with the conduction of electricity through gases, J. J. Thomson (who later became Sir Joseph Thomson) provided proof of the corpuscular nature of electricity. It is now generally accepted that an atom consists of a positively charged nucleus containing protons surrounded by one or more negatively charged electrons.

According to the Rutherford-Bohr theory, the electrons describe orbits of different diameters around the nucleus like a solar system and rotate on their own axes. All atoms are assumed to be made up in this way and it is the atomic number, or the number of external electrons per atom, that determines what the element is. A hydrogen atom, for instance, has only one electron in one orbit ; a mercury atom has eighty electrons in six orbits. Obviously, the nucleus of an electrically neutral

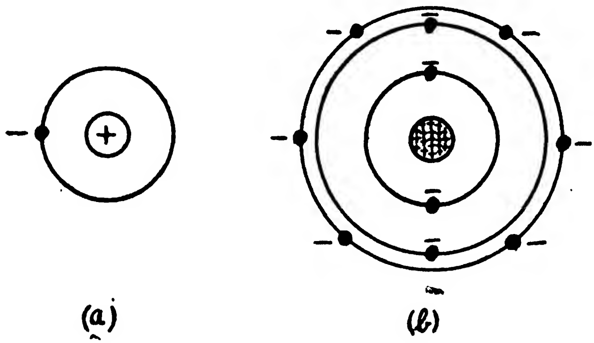


FIG. 3.—Structure of (*a*) Hydrogen Atom, (*b*) Neon Atom.

atom will have a positive charge sufficient to balance the combined negative charges of its electrons.

It is important to remember that all electrons have the same mass and charge. On the other hand, a nucleus differs according to the element to which it belongs.

A proton has a weight 1,845 times that of an electron.

In recent years two additional constituents of the atom—the neutron and the positron—have been discovered. The neutron, which has a mass about the same as the proton, was found by bombarding the element beryllium with radio-active particles. This resulted in the emission of a very penetrating radiation which carried no electric charge and was therefore called a " neutron ". The positron, a positively charged constituent, has the same mass as an electron with which it combines very readily.

Another comparatively recent discovery, the nucleus of the heavy hydrogen atom, has the same charge as the proton but has twice its mass. Water, which, as we know, consists of two hydrogen atoms and one oxygen atom, sometimes contains these heavy hydrogen atoms and is then known as " heavy water ".

Under certain conditions an atom may lose one of its external electrons. When this happens, and this is important in electric discharge tube technique, the positively charged remainder is known as an " ion ". In comparison with that of the electron, the mass of an ion is large, and this has considerable effect on their relative velocities under the influence of a given electrostatic field.

One or more atoms make up one molecule. A hydrogen molecule consists of two hydrogen atoms ; a water molecule is made up of two hydrogen atoms and one oxygen atom.

Ionization

Reverting to our sealed glass discharge tube with a conductor or electrode at each end and containing a small quantity of rare gas, we can now consider what happens when electric current is applied.

If a sufficiently high voltage is applied at the electrodes the equilibrium of the atoms inside the tube is disturbed. Under the influence of the electric field some of the electrons are released and this gives rise to a number of collision processes.

When the atom receives a sudden knock or jolt one of three things can happen to an electron within its orbit. They are : (1) In the case of a small jolt—an elastic rebound ; (2) in the case of a jolt of just sufficient energy to move it to another sphere—an inelastic transfer of energy ; or (3) in the case of a jolt of considerable magnitude—the electron may be jerked altogether from its parent atom and the atom may become ionized.

These alternatives, which can be caused by collision of a fast-moving electron with the atom, are known as " collisions of the first kind ". When the collision involves an atom which is already excited it is called " of the second kind ".

The kinetic energy (electron-volts) of a colliding electron that is required to move an electron after collision is called the excitation potential.

The energy required for ionization (ionization potential) is that necessary to eject an electron from its parent atom.

Emission of light or radiation usually takes place after an extremely short interval, usually of the order of 10^{-8} second, but in some cases atoms may remain excited for a much longer period. The atoms are then said to be " metastable ".

Metastable atoms, due to their comparatively long period, are able to excite and ionize other atoms. Thus, they are of great importance in luminous electric discharge technique. They are mainly confined to atoms of mercury and the rare gases.

The Discharge Tube

A cold cathode luminous electric discharge tube consists fundamentally of a sealed glass tube containing rare gas and/or mercury at low pressure and fitted with a metal electrode at each end to which the electric supply source is connected.

In the case of a low-pressure discharge tube excitation occurs throughout the length of the glass envelope and results in the production of light at all points. This source of radiation is known as the positive column. The colour of the visible radiation produced is dependent on the gas or vapour used ; neon gives an orange-red glow, argon a pale blue.

Argon gas is never used alone on account of its poor illumination factor. Argon in combination with mercury vapour, however, is used in the majority of cold cathode fluorescent tubes. The mercury is responsible for the production of the necessary ultra-violet radiation, and the argon maintains a carrier function.

Temperature has considerable effect on an argon with mercury vapour discharge. At very low temperatures, the spectrum would be that of the gas only. Conversely, at very high temperatures, the mercury vapour spectrum would replace that of the argon.

During the life of a cold cathode discharge tube there is a gradual disintegration of the electrode surface due to ionic bombardment. This effect, which is known as sputtering, results in a lowering of the gas pressure inside the tube. The rate of sputter in a given type of tube depends on the electrode material and the original gas pressure, temperature, and current density at the electrode. A thin cylinder of Swedish iron is found to be the most satisfactory electrode material. The usual gas pressure is between 5 and 10 millimetres of mercury (roughly 0·2 to 0·4 in.). Cathode temperatures are about 150° C. Maximum current density for minimum sputter was found by Claude to be about 24 square inches per ampere.

One method of reducing the size of electrode required is to treat the surface with borax or an alkali earth oxide. Barium and strontium oxides are found particularly suitable for this purpose.

The voltage necessary to strike up the discharge in a cold cathode tube is greatly in excess of the voltage required to maintain the discharge. If a choke or ballast is used, the difference between the striking and operating voltage is absorbed as a volts drop in the ballast. If, however, the transformer is designed with high leakage reactance it can be used for the dual purposes of providing the high voltage for ionization and acting as a ballast during subsequent operation of the tube. To provide the necessary resistance, a transformer of this kind is fitted with magnetic shunts. The average ratio of short circuit current to operating current is six to five.

When high voltage alternating current, derived from a step-up transformer, is applied to the electrodes of a cold cathode tube, electrons will be liberated and will travel backwards and forwards throughout the tube. The continual reversal in direction is due to the fact that each electrode will be anode and cathode in turn as the current alternates. During each half-cycle after ionization the electrons will be directed to each electrode. Thus, there will be many collisions and ions will strike or bombard the electrode.

Some of the operating voltage is taken up by a fall of potential at the cathode (cathode fall). The acceleration of the ions will therefore be highest at this point in the tube. Assuming that each ion on impact liberates an electron from the cathode surface, it follows that bombardment of the cathode by the ions causes an emission of electrons which in turn leads to a flow of current.

The glow discharge obtained from a cold cathode device can therefore be said to have natural means of releasing electrons from the cathode as required. This condition does not apply to the arc discharge of hot cathode lamps which are provided with thermionic cathodes for release of electrons.

Discharge Characteristics

Reference has already been made to the necessity of applying high voltage to the electrodes in order to ionize the gas. When this high voltage is removed the ions re-combine to form neutral atoms, but not immediately. Experiments have shown the presence of a small proportion of ions in a neon-filled tube some hours after the electric supply was cut off. The high striking voltage is therefore necessary on switching on only, and not at the beginning of each half-cycle.

It follows that the greater the current flowing through the tube, the more gas is ionized. Therefore, increase in current applied to the cold cathode tube will reduce the potential drop between the electrodes. This, of course, is contrary to Ohm's Law for the flow of electricity through liquids and solids. The drop in voltage with increasing current is termed the " negative characteristic " of the discharge tube.

As a result of the negative characteristic the discharge in a cold cathode tube will tend to build up, the voltage decreasing and the current rising in proportion, until the tube is destroyed. It is for this reason that some form of reactance—either from a choke or a leakage transformer—must be included in the circuit.

In addition to the flow of ions to the cathode, there is also a flow of electrons to the anode. Thus, there is both a cathode drop and an anode drop, but the latter is exceedingly small, and may be neglected for all practical purposes.

The resistance of the positive column or luminous portion of the discharge will depend on the kind and pressure of the gas used and on the length and diameter of the tube. Obviously, the longer the tube, the greater will be the resistance. Conversely, the larger the tube diameter the smaller will be the resistance. Both of these factors, however, are limited in practice.

A gas with good conductivity does not necessarily give the best luminosity. In fact, some of the best conducting (easily ionized) gases are unsatisfactory from the point of view of illumination.

So far we have been concerned rather more with the cause than the effect of the conduction of electricity through a gas and vapour. The remainder of this chapter will be devoted to what is emitted or radiated from our rudimentary cold cathode discharge tube.

Radiation

When a stone is thrown on to the smooth surface of still water a circle of ripples radiates from the spot where the stone entered the water. This is due to the loss of energy of the stone on impact which is taken up in disturbing the water in gradually diminishing ripples or waves. The distance between the ripples (the wavelength) is governed by the speed and size of the stone. When electric current is applied to any discharge tube, ripples, or electro-magnetic radiations, of definite wavelengths are created.

Electro-magnetic radiations travel at the rate of 186,000 miles per second. Therefore, the distance between the crests of adjacent waves multiplied by the number of waves occurring per second will always equal the speed of the radiations. For example, if the frequency was 1,000 cycles per second, the wavelength would be 186 miles. The wavelengths of the radiations are used to classify them (e.g. infra-red, visible, ultra-violet, etc.).

According to the electro-magnetic theory, radiation is the name given to energy which is emitted by material bodies and which traverses space by means of wave motion in the ether. We know from the release of electrons and dislocation and recombination of ions within the atom that this theory requires some modification.

Electro-magnetic radiations, however emitted, extend from cosmic rays (of the shortest wavelength) to long-wave electric oscillations, visible radiations occupying only about one-seventieth of the whole.

In the ordinary electric filament lamp most of the radiation is emitted in the invisible infra-red region, that is, as heat. Only a very small proportion of the energy radiated is in the visible portion of the spectrum. Obviously, the incandescent lamp has a very low efficiency.

Although the cold cathode mercury discharge is rich in invisible ultra-violet radiation, this energy is not wasted but is utilized to activate fluorescent materials coated on the inside walls of the tubes. Very little infra-red radiation is emitted. Thus, this type of light source is highly efficient.

The human eye is most sensitive to radiation having a wavelength of 5,550 Angstroms. This is the yellow portion of the spectrum. The eye is least sensitive to radiations at the spectrum extremes of red and violet. Therefore, to judge the visibility of light emitted by a source, the response of the eye to that particular radiation must be taken into account.

Radiant heat, light, X-rays, and all other electro-magnetic disturbances were at one time assumed to have the same fundamental nature. This electro-magnetic theory of radiation, as we shall see presently, leaves a great deal unexplained.

If we heat a piece of iron in a darkened room it will begin to glow, first dull red then finally white. Raising the temperature still higher would cause a bluish tinge to appear. This change could not be explained by the early wave theory.

Max Planck later concluded that the vibrating atoms of the hot iron did not radiate energy continuously, but intermittently. Energy, he explained, was emitted in discrete quantities. The exact quantity was dependent on the rate of vibration of the radiation (the shorter the wavelength, the higher the rate of vibration).

Spectra

From the foregoing we have seen that in the cold cathode tube light is produced by the projection of free electrons from the cathode, resulting in ionization of rare gas or metal vapour contained in the tube; ionization being regarded as the removal of an electron from its parent atom. The visible radiations emitted have spectra which cover a considerable range of colour and which are characteristic of the gas or vapour used. The energy changes resulting in visible light are, however, confined within narrow limits; a change below the limit producing infra-red radiation and a change above it resulting in ultra-violet radiation.

An ordinary tungsten lamp gives a continuous spectrum but typical atomic spectra for neon and mercury-vapour are made up of lines (i.e. they consist of very narrow bands each of a definite wavelength). It is customary to speak of wavelength in Angstrom units, an Angstrom unit being one 10^{-8} of a centimetre.

For the average person the visible spectrum extends from 7,000 to 4,000 Angstroms. This range includes red, orange, yellow, green, blue, violet, and extreme violet. Radiation from the sun includes, of course, all wavelengths within the visible range, and is the basis of comparison in quality of artificial light sources.

There are a number of energy levels above the first excitation level in the atoms with which we are here concerned. Consequently, the output from cold cathode tubing consists of radiation of many wavelengths. Mercury vapour, for instance, has a line spectrum in the six main lines in the visible region of violet, blue, green, and yellow. Neon gives about 15 lines clustered in the yellow, orange, and red regions. Helium has a component in almost every part of the visible spectrum.

When a single gas or vapour fails to give the spectral distribution required for illumination, it would appear that a mixture of gases and/or vapours could be used. In practice, however, this cannot be done satisfactorily. One reason is that the discharge would tend to take place mainly through the gas or vapour having the lowest excitation potential, and the radiation from this would mask that of the others. Another reason is that the efficiency of the device would be impaired, mixtures of gases in a discharge tube usually resulting in one of the constituents being " cleaned up " or dissipated.

It is important to note that in the non-fluorescent luminous discharge tubes dealt with so far the invisible ultra-violet radiation has been discounted.

Fluorescence

Fluorescence is the phenomenon by means of which short-wave invisible radiation is converted into long-wave visible light. In so far as the fluorescent cold cathode discharge tube is concerned, the passage of electricity through the mixture of rare gas and mercury vapour produces ultra-violet radiation which is changed into light by means of fluorescent powders coated on the interior of the glass tube.

Radiations are concerned with the transfer of energy. Therefore, the absorption of radiation by a substance must involve some transformation of energy. Fluorescence is concerned with the absorption of invisible ultra-violet rays by fluorescent substances which re-emit the energy in the form of radiation of longer wavelength.

Solid fluorescent materials are called phosphors. Some years ago it was discovered that coatings of zinc sulphide and willemite, to which traces of heavy metal had been added, when applied to the interior walls of cold cathode argon-mercury-vapour discharge tubing, appeared to be converted into tiny crystals, each a light source in itself, by irradiation with ultra-violet of suitable wavelength. These powders enabled the range of available colours to be extended, but contributed little to the efficiency of the tubing as a source of light.

Investigation proved that the fluorescent effect was a feature of the molecular structure of the phosphor. It was also discovered that the addition of small amounts of impurities to a solid phosphor was essential for the required energy transformation.

Considering a single molecule of a crystalline phosphor, it is known that the individual atoms are arranged in lattice formation. Each atom, however, is capable of restricted motion, and it is necessary for the molecule of the impurity or activator actually to fit into the crystal lattice of the phosphor in order that the transformation from ultra-violet to visible radiation can take place.

When the phosphor in our cold cathode tube is activated by photons of the positive column, electrons are liberated. Also the atoms of the activator are excited to higher levels by absorption of energy from the incident radiation. Some of the electronic energy resulting from the change in levels is taken up in the emission of light. This light was proved by Stokes to be always of longer wavelength than the incident radiation.

The light output of phosphors differs from that of a low-pressure discharge in that the spectrum of the fluorescent substance is in the form of a continuous band instead of a resonance line.

Shortly before the outbreak of World War II it was found that zinc beryllium silicate suitably activated, when excited by low-pressure mercury discharges, fluoresces with high efficiency of light output. This substance could, by varying the activator, be made to give various colours of fluorescence. This was a definite milestone in fluorescent lighting development.

Other phosphors employed are calcium and magnesium tungstates, zinc silicate, and chlorophosphate and borate of cadium.

CHAPTER III

MANUFACTURE

Having dealt with the operational considerations relating to cold cathode fluorescent lighting, we shall now proceed to the constructional aspect. Although, on the face of it, it would seem that we have only to coat the internal wall of a glass tube with fluorescent powder, fit an electrode to each end, draw out the air and admit a small quantity of rare gas and mercury, the process is not quite so simple as it might appear. However clean we may be in the preparation of our materials, there are bound to be impurities present as soon as the temperature is raised slightly by the application of electric current. These impurities, if left inside the tube, would cause all kinds of complications which would adversely affect the functioning of the tube. To remove these unwanted or extraneous gases, we must first bombard the tube.

The processes comprising manufacture of cold cathode fluorescent tubing are therefore : (1) applying the luminescent powder ; (2) cutting and bending the tubes to the desired size and shape ; (3) fitting the electrodes ; (4) sealing the tubes to the exhaust system ; (5) bombarding to remove the extraneous gases from glass and electrode metal, and (6) filling with argon and mercury at low pressure.

Glass

Glass tubing is supplied in lengths or " canes " of about 5 feet, in various diameters and wall thicknesses. It can be manipulated by torches or burners supplied with a mixture of coal gas and compressed air. Lead glass as used in the U.S.A. has a lower softening temperature range than soda glass which is used extensively in Europe. But, since the former contains lead oxide, it cannot be worked by the same type of flame that is used for soda glass, as the reduction of the oxide to metallic lead would be caused by the unburnt coal gas. The tendency is overcome by the use of a flame containing a greater proportion of air.

Since glass generally is a relatively poor conductor of heat, it is very prone to crack if cooled too quickly ; the outer layers, setting first, cause internal stains to be set up. Consequently, all bends and joints in glass tubing must be "annealed" after completion. By annealing is meant the retarding or cooling of the outer layers by the application of gradually lessening heat. In practice the flame of the glass-bender's torch or burner is turned down slowly until it blackens the glass with soot deposit.

Devitrification, an undesirable change in the composition of the glass, can be caused by ageing, weathering, or by repeated heating. The effect of devitrification from the first cause, known as "surface devitrification", is an efflorescence which can be cleaned off with a solution of dilute hydrofluoric acid. Excessive heating and cooling causes the glass tubing to wrinkle and renders it more difficult to work. The solution here is prevention, as there is no simple cure.

Fluorescent Powder Coatings

The fluorescent powders or phosphors used in cold cathode fluorescent tubing must be capable of absorbing the ultra-violet produced and emitting the desired colour of light either alone or in combination with other powders. The powders most commonly used are :—

For green . . .	Zinc Orthosilicate.
For blue . . .	Calcium tungstate.
For blue-white . .	Magnesium tungstate.
For pink/yellow . .	Zinc beryllium silicates.
For red . . .	Cadium phosphate, chlorophosphate, or borate.

These powders, as explained previously, must not be chemically pure but must contain a minute quantity of some impurity or activator. They are fixed to the interior walls of the glass tube by means of binders, which are specially chosen both for their adhesive properties and their non-activity with either the powders or the discharge.

In the early days of cold cathode fluorescent tubes the method of fixing the powder to the glass consisted of applying either waterglass, glycerine and boric acid, or alcohol and phosphoric acid and then shaking or blowing the powder on to this binder. The tubes were afterwards baked in an oven to dry and harden the binder. A later method employed a volatile binder and after the powder was applied the tubing was heated to the softening temperature of the glass in order to leave the powder directly fused to the glass. The modern method uses a mixture of fluorescent powder and binder which can be directly coated on to the interior walls of the tubes.

According to this latest method the fluorescent powders, having been ground to the required particle sizes, are mixed in nitro-cellulose to the consistency of thin cream. The glass tubing, having been cut to length and thoroughly dry-cleaned internally, is then arranged vertically over the tanks containing the mixture with the lower ends of the tubing immersed in the liquid. The fluorescent mixture is forced up to the top of the tubing by the application of compressed air. As the mixture is drained back through the tubing it leaves an even coating of the mixture on the interior glass wall. After draining the tubing is dried and heated to the temperature necessary to decompose and evaporate the binder, thus leaving a thin dry coating of powder adhering to the glass.

In using this method successfully a great deal depends on obtaining the correct particle sizes of the powders and on the proper and constant viscosity of the mixture, which should therefore be kept agitated. A too thick or too thin coating of fluorescent powder will affect the efficiency of the completed luminous tube.

At the present time no single powder can be used alone to give a white light suitable for general illumination. In the case of a " daylight white " tube it is necessary to mix powders in suitable proportions so that red, yellow, and blue emissions combine to provide resultant light of the required colour temperature. Warm-white or peach tubes would naturally contain a greater proportion of red-emitting powder.

Glass Manipulation

Glass tubing of small diameter may be cut by scratching the surface with a file and bending away from the scratch, pulling the glass at the same time. Instead of pulling at the scratch the molten tip of a scrap spindle of glass may be applied to the extremity of the scratch ; this method is particularly useful for breaking off a piece of glass cleanly near the end of the tube.

A carborundum wheel is often used for cutting large-diameter tubing, the glass being lightly pressed against the revolving wheel and rotated. Sometimes the final severing is done in a flame.

There is a diamond cutter on the market for cutting tubing of very large diameter. The cutting jewel is fixed at the end of a long spindle which is inserted into the tube for the requisite distance, the tube then being rotated so that a scratch is made completely round the internal wall. When the tube is subsequently placed in a flame the scratch develops into a clean break.

Hot wire cutters are usually connected to a low-voltage electric supply. The tube having been scratched, is inserted at this point in the loop, which is then tightened and the current switched on.

Glass-working of luminous tubes is best carried out in subdued lighting. This enables the operators to distinguish the flame variations. Special goggles are sometimes worn.

The equipment necessary for glass manipulation includes bench-burners, hand-burners, and ribbon-burners. Tools mainly used are reamers (for opening flanges, etc.), glass-knives or files (to scratch the surface of the tubing preparatory to breaking), and chinagraph grease pencils (for marking). In addition, set-squares, adjustable holders of various types, rubber blow-tubes with filters, lead weights, and various sizes of corks are generally available.

Compressed air must be applied to the burners, A sufficiently large industrial coal gas main to operate all available burners should also be provided.

Machines for delivering the air under pressure generally consist of an ordinary compressor directly driven from an electric motor. To maintain an even pressure a tank is sometimes included in the compressed air pipe line.

The usual complete compressor unit is directly coupled to an induction motor and includes cooling fan, automatic relief valve, baffle chamber, and filter cap. Obviously the unit should be installed as near as possible to the glass-bender's burners, and every precaution taken against leakage.

Hand-burners, which are used for sealing tube sections on and off the manifold, for joining on electrodes, and for repairs,

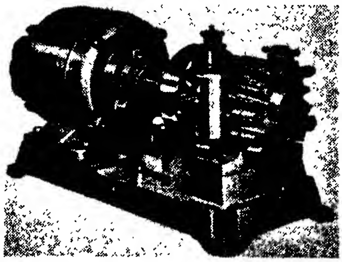


FIG. 4.—Vacuum Pump and Compressor. (W. Edwards and Co. (London), Ltd.)

etc., are of three types. For general use a hand-burner with independent gas and air taps, permitting fine adjustment of the flame, is quite suitable, but for repetition work the type having a single valve control is preferable, being simpler to operate. The " Double-tipping " hand-burner, which has two jets fixed at 90° for very uniform heating, is used for special work.

