ELECTRIC LAMPS

E.L.M.A

ELECTRIC LAMP MANUFACTURERS ASSOCIATION OF GREAT BRITAIN LTD

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ELECTRIC LAMPS

The E.L.M.A. Lighting Service Bureau was set up in 1924 *by the Electric Lamp Manufacturers' Association of Great Britain to promote the full and proper use of electric light in the service of the community. Throughout the ensuing years this policy has been consistently pursued, until to-day, backed by the vast resources of the manufacturers who maintain it, the Bureau is able to offer an unrivalled service in the electric lighting field. The E.L.M.A. Lighting Service Bureau is maintained by the Manufacturers of the following brands of Electric Lamps:*

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ELECTRIC LAMPS

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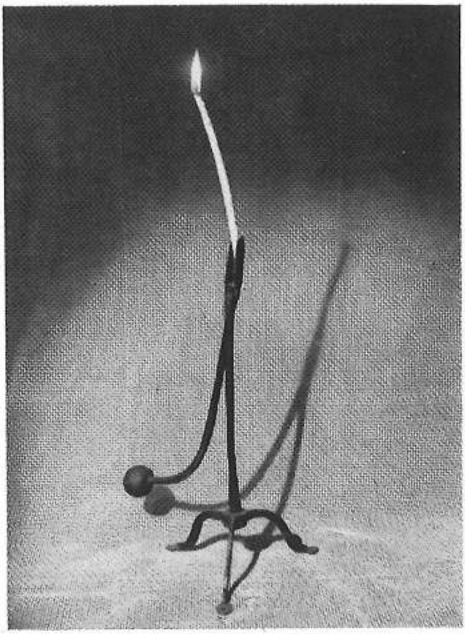


ABOVE: Simple candle guard and lanterns

RIGHT: Rushlight and holder

realised that a proper mixture of air and oil vapour must be provided for a smokeless flame to be obtained, or the means of doing so were not apparent, until in 1784 the Argand burner showed the way.

This lamp had a glass chimney and a tubular wick to which air had access both on the outside and inside. The draught of air flowing around and within the flame made combustion nearly complete and a bright and almost smokeless flame was the result.

About the middle of the nineteenth century the discovery of petroleum in quantity marked a further step forward in oil lamp performance, for its higher volatility gave a greater intrinsic brilliance to the flame. From that time onwards improvement in oil lighting has been chiefly dependent on perfection of the incandescent mantle developed by Welsbach in 1885–93.

CANDLES

The earliest form of candle, known as the Rushlight, was made by stripping a rush stem of all but the thinnest rind and dipping it repeatedly in hot fat until a thick wall was built up; and in the fourth century A.D. the Phoenicians brought to Byzantium candles of bleached wax, probably with fibre wicks. All earlier types of candle were soft and were usually stuck on a spike (Pique, Pricket). Until about the sixteenth century they were not in common domestic use but were employed chiefly for religious purposes.

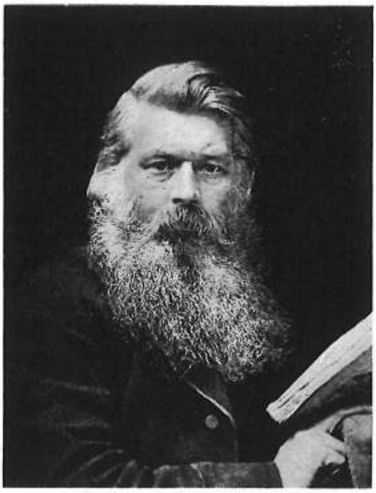
Early candles needed frequent snuffing or trimming of the wicks, which did not burn away as quickly as the candle and tended to lean over into the molten wax, but the introduction of plaited wicks (about 1840) and the discovery that sperm oil could be used for making the candle obviated this trouble, as the end of the wick burned away in the hot outer part of the flame.

GAS LIGHTING

The first large scale experiments in the use of gas for lighting were made by Murdoch in 1779, but lack of purification of the gas and the meagre light provided delayed the popularity of gas lighting until the latter part of the nineteenth century.

The first burners were simple open tubes, which were later closed at the end and pierced by three holes giving the "Cockspur" flame. In the same year (1808) a row of small holes gave the "Cockscomb", while in 1816 the holes were merged into a narrow slit giving the "Batswing" burner. Finally, in 1820 the "Fishtail" burner was produced wherein a flat flame resulted from the union of two equal oblique jets. The effectiveness of all these types depended entirely on the luminosity of the gas flame itself, the heating effect being of no importance whatever.

From 1885, however, Welsbach had been investigating the properties of rare earths when heated, and he introduced the incandescent mantle in 1893. Here the lighting effect is dependent not on the luminosity of the flame but on the degree of incandescence to which the mantle can be raised, i.e. on the heating effect of the gas. Subsequent improvements in gas lighting have been the result of detailed investigation into the heating power of the gas, the shape and construction of the burners and mantles to work efficiently together, the air flow, and the avoidance of dirty products of combustion. Methods of distant control have also been devised, and are in fact still being investigated.



Born in 1828 Joseph Wilson Swan was a brilliant scientist who discovered, among other things, new methods of photographic printing and how to make artificial silk. Becoming interested in electric lamps in 1845, he eventually succeeded in producing a commercial carbon lamp in 1878, and can be classed, with Edison, as the pioneer of electric lighting. He died in 1914

But there does not seem to be much future for any kind of lighting which is primarily dependent on flame.

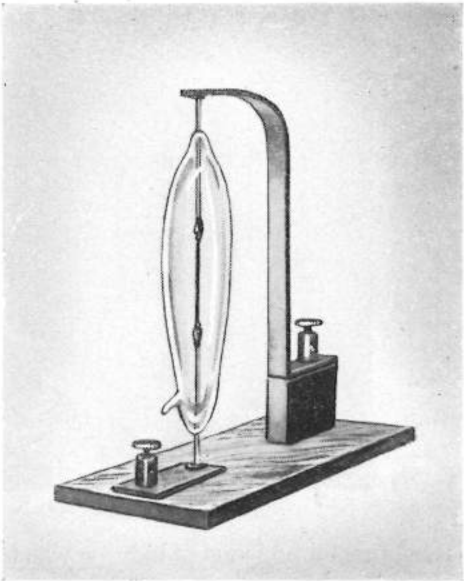
ELECTRIC LIGHTING

Early experimenters with electric light were handicapped by lack of any large scale and permanent sources of electricity, though as early as 1810 Sir Humphry Davy used thousands of batteries to demonstrate an intensely luminous arc struck between carbons which had been touched together, then separated by a short distance. Carbons connected to a D.C. supply burned unevenly, however, and complicated apparatus had to be devised to keep the arc steady.

It was Faraday's discovery, in 1831, of the principles of electro-magnetism that gave birth to the electrical industry of modern times, for he showed how electricity could be produced by mechanical means in greater quantity and far more conveniently than by the chemical means hitherto employed. Even so, electric generation on a large scale was not attempted until 1849 from which time arc lights were used temporarily for an increasing number of isolated applications. The first permanent installation of electric arc light, in the Dungeness lighthouse, was completed in 1862.

INCANDESCENT CARBON FILAMENT LAMPS

The fact that an electric current will heat up a conductor through which it passes has been known for many years, and scientists of the early nineteenth century repeatedly tried to obtain light through incandescence of