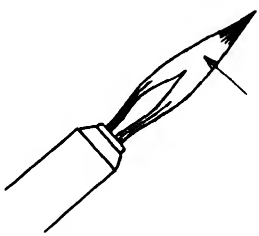


FIG. 5.—Hottest Portion of Flame.

Single bench-burners can be supplied with either ball and socket or clamp bases. With the clamp base the burner can be rotated through 360° and tilted to any desired angle. The ball and socket type can be instantly and rigidly held in any position. For dual processes involving the use of flames differing either in size or characteristics, double bench-burners are necessary. The jet change-over is quickly effected by a thumb-operated valve. This burner is admirably suited for localized heating followed by general heating over larger area.

Ribbon burners, for heating and bending long lengths of tubing, are made in lengths from 3 inches to 18 inches for use with either high-pressure gas or low-pressure gas with high-pressure air. The grid type head ensures an even flame and freedom from lighting back.

Correct adjustment of the burners is an essential part of all glass manipulation, different jets being used for various classes of work. The greatest concentration of heat is found to be slightly above the blue cone in the centre of the flame.

Electrodes

Cold cathode fluorescent tube electrodes are mostly of the plain cylindrical type. The metal commonly used is thin

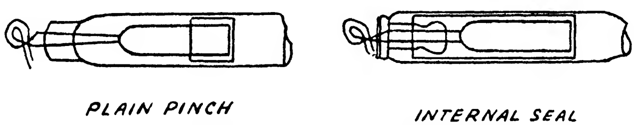


Fig. 6.—Electrode Seals.

Swedish iron which is supplied especially for the purpose and which has a low sputter factor. The support wires are usually spot-welded to the cylinder, and the pinch seals, through which the air passes to an external connection, are machine made.

The size of an electrode depends, to some extent, on the diameter of the tubing in which it is to be used. For the most popular size of cold cathode fluorescent tube (0·8 in. diameter) the cylindrical portion is about 2·5 in. long and 0·6 in. in diameter, the diameter of the tube being sightly increased at each end to accommodate the electrodes. Ceramics or sheets of mica are sometimes used to insulate the electrode metal from the glass.

Electrodes are sometimes coated with an electron-emitting material. This permits a reduction of the effective surface area (and consequently the electrode dimensions) for a given size of cold cathode tube.

The original method of coating electrodes with a mixture of barium and stronium carbonate during bombardment was rather unsatisfactory. In some cases the electrodes were overheated and in other cases were not heated sufficiently to break down the carbonates themselves.

A new electron-emitting chemical (Bakers R100) for the cold cathode lighting industry has recently been developed in the U.S.A.

The electrodes are either dipped into or sprayed with the chemical. They are then allowed to dry, mounted in the tube, and subjected to bombardment in the usual way. For the breakdown of the material, the electrodes should be heated to a very light cherry red heat, although, due to variations in the design of equipment, manufacturers are advised to try out different heat treatment periods in order to find the best method to suit individual apparatus.

It is not necessary to use the electrodes immediately after coating, but it is advisable to exhaust and seal up electrodes that are to be kept in stock, since prolonged exposure to the air will lead to absorption of carbon dioxide and moisture.

Pumping

Cold cathode fluorescent tubing, having been fitted with electrodes, is sealed on to the manifold or exhaust system by means of a " tubulation " or small diameter tubing. Exhaustion

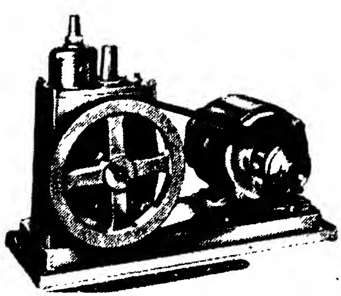


FIG. 7.—" Speedivac " High Vacuum Pump. (W. Edwards and Co. (London), Ltd.)

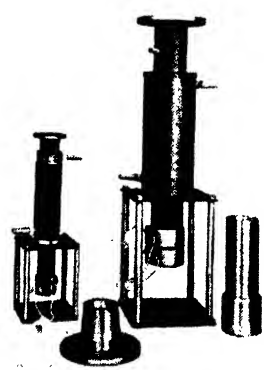


FIG. 8.—Mercury Diffusion Pumps. (W. Edwards and Co. (London), Ltd.)

of air is usually carried out by an electrically driven high vacuum-pump.

Usually the high vacuum pump is switched on and the air withdrawn from the tube until a point is reached when evacuation of the air from the tube will lower the resistance sufficiently to cause a luminous discharge when the electrodes are connected to the bombarding transformer.

There are many alternative types of pump systems. A mechanical pump may be used either alone or as a backing to a diffusion pump which can be of the mercury condensation type or butyl phthalate oil type.

Internal Bombardment

A discharge tube in which the internal pressure has been lowered considerably by means of a vacuum pump will heat up when high-voltage electric current is applied to its electrodes. In the process of internal bombardment the heat thus produced is utilized to release all volatile impurities from the electrodes and internal surface of the tube. The impurities so released can then be removed by a vacuum pump.

The value of the current that may be passed through the discharge tube determines the amount of heat produced at a given pressure. Also, the longer the tube and the smaller its diameter the greater will be the voltage required for ionization. Thus the bombarding transformer must be variable over a wide range.

Transformers for use in the internal bombardment of luminous tubing are usually of the oil-cooled type contained in steel tanks ; on the average they have a short-time rating of 7 kVA with a secondary terminal voltage of 15,000 with mid-point earthed.

The input of the transformer primary is controlled, the voltage being capable of adjustment to almost any value between zero and maximum ; thus producing a corresponding variation in the secondary output. Control of most bombarders is effected by use of a potentiometer choke connected across the supply to the primary. Two parallel choke coils in series with the main supply, with the primary of the main transformer connected to them, provide a suitable arrangement. As a rule, chokes thus employed have movable cores so disposed that, when one is inserted fully into the coil the core of the other choke is withdrawn, thereby giving the effect of a kind of variable auto-transformer. The voltage applied to the primary of the transformer is a minimum when the core of a choke in series with its primary is fully inserted.

Operation of the choke system may be provided by the drive from a hand-wheel arranged so that variation of the voltage from zero to maximum can be obtained by one complete turn of the wheel.

Obviously, the aim of bombardment should be to heat the glass tubing and electrodes at the same time. Too high a

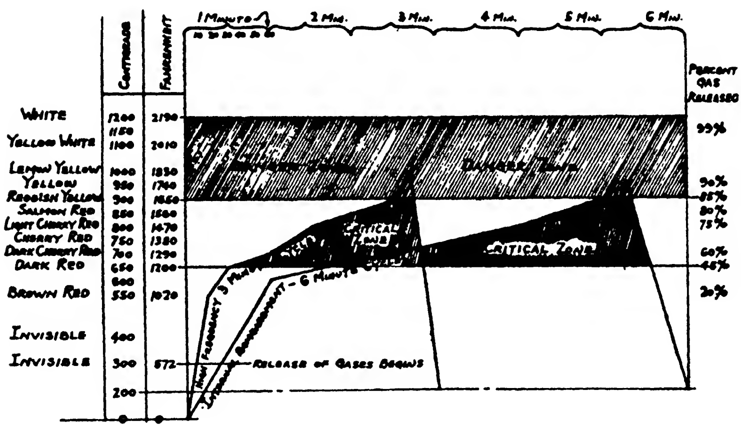


Fig. 9.—Bombardment Chart, developed by Colorescent Laboratories, with tests and all readings based on electrodes of their manufacture. Note the steel colours in relation to temperatures. If judgment of temperatures is visual, observations should be taken in dark or only slightly lighted rooms—never in direct light.

pressure will result in the glass heating before the electrodes ; whilst if the pressure is too low the electrodes may become red hot without appreciable heating of the tube. The ideal pressure is the one at which both glass and metal reach the requisite temperature at approximately the same time. This, naturally, varies for different sections of tubing.

Bombardment at too low pressure, in addition to overheating the electrodes will cause excessive sputtering. This has the effect of shortening the useful life of the discharge tube.

Cold cathode tubes should therefore be bombarded at the highest possible pressure without softening the glass, as the glass walls can only be heated internally if there is sufficient gas to convey the heat from the electrodes.

The initial discharge may take place in hydrogen which is easily liberated by gentle heat. If the pressure is reduced too much at first, quantities of carbon dioxide may be liberated from the electrodes and this would cause them to become oxidized, consequently lengthening the process of bombardment.

After slight preliminary exhaustion and connection of the bombarding transformer a mixture of hydrogen, carbon monoxide with possible traces of nitrogen is usually released in the tube. Because of the relatively poor conductivity of these gases considerable heat is developed. As more and more gas is released, the pressure inside the tube rises rapidly and consequently the electrical resistance of the discharge increases. To maintain the current within limits the tube may be slowly exhausted in stages during this heating process. At the same time, the bombarding current can be continually adjusted.

When the high temperature has been maintained for a sufficient length of time, dependent on the equipment and the size of the cold cathode tube, the tube may be completely exhausted and a small quantity of rare gas admitted. The heating process can then be repeated until the discharge no longer changes colour. At this stage the bombarder current should be constant and the tube is ready for final filling.

There are several alternative methods of internal bombardment, and the above should be taken as representative only. In one process a continuous stream of rare gas is maintained through the tube in a circulating fashion, and a trap is provided to absorb the impurities.

Eddy Current Heater Bombardment

Another method of bombarding luminous tubes consists of heating the electrodes by high-frequency eddy currents in order to release extraneous gases, relying on the subsequent baking of the tubing to liberate impurities from the interior of the glass wall. The apparatus necessary for heating the electrodes is similar to that used in the manufacture of radio valves and cathode ray tubes, utilizing the principle that a coil carrying a substantial radio-frequency current placed close to a conductor in vacuum will induce eddy current in that conductor, consequently raising the temperature.

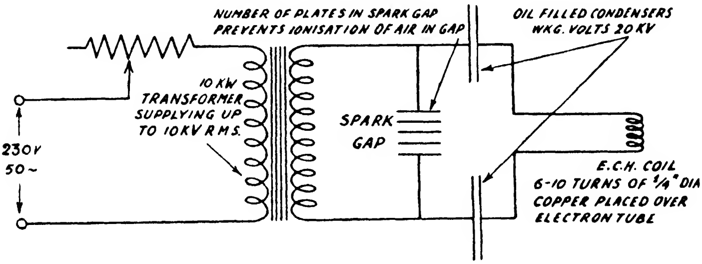


FIG. 10.—Basic Circuit of a Spark Eddy-current Heater (From " High Vacuum Technique by J. Yarwood, B.Sc.(Hons.) (Chapman and Hall, Ltd.)).

Either a spark or valve oscillator circuit may be used for producing high-frequency currents. A typical 230 volt 50 cycle input spark oscillator (supplying 10 kV R.M.S. max.), two oil-filled condensers suitable for working voltage of 20 kV, a plate type spark gap, and an eddy current heater coil

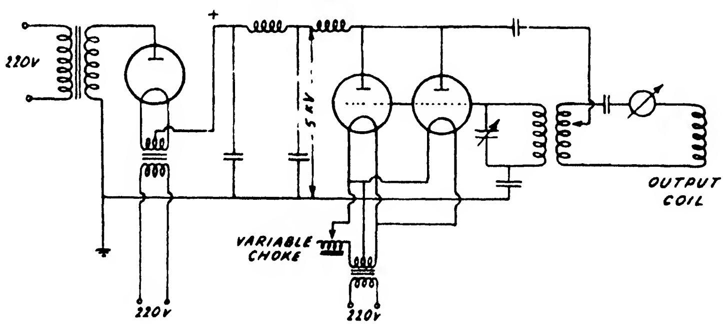


FIG. 11.—Basic Circuit of a Valve Eddy-current Heater (from " High Vacuum Technique " by J. Yarwood, B.Sc.(Hons.) (Chapman and Hall, Ltd.)).

comprising 6–10 turns of copper tubing through which cooling water flows will give up to 50 amps at a frequency of about 100 kilocycles per second. Much higher frequencies (up to 1,000 kilocycles) can be obtained from a valve oscillator employing rectifying valves and four valves operated in parallel, or a push-pull arrangement of two valves.

The coil itself is provided with a long insulated handle and the cables leading to it should be water-cooled and of sufficient cross-section to reduce skin resistance losses as far as is possible.

Measurement and Testing

A luminous tube, after being filled with gas or vapour, will have a pressure of between 0·2 and 0·6 in. of mercury. The simplest way of measuring this is by inserting in the pumping system a U-shaped tube partly filled with mercury and backed by a calibrated scale. The difference in the levels of the mercury columns is the pressure inside the tube. This type of rough gauge is known as a " Manometer ".

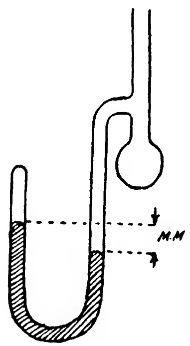


Fig. 12.—Simple U-gauge or Manometer (Measures down to 0·04 in. Hg. Introduce dry clean mercury ; exhaust tube ; tilt so that closed limb is full).

The accuracy of a manometer is limited to the smallest difference in mercury levels that can be visually estimated ; roughly about 0·04 in.

Since the pressure in a luminous tube before filling is of the order of 0·00004 in. Hg., it is obviously advisable to have a more accurate gauge. A manometer employing oil of negligible vapour pressure has been developed which, it is claimed, has a sensitivity about 16 times that of the mercury U-tube. However, for extremely low pressures the improved type of McLeod gauge is still the most practicable.

The McLeod gauge depends for its action upon Boyle's Law, which states that, providing the temperatures remain constant, the volume of a gas varies inversely as the pressure.

A known volume of gas is compressed from a large bulb into a capillary tube of comparatively small volume. The gauge measures the pressure necessary to carry out this compression

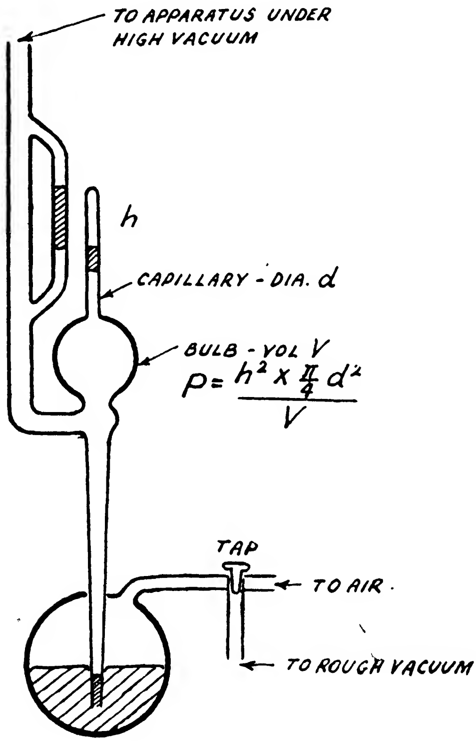


Fig. 13.—McLeod Gauge (Factory Pattern).

and, from this, the original pressure of the gas is calculated from the following simple relationship :—

$$\text{Original Pressure} = \frac{Pv}{v + V}$$

where Pv is the difference in mercury levels, V is the volume of the bulb, and v the volume of the capillary tube.

The Vacustat is a modification of the McLeod gauge, but although the two gauges are similar in principle they differ considerably in construction and in method of use.

Whereas the normal type of McLeod gauge must have an overall height well in excess of the barometric column, the

Vacustat is only 9 inches (23 cm.) in height and requires a very small quantity of mercury (approximately 8 c.c.), which makes the instrument portable. The necessity for raising the mercury level to compress the gas, as in the McLeod gauge, is obviated by constructing the Vacustat so that rotation about its centre causes the compression, thereby making this the only operation necessary to take a reading. The glass part of the gauge is mounted on a metal stand with direct reading scale and is provided with a stainless steel outlet. Connection to the vacuum system is made by rubber tubing, which also provides the necessary flexibility for rotation through 90°. The gauge is left in the horizontal position during exhaust, and simply turned to the vertical position when a reading is desired. A clear

FIG. 14.—Pirani Gauge. (W. Edwards and Co. (London), Ltd.)

direct reading scale covers the range from 10 mm. (0·4 in.) to 0·01 mm. (0·0004 in.).

A Pirani gauge is useful for indicating—or even recording—rapid fluctuations of pressure, also for occasions when it is important to know the total pressure rather than the partial pressure of the true gases.

Messrs. W. Edwards and Co., Ltd., manufacture a direct reading gauge which is a development of the Pirani type, with improved characteristics. This instrument has a range of from 1·0 to 0·0001 mm. Hg. (0·04 to 0·000004 in.), its principle being that the thermal conductivity of a gas is related to its pressure by the relationship :—

$$K = a.p.$$

in which K is the thermal conductivity and p the pressure of a gas, and a is a constant. This holds good so long as the pressures are below values where the gas layer thickness is of the order of the mean free path.

Essentially, the instrument consists of a hot filament which is contained in the exhaust system, and changes in thermal conductivity which occur at different pressure alter the filament resistance, which is recorded by means of a Wheatstone Bridge arrangement.

For laboratory use the electrical apparatus is housed in one cabinet, together with the indicating instrument. The standard units are for operation on 50 cycles a.c. or d.c. mains between 200 and 250 volts, readings being independent of normal mains fluctuations. They are supplied with 3 in. dial indicator, sloping front metal cabinet, and simple unprotected gauge tube fitted with a glass cone. For works' use the gauge

FIG. 15.—Philips Gauge. (W. Edwards and Co. (London), Ltd.)

should be protected by a metal case and the gauge is generally connected to the vacuum system by a flange. For industrial purposes, the indicating instruments may have to be mounted at some distance from the vacuum apparatus. Recording instruments are sometimes used.

The Philips' gauge (British Patent No. 474845) provides the most convenient means of measuring directly pressures in the range $0 \cdot 2 \times 10^{-3}$ to 10^{-5} in. Hg. It gives a continuous indication even with rapidly varying pressures and operates simply by connection to a.c. mains, the pressures being read in terms of the ionization current produced by applying a voltage across the electrodes sealed into a discharge tube.

The discharge tube is connected to the system the pressure of which is to be measured ; the electrodes are maintained at constant potential. The glow discharge current is a function of pressure but, as this would normally be too small to measure at very low pressures, a magnetic field is arranged at an angle to the discharge tube in such a manner that the electron path is lengthened and the probability of ionization by collision is greatly increased. In this way an appreciable current will flow even at pressures so low that a discharge would normally be impossible.

The instrument in its final form consists of two parts—the Power and the Measuring Units. The former is provided with

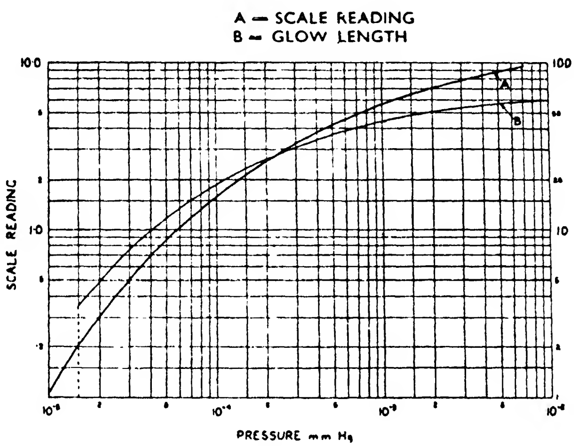


Fig. 16.—Calibration Curve for Philips Gauge. (W. Edwards and Co. [London], Ltd.)

a plug for mains connection, and an indicating instrument from the reading of which the pressure is obtained by reference to a calibration curve. The Measuring Unit is connected to the vacuum system by a standard cone joint, and is provided with a glow discharge lamp and scale. The length of the glow discharge gives an alternative approximate indication of the pressure.

A Philips' gauge will indicate the pressure of vapours as well as true gases, and this makes it particularly suitable for use in the processing of luminous tubes. It must, however, be isolated by suitable traps from mercury pumps or McLeod gauges.

These instruments are sometimes called "Ionization

Manometers" to distinguish them from ordinary Ionization gauges which, although capable of measuring extremely low pressures, are far less robust. Philips' gauges cannot be damaged by accidental increases of pressure above their normal range.

Double calibration curves are supplied with the gauges, giving the relation between pressure and indicator reading, and also (approximately) between pressure and glow length. By the provision of suitable relays, these units can be arranged for recording or control purposes.

A source of high-frequency current is particularly useful for testing vacuum systems, and it provides a simple means of determining the approximate degree of vacuum. When the high-voltage electrode is placed close to the glass surface after the apparatus is partially exhausted the discharge has a red or violet colour. The vacuum is then of the order of 0·004 in. Hg., and as this pressure is reduced the colour changes towards green until at 0·00004 in. Hg. only a green fluorescence of the tube remains. As the vacuum is still further improved this fluorescence will gradually disappear. These pressures and the corresponding discharges must be taken as approximate only.

The locating of minute leaks in glass vacuum assemblies is another extensive application of high frequency. If the electrode is passed over the glass surface the spark from it will be seen to concentrate and pass through any crack or small hole, generally producing a yellow glow at this spot. When the leaks are so small that direct finding by this procedure is uncertain, a further test may be made by adjusting the pressure in the system to give a violet discharge and then painting the glass with alcohol where leaks are suspected. The normal violet colour will turn to bluish-white where the alcohol vapour enters the leak.

Exhaust System

There are no hard and fast rules for the construction and arrangement of the manifold system for luminous tube manufacture, except that it should be vacuum-tight and robust, and have as large a bore as is practicable. The bombarding transformer is usually on the floor, underneath the pumping bench, with its control in an easily accessible position. The top of the bombarding bench should, naturally, be asbestoscovered, with sufficient free surface to accommodate the most unwieldy tube sections.

Some manufacturers recommended that a separate shelf be provided for the diffusion pumps, gauges, and associated

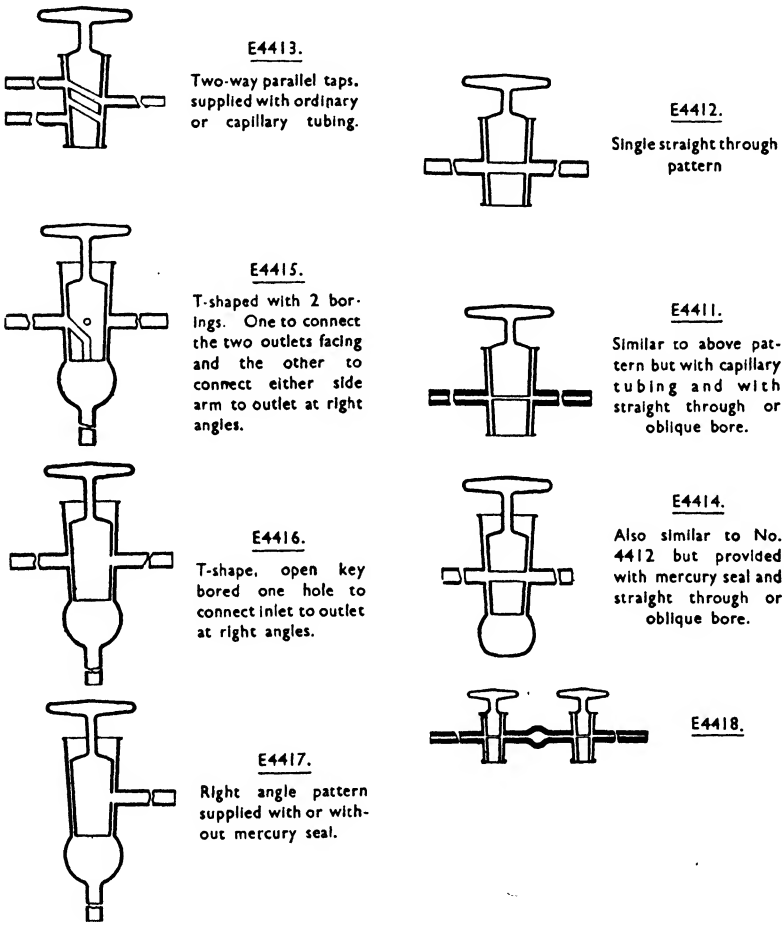


Fig. 17.—Glass Stopcocks for Exhaust System. (W. Edwards and Co. [London], Ltd.)

equipment, with a separate stand for the rotary pump, and provision for the rare gas containers at the end of the bench.

Factory Act regulations demand that some form of automatic switching should protect the operator from inadvertently touching the high tension leads from the bombarding transformer. This is usually complied with by a wire mesh shutter arrangement which covers the front of the exhausting and bombarding system, and is provided with a switch contact which cuts off the transformer supply as soon as the shutter is lifted.

From the point of view of pumping it is important to avoid any constrictions in the exhaust system, as these may reduce considerably the speed of pumping. For this reason all stopcocks should have as large a bore as possible, and all connections should be short.

Apart from the connection to the intake of the rotary pump, rubber connections should not be used ; they are always a potential source of leakage.

It is recommended that all stopcocks used in the exhaust system have a minimum bore of 0·4 in., be well ground, and coated with good quality tap grease of negligible vapour pressure.

Constrictions in the gas-filling portion of the system are not likely to have such an adverse effect, but it is more than ever necessary to guard against leakage, as this will result in contamination of the rare gas.

The detection of tiny leaks in the manifold system is by no means an easy matter. A portable high-frequency generator, as described earlier, or Tesla coil, will be found useful as, when this is passed slowly over the glass tubing the leak can be often located by the glow discharge that occurs when the metal probe is over the leak.

To trace an extremely small leak the system may have to be exhausted to as low a pressure as possible and isolated section by section by means of the stopcocks and plugged up with wax at suspected portions so that the pressure gauge will serve as an indicator when the leak is prevented.

Chapter IV

OPERATION

As mentioned earlier, collision processes taking place during the operation of a cold cathode tube result in the ejection of electrons and the formation of positive ions. Thus, in our low pressure discharge during each half-cycle, there will be a drift of electrons in one direction and of ions in the opposite direction. Due to the high velocities acquired by the ions, they will continually bombard the cathodes and cause emission of further electrons. It is obvious that once ionization has started, the process will tend to be cumulative and unless some stabilizing influence is introduced the increasing conductivity will lead to a flow of current sufficient to destroy the tube.

Nowadays, the employment of leakage reactance transformers alone, without the aid of any additional device, is found to provide quite satisfactory control, but in the past several other methods of stabilizing or "controlling" cold cathode tubes have been attempted.

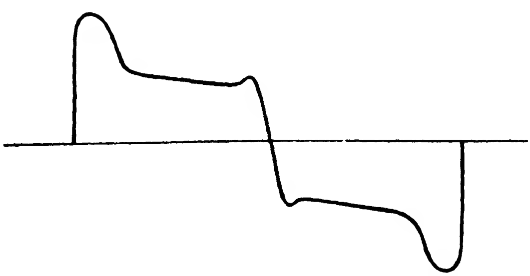


Fig. 18.—Oscillogram of Tube Voltage of Cold Cathode Neon Tube.

Resistance Control

Due to the negative characteristic of glow discharges, resistance control is bound to be unsatisfactory except for small lamps of the beehive type. A waveform oscillogram obtained using this type of circuit shows that the current does not persist for a full half-cycle. This causes a flicker or stroboscopic effect which is bad from an illumination point of view.

Even with step-up transformer operation, the connection of resistance in the primary circuit would not be a practical proposition owing to the relatively high consumption of energy.

High resistances for stabilization have been used experimentally in cold cathode transformer secondary circuits. Due to the technical difficulties encountered with high voltage resistances, however, they would always be a potential source of breakdown. Moreover, they would increase enormously the cost of installation.

Condenser Control

The use of a condenser in the transformer primary as a means of control is also unsatisfactory for a continuous light source. Although the high losses encountered with resistance control would be obviated, and the power factor would be improved, the stroboscopic effect due to the short conduction period would make the circuit impractical.

Choke Control

Chokes have also been used as an additional means of control in transformer-operated cold cathode lighting installations. Chokes have relatively small losses and are more satisfactory than either resistances or condensers.

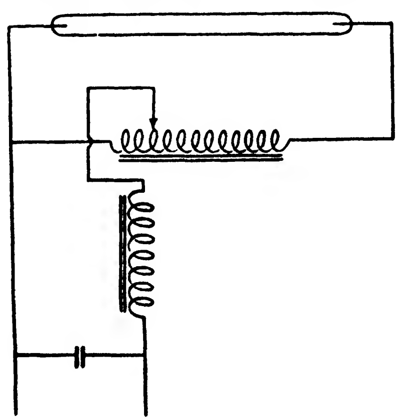


Fig. 19.—Auto-transformer with Choke in Primary.

In the early days of tube lighting cold cathode circuits included a separate choke in the transformer primary. This did not in any way limit the length of tubing that could be operated by the transformer; as many tubes could be

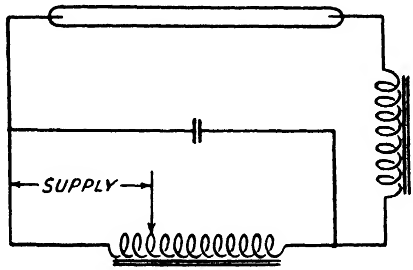


FIG. 20.—Auto-transformer with Choke in Secondary.

connected in series with the secondary as it was capable of striking.

Immediately after switching on, and before the tubing lit

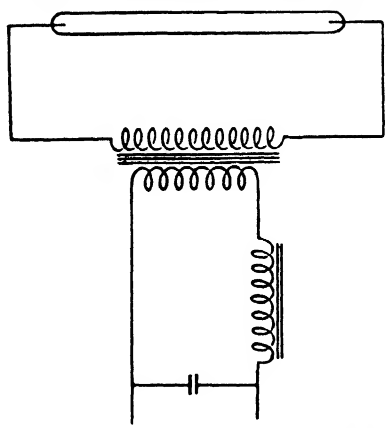


FIG. 21.—Double-wound Transformer with Choke in Primary.

up, hardly any current would flow. As soon as the tubing struck, the choke began to consume energy, so that the secondary voltage dropped. As a general rule the chokes provided were adjustable, so that the current through the cold cathode tubes could be varied.

These low voltage chokes were large, heavy, and expensive.

They were discontinued after a short time, and replaced by high-voltage chokes.

High-voltage chokes for connection in the secondary circuit were much smaller and less expensive than low voltage chokes. Their advantage was that they allowed lengths of cold cathode tubing to be connected in parallel across the transformer secondary.

Without chokes in the secondary circuits it is not practicable to connect cold cathode tubes in parallel. However carefully they are processed, the tubes are certain to have slightly different characteristics ; their striking voltages will differ.

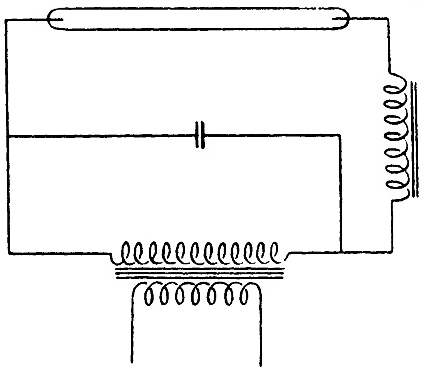


Fig. 22.—Double-wound Transformer with Choke in Secondary.

When the tubes are each connected in series with a choke and each tube and choke are paralleled across the transformer secondary, any difference in starting potential of the tubes is compensated by the chokes.

This type of circuit required a lower secondary voltage and a much higher current than was necessary using other circuits. This made the installation uneconomical, and the system was never universally adopted.

Auto-Transformers

Chokes and condensers for control purposes may be used in the secondary circuits of auto-transformers. An auto-transformer may be used to operate comparatively short lengths of cold cathode fluorescent tubing. It consists of a single winding on a laminated core, and its advantage over the more usual double-wound transformer is the saving in copper and the reduction in dimensions. Auto-transformers are only employed when the transformation ratio required is not large.

Two cold cathode tubes operated by an auto-transformer can be interconnected in much the same way as hot-cathode fluorescent tubes. Each tube in the circuit known as a " constant current " circuit is controlled by a series inductance and capacitance.

When the alternating current passes through zero the reduction in light output may cause some stroboscopic effect, or

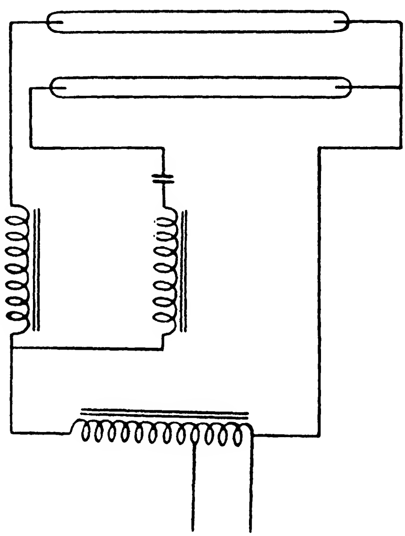


FIG. 23.—Twin-tube Ballast.

flicker. Since the time element would normally be very small this effect should be negligible in most cases.

The core flux densities of the transformers used for the purpose are high and tubes operated in this way give reasonably constant illumination value even with small changes in the primary input voltage.

By controlling one tube by an inductance and the other by an inductance and capacitance in series, the twin tube arrangement is improved in two ways. Firstly, the flicker resulting from stroboscopic effect is minimized. Secondly, the overall line power factor is considerably improved.

If, however, a decrease in line voltage occurs, there may be a difference in tube current which, in turn, will affect lumen output.

Double-Wound Transformer Circuits

The majority of cold cathode installations employ a double-wound transformer specially designed to have a certain amount of magnetic leakage to compensate for the difference between striking and running voltages of the tubes.

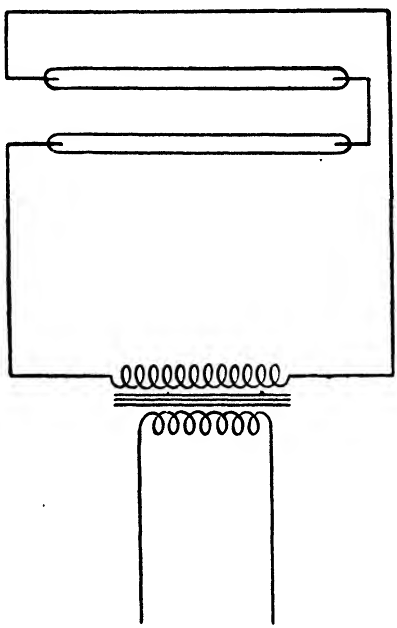


Fig. 24.—Simple Series Circuit.

Under " no-load " conditions as we have seen, the effect of the flux on the primary coil is to cause this winding to act as a choke by carrying a wattless current. As soon as the tubing lights up, the magnetic leakage causes a loss of voltage at the secondary, thus limiting the current through the tubing. No starting switch or auxiliary circuit is necessary.

Unfortunately, a breakage or failure of one tube connected in this way will cause extinction of any other tubes connected to the same transformer. In cases where there are several cold cathode tubes in the secondary circuit, the maintenance electrician may have to spend some time testing out to locate the faulty tube or tubes and if more than one tube has failed the difficulty of location is increased enormously.

For the purpose of safety and to minimize any difficulty in locating a faulty tube, the centre-point of the tube circuit can be earthed. This method of connection has the additional

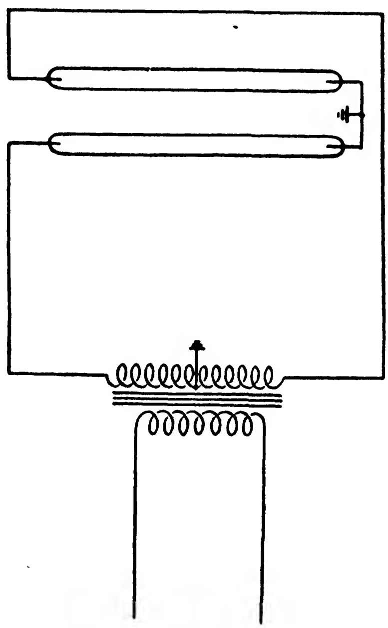


FIG. 25.—Earthed Centre-point Circuit.

advantage that when a tube fails, one-half of the tube circuit (the half that does not include the bad tube) will continue to operate.

In large cold cathode lighting installations some of the transformer primary coils may have a common connection in the supply mains. It is necessary in this case to make sure that the connection is made in such a way that the secondaries will be additive.

These circuits are particularly useful for multiple tube schemes.

Electrode drop

Apart from the voltage drop in the positive column there is also a drop of potential at the electrodes. Close inspection of a cold cathode tube shows that the glow is slightly separated from the electrode surface by a non-luminous space where the

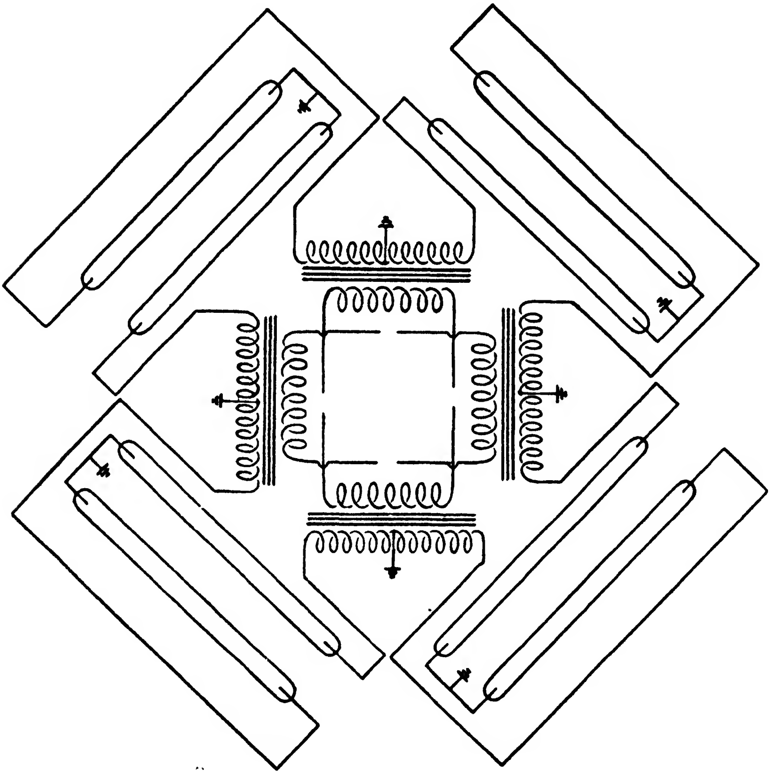


FIG. 26.—Multi-transformer Circuit.

flow of current from electrode to gas is taking place. The voltage drop at this portion depends largely on the current density, but for the average cold cathode fluorescent tube containing argon and mercury is about 300 per pair of iron electrodes.

The internal gas pressure of the tube has considerable influence on the electrode drop. Also, if slight impurities are present the drop is further affected.

It is important to remember that the electrode drop remains constant only so long as the surface of the electrode is partly covered by the negative glow. When the whole of the surface is covered by the glow the drop increases abnormally.

The low drop obtained with alkaline earth metals would lead one to believe them ideal for electrodes. Due to their high chemical activity, however, they are not suitable for electrode construction, but can be coated on iron electrodes. One such method consists of applying barium azide, which is soluble in water, to the surface of the electrode, and then decomposing by means of heat treatment. Unfortunately, this treatment is only successful with neon-filled tubes, due to the tendency of the coating to amalgamate with mercury.

Operating Voltage

The minimum secondary voltage of a transformer required to operate a particular cold cathode tube depends on both the diameter and the length of the tube ; the larger the diameter and the shorter the length the lower will be the voltage necessary.

The internal gas pressure of the tube affects its operating voltage, electrical resistance, and its life. Too low a pressure means that there is a scarcity of atoms, and thus less than normal opportunity for collision processes. Therefore, the possibilities of ionization will be lessened and consequently the electrical resistance will be increased. Also, since the amount of gas will be less than normal, it will be cleaned up sooner and the life of the tube will be comparatively short. Again, an abnormally high pressure will result in too many atoms in the path of the electron stream ; electron speed will be lowered, causing reduced ionization.

The high voltage secondary circuit necessitates several safety precautions and many attempts have been made to devise a method of operating cold cathode tubing direct from mains supplies without the use of a step-up transformer. One method of achieving this result consists in fixing a metallic strip backed with insulation over half of the glass tube, so that it extends from one electrode almost to the other. The discharge then starts up across the gap between the metallic strip and the adjacent electrode, the glass wall of the tube forming the dielectric of a condenser. An ohmic resistance is usually connected in these circuits for stabilization purposes.

Cold cathode tubes operated in this way are inclined to be erratic in performance, and are of necessity short in length. They have been used for small portable table lamps.

Operating Current

It is important that the correct value of current should be passed through cold cathode tubes. Too high a current would cause overheating and would shorten the effective life of a tube. Too low a current would result in a loss of luminosity. The provision of ultra-violet radiation of the right wavelength for fluorescing the powders is also dependent to some extent on the current.

The correct operating current for any given cold cathode tube depends on the diameter of the tubing ; the larger the diameter the higher the value of current required. Current values also differ slightly in tubing of different manufacturers ; for the kind of electrodes and certain factors in processing have to be taken into account.

The flow of electric current through the tube is accompanied by the passage of free electrons and ions. Thus, increase in current causes an increase in electrons and ions and consequently an increase in the number of collisions. In addition, the bombardment of the electrodes becomes more intense, and the process of disintegration is accelerated.

Cold cathode tube operating currents are expressed in milliamperes (thousandths of an ampere). The most popular type of cold cathode fluorescent lighting unit in this country is supplied from a transformer with 120 milliamperes output.

Sputtering

When the electricity supply to a cold cathode tube is switched off the atoms are returned to their normal state. It would therefore appear that since there is no permanent change the tube would last indefinitely. Actually, there is a slow decrease in the internal pressure of the tube throughout operation. This is due to a process, technically known as sputtering, during which ions impinge on the electrodes and knock off minute particles of metal. The particles so released envelop the ions and are deposited by electrostatic action on the portion of the glass tube round the electrodes, thereby trapping some of the gas. Since the total number of ions present is in proportion to the current through the tube and the size of the electrodes used, the rate of sputtering will depend mainly on these two factors.

Obviously the metal of which the electrode is made and its treatment during processing also influence sputtering. Even Swedish iron, with a low sputter factor, if contaminated with grease will sputter rapidly, particularly if the current applied during the pumping process is excessive. Irregularities of the electrode surface also increase sputtering.

According to Schallreuter, the life of a correctly operated cold cathode tube may be expressed by the following formula:—

$$T = C\frac{p^x}{i^y}.V.\frac{e.g.}{w^z}$$

in which T means the time in burning hours, C is a constant depending mostly on the individual manner of manufacture of the tube, p is the pressure, i is the current density with respect to the electrode surface, V is the volume of the tube, e is a factor dependent on the material of the electrode, g is a factor dependent on the gas filling, and w is a function relating to the frequency of the electric supply.

Stroboscopic Effect

Most alternating supplies in this country have frequencies of 50 cycles per second. In the case of an ordinary incandescent electric lamp the filament gets cooler and hotter in accordance with the cyclic variation of the supply. However, since the tungsten filament has sufficient mass to retain most of the heat there is hardly any noticeable flicker. This is not so with discharge tubes, in which there is negligible thermal lag.

With cold cathode fluorescent tubing the slight phosphorescence or afterglow produced by the powders counteracts to some extent the cyclic variation in light output. The slight remaining flicker or stroboscopic effect is only apparent in situations where there is rotating machinery. Dependent on the speed of rotation, such machinery may appear under discharge lighting to be either stationary or revolving at a different rate from that at which it really is rotating. This effect can be reduced by operating adjacent tube lighting points on different phases of a three-phase supply.

Reduction in stroboscopic effect could, of course, be achieved by employing current of a higher frequency than the usual 50 cycles per second. In this way the size of transformers, chokes, and condensers used for controlling the cold cathode tubes could also be reduced.

High Frequency Operation

If a reasonably cheap and reliable source of high frequency were available several advantages could be obtained by operating cold cathode tubing in this way. Many of the potential dangers from shock attendant on high voltage low frequency operation would be removed and operation of a number of tubes in parallel would be possible. Unfortunately, the output of the more usual types of high frequency generators is not stable enough to operate cold cathode lighting tubes.

A potential application of a source of high frequency, such as a synchronous vibrator, is the operation of cold cathode tubing installed in motor vehicles. In this case the vibrator would be supplied with direct current from the battery and would deliver interrupted current of high frequency to the primary of a suitable step-up transformer.

Radio Interference

Properly installed cold cathode tubes should not normally cause radio interference. When this occurs the most likely causes are : (1) flickering tubing due to gas failure or hardening or to incorrect operation of the transformer ; (2) static discharges between high voltage connections and adjacent metal due to defective insulation ; (3) loose contacts ; (4) accumulation of dirt or moisture round high voltage connections, and (5) faulty earthing.

If there is interference with broadcast reception in the immediate vicinity of the tubes and none of the above defects can be found, the connection of two condensers with low impedance at radio frequencies across the transformer primary, interconnected with the centre-point earthed, will generally suffice. There are various forms of acceptor or rejector circuits employing condensers and chokes that may be used in different cases.

Energy at radio frequencies may in exceptional cases be radiated either from the tubes or from the wiring. Sometimes radiation from the tubes themselves may be eliminated by orientation. Sometimes re-connection or even screening may be necessary.

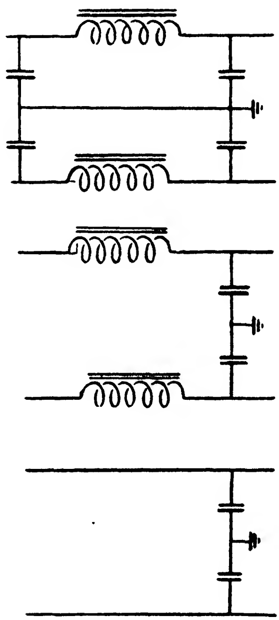


FIG. 27.—Radio Interference Suppression.

Dimming

Small cold cathode lighting installations can be dimmed by inserting a variable resistance in the primary circuit. This is rather a wasteful method, since the wattage is practically the same whether the illumination is at the maximum or minimum. At the minimum position most of the energy will be dissipated by the resistance.

Owing to the flicker at low current values cold cathode tubes are not dimmed to extinction. Neon-filled tubing can be effectively dimmed to about 15 per cent of its maximum light output. White or blue tubes, however, may be reduced satisfactorily to 10 per cent of the maximum.

By utilizing a variable voltage auto-transformer the tube lighting can be continuously controlled over the dimming range. With this method the consumption of electrical energy varies according to the light output. The auto-transformer itself absorbs little energy.

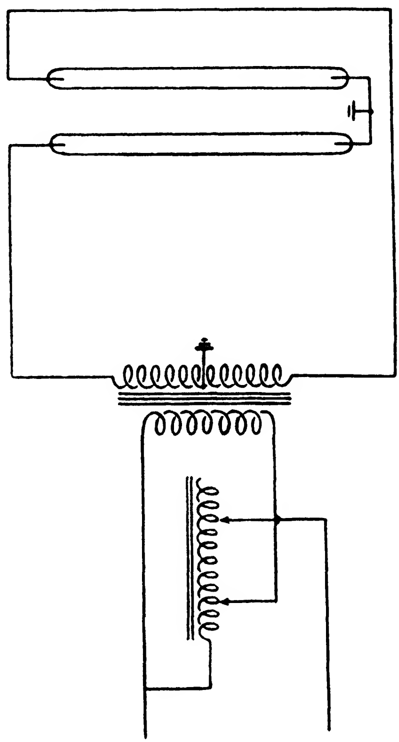


FIG. 28.—Dimming by Variable Voltage Transformer.

An advantage of this method of control is that the light output from the cold cathode tubes can be kept fairly constant throughout the useful life of the tubes. For instance, as the tubing " hardens " or increases in its electrical resistance the applied voltage can be increased by means of the auto-transformer.

The saturated core reactor method of control is rather more complicated than those previously described. In this circuit the transformer input is in series with two coils of a reactor, the third or centre coil being connected to a variable direct current source.

Magnetic saturation of the core of the reactor is produced by applying a small d.c. through the centre coil. This has the effect of reducing the effective impedance, which causes a corresponding increase in current through the cold cathode tubes.

Saturation of the reactor core may be provided by the rectified output of two thyratrons. This is quite a popular method of dimming, as it can be applied to a large number of circuits.

An interesting application of thyratron reactor control to ballroom lighting was tried out a short time ago. The dimming equipment was arranged for sound control, and the lighting was divided into banks of red, blue, and green.

By using a microphone in conjunction with the thyratron saturable reactor circuit, the colour of the lighting was made to vary in accordance with the characteristics of the music. The intensity of the illumination depended on the amplitude of the sound emitted.

Safety Devices

To provide protection against open-circuit on the secondary side, an increased voltage may be arranged to operate a spark gap across the transformer output. This, in turn, may be caused to melt a fuse.

Another protective device, which is the subject of British Patent Specification No. 496,083, depends on the action of a relay. Its function is to interrupt the main supply to the transformer primary if an open circuit or earth fault occurs.

The circuit comprises an electro-magnetic relay connected in series with the cold cathode tube circuit. Whenever the secondary coil becomes overloaded—for example, in the case of an earth fault—the voltage is automatically reduced below the ionization value of the tubes.

If the circuit becomes broken, automatic open circuit protection is provided.

In the circuits where the transformer secondaries are earthed at their centre points, two differential relays are used in order to protect each half of the circuit. Movement of either relay armature due to the fault will cause disconnection of the primary supply.

CHAPTER V

AUXILIARY EQUIPMENT

Reference has already been made to the high-voltage alternating current necessary to operate cold cathode fluorescent tubing. This is provided by a step-up leakage reactance transformer which steps up the voltage from the a.c. electricity supply mains and at the same time acts as a choke to stabilize the discharge.

Transformers

A double-wound transformer consists essentially of two coils, a primary and a secondary, wound on a common magnetic core made up of thin laminated sheets of steel. The primary contains a number of turns of relatively thick wire. The secondary contains very many more turns of fine wire. Cold cathode transformers are usually split secondary. This means that their secondary coils are divided into two, the centre point being connected to the core which is subsequently earthed.

There are two types of double-wound transformers suitable for operating luminous tubes. They are core type (5 to 20 volts per turn) with concentric coils, and shell type (10 to 35 volts per turn) having a sandwich arrangement of coils.

If T_1 and T_2 are the number of turns in primary and secondary windings respectively, and E_1 and E_2 are primary and secondary induced e.m.f.'s respectively, R.M.S.,

$$\text{Transformation Ratio} = \frac{T_2}{T_1} = \frac{E_2}{E_1}$$

(i.e. 40 for a transformer with 10,000 volts output operated from 250-volt supply).

If ϕ is the maximum flux linking both windings, f is the frequency of the supply, and A is the cross sectional area of the magnetic circuit, then :—

$$E_1 = 4{\cdot}44 f . \phi . T_1 \times 10^{-8} \text{ volts, and}$$
$$E_2 = 4{\cdot}44 f . \phi . T_2 \times 10^{-8} \text{ volts.}$$

The maximum flux density $B = \frac{\phi}{A}$ lies between 9,000 and 13,500 lines/cm.[2] depending on the supply frequency.

The " regulation " of a transformer is the change in the secondary terminal voltage when full load at the specified power factor is removed, expressed as a percentage of the no-load secondary terminal voltage, the primary voltage remaining unchanged.

Since luminous tubes require considerably larger voltage to strike up the discharge than to maintain it, transformers intended to operate the tubes must have low regulation.

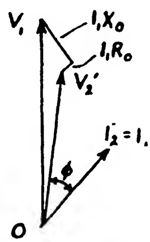


FIG. 29. — Equivalent Circuit Diagram.

Neglecting the magnetizing current and the small angle between V_2 (the secondary equivalent terminal voltage referred to the primary) and V_1 (the primary voltage), the regulation is given by :—

$$\text{Percentage Regulation} = \frac{I_1\,RO\cos\phi + I_1\,XO\sin\phi \times 100}{V_1}$$

Smaller sizes of transformers for operating enclosed fluorescent tube lighting units may be open type, but in exposed situations the transformers should be enclosed in earthed metal casings. They may be filled with transformer-oil or, more generally, a bitumen compound. Suitable glands are provided for watertight entry of low and high tension cables, and the transformer's casings and lids should be prominently marked with the wording " Danger—High Voltage ".

A typical fluorescent tube transformer consists of a primary of about 300 turns of copper wire and a secondary comprising over 12,000 turns of very much finer copper wire—altogether about three miles of wire. The primary and secondary coils are wound in exact layers insulated from one another, and then impregnated with insulating compound.

The core is made up of a large number of thin sheets of silicon steel in order to reduce as far as is possible eddy current losses.

After assembly the coils and core and shunt paths are impregnated with special insulating varnish and fitted in their

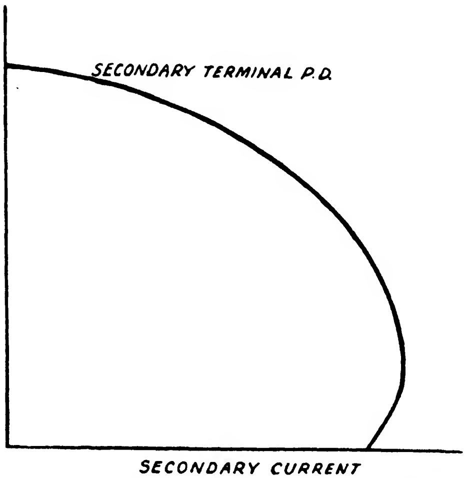


FIG. 30.—Characteristic of High Leakage Reactance Step-up Transformer.

steel case, which is then filled with compound. After this the transformer is ready for terminal mounting.

Mica insulation is provided where necessary and the connections from coils to terminals are sleeved ; primary and secondary terminals are fixed on separate insulation strips. The primary is usually tapped in order that the transformer can be used on different supplies and is also provided with some magnetic leakage for fine adjustment.

When completed the transformer is tested for short circuit, normal and overload conditions.

In operation the transformer automatically varies in accordance with the luminous tube load. Immediately on switching on, and before the discharge strikes across the tube, the current in the primary will cause a magnetic flux in the core and as no current is taken at the secondary the magnetic leakage will have no effect. Thus, under this "no load" condition, full secondary voltage will be applied at the tube electrodes.

As soon as the tube strikes, however, current will flow through the secondary coil and the magnetic leakage will come into operation. The resultant leakage flux will cause a reduction in secondary voltage. This reduced voltage, although sufficient to maintain the discharge, would not have been high enough to cause it to strike.

Due to the self-inductance the current in the circuit is caused to lag behind the voltage. Therefore, the energy is only equal to the product of the instantaneous values of voltage and current. In order to obtain the true wattage it is necessary to multiply the voltmeter and ammeter readings by a factor called the "power factor".

In view of the fact that a large part of the current through a cold cathode circuit is wattless and is not recorded by the meter, supply authorities insist on the correction of power factor. Usually the power factor is between 0·4 and 0·6, and this must be improved to at least 0·8.

Condensers

The usual method of correcting the power factor of a cold cathode fluorescent tube installation is by connecting static condensers across the supply leads to the transformer primary. This introduces capacity into the circuit.

We have seen that the effect of inductance introduced by the transformer is to cause the current to lag behind the voltage. The capacity of the condenser has the effect of making the current lead the voltage. Hence, the effect of some of the wattless current will be cancelled out, resulting in an improvement in the power factor.

The size of the condenser required depends on the voltage and frequency of the electric supply and on the load. If A is the existing (uncorrected) power factor and B the power factor to which it must be corrected, the compensation of wattless component in terms of the initial kVA of a cold cathode fluorescent tube circuit is given by the formula—

$\sqrt{(1 - A^2)} - \frac{A}{B}\sqrt{(1 - B^2)} \times 100$ per cent of initial (uncorrected) kVA.

The value given by the formula will, of course, be kVA. To convert this to the capacity of the condenser required in microfarads it will have to be multiplied by

$$\frac{10^9}{(2\pi.f.e.^2)}$$

in which e is the voltage applied, to the condenser and f is the frequency of the electric supply in cycles per second.

The internal losses of static condensers are small, and never exceed 0·5 per cent of the kVA rating of the condenser.

The correcting volt-amperage to improve the power factor by a given amount increases rapidly as the ultimate power factor approaches unity. If it were required to increase the power factor from 0·95 to 1, it would be necessary for the condenser to neutralize a wattless component numerically equal to 33·3 per cent of the total (uncorrected) current.

The best type of condenser for power factor correction of luminous tube installations is the petroleum-jelly-impregnated-paper condenser. A complete unit of this type consists of a number of elements connected in parallel ; each individual element comprises two aluminum foils interleafed with linen rag tissue, forming continuous multi-turn cylinders. Silver-plated copper strips are generally connected to the foils during the winding operation, so that the elements can be readily connected up.

After winding, the condenser elements are clamped under pressure, pre-heated to remove moisture, and placed in vacuum tanks at high temperature. Finally, they are impregnated with liquid petroleum jelly, and cooled.

The average insulation resistance of an element is 15,000 megohms microfarad.

When the units have been assembled the case is filled with petroleum jelly and hermetically sealed, the terminals being affixed at this stage.

Capacity tolerance for this type of condenser is plus or minus about 5 per cent, and the minimum acceptable insulation resistance 1,000 megohms microfarad. There is usually a flash test of four times the rated working voltage.

A discharge resistance is sometimes connected across the terminals by the manufacturers.

Chokes

The chokes occasionally used in fluorescent tube work are similar in construction to the transformers except that, of course, they have only one winding. They are mainly used for dimming.

Chokes for dimming purposes have movable cores which provide a means of regulating the light output of the fluorescent tubing with which they are in circuit. The chokes are, naturally, connected in series in the primary circuits. For constantly varying illumination the cores must be mechanically driven.

Time Switches

Apart from street lighting and sign control, time switches for controlling cold cathode fluorescent lighting are mostly used for shop window lighting installation. By means of a time switch luminous tube lighting can be set to switch on and off automatically at predetermined times. They are inserted in the primary supply to the transformers.

Time switches may be of the 8-, 15-, or 45-day variety, either hand-wound or electric, with mercury break, for controlling loads of up to 50 amperes; heavier currents may be controlled by oil-break contacts. Double-pole time switches are undoubtedly the best for fluorescent tube work. The temperature should not rise above that of the surrounding air more than 36° F. (20° C.) in the case of switches rated below 100 amperes, and the switch should be capable of breaking the circuit without permitting an arc to be maintained when a current 50 per cent greater than its rated capacity is flowing under a pressure of the supply.

The Venner Time Switch is provided with a mercury cup which permits an actual copper-to-copper contact, only a very small quantity of mercury being necessary.

Arrangements are made in some time switches for omitting Sundays, and operating earlier on closing days.

Photo-Electric Relays

A photo-electric relay for controlling fluorescent tubes comprises a tapped transformer, an amplifier valve, a photo-electric cell, a sensitive relay, and a small contactor. The whole equipment can be obtained as a complete unit in a metal case. If used for controlling d.c. circuits an external resistance box must be connected to the unit.

A unit required to control a load up to about 2 kilowatts usually has a range of adjustment of from 0·2 to 10 lumens per square foot. The power consumption of the unit will probably be approximately 15 watts with the contactor closed, and 8 watts with the contactor de-energized. The external resistance box may increase the power consumption on d.c. circuits to something like 200 watts.

The life of the amplifier and photo-cell have been estimated to be normally over 17,000 hours.

As a rule in shop window lighting the contactor is set to close at nightfall, but a small change-over switch is usually provided to suit special conditions. The unit is fixed in an exposed position and connected to the tube circuits, so that when the daylight falls below a stipulated minimum the photo-cell will cause the contacts to close and will switch on the luminous tubes.

Rotary Converters

When cold cathode fluorescent tubes have to be installed somewhere where the only available electricity supply is direct current, some device must be provided to convert this supply to alternating current suitable for operating the transformers. Such a device is the rotary converter. It is really a direct-current motor and an alternating-current generator mounted on the same shaft. Direct current from the mains is supplied to the commutator and the generated alternating current is obtained at the opposite end of the machine.

Rotary converters for fluorescent tube work are almost invariably of the single-phase type, having kVA outputs of from 0·16 to 15. The smaller machines run at 3,000 r.p.m., but converters delivering comparatively large output are usually rated at about half this speed.

There is only one armature winding in a rotary converter, and both alternating and direct current flow through the same conductors. Thus, since one is a motor current and the other a generator current, these flow in opposite directions, making the actual current flowing through the winding a relatively small one ; this explains the comparatively small size of the machine for a given rating.

The brushes on the commutator are normally arranged at positions to give maximum voltage (no-load neutral position). Slip-ring tappings are a pole pitch apart. Obviously, the d.c. voltage will be equivalent to the maximum value of the a.c. supply. The current ratios, neglecting losses, are :—

$$E_a I_a \cos \phi = E_d I_d$$

in which E_a and I_a are a.c. values, and E_d and I_d are d.c. values. Thus, $I_a = 1 \cdot 414\, I_d$.

Small convertors are often wave wound, but the larger ones are provided with lap windings.

It is advisable to install the rotary converter in a cool, accessible position and on a solid foundation ; sometimes it is necessary to provide a base of sheet rubber to damp the vibration and lessen the noise.

The smaller size converters may be switched direct on to line. A double-pole circuit breaker with combined overload and inverse time limit trip and magnetic blow-out coils is suitable for these small converters. Remote control by automatic starters in conjunction with 3-wire " start " and " stop " push buttons is permissible.

The rotary converter should be run up to speed before switching on to the luminous tube transformer load. Naturally, the frequency of the alternating current output is dependent on the speed of the machine and if the transformers are supplied with current of lower than their rated frequency they may be damaged.

As a rule rotary converters require little attention apart from occasional oiling of the bearings.

Inverters

Alternating current suitable for operating luminous tube transformers may also be obtained from a direct current supply by means of a stationary apparatus known as an inverter.

An inverter is essentially a high efficiency valve oscillator employing gas-filled relays (i.e. hot cathode gas-discharge triodes). It is thus an entirely static apparatus ; mechanical noise is eliminated and servicing is practically negligible. The normal life of a gas-filled relay is more than 2,000 operating hours. First cost and efficiency of inverters compare favourably with those of rotary converters.

A quite simple inverter incorporating two gas-filled relays is capable of operating (from 230 volt d.c. mains) about 25 feet of 0·4 in. tubing, or 35 feet of 0·6 in. diameter tubing. The efficiency of conversion is about 65 per cent, including cathode heating.

The efficiency of inverters is even greater when operating on 460-volt supplies, and roughly double the above lengths of luminous tubing could be supplied from the simple inverter in this way.

It is important to remember that the output voltage wave from this type of inverter is not sinusoidal, but is practically rectangular in shape. Therefore, the glow from fluorescent tubing operated from the inverter will be uniform over a considerable portion of each cycle, resulting in less apparent flicker for a given frequency.

Locking Switch

The I.E.E. Regulations for the Electrical Equipment of Buildings (Eleventh Edition) provide that " each primary final sub-circuit supplying a fixed luminous discharge tube installation shall be controlled by a locked switch, arranged to open and close the circuit on all poles except the ' neutral ' in a three-phase four-wire circuit. The locked switch shall be fixed in a readily accessible position and shall preferably be that normally used for controlling the luminous discharge tube installation. . . ."

For a single-phase circuit the locking switch usually takes the form of a double-pole ironclad switch with a detachable handle. The handle has a special flange and the device is so constructed that the switch cannot be put in the "on" position until the handle is properly inserted and turned. To remove the handle the switch must first be turned into the "off" position. In addition it is necessary for the cover of the switch to be secured in such a way that it cannot readily be opened without the use of a key or a special tool, which may be incorporated in the handle.

As an additional precaution the "off" position of the locking switch should be clearly marked, and a notice worded as follows fixed adjacent to it: "Before working on or near electrical discharge tube installation remove and retain key of locked switch." The size and colouring of the notice is specified in the appropriate I.E.E. Regulation.

Thus, whenever it is necessary for an electrician to carry out work in connection with a cold cathode fluorescent lighting installation (e.g. for maintenance purposes), he can switch off, remove the key of the locking switch and place it in his pocket and be assured that the high voltage will not be inadvertently switched on before he is clear.

If a distribution fuseboard is used exclusively for cold cathode tube lighting one locking switch can be used to control the busbars of the fuseboard.

Fireman's Switch

A fireman's switch comprising a double-pole ironclad switch should be installed to control an exterior high-voltage lighting installation or an interior installation which runs unattended (e.g. for window lighting or display purposes).

This fireman's switch serves to isolate the luminous tube installation in cases of emergency. It is painted red and a nameplate must be fixed adjacent to it marked "Fireman's Switch" in lettering legible from the ground. The "off" position is at the top and this and the "on" position should be clearly indicated. To prevent the switch being inadvertently or accidentally returned to the "on" position it is desirable that it should be provided with some form of lock or catch.

The maximum permissible height from the ground of the switch is 9 feet, except in the case of an agreement to the contrary with the local fire brigade authority. Naturally, it should be fixed in a conspicuous position reasonably accessible to firemen. For interior installations it is situated preferably in the main entrance to the building. For exterior installations it should be as nearly as possible vertically below the luminous tubes.

Low-Voltage Wiring

The wiring from the electricity supply point to the transformer primary usually consists of standard wiring. It is important that the voltage of the electric supply should be within the range suitable for the transformer primary, for over-volting the transformer would probably cause burn-out and under-volting would lead to unsatisfactory operation of the luminous tubes. Similarly, it is necessary to be sure that the current supply is of the correct frequency for the transformer.

In compliance with the I.E.E. Regulations, a final sub-circuit which forms the primary circuit of a fixed cold cathode fluorescent lighting installation must be reserved solely for that purpose. Also, a separate primary final sub-circuit should be provided for each transformer or for each group of transformers having an aggregate input not exceeding 1,000 volt amperes.

Earthing should be carried out in the manner laid down for low-voltage wiring.

The total steady current in a final sub-circuit supplying cold cathode luminous tubes must not exceed 80 per cent of the rating of the final sub-circuit.

Each portion of a final sub-circuit controlled by a separate switch should have separate power factor correction. Every capacitor used for power factor correction should be provided with means such as a high-resistance leak for its prompt automatic discharge immediately the supply is disconnected.

An effective method must be provided for the isolation from all poles of the supply of every self-contained fitting or alternatively of every circuit supplying a high-voltage discharge tube.

High-Voltage Wiring

The r.m.s. voltage of a circuit supplying a cold cathode lighting installation must not exceed 5,000 volts to earth measured on open circuit and every transformer should have one point of its secondary earthed.

A high-voltage circuit supplied from a transformer of more than 500 watts input must have some means of automatically disconnecting the supply in the event of short circuit or of earth leakage current in excess of 20 per cent of the normal steady current.

Although in the case of a self-contained cold cathode fluorescent lighting unit the secondary wiring is already provided, this does not apply to the luminous tube decorative lighting which is designed to suit a particular situation. This type of installation requires special cable for connecting the transformer secondaries to the luminous tubes.

High-voltage wiring must in all cases be kept as short and straight as is possible. Sharp turns and bend-backs should be avoided, as these cause both electrical and mechanical strain. It is recommended that this wiring be kept at least 2½ inches away from metallic fixtures. Actual connections to the transformers are made by means of screw terminals contained in porcelain housings. If it is necessary for one high-voltage cable to cross another they must be separated from one another.

The revised Section 8 of the I.E.E. Regulations for the Electrical Equipment of Buildings specifies that metal-sheathed, armoured or metal-sheathed and armoured cable shall be used for high-voltage connections except in :—

(i) Exterior installations for series connections not exceeding 10 feet in length which are not exposed to the likelihood of mechanical damage, or which are installed in box signs ;

(ii) Interior installations, in self-contained fittings, where insulated and braided cable may be used.

For high-voltage series connections not exposed to the likelihood of mechanical damage and not exceeding 36 inches in length bare or lightly insulated conductors of copper (preferably tinned) or nickel may be used. Such conductors should have a cross-sectional area of at least 0·0006 sq. in. and must be supported at intervals not greater than 18 inches.

The conductors should be protected throughout their lengths by non-ignitable, non-hygroscopic insulating material, which if in the form of glass tubing, has a wall thickness not less than 0·04 in. and an overall diameter not less than 0·2 in., and is so arranged as to be reasonably secure against being so displaced as to expose any part of the live metal.

Bare or lightly-insulated conductors may also be used in enclosures to the interior of which only authorized persons can have access.

Metal-sheathed, armoured or metal-sheathed, and armoured cables must have their metal sheathing and armouring earthed, and should be supported at intervals not greater than the following :—

Cable Run.	*Metal-Sheathed.*	*Armoured or Metal-Sheathed and Armoured.*
Horizontal . . .	30 in.	36 in.
Vertical . . .	48 in.	60 in.

Insulated and braided cables should be supported at intervals not greater than the following :—

Cable Run.	
Horizontal . . .	18 in.
Vertical . . .	30 in.

Cables should be supported close to each terminal connection. If glazed porcelain housings are fitted to the electrodes the supports may be at a distance no greater than 12 inches from the terminal connections, otherwise the maximum permissible distance is 6 inches.

Clearances of high-voltage cables from conducting surfaces should be in accordance with Regulation 861.

When a connection to a conductor of a metal-covered high-voltage cable is to be made, the metallic covering and armouring (if any) of the cable should, according to the I.E.E. Regulations, " be stripped back beyond the insulation for a distance in inches not numerically less than the value obtained by dividing by 2·5 the number of kilovolts to earth of the open-circuit secondary voltage (root-mean-square value) of the transformer. The part of the insulation exposed by stripping back the close-fitting metallic covering and the armouring (if any) of the cable shall be protected from the effects of ozone by means of a thimble of ceramic material sealed with ozone-proof compound."

Fixtures

Apart from coloured cold cathode decorative lighting, the fluorescent tubes, usually about 8 ft. 9 in. long, are fixed to a metal batten with a housing box at each end. They are conveniently arranged in triple-tube formation, so that the

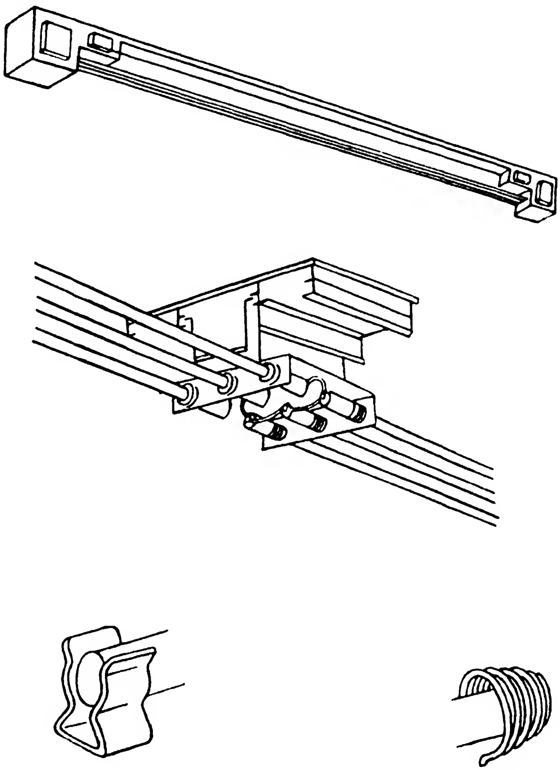


Fig. 31.—Cold Cathode Lighting Fixtures. (*a*) Triple-tube Fixture (General Electric Co., Ltd., London), (*b*) Intermediate Assembly (General Luminescent Corporation, Chicago), (*c*) Phosphor-bronze Clip Housing, (*d*) Helical Spring Housing.

three lines of tubing run parallel along the batten or ceiling plate with their electrodes entering the housing boxes which also contain the transformers. The tubes are attached to the ceiling plate by spring clips mounted on an insulating base affixed to the ceiling plate. The spring clips are flanged in order that the tubes may be secured with " tie-on " wire.

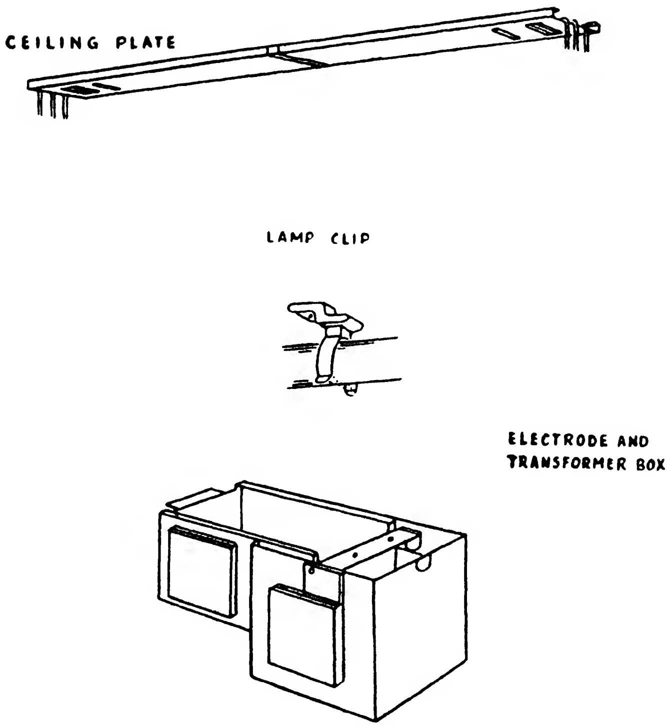


FIG. 32.—Cold Cathode Fluorescent Lighting Assembly.
(General Electric Co., Ltd.)

All wiring is contained at the back of the ceiling plate and all high-voltage connections pass through into the housing boxes. Provision is made for power factor correction condensers.

An important electrical feature of this type of cold cathode fixture is the tandem connection of the two transformers which are, for all practical purposes, electrically and mechanically identical and which are connected in such a way that their secondary voltages are 180 degrees out of phase.

These self-contained fixtures or units are about 10 feet in length, including transformer boxes, and are generally finished in white enamel.

An alternative type of self-contained fixture has a circular housing box in the centre, with a double line of luminous tubing curved at the ends.

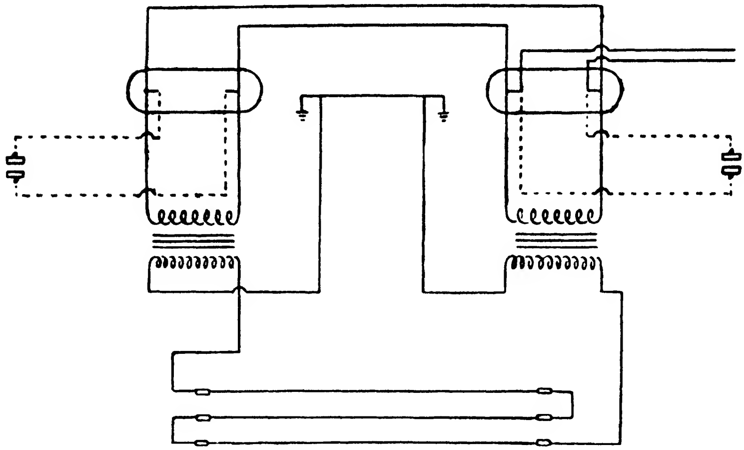


FIG. 33.—Wiring Diagram for Cold Cathode Fluorescent Lighting Assembly. (General Electric Co., Ltd.)

Chapter VI

PRACTICAL COLD CATHODE LAMPS

Beehive Lamps

Before the advent of the tube light source the glow discharge was utilized in low-wattage "beehive" neon lamps. These lamps, which were used as indicators in signalling and as advertising novelties, were fitted with ordinary bayonet caps incorporating series resistances for control purposes. The electrodes usually consisted of a circular metal plate surrounded by a wire spiral; normal current consumption was about 5 watts.

The discharge obtained from the beehive lamp is self-maintaining, that is it requires no auxiliary ionization. Electrons are supplied solely by bombardment of the cathode by ions. The time lag in starting the discharge is extremely short, which makes the lamp particularly suitable for intermittent lighting as required for signalling and television.

Beehive lamps were sometimes filled with argon, but this gas needs a relatively high current density in comparison with neon. A very small quantity (about 1 per cent) of argon is usually introduced into a neon lamp to reduce the striking voltage.

Neon Tubes

Cold cathode neon tubes which comprise a cylindrical iron electrode fitted at each end of a glass tube containing neon gas, are sometimes referred to as positive column lamps. The main discharge or source of radiation is the orange-coloured positive column. To obtain the maximum efficiency with this type of light source the tube must be as long as is practicable. In addition the voltage drop in the positive column must be large.

Although loosely termed "neon" tubes, these tubes often contain argon and mercury and occasionally helium. A fairly wide range of colours is obtained by using coloured glass tubing, although this lowers the light output.

The main application of cold cathode neon tubing is to advertising signs.

Cold Cathode Fluorescent Tubes

These are similar in principle to neon tubes except that the inside surface of the tubing is coated with fluorescent powder. The powder is excited by the ultra-violet radiation of the low-pressure mercury vapour discharge. In addition to the well known range of daylight, intermediate, and warm white, many different colours can be obtained by variation of the fluorescent powders used.

The voltage drop in the positive column of mercury tubing is lower than for neon tubing, but the electrode drop is slightly higher.

Cold cathode fluorescent tubing for use in a straight self-contained lighting unit usually has a luminous portion about 8 feet long and a diameter of about $\frac{3}{4}$ in. The operating or running voltage per tube is from 400 to 650 ; current approximately 120 milliamperes. A common arrangement consists in connecting three tubes in series and operating them from two transformers in tandem with the secondary voltages 180 degrees out of phase.

Differences between Hot and Cold Cathode

To explain the essential differences between hot and cold cathode fluorescent tubes, the following questions and answers have been evolved by the Sola Electric Company.

What is a " Hot Cathode " Fluorescent Lamp ?

It is generally stated that a Hot Cathode fluorescent lamp is designated as such because the filament or cathode of the lamp is preheated before the lamp is lighted. This preheating is accomplished by installing a " starter " in the lamp circuit. The starter provides a short period of time during which a current flows through the filaments and heats them to incandescence. The filament also remains hot during operation.

What is a " Cold Cathode " Lamp ?

Cold Cathode lamps differ from " Hot Cathode " in that the lamps are designed to light without previous preheating. No starting device other than the transformer is necessary.

How "Cold" is a Cold Cathode Lamp?

The electrode of a Cold Cathode lamp operates at approximately 150° C. (300° F.).

How "Hot" is the Hot Cathode Fluorescent Lamp?

The conventional fluorescent lamp operates at a filament temperature approximately 900° C. (1,652° F.).

Is it true, then, that the Cold Cathode Lamp operates cooler than the Hot Cathode Fluorescent Lamp?

No. The amount of heat produced depends entirely upon the wattage consumed by the lamp. A 40-watt Cold Cathode lamp would produce exactly as many B.T.U.'s (heat units) as a conventional 40-watt Fluorescent lamp.

What is the difference in the Electrodes of the Two Types of Fluorescent Lamps?

The Cold Cathode lamp has a hollow shell, usually made of pure iron or nickel, while conventional Fluorescent lamps have a coiled tungsten filament. The shells in the Cold Cathode lamp act as both anode and cathode, while the tungsten filament used in Hot Cathode lamps is supplemented by small wire prongs that act as the anodes, as the current changes from positive to negative during the a.c. cycle. Both types of electrodes may be treated with an emissive material which is a mixture of barium and strontium salts.

What is the difference in the Method of Producing Light in the Two Sources?

There is no difference. Eliminating the electrodes and thinking only of the glass portion between them, it is found that both produce light from the passage of an electrical discharge through a gaseous column. This gaseous column in both cases contains Argon (a rare gas) and vaporized mercury. The electrical discharge passing through the vaporized mercury produces short-wave ultra-violet radiations (2537A wave-length). These radiations when striking the fluorescent coating on the inside wall of the glass tubing are converted into longer radiations, that we call visible light. This phenomena is called " Fluorescence ".

Are the Fluorescent Powders the same in both Hot and Cold Cathode Lamps ?

Yes. Various mixtures, however, are used to produce different colours and shades.

Why is it necessary to use a Transformer with a Higher Voltage Rating to operate Cold Cathode Lamps ?

Referring to two comparable lamps, the 40-watt, 48 in. Hot Cathode and the 42-watt, 93 in. Cold Cathode lamps, we find that in the former a starter is used in parallel with every lamp. As mentioned before, its purpose is to provide a short period of time during which a current flows through the filaments, heating them to incandescence.

While the filaments are hot the emission material on them gives off a stream of electrons into the gas column (thermionic discharge). The heat from the filaments also provides vaporization of the mercury which is used in all fluorescent lamps. The electronic bombardment ionizes the gas in the lamps, thereby lowering the internal resistance to a point where a momentary high voltage surge (minimum of 200 volts) starts the current flow through the lamp. As the current flows the starter ceases to function.

The Cold Cathode lamp uses no starter and does not require a preheating period. As a result a somewhat higher voltage transformer is used (750 volts for 93 in. lamp) in order to drive the electrons from the cathode or filament (positive ion bombardment) and produce ionization of the gas. The voltage required to start the Cold Cathode lamp varies, depending upon several factors. Length, diameter, gas pressure, and type of gas used determine the voltage necessary for proper starting.

What is the Operating Voltage and Current of 42-Watt 93 in. Cold Cathode and 40-Watt Hot Cathode Fluorescent Lamps ?

The 93 in. Cold Cathode lamp when processed at about 4 mm. gas pressure operates between 400 and 450 volts with a current of 120 milliamperes. The 40-watt fluorescent lamp operates at approximately 108 volts, with a current of 410 ma.

Is it possible to Operate a Hot Cathode Lamp using a Cold Cathode Ballast ?

The preheated Hot Cathode lamp may be operated using a Cold Cathode Ballast without the need for a starter. It should be remembered, however, that the lamp and ballast were not designed for one another and short lamp life will result, due to the elimination of the preheat period. Overheating of the ballast may also be expected as the lamp resistance is considerably less than that of the 8 ft. Cold Cathode lamp. This would result in an abnormally high secondary current and consequent overheating of the secondary windings. While the secondary current would be higher than the ballast is rated, it would be considerably lower than the normal lamp operating current. This would mean the light output would be far below normal.

What is " Instant Start Fluorescent " ?

Instant start ballasts were brought out about 1941. These ballasts are of the high-voltage type, designed to operate a special 40-watt hot cathode type fluorescent lamp.[1] Operation with the " instant start " ballast eliminates the " starter " used in the conventional circuit. The starting voltage is approximately 450 volts and operating voltage 108 volts.

The disadvantage of the " instant start " is that the ratio of striking to operating voltage necessitates a large ballast of considerably less efficiency than either conventional hot or cold ballasts. This reduces the overall efficiency of light production approximately 10 to 15 per cent.

How do the Two Types of Lamps compare in Operating Current ?

Comparing the 40-watt Hot Cathode lamp with the 93 in. Cold Cathode lamp again, the lamp manufacturers recommend an operating current of 410 milliamperes for the Hot Cathode lamp. The standard 93 in. Cold Cathode lamp operates at approximately 120 milliamperes. There are

[1] If the standard preheat type lamp is used with the instant start ballast, short lamp life can be expected.

also installations, particularly where the high voltage (5,000 to 10,000 volts) transformers are used, where the operating current may be 96 or 48 milliamperes.

Is the Light Output of the Cold Cathode Lamps in proportion to the Operating Current?

No. The light output is proportional to the lamp wattage.

Two Cold Cathode Ballasts are made for 8 ft. Lamps. One is Rated at 900 Volts, the other 750 Volts. What is the purpose of having these Two Ratings?

In the processing of Cold Cathode lamps two procedures are followed. One is to process the lamps with a low gas pressure, the other is the use of higher pressures. These pressures vary with the lamp manufacturer, but in general low-pressure lamps are approximately 4 mm. of Argon gas, and high 6½ to 7 mm. of Argon and neon mixture. The voltage required to start a Cold Cathode lamp depends to a great extent upon these gas pressures. A high-voltage transformer is, therefore, used by those manufacturers who make the high-pressure lamp and a lower-voltage transformer by those who process at low pressures.

How does this affect the Light Output of the Lamps operated by the Two Ballasts?

As previously mentioned, the light output depends upon the lamp wattage. Therefore, if the fluorescent phosphors inside the lamps are of the same quality, the light output will be slightly less, using the high-voltage transformer operating high-pressure lamps.

Although the secondary current is only 100 ma. the operating voltage is up, which means that the lamp wattages will be of the order of 40 watts when using a 900-volt unit as compared to 42 watts with a 750-volt unit. These figures will, of course, vary somewhat depending upon the lamps.

How do the Cold Cathode Lamps perform in Cold Weather as compared to Hot Cathode?

As the fluorescent lamp depends upon a mercury vapour for its efficiency, cold weather, which condenses the vaporized mercury, will affect the light output.' Generally, neither the

Hot nor Cold Cathode lamp will perform too well in temperatures below freezing.

Best cold weather results with Cold Cathode lamps have been obtained by using them in series with the high-voltage transformers operating at approximately 85 to 90 per cent of their short circuit rating. Such operation is obtained by using fewer lamps in the circuit than are normally recommended. This ensures adequate striking and operating voltage and greatly increases dependability during cold periods. Special " cold " lamps are available in the Hot Cathode type.

What are the advantages of operating the Cold Cathode Lamps in Series with High Voltage Transformers ?

The high-voltage transformers range from 5,000 to 10,000 volts. The greatest advantage is the simplicity of wiring, as the transformers operate as many as 12 lamps in series, depending upon the transformer size. This is highly desirable in cove installations as very little secondary wiring is required. The lamps, with very short connections between each, comprise the secondary circuit, and often the transformer can be placed outside of the room. In exposed ceiling installations using the high-voltage series transformers, the elimination of return connections between the lamp holders and transformer makes the installation quite simple. Such circuits minimize the need for additional outlets.

How does the New " Slimline " Fluorescent Lamp differ from the Hot or Cold Cathode Lamps ?

The Slimline lamps are of the instant start type and consequently do not require a preheating period. Like the Hot Cathode lamps, these new lamps have coiled coil tungsten filaments. The filaments are heavy to withstand the effects of high-voltage starting and, like the hot cathode lamp, the filaments remain hot during operation.

Although the filaments or electrodes of these new lamps are entirely different from the cold cathode electrodes, the electrical characteristics of the lamps are quite similar to those of the cold cathode.

The following figures give the electrical characteristics of the various lamps mentioned in these pages :—.

Lamp Type.	*Length. (in.).*	*Watts.*	*Operating Current. Amps.*	*Operating Voltage.*	*Open Circuit Voltage.*
Hot Cathode	48	40	·410	108	220
Cold Cathode	93	42	·120	420	750
Slimline	93	29	·100	335	750
Slimline	93	51	·200	290	750
Instant Start Hot Cathode .	48	40	·410	108	450

Can the Slimline Lamps be Operated in Series using the High-Voltage Transformers?

Yes. However, special sockets are necessary for such operation.

Flash Tubes

These are cold cathode tubes designed for operation by a condenser discharge in order to produce short flashes of light of very high intensity. They consist of Xenon-filled hard glass tubing in the form of a helix contained in an outer bulb. As the current density must be extremely high, the condenser to which the electrodes of the tube are permanently connected has to be charged to a high voltage. Striking of the discharge is effected by connection of an induction coil or a Tesla coil to an auxiliary " triggering " electrode. The coil applies the high-voltage pulse necessary for ionization of the Xenon.

As soon as the high-voltage pulse is applied current from the condenser starts to build up its maximum value and afterwards dies down. The flash takes place in an extremely short space of time (from 1 to 1,500 microseconds). The condenser is charged from a transformer through a rectifying valve and a resistance.

The colour of the light emitted from xenon-filled flash tubes closely approximates to sunlight. Some flash tubes contain a mixture of argon and nitrogen.

Cold cathode flash discharge tubes are used in high-speed photography, stroboscopes, and in study of ballistics.

Chapter VII

LIGHTING INSTALLATIONS

There are two main types of cold cathode fluorescent interior lighting installation. In one type—the self-contained unit—the tubing is affixed to a metal backing or reflector and the transformers and high-voltage wiring and connections are housed within the unit. In the other type, used mainly for decorative effect, the transformers may be housed somewhere remote from the tubing ; this type can be curved to suit architectural or other features, and is usually coloured.

Due to their lower operating temperature, the effective life expectancy of cold cathode fluorescent tubes is much greater than that of hot cathode fluorescent lamps, and in some cases is as high as 10,000 hours of operation. Unlike hot cathode lamps, however, cold cathode lamps must be permanently connected in their circuits, and are replaceable only by a qualified person. The usual arrangement, and this is recommended in the I.E.E. Regulations, is for the whole of the apparatus and cables connected to the secondary circuit to be examined not less frequently than once every three months by a competent engineer.

Owing to the sturdy construction of the tubes and the mechanical simplicity of the housings, cold cathode lighting is highly resistant to vibration. Light output is not impaired by low temperatures and the lighting is available for outdoor use in cold climates and for cold indoor spaces. However, although there have been some recent improvements in the design of cold cathode auxiliary gear, it is still somewhat bulkier and heavier than that used for hot cathode lamps.

If the transformer location is suitable, secondary (high voltage) wiring in decorative lighting schemes may be almost entirely eliminated by using the tubes themselves to act as return conductors. In this case a minimum number of primary outlets would be needed.

The colours available for general lighting in self-contained units are : daylight, warm white, intermediate white. For decorative lighting, the range includes : red, orange, yellow, light green, dark green, dark blue, light blue, white.

If well distributed and carried out in tubing of normal diameter, cold cathode installations provide almost shadowless and glare-free lighting. Intensity of illumination is also satisfactory in comparison with other fluorescent light sources.

At the present time the initial cost of installing cold cathode lighting is slightly higher than that of hot cathode fluorescent lamps, but standardization of tubing and equipment would no doubt remedy this. But even on the present-day basis, the slightly higher installation cost is counterbalanced by the low replacement cost due to the long life of the tubes.

In most cases the replacement of filament lighting by cold cathode tubes necessitates no additional wiring, since the fixtures can be obtained each as a self-contained unit with transformer completely enclosed.

Mention has already been made of the low operating temperature of the tubing. As a rough comparison, the heat radiated by cold cathode tubes as compared with that from filament lamps giving the same light output is one-tenth. This factor is most important in situations where, for instance, food is to be stored.

Another advantage of cold cathode lighting, particularly for store lighting, is the slower rate of fading caused by the blue and violet end of the spectrum as compared with other portions. Experiments carried out by Luckeish and Taylor indicate that the amount of fading caused to materials depends on the intensity of the illumination and the duration of exposure.

Where a light casting soft shadows is required as, for example, in displaying gowns, cold cathode fluorescent lighting is ideal, as the length of the source obviates the patchy effect so often obtained by filament lighting. Above all, the tone of the lighting gives a " fresh " appearance to the display.

In situations such as hosiery factories, when tedious operations have to be carried out, cold cathode lighting has many applications. The lighting system can be designed to combine localized lighting with diffusion. The daylight tubing is particularly applicable to operations involving colour discrimination.

Engineering industries find the long continuous lines advantageous both for machining and assembling work. The inspection of small parts provides another example of the utility of cold cathode. Apart from the absence of heat discomfort due to the necessarily low mounting height of the fixtures and the freedom from glare of polished surfaces, the light provided is of uniform intensity on the parts to be inspected.

Certain operations involve the ability of the operator to distinguish quickly shapes and sizes of small accessories. Here, again, cold cathode fluorescent tubing makes for increased efficiency.

Home Lighting

The ideal cold cathode lighting scheme for a living room about 20 feet by 30 feet comprises cove fixtures, centre fixture, bookcase and glass brick lighting, and wall brackets. Using this scheme, about 8 ft. candles can be provided at table height, except under the centre fixture which provides 25 ft. candles. The wall brackets give just sufficient colour to produce a cosy effect. The tubing over the glass brick windows lights up the interior and at the same time provides illumination for the outside entrance. This particular scheme was designed by George F. Meyers for the home of Walter Ruth, of New York.

In the office and den one cold cathode unit is centred over the desk to provide 20 ft. candles of illumination.

The combined kitchen and breakfast room, which is 14 feet by 18 feet, has a general illumination of 10 ft. candles, with 25 ft. candles over the sink.

Soft lighting is provided throughout in the bar and game-room, most of the light being concentrated around the bar. From 3 ft. to 4 ft. candles are provided, with a touch of colour in the ceiling fixture. The general lighting of the bar consists of a mixture of pastel shades, blending rose, gold, and blue tubing.

Arrangements were made for an automatically changing transparency along one side of the game-room. Using cold cathode lighting, the transparency is designed to make a

Installation Detail of Modern Home Lighting

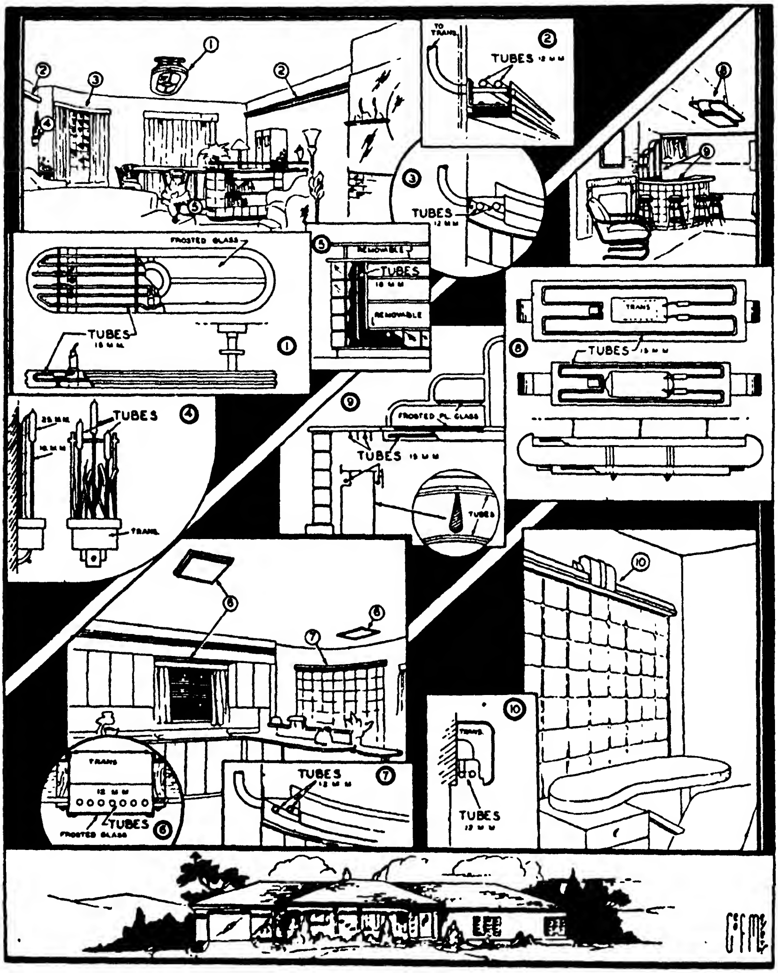


FIG. 34.—(Reproduced from the article by George F. Meyers in *Signs of the Times*—Fluorescent Lighting Section, by kind permission of the Proprietors of that journal.)

complete change every twenty minutes, showing various scenes of the 24-hour cycle—sunset, moonshine, etc.—to provide an outdoor atmosphere.

The details of this home lighting scheme are given here by the courtesy of *Signs of the Times* magazine, New York.

Assembly Hall Lighting

For some assembly halls it is necessary to have a lighting scheme to harmonize with the architectural features of the interior. Here, again, the flexibility of cold cathode tubing makes it the best medium. If necessary special fixtures can be designed to house all auxiliaries and act as reflectors for the fluorescent tubing.

Many halls are circular in plan and therefore require a circular lighting scheme. This presents no difficulty to the cold

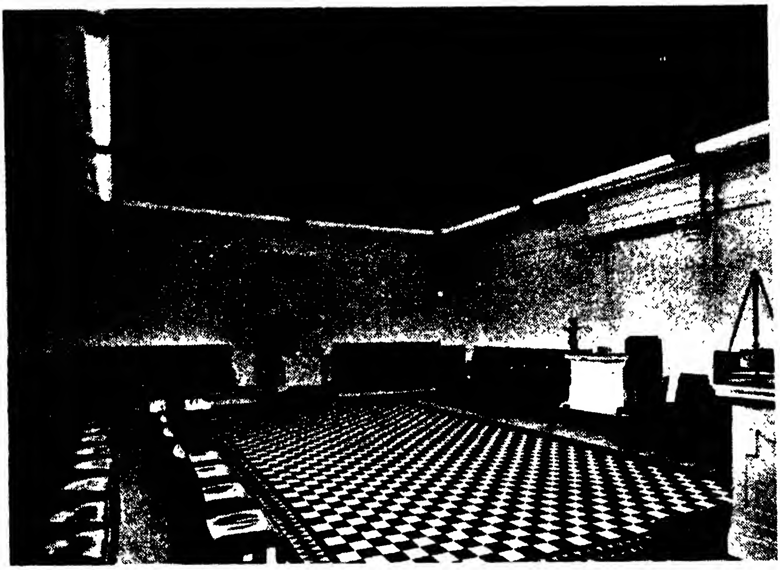


FIG. 35.—Cold Cathode Fluorescent Lighting in Masonic Assembly Rooms, Birmingham. (British Thomson-Houston Co., Ltd.)

cathode lighting designer, who can adapt the tubing to suit the particular features.

Ballroom or dance-hall lighting is another example in which cold cathode tubing can be installed to advantage. In most cases intense illumination is not required ; a soft warm amber glow is best to promote the necessary atmosphere.

The run of the general lighting will, of course, depend on the particular situation. But in general a decorative centre fitting will be found to be an asset. Lines of fluorescent red, blue, green, or amber tubing can be used for decorative effect, with soft white tubing to provide the main illumination.

The main cold cathode lighting scheme, too, could be made up of various colours which could be separately switched or dimmed in order to give alternative lighting tones as required. By connecting the lighting system through a thyratron reactor to the microphone, the lighting would be made to vary with the band music.

The comparatively small diameter of cold cathode fluorescent tubing enables it to be bent into practically any outline. Circles, stars, and even pictorial designs can be outlined in this way. As a subsidiary to the general lighting scheme, pictorial

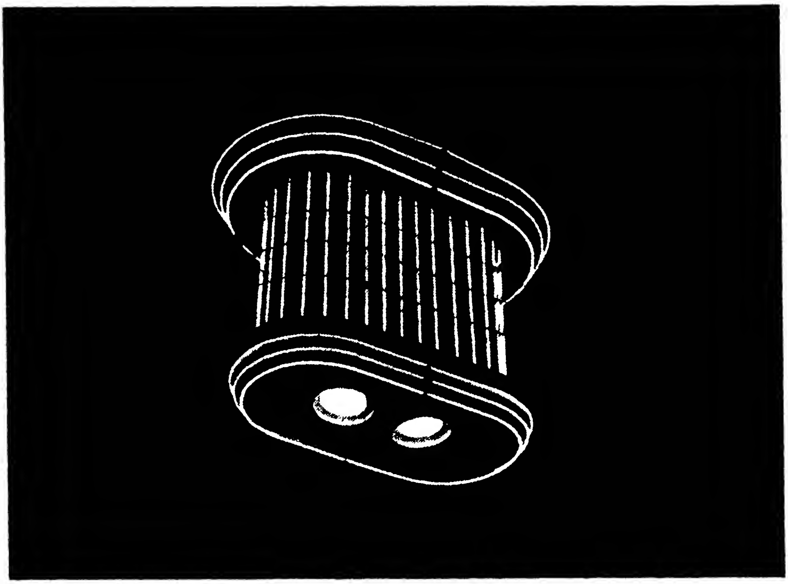


FIG. 36.—Cold Cathode Ballroom Lighting Unit. (Miller Electric Co., Ltd.)

frieze lighting is ideal for hotels, restaurants, and cinema and theatre entrance halls.

The design is first painted in colours with high reflection factors on some fire-resisting panelling. Then cold cathode tubing is fixed to form a luminous outline to the figures or designs. If the panelling is stepped out from the main wall for a short distance, all transformers and high-voltage wiring and connections are concealed. If it is essential for the decorative lighting to be within reach of the public it is advisable to cover the frieze with glass.

Some provision must be made for replacement and maintenance of the tubing and auxiliaries. This may take the form

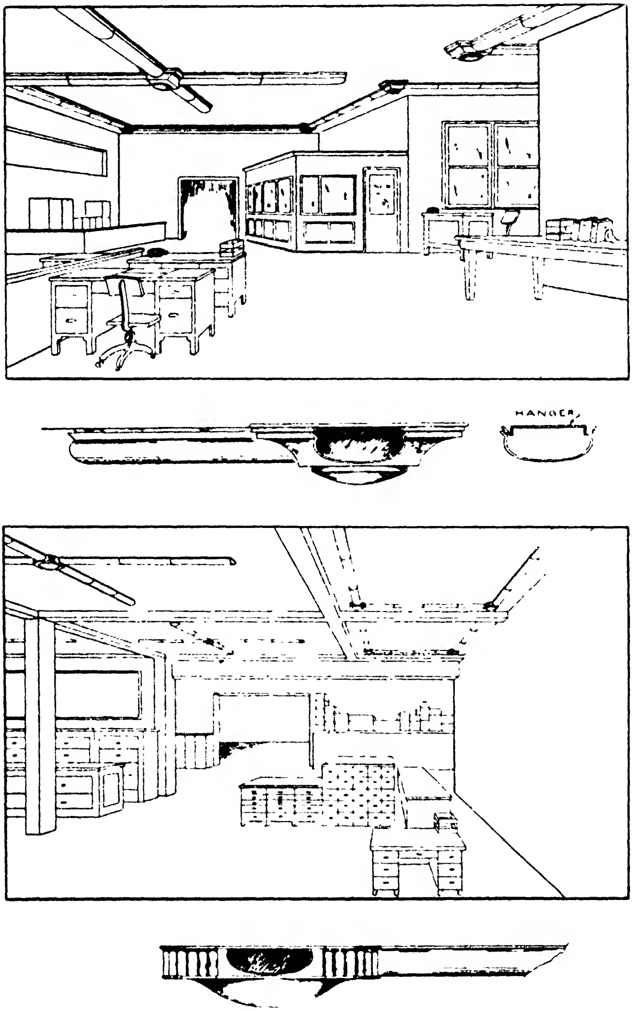


Fig. 37.—Cold Cathode Office Lighting. (Acme Electric Corporation.)

of hinged doors at appropriate intervals or, in the case of a small frieze, the whole panel may be made detachable.

Office and Shop Lighting

A neat form of office lighting consists of luminous tubing fitted into a rectangular channel reflector. The luminous tubing is arranged in triple-tube formation. Either warm-white or daylight-white tubes may be used, but in the latter case it is advisable to include a certain amount of red tubing to give sufficient long-wave light output.

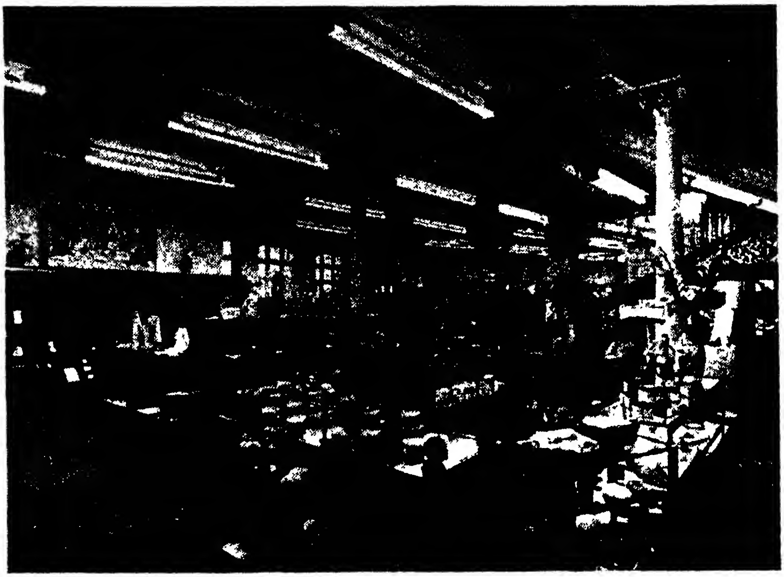


FIG. 38.—Cold Cathode Fluorescent Lighting in Bright's Stores, Bournemouth. (General Electric Co., Ltd.)

A typical installation of this type was recently carried out in the office of Mr. G. Hillstrom, President of the Acme Electric and Manufacturing Co., Cuba, New York. The office, which is 19½ feet long by 15 feet wide by 12 feet high, is entirely illuminated by fluorescent high-voltage tubing.

Built into the ceiling, equidistant from the four walls and centre of the room, is a 7 in. wide, 4½ in. deep channel reflector made of sheet metal and painted inside with white paint of high reflection factor. Overall dimensions of the rectangular reflector are 13 ft. 4 in. by 8 ft. 11 in.

Suspended in the channel is an arrangement of triple tube 0·5 in. diameter daylight white fluorescent high-voltage tubing. At the centre of each side of the rectangle a 3 ft. 10 in. length of 0·5 in. red tubing is fitted. Thus there is a total of 127 feet of tubing. The channel reflector has a total radiating area of 25 square feet.

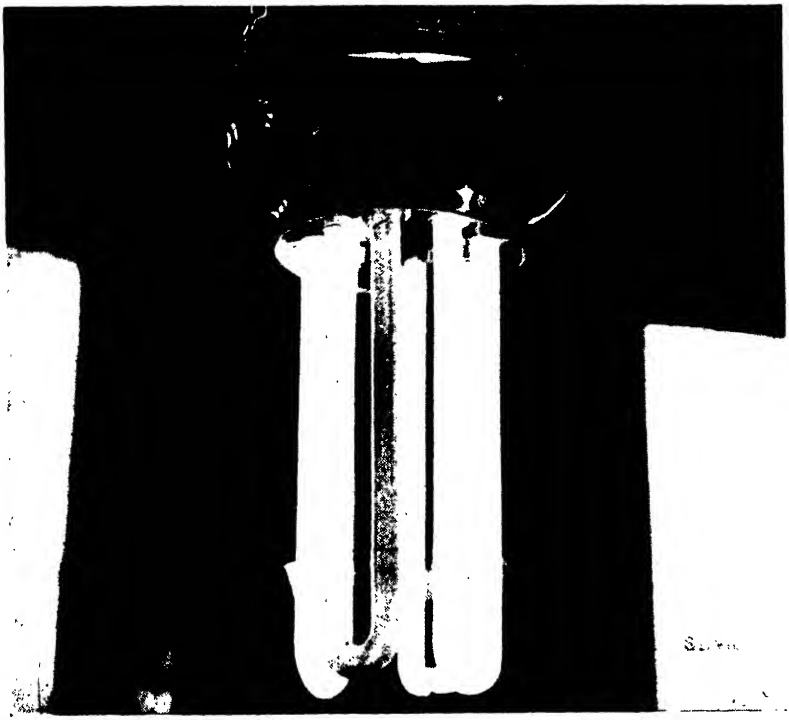


FIG. 39.—Cold Cathode Porch Lighting Unit.
(Miller Electric Co., Ltd.)

The luminous tubing in this instance operates at 55 milliamperes. Two 12,000 volt 60 milliamperes and two 15,000 volt 40 milliamperes transformers are used.

An interesting application of cold cathode tubing to store lighting was provided some time ago in a London suburb. The scheme comprised about 3,000 feet of 0·8 in. diameter fluorescent tubing in triple-tube formation. Although the tubing was mainly white, certain sections of the store were given an amber tint and other sections a blue tint, according to the requirements of the merchandise displayed.

The tubing was mounted over the counters at a height of 9 feet above floor level and suspended by brackets arranged over wall-counters and island-counters. Tubing lengths were standardized at about 9 feet between electrode housings, and separate switching in counter groups was arranged.

Goods displayed under this lighting are shown in colour fidelity except where emphasis on a particular hue is desirable. Above all a congenial atmosphere is created which has a favourable psychological effect on customers.

Hall Lighting Unit

A decorative unit, suitable for hall or vestibule lighting, is now on the market. This comprises U-shaped fluorescent tubes, 0·5 in. in diameter, of different colours. The electrodes and high-voltage connections are contained in a chromium-plated gallery, and the unit is arranged for chain suspension from the ceiling.

Transparent plastic discs are fitted round the luminous tubing. These not only add to the decorative effect but assist in some measure in diffusion of the light.

Cinema and Theatre Lighting

It has been mentioned earlier that cold cathode fluorescent lighting forms an ideal medium for the illumination of cinema and theatre foyers and waiting rooms. One method that has been found very satisfactory consists of concealing triple-tube lighting units behind cornices. If a suitable combination of red, blue, and green is used, a resultant light of a warm rose-amber is obtained which creates a cheerful atmosphere. The units must, of course, be self-contained, with transformers and high-tension wiring and connections all contained in the body of a sheet steel reflector-housing.

In the auditorium, recessed ceiling fittings can be surrounded by rings of cold cathode tubing arranged for progressive dimming. Concealed tube lighting has actually been tried round the screen itself and, although this would naturally reduce the edge of the picture contrast, it is said to create the impression that the picture is nearer the audience than it really is. The arrangement is improved when the screen is set forward for some distance from the back wall.

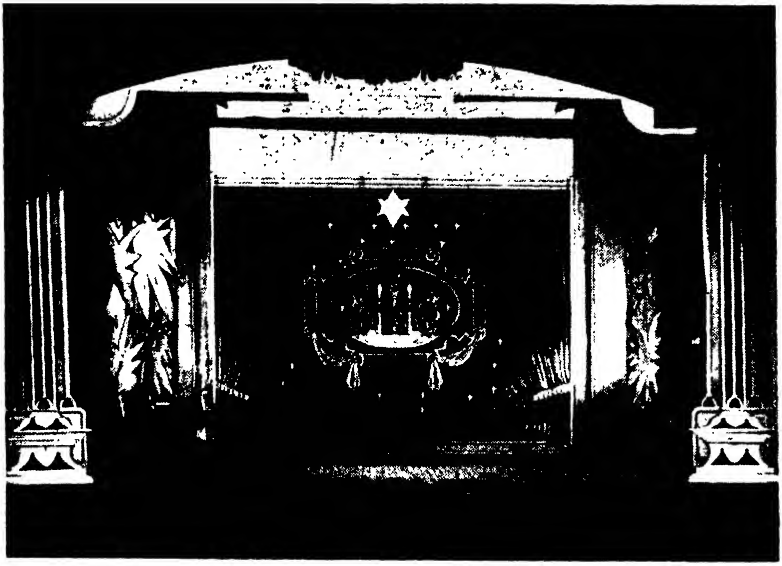


Fig. 40.—Fluorescent Curtain, employing over 1,000 feet of tubing, at the Metropole Theatre, Glasgow. (Franco-British Electrical Co., Ltd.)

Fluorescent Curtain

The scheme illustrated is installed in Glasgow Metropole Theatre and is the first of its kind. It comprises a hollow alloy box 20 feet by 18 feet and 14 inches deep. Provision is made by means of a winch system to raise it up solidly into the flies. Gearing is arranged so as to eliminate all possibility of damage or vibration. Operation is, of course, wholly electric.

The traditional Scottish design of thistles, lions, and tartan is carried out in red, blue, green, and white fluorescent cold cathode tubing; a total of over 1,000 feet being employed. The luminous stars are controlled by suitable animation gear to create " twinkling ".

Railway Platform Lighting

In situations of this type fairly even diffusion that avoids alternations of bright and dark patches is required. It has already been proved that covered-in platforms are ideally illuminated by continuous lines of cold cathode fluorescent tubing.

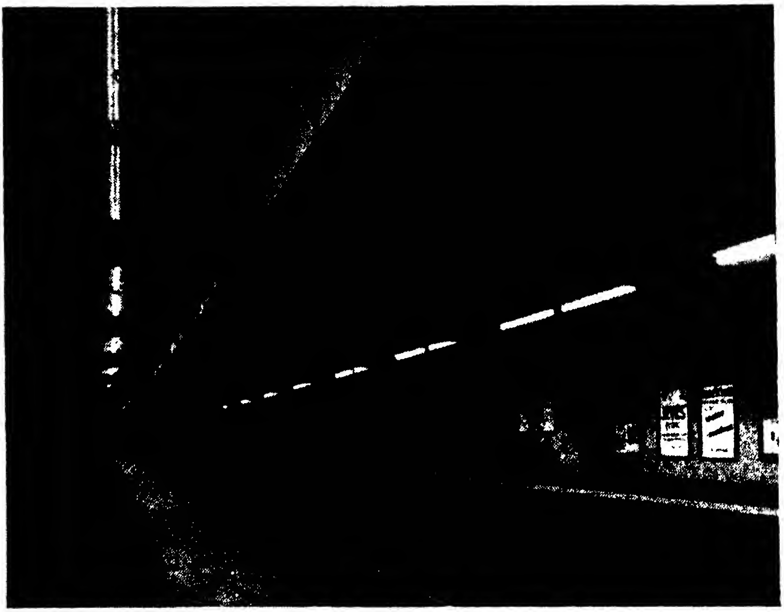


FIG. 41.—Cold Cathode Fluorescent Lighting at Malden Manor Station (S.R.). White lighting produced by two lines of tubing of complementary colours. (General Electric Co., Ltd.)

Although artificial daylight, either by means of blue-white tubing or by use of complementary colours, is generally accepted to be the most suitable for the purpose, it is necessary to bear in mind that the passengers' eyes at night-time are adapted to artificial light. Possibly the perfect tone may prove to be somewhat more yellow than the 3,500° K daylight usually employed.

A continuous line of lighting obviates the dimly-lit portions often found at intervals along the edge of an underground platform which make it rather difficult to distinguish the step of the train.

Anodized aluminium reflectors are used in conjunction with the luminous tubes for platform lighting. These have proved to be more lasting than other types, but are by no means non-corrodible.

It has been suggested that in the various waiting and refreshment rooms on a ground-level platform judicious use

FIG. 42.—Cold Cathode Fluorescent Lighting in Victoria Station. (General Electric Co., Ltd.)

could be made of coloured light. An underground example of the pleasing contrast obtained in this way may be seen on the western platform at Piccadilly.

Ship Lighting

In the cabin cocktail bar of R.M.S. *Queen Elizabeth* cold cathode fluorescent lighting has been used to advantage. About 64 feet of Osram high-voltage tubing is semi-recessed into the ceiling above the bar counter. The colour of the lighting is warm white.

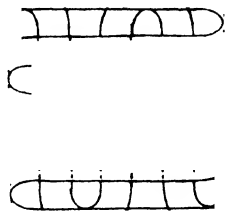


FIG. 43.—Cold Cathode Enlarger Lighting.

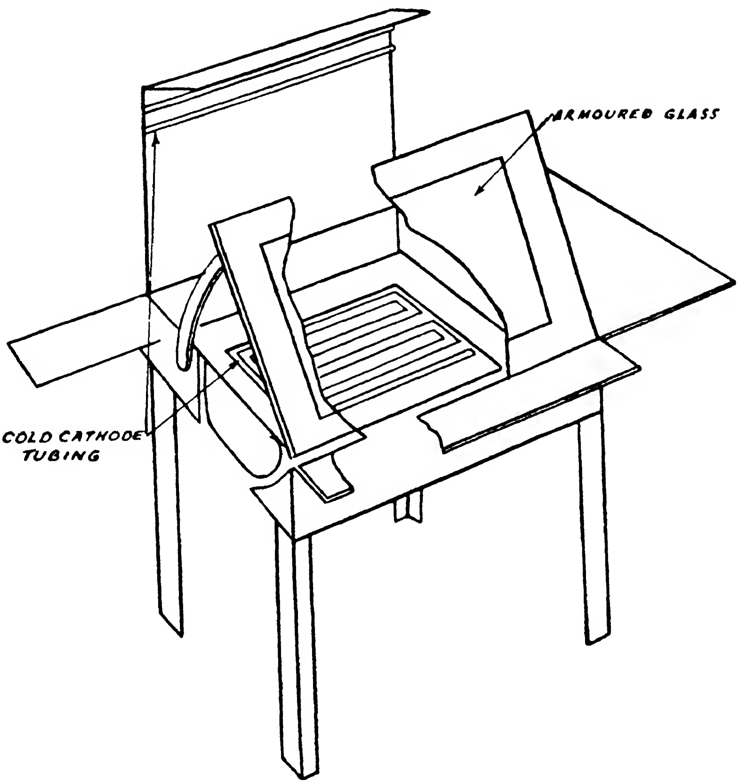


FIG. 44.—Retouching-Frame Lighting.

Photographic Enlarger Lighting

Daylight cold cathode tubing has been used successfully to replace mercury lamps in photographic enlargers. The tubing is concentrated in the form of a " grid " specially designed to fit into the enlarger aperture. Auxiliaries are carefully housed within the apparatus.

Although somewhat slower in action than Cooper-Hewitt mercury vapour lamps, the cold cathode tubing results in a superior print, giving more natural light and shade values.

Retouching-Frame Lighting

The illumination of frames for retouching photographic prints is another new application of cold cathode fluorescent tubes. As with enlarger lighting, the tubing is arranged in the form of a rectangular grid which is housed underneath the frosted glass top of the table. A similar but smaller grid is fitted over the vertical portion of the frame. Due to the small amount of heat produced by cold cathode tubes and the freedom of dazzle, operatives prefer this form of lighting to any other.

CHAPTER VIII

SIGN AND DISPLAY LIGHTING

In this chapter we shall review the technique of luminous tube sign or display lighting which was interrupted during World War II and the subsequent fuel crisis. Cold cathode fluorescent tubing forms an excellent medium for decorative exterior lighting and artistic directional and advertising signs, and the following notes are intended to give some idea of its potential scope in this field.

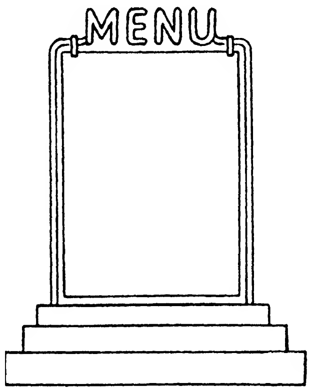


FIG. 45.—Interchangeable Plug-in Unit.

Interchangeable Plug-in Signs

The small type of luminous tube sign forming a self-contained plug-in unit, which can consist either of lettering, bordering, or a pictorial design, is usually incorporated in a shop window or counter display.

Its advantages are : (1) cheapness ; (2) portability (it can be plugged into the nearest socket outlet) ; (3) the luminous tube unit is interchangeable, a fresh wording or design being used for each display.

The luminous tube electrodes are specially designed to engage in spring or clip sockets contained in the transformer housing. The transformer assembly can be used as a base or, by modification of the socket arrangement, can be fixed direct to the ceiling so that the tube unit is suspended.

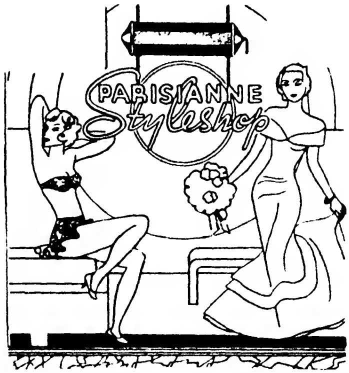


FIG. 46.—Showing use of Interchangeable Plug-in Unit for Window Display. (Acme Electric and Manufacturing Co., Cleveland, Ohio.)

Bordered Window Units

Like the plug-in units, these are one of the cheapest forms of luminous tube sign. Designs of the bordered units are many and various ; some have black backgrounds to which interchangeable white letters may be affixed ; others have a

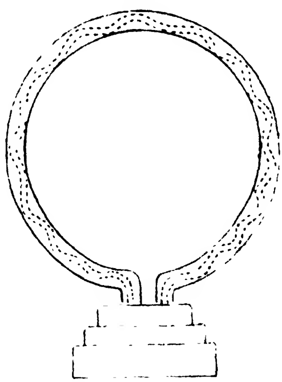


Fig. 47.—" Ripple "-tube Window Unit.

permanent opal glass panel in front of which silhouetted advertisement panels can be fitted. In all cases the illumination is provided by luminous tube borders.

The small open-type transformers used in these signs are generally housed in the metal body of the unit itself.

Glass Panel Signs

These are usually sheets of $\frac{1}{4}$ in. plate glass with the luminous tubing clipped directly to them. The panels are sandblasted or drilled according to full-sized layouts ; about $\frac{1}{4}$ in. diameter holes are usually provided for the clip supports, and 1 in. diameter holes for the electrodes (if they are to pass through the panel at right angles). Sometimes the panels are lettered in enamel and the luminous tube lettering superimposed on this.

The regulations require that all high-voltage connections at the back of a glass panel sign be covered in by a suitable fireproof material, although a fine wire mesh guard is generally accepted.

If the panel is suspended on chains the leads from the transformer secondary may be attached to these, which, although a rather unwieldy arrangement, is usually the most convenient. The transformer and power factor correction condenser are best affixed to the ceiling, in most cases midway between the suspension chains.

Wireless Light Signs

These signs are principally in the form of glass panel window signs. They were introduced some years ago, before the development of fluorescent tubing, but were not adopted to a very great extent.

Wireless light signs are not operated from a step-up transformer, but are supplied from a high-frequency generator through an oscillator. Hence they can be used on either direct or alternating current supplies. The average consumption of this type of sign is about 60 watts. There is no danger of electric shock from wireless light signs or from the wiring and connections thereto. In some cases the high-frequency supply is taken to the tube electrodes in bare wires carried through the suspension chains.

The glow in the tubes is sometimes a little unstable, but a ready means is provided of adjusting the generator, which should, therefore, be fixed in an accessible position. However, a slight buzz from the apparatus is unavoidable.

A flasher can be incorporated if desired.

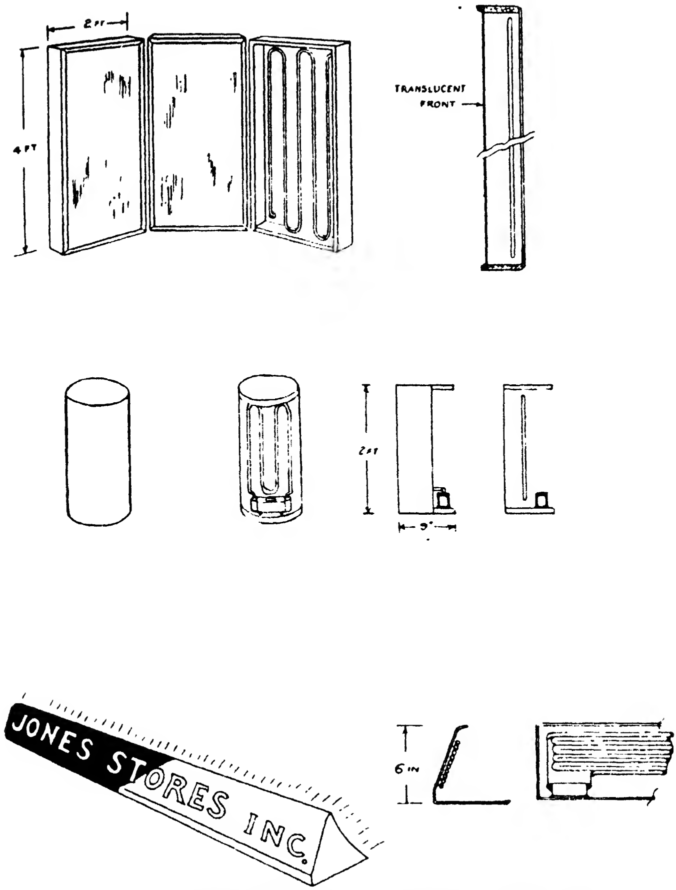


FIG. 48.—Novelty Effects. (Acme Electric Corporation.)

Window Outlining

Shop window outlining tubing can have two functions : it attracts prospective customers to the window, and may contribute to the display illumination.

Where the outlining is designed to run round the extent of the window, special designs, known as " curlicue " designs are often employed at the corners. Sometimes several parallel lengths, arranged vertically or horizontally, can be incorporated in the scheme with advantage.

Transformers can be conveniently fitted under the window-sill or on or above the ceiling.

Pictorial Friezes

The pictorial frieze is as yet only in its infancy as a potential advertising medium. Since it is indoors it must be artistically designed to harmonize with the surrounding decoration and lighting scheme, and bizarre effects should nearly always be avoided. Pastel shades of fluorescent tubing are generally the best for this purpose.

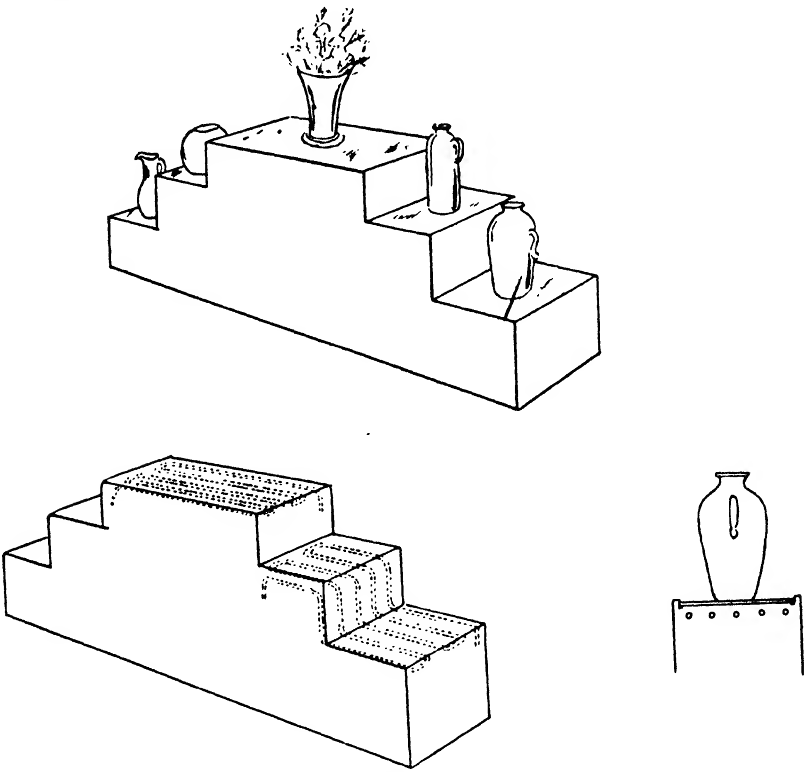


Fig. 49.—Illuminated Display Stand. (Acme Electric Corporation.)

Luminous tube frieze panels are preferably provided for in the original scheme designed by the architect or builder, as provision must be made for concealing transformers and high-voltage wiring, yet, at the same time, these must be readily accessible for maintenance purposes. It is always advisable to ascertain local authorities' requirements in this respect before installing luminous tubing inside public buildings.

Grille Signs

"Grille" or "Cut-out" signs have the advantage of changeability. They consist either of painted glass panels with the lettering left clear or of sheet metal with the letters stencil-cut; illumination is provided by grilles of cold cathode fluorescent tubes.

This type of sign is usually double-sided, since the two sides can be illuminated by the same grille. Their main function is to provide an inexpensive interchangeable sign where a comparatively large amount of small lettering is required.

Illuminated Clocks

Small luminous tube illuminated clocks for interior use generally consist of a glass, Masonite, or sheet metal clock face, with the clock mechanism and transformer boxed in at the back; they can be fixed rigidly, designed to stand up, or even arranged to hang on chains.

The actual hands of small clocks are rarely fitted with luminous tubing, since the weight of glass is in most cases too great for the small synchronous clock movements used. Illuminated advertising matter can either take the place of numerals or can be fitted on spare portions of the clock face; recessed luminous tubing has the advantage of leaving ample clearance for the clock hands.

Outdoor clocks with fluorescent luminous tubing superimposed generally have angle-iron frameworks with sheet metal sides and moulded panels. Both hands and figures (or representative letters or strokes) can be fitted with luminous tubing in larger clocks.

Advertising matter and decorative bordering is often contained on panels quite separate from the clock faces. Large outdoor clocks of this type are nearly always double-sided.

The value of a luminous-tube illuminated clock from an advertising point of view is obvious.

Luminous Tubes on Wood Letters

Burma teak of from 1 in. minimum finished thickness is the best hardwood to use for this purpose. It should be thoroughly primed and the letters painted at least two coats of lead paint, the faces and edges being finished in good quality enamel.

The most common form of illuminated-wood-letter sign consists of the teak letters mounted either horizontally or vertically on angle-iron runners fixed to brackets which are designed to give sufficient clearance behind the sign for high-voltage connections and, often, the transformers.

Box Signs

These take many forms—rectangular, circular, triangular, and even complicated designs. They are, as a rule, the cheapest proposition for an advertiser requiring self-contained projecting luminous tube lettering out of doors.

Luminous tube box signs generally consist of angle-iron frameworks with sheet metal sides and panels of Masonite, Flexometal, or sheet metal. The transformers are mainly of the open-type housed inside the box itself, which obviates the necessity for long high-voltage leads.

Where the above method is adopted and the electrodes are to pass through the panels at right-angles, great care must be taken to design the box of sufficient width and to arrange the electrodes at positions that will give maximum clearance from the transformers, from adjacent metal, and—if the sign is double-sided—from opposite electrodes.

The fluorescent tubes may be clipped direct to the panels or superimposed on teak or metal letters affixed to the panels.

A door—or two or three doors in some cases—must be provided in the box to permit access to the transformers and connections for maintenance purposes.

Luminous tube box signs are rigidly fixed by means of wrought iron brackets and are usually stayed in addition.

Fascia Signs

There are many different kinds of shop fascia neon signs. Probably the most popular arrangement is tube-illuminated built up sheet metal letter and designs, affixed to some kind of panel, with provision made for recessing the fluorescent luminous tubes and concealing the high-voltage wiring and transformers. Many attractive schemes of this kind can be carried out in stainless steel facing and letters superimposed with luminous tubes.

Silhouette Signs

Silhouette signs usually consist of a background of fluorescent luminous tubing with opaque lettering fixed in front. Many attractive effects can be obtained by controlling the background by a flasher in order to give a shutter effect, changing colours, or—in the case of choke control—variable brightness.

Irradiation is here most important, as the visibility of such a sign is largely dependent on the background brightness. The following figures apply to a luminous tube background of 150 to 300 ft. Lamberts Brightness :—

Viewing Distance.	*Height of Letters.*
200 feet	4½ inches
400 ,,	7½ ,,
600 ,,	11 ,,
800 ,,	15 ,,
1,000 ,,	18 ,,

V-Shaped Signs

V-shaped signs are useful in situations where signs flat against the building line or at right-angles to it would not be effective owing to peculiar local conditions (e.g. street junctions). They may be either horizontal or vertical, and can consist of panels, separate letters on runners, or even a boxed-in framework.

Where right-angular electrodes occur near the apex the amount of clearance at this point must be carefully designed unless the angle between the two sides is very obtuse.

The final decision as to whether a V-shaped sign will be most advantageous in a particular instance will depend to a large extent on local regulations regarding the amount of projection allowed from the building line.

Self-Supporting Panel Signs

For railway stations, particularly the smaller junctions, fluorescent-tube illuminated name signs are extremely useful at night. The panel, preferably with teak cut-out lettering, is supported from the platform by uprights, the transformer being affixed to the back, and high-voltage connections protected by a hinged or easily-removable cover.

Due to the possibility of confusion with signals, red or green tubing may not be used.

Pedestal Signs

Pedestal signs are used mainly for garages (petrol pumps) and bus stages. They are usually double-sided, the transformers being housed in a case situated conveniently near to the panels. The low-voltage supply may be run through the hollow pedestal stand.

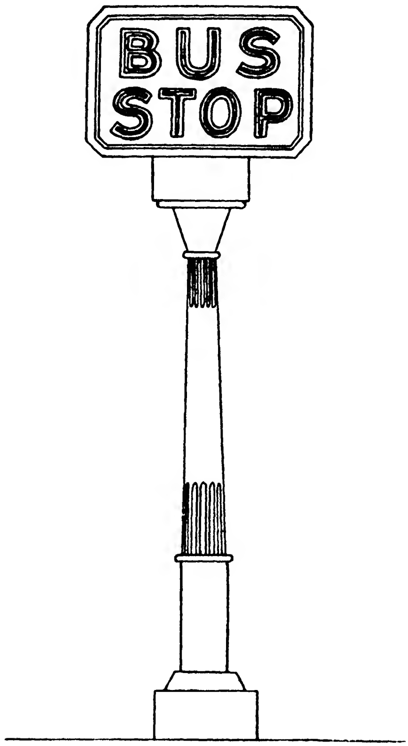


FIG. 50.—Pedestal Sign.

Canopy Signs

These are mainly used for cinemas and restaurants, and are particularly effective when illuminated by cold cathode fluorescent tubing. A striking example of this type of installation was completed shortly before the outbreak of hostilities at the Odeon Cinema, Leicester Square.

* The installation had 132 separate tubes, the white tubes

* By courtesy of the British Thomson-Houston Co., Ltd.

alone totalling one quarter of a mile lit length of tubing which, together with some ornamental blue tubing, made a total tube footage of 1,439 feet.

On the canopy over the main entrance were three horizontal banks of 11 ft. 7 in. long white tubes at 2 in. centres, held between anodized aluminium faced electrode boxes, and backed by horizontally fluted anodized aluminium. Three curved blue tubes were mounted vertically on each of the four 15 in. wide electrode boxes, contrasting effectively with the white background of tubes. This was supplemented by six banks of eight 10 ft. 6 in. straight white tubes mounted in a similar way along the under surface of two side balconies and, in addition, the upper canopy which surmounted the main vestibule at a height of some 30 feet outlined by twelve white tubes with turned back electrodes.

It was found possible in the design of the scheme to arrange that the tubes themselves served as their own high voltage wiring. The only high-voltage cable used was that to connect the high-voltage winding of the leakage reactance transformers to the electrode boxes.

The technical details of the luminous tubing used were as follows :—

Tube diameter	0·8 in.
Maximum illuminated length	Approx. 13 ft.
Electrode chambers	1·2 in. diameter, 5 in. long.
Operating current	40 to 65 milliamperes.
Arc voltage	70 volts/ft. approx.
Open-circuit voltage	170 volts/ft. approx.
Luminous efficiency	As for mains voltage fluorescent lamps.

Interchangeable canopy (or marquee) fluorescent luminous tube signs are used extensively in the United States. One type, designed by the Swanson-Nunn Electric Company, of Evansville, Indiana, utilizes a U-tube arrangement of daylight white tubes operated by 60 milliampere transformers. The tubes are set in spring housings situated at the bottom front of the marquee, and are suspended from hooks in order to facilitate maintenance. Flashed opal glass is used for the front of the sign, the luminous tubing being about 5 inches behind this ; reflectors are fitted behind the tubes. Either stencilled or silhouette sheet metal letters may be used in conjunction with this type of sign.

Façade Outlining

The large diameter luminous tubing commonly employed in this class of display is usually fixed directly to buildings by means of bracketed clip supports. Wherever possible the transformers should be concealed but, at the same time, excessively long runs of high-voltage cable should be avoided.

In the case of new buildings, special provision can be made for the luminous tubing and the positioning of transformers. However, in all cases, the fluorescent luminous outlining should not be erected indiscriminately, but should harmonize with architectural features.

Changing Messages

These consist of a large number of very short lengths of cold cathode fluorescent tubing arranged on a panel in such a way that the wording of the sign can be varied by means of a controller. The tubing is arranged in similar consecutive blocks, each block having the necessary formation to make up any letter of the alphabet, and each length or " knuckle " of tube being controlled by the flasher mechanism.

Possibly the best application of this device is its employment as an illuminated news message with the advertising matter interposed between the news items.

Vehicle Signs

The introduction of the Neoverter some years ago considerably enhanced the value of the delivery van as a potential advertising site. The construction of the luminous tube sign itself must in this case be as robust as is practicable, and special attention is necessary to the high-voltage connections and clip supports.

APPENDIX I[1]

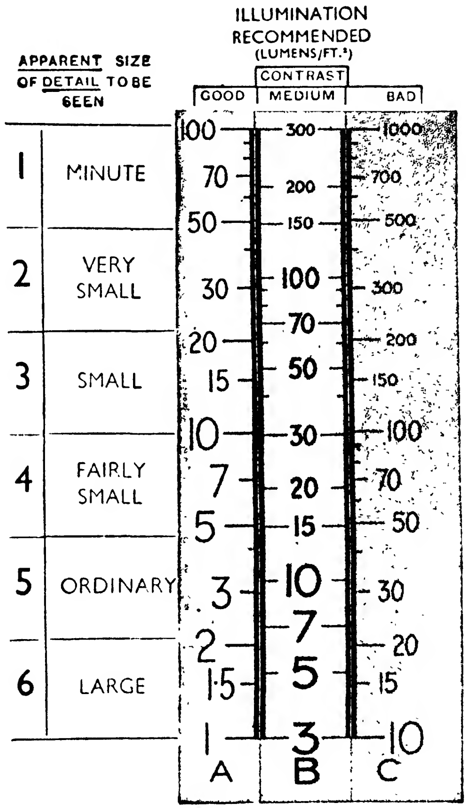
METHOD OF ASSESSING ILLUMINATION REQUIRED

If the reflection factor or colour of the detail to be seen differs widely from that of its immediate background, use Scale A. If it differs moderately, use Scale B. If it differs little, use Scale C.

Scale B represents average conditions, and is therefore shown in heavy type. General lighting is recommended for values shown in large type.

General or (general plus local) lighting is recommended for values shown in medium type.

Local supplementing general lighting is recommended for values shown in small type.



First decide what is the *apparent* size of detail to be seen (this depends both on the actual size of critical detail and on viewing distance). Opposite the appropriate " size " scale will be found ranges of illumination depending on whether the contrast of the object with its immediate background is good (Scale A), medium (B), or bad (C).

Thus, for instance, in the case of a colliery picking belt, the material dealt with is " large " in size, but there is very bad contrast (C) between the coal and the impurities to be seen. Therefore, the illumination should fall between about 10 and 20 lumens per square foot, the actual value recommended being 20 lumens per square foot on account of the unusually difficult contrasts.

[1] Reproduced from " Electric Illumination Handbook No. 2 " by courtesy of the Lighting Service Bureau.

APPENDIX 2[1]

RECOMMENDED VALUES OF ILLUMINATION

The values given below are service values of average illumination and agree with those published by The Illuminating Engineering Society.

ILLUMINATION RECOMMENDED FOR ADEQUATE SEEING CONDITIONS

GENERAL

	L/ft^2	Grade	
ART STUDIO			Special lighting
AUTOMOBILE SHOW ROOM ...		4B	Special lighting
CHURCH			
Church	7	5B	
Church Hall .. .	7	5B	
CINEMA .. .			Special lighting
CORRIDORS AND STAIRWAYS	3	6B	
DANCE HALL			Special lighting
DENTIST			
Waiting Room	7	5B	
Surgery (Operating Area) ..	70	2B	
DRAWING OFFICE			
Boards	30	4B	
General	10	5B	
GARAGE			
Garage	7	5B	
Garage Repair Department .	20	4B	
GYMNASIUM ...	10	5B	Special lighting for Games
HOSPITAL			
Wards and Private Rooms .	3	6B	
Waiting and Receiving Room	7	6B	
Operating Table	300	1B/C	Special lighting
Operating Room . .	30	4B	
Laboratories ..	20	4B	
HOTEL			
Lounge and Dining Room	7	5B	Often special lighting
Writing Room			
General	7	5B	
Tables .		4B	Special lighting
Kitchen	7	5B	
Bedrooms	5	6B	Bed-head lights, etc., also required
INDOOR RECREATIONS			
Bowling (on Alley, Runway, and Seats)	15	5B	
(on Pins) ...	20	4B	Special lighting
Billiards (General) ..	3	6B	
(on Table)	20	4B	
Racquets, Badminton, Squash and Indoor Tennis		4B	Special lighting
Skating Rinks	7	6B	

[1] Reproduced from " Electric Illumination Handbook No. 2," by courtesy of the Lighting Service Bureau.

INDUSTRIAL—*cont.*	L/ft^2	Grade	
CARPETS—*cont.*			
Chenille Cutting, Axminster Spool Winding, Tapestry Printing ...	10	5B	
Finishing, including Sizing, Brushing and Steaming, Cropping and Rolling ...	7	6B	
CHEMICAL WORKS			
Hand Furnaces, Boiling Tanks, Stationary Driers, Stationary or Gravity Crystallizing, Mechanical Furnaces, Generators and Stills, Mechanical Driers. Evaporators, Filtration, Mechanical Crystallizing, Bleaching	7	6B	
Tanks for Cooking, Extractors, Percolators, Nitrators, Electrolytic Cells ...	10	5B	
CLAY PRODUCTS AND CEMENTS			
Grinding, Filter Pressing, Kiln Rooms ...	7	6B	
Moulding, Pressing, Cleaning and Trimming ...	10	5B	
Enamelling, Colouring and Glazing	10	5B	
CLOTH PRODUCTS			
Cutting, Inspecting, Sewing, Cloth Treating (Oil Cloth, etc)., Medium Colours ...	20	4B	
Pressing ...	10	6C	
COAL BREAKING AND WASHING, SCREENING			
Control Points ...	7	6B	Band lighting extra
Picking Belt ...	20	6C	
DAIRY PRODUCTS ...	10	5B	
DIE SINKING ...	100	2B	
DYEING PROCESSES			
Colour Matching ...	70	4C	
Printing (Block Machine) ...	20	4B	
Hank Winding or Slubbing ...	7	5B	
General (all forms) ...	7	5B	
ELECTRICAL MANUFACTURING			
Battery Manufacture, Coil and Armature Winding, Mica Working, Insulating Processes ...	20	4B	
ENGRAVING			
Hand ...		1B	
Stone and Machine ...	50	3B	Special Lighting
FLOUR MILLING			
Cleaning, Grinding, or Rolling ...	10	5B	
Baking or Roasting ...	10	5B	
Flour Grading ...	50	4C	

GENERAL—*cont.*	L/ft^2	Grade	
LIBRARY			
Reading Rooms (General Lighting)	7	4A	
Reading Rooms (on Books) ...	15	3A	
Book Room	7	4A	
MARKET	10	5B	
MUSEUM	7	5B	Extra lighting for showcases
OFFICES AND BANKS			
General Office Work .	20	4B	
Private Office	15	3A	
Typing and Book-keeping .	20	4B	
Filing	20	4B	
PUBLIC HALL	7	5B	Sometimes special lighting
REFRESHMENT ROOM ..	7	5B	
RESTAURANT	7	5B	
SCHOOL			
Day Class Rooms	15	4B	
Drawing and Art	20	4B	
Gymnasiums	10	5B	
Laboratories	15	4B	
Lecture Theatre	10	5B	
Manual Training (*see* Industrial Lighting)			
Sewing	20	4B	
SHOPS			
Interiors	10 and upwards		
Display Windows	100 and upwards		
TELEPHONE EXCHANGE (Private)	7	5B	
THEATRE			Special lighting
TOILET AND WASHROOM ...	7	6B	
WAITING ROOM	7	6B	
INDUSTRIAL			
ASSEMBLING SHOP			
Rough Work	7	6B	
Ordinary Work	10	5B	
Medium Work	20	4B	
Small Mechanisms	50	3B	
Very Small Work	100	2B	
BAKERY	10	5B	
BOOKBINDING			
Assembling, Embossing, Cutting...	30	5C	
Pasting, Punching, Folding and Stitching	10	5B	
CANNING	10	5B	
CARPETS			
Weaving, Designing, Jacquard Card Cutting, Tapestry Setting and Beaming, Mending, Sewing and Fringing	20	4B	

INDUSTRIAL—*cont.*	L/ft²	Grade	
FOUNDRY			
Charging Floor, Tumbling, Cleaning, Pouring, and Shaking Out		6B	
Rough Moulding and Core Making	10	6C	
Fine Moulding and Core Making	20	5C	
GLASS WORKS			
Mix and Furnace Rooms... ..	5	6B	
Glass-Blowing Machines, Grinding, Cutting Glass to size, Silvering, Pressing	10	5B	
Fine Grinding, Bevelling, Inspection, Etching, and Decorating .	20	4B	
Glass Cutting (cut glass), Fine Inspecting	50	3B	
GLOVE MANUFACTURING			
Cutting, Pressing, Knitting, Sorting, Stitching, Trimming and Inspecting	20	4B	
HAT MANUFACTURING			
Dyeing, Stiffening, Braiding, Cleaning, Refining, Forming, Sizing, Pouncing, Flanging, Finishing, Ironing	10	5B	
Sewing	20	4B	
HOSIERY			
Lockstitch and Overlocking Machines (Dark)	30	5C	
(Light)	15	5B	
Mending, Examining and Hand-Finishing:			
(Dark)	50	4C	
(Light)	20	4B	
Circular and Flat Knitting machines, Universal Winders, Cutting Out, Folding and Pressing	15	4B	
Linking or Running on		4B	Special lighting
ICE MAKING		6B	
INSPECTION			
Ordinary	10	5B	
Medium	20	4B	
Small	50	3B	
Very Fine	100	2B	
Minute	200	1B	
JEWELLERY AND WATCH MANUFACTURING	100	2B	
LAUNDRIES AND DRY CLEANING			
Washing	7	6B	
Drying Room		6B	
Calendering	10	6C	
Receiving, Sorting and Checking, Ironing and Pressing	15	4B	
Despatch	7	5B	

INDUSTRIAL—*cont.*	*L/ft*²	Grade	
LEATHER MANUFACTURING			
Vats		6B	
Cleaning, Tanning and Stretching	7	6B	
Cutting, Fleshing and Stuffing ...	5	6B	
Finishing and Scarfing	15	4B	
LEATHER WORKING			
Pressing and Winding			
Medium colours	15	5B	
Grading, Matching, Cutting, Scarfing, Sewing			
Medium colours	30	5C	
MACHINE SHOPS AND FITTING SHOPS			
Ordinary Bench and Machine Work	10	5B	
Rough Bench and Machine Work	10	5B	
Medium Bench and Machine Work, Ordinary Automatic Machines, Rough Grinding, Medium Buffing and Polishing	20	4B	
Fine Bench and Machine Work, Fine Automatic Machines, Medium Grinding, Fine Buffing and Polishing	50	3B	
Very Fine Bench and Machine Work, Grinding (fine work) ..	100	2B	
PACKING			
Crating	7	6B	
Boxing	7	5B	
PAINT MANUFACTURING	15	5B	
PAINT SHOP			
Dipping, Spraying, Firing ...	7	6B	
Rubbing, Ordinary Hand Painting and Finishing	15	5B	
Fine Hand Painting and Finishing	30	5C	
Extra Fine Hand Painting and Finishing (Automobile Bodies, Piano Cases, etc.)	70	4C	
PAPER BOX MANUFACTURING			
Making Fancy Boxes	15	4B	
Cartons	7	6B	
PAPER MANUFACTURING			
Beaters, Grinding	7	6B	Fittings grouped round work
Calendering	10	5B	
Finishing, Cutting and Trimming	20	4B	
PLATING	7	6B	
POLISHING AND BURNISHING		4B	Very well diffused
POWER HOUSE			
Boilers, Coal and Ash Handling ...		6B	
Storage Battery Rooms, Auxiliary Equipment, Oil Switches and Transformer Switches Boards, Engines, Generators, Blowers, Compressors	7	6B	

INDUSTRIAL—*cont.*	L/ft²	Grade	
PRINTING INDUSTRY			
Matrixing and Casting, Miscellaneous Machines, Presses ...	10	5B	
Proof Reading, Lithographing, Electrotyping, Linotype, Monotype, Type-setting, Imposing, Stone Engraving	20	4B	
Typesetting by hand (up to 6-Point Type), Setting Tabular and Mathematical Matter	30	3B	
Sorting and Packing	7	6B	
RUBBER MANUFACTURING AND PRODUCTS			
Fabric Preparation, Creels ..	7	6B	
Dipping, Moulding, Compounding Calendars, Tyre and Tube Making	7	6B	
SHEET METAL WORKS			
Miscellaneous Machines, Ordinary Bench Work, Punches, Presses, Shears, Stamps, Welders, Spinning, Fine Bench Work	15	5B	Very well diffused
Tin Plate Inspection ..		5B	Special lighting
SHOE MANUFACTURING			
Hand Turning, Miscellaneous Bench and Machine Work, Cutting, Lasting and Welting ...	15	4B	
Stitching, Inspecting and Sorting	20	4B	
SMITH SHOP			
Forging and Welding . .	7	6B	
SOAP MANUFACTURING			
Kettle Houses, Cutting, Soap Chip and Powder	7	6B	
Stamping, Wrapping and Packing, Filling and Packing Soap Powder	7	6B	
STEEL AND IRON MILLS, BAR, PLATE, AND WIRE PRODUCTS			
Soaking Pits and Preheating Furnaces, Hot Rolling .		6B	
Charging and Casting Floors ..	7	6B	
Muck and Heavy Rolling, Shearing rough by gauge, Pickling and Cleaning	7	6B	
Plate Inspection	10	5B	
Automatic Machines, Rod, Light and Cold Rolling, Wire Drawing, Shearing, fine by line ..	10	5B	
STRUCTURAL STEEL WORKS		6B	
SUGAR GRADING	50	4C	
SWEET MAKING	10	5B	
TESTING			
Rough	7	6B	
Fine	50	3B	
Very Fine Instruments, Scales, etc.	100	2B	

INDUSTRIAL—*cont.*	L/ft^2	Grade
TEXTILE MILLS		
Cotton		
Bale Breaking, Scutching, Carding, Combing and Roving	7	5B
Twisting and Winding ...	10	5B
Spinning	10	5B
Warping	15	4B
Looms		
Dark Colours (Fine Counts)	30	3B
Light Colours (Fine Counts)	20	3A
Grey Cloth	10	5B
Silk		
Winding and Throwing ...	15	5B
Quilling, Warping, Weaving and Finishing	20	4B
Woollen		
Scouring, Washing, etc. ...	7	6B
Carding and Combing (white), Blending, Drawing, and Roving	7	5B
Spinning, Winding, Sorting, Combing (Coloured) Twisting	15	5B
Warping	20	4B
Weaving		
Looms		
Fine Worsteds	50	3B
Medium Worsteds and Fine Woollen	30	4B
Heavy Woollen	10	5B
Burling and Mending ...	50	3B
Perching	70	2B
TOBACCO PRODUCTS		
Drying, General		6B
Grading and Sorting	20	4B
Stripping	7	5B
UPHOLSTERING		
Automobile, Coach and Furniture	15	5B
WAREHOUSE		5B
WELDING		
Fairly Small Soldering and Contact Welding	20	4B
Ordinary	15	5B
Flame Welding and Brazing ...	7	5B
WOOD WORKING		
Rough Sawing and Bench Work ...	7	6B
Sizing, Planing, Rough Sanding, Medium Machine and Bench Work, Glueing, Veneering, Cooperage	15	5B
Fine Bench and Machine Working, Fine Sanding and Finishing ...	20	4B

APPENDIX 3

Tables and Data

Representative Levels of Illumination

	Lumens per sq. ft.
Starlight	·0002
Moonlight	·02
Well-lighted street	1·00
Daylight—At north window	50–200
In shade outdoors	100–1,000
Direct sunlight	5,000–10,000
Well-lighted interior	50–100

Reflection Factors of Coloured Interiors

Colour.	*Average Reflection Factor. (White Cold Cathode Lighting.)*
White	·88
Very Light—	
Blue-green	·75
Cream	·80
Blue	·65
Buff	·75
Grey	·83
Light—	
Blue-green	·73
Cream	·70
Blue	·55
Buff	·70
Grey	·75
Medium—	
Blue-green	·55
Yellow	·65
Buff	·63
Grey	·62
Dark—	
Blue	·09
Yellow	·50
Grey	·25
Green	·08
Wood Finishes—	
Maple	·43
Walnut	·16
Mahogany	·13

Radiation Characteristics of Black-Body Radiator

Temperature (° K.).	*Watts per sq. cm.*	*Optimum Luminous Efficiency* (*Lumens per Watt*).
2,000	91·4	153·0
3,000	426·4	206·7
4,000	1,462·0	219·6
5,000	3,560·0	229·3
6,000	7,403·0	221·1
7,000	13,170·0	212·9

Effect of Fluorescent Lighting on Wall Colours

Colours of Paints Tested.	*Daylight.*	*White.*	*Soft White.*	*Filament* (*100-watt*).
Cascade blue (pastel) (bluish-green)	Bluish-green (preferred)	Greyish-green	Slightly greyish	Yellowish faded blue
Palmetto green (pastel) yellowish green	Fresh blue-green (preferred)	Yellowish green	Slightly greyish	Yellowish pale green
Peach (pastel)	Good—slightly pink	Normal—slightly cold	Normal—slightly pinkish	Normal—same as white
Blossom pink (pale)	Purplish pink	Yellowish	Intensified normal pink	Yellowish
Maize tan (pastel)	Greyish—cold	Yellowish	Cream—good	Strongly yellow
Sun tone (cream)	Faded grey	Slightly greenish	Cream—good	Cream—good
Deep cream (Williamsburg)	Bluish—excellent	Intensified—good	Slightly greyed—good	Yellowish—fair
Governor's red (Williamsburg)	Slightly bluish—good	Yellowish—good	Warmer—good	Yellowish—good
Deep blue (Williamsburg)	Vivid—good	Richer—good	Vivid blue (preferred)	Greyed
Dusky rose	Bluish	Yellowish	Vivid (preferred)	Yellowish
Deep yellow	Greyish—unattractive	Vivid	Slightly grey—good	Reddish

Effect of Fluorescent Lighting on Human Skin

Illumination Level on Skin—50 lumens per sq. ft.

Description.	*Daylight.*	*White.*	*Soft-White.*	*Filament* (*100-watt*).
Untanned skin	Pale—slightly grey	Sallow—slightly greenish for older skins	Enhanced	Yellowish—appearance of slight tan
Observer's rating	Fair	Acceptable	Preferred	Good
Tanned skin (medium)	Greyish tint	Intensified greenish tint, very sallow	Healthy glow	Intensified reddish tint
Observer's rating	Fair	Fair	Good	Preferred
Deep pigmentation	Intensified greyish tint	Intensified greenish tint, very sallow	Healthy glow	Deep rich brown
Observer's rating	Poor	Fair	Good	Preferred
Sunburned skin—red	Slightly reddish—purple tint	Tanned appearance	Slightly reddish	Fiery red
Observer's rating	Fair	Preferred	Good	Poor
Untanned skin—light make-up	Over-emphasized make-up in contrast to skin	Make-up greyed-sallow appearance	Blended skin and make-up—improved appearance	Intensified make-up—slightly sallow appearance
Observer's rating	Poor	Fair	Preferred	Good
Untanned skin—heavy make-up	Further over-emphasis of make-up—very pale skin	Sallow appearance of unpainted skin intensified	Enhanced skin and make-up	Slightly sallow
Observer's rating	Poor	Fair	Preferred	Good

Resonance and Ionization Potentials

	Resonance.	Ionization.
Helium	19·77	24·50
Xenon	18·39	12·08
Neon	16·58	21·50
Argon	11·57	15·70
Krypton	9·98	13·94
Mercury Vapour	4·68	10·39

Tube Characteristics

Colour.	Filling.	Initial Lumens	Depreciation Factor (% loss after 1,000 hours).
Green	Argon and Mercury Vapour	31	32·0
White	" " "	31	30·0
Soft White	" " "	29	30·0
Blue	" " "	15	18·0
Gold	" " "	25	20·0
Yellow	" " "	15	18·5
Amber	Neon plus 1% Helium	20	9·5
Pink	" " "	25	10·0
Orange	" " "	10	7·5

Triple-Tube Combinations

Combination.	Resultant Colour.	Remarks.
1 red, 2 green	Soft pink-white	Suitable for cinema and theatre foyers, etc.
1 green, 2 gold	Warm amber	Hotel bars and ballrooms, etc.
1 red, 2 white	Pink-white	General applications of decorative lighting.
1 red, 1 green, 1 blue	Off-white	Indirect lighting with separate colour control.
1 red, 1 green, 1 gold	Pink-amber	Restaurants, etc.

Cathode Drop

	Cathode Drop in—		
Electrode Metal.	Neon.	Helium.	Argon.
Copper	210	170	150
Iron	153	161	166
Magnesium	122	126	150
Aluminium	120	165	145
Potassium	68	69	71
Sodium	75	80	73

Increase in Current with Increase in the Tube Diameter (Current Density Constant)

Diameter of Tube. Mm.	(In.).	Ma.	Ma.	Ma.
5	0·2	4	5	6
10	0·4	15	20	25
15	0·6	35	45	55
20	0·8	60	80	100
30	1·2	135	180	225
45	1·8	300	400	500

OPERATING VOLTAGE DROP PER FOOT

	0·4 in. Diameter, 25 ma. Current.	*0·6 in. Diameter, 35 ma. Current.*	*0·8 in. Diameter, 75 ma. Current.*
Neon	170	120	90
Mercury-argon	130	95	70
Helium	370	250	190

CHARACTERISTICS OF MODERN COLD CATHODE FLUORESCENT LIGHTING

	American.	*British.*
Usual type of assembly	2 tubes on 1 auto-transformer.	3 tubes on 2 double-wound transformers.
Length of tube	7 ft. 9 in.	9 ft. 10 in.
Diameter of tube	1 in.	0·8 in.
Operating current	120 ma.	120 ma.
Running voltage	460	630
Tube wattage	54	70
Watts loss per transformer	14	15
Colours available	3,500° K. white, Soft white, Daylight.	Warm white, sunlight. Intermediate white. Daylight.

BIBLIOGRAPHY

" Building Product Facts," from *Progressive Architecture*, October, 1945, Serial No. 16.

Handbook of Cold Cathode Illumination. Fluorescent Lighting Association, 60 Beaver Street, New York, N.Y.

" Modern Lighting for the Modern Home," by GEORGE F. MEYERS (" Signs of the Times "—Fluorescent Lighting Section), New York, N.Y. U.S.A., June, 1944.

The following articles in *Illuminating Engineering* (Journal of the Illuminating Engineering Society, New York, U.S.A.) :—

" Cold Cathode Fluorescent at War," by JOHN C. SABATINI, April, 1943.

" High- and Low-Voltage Fluorescent Lamps," by J. W. MARDEN and G. MEISTER, December, 1941.

" Application of High-Voltage Fluorescent Tubing to Lighting Problems," by D. P. COVERLY, December, 1941.

" Some Engineering Aspects of Lighting from Cold-Cathode Fluorescent Sources," by H. J. CHANON and A. C. BARR, December, 1942.

" Fluorescent Sources at Work," by R. D. BRADLEY and F. B. LEE, January, 1944.

" Transformers and Ballasts for Cold Cathode Lighting Installations," by E. A. MILLER, September, 1945.

" Cold Cathode at War," by JOSEPH M. SMITH, Technical Director, Fluorescent Lighting Association, September, 1945.

Notes on Processing Cold Cathode Fluorescent Tubes, by PAUL A. KOBER (Colorescent Laboratories, Newark, N.J., U.S.A.).

Colovolt Application Data (General Luminescent Corporation, Chicago, U.S.A.).
Engineering Service Releases (Acme Electric and Manufacturing Company, Cuba, N.Y., U.S.A.).

"Circuits for Discharge Lamps," by R. MAXTED, B.E.(Elec.)., M.I.E.E., and J. N. HULL, B.Sc.(Eng.), A.M.I.E.E. (*Transactions of the Illuminating Engineering Society, London*).

And various articles by the author which have been published from time to time in *The Electrical Engineer, The Electrical Review, The Electrical Times, The Electrician, Signs, Display, Light and Lighting*, and *Sign and Display.*

INDEX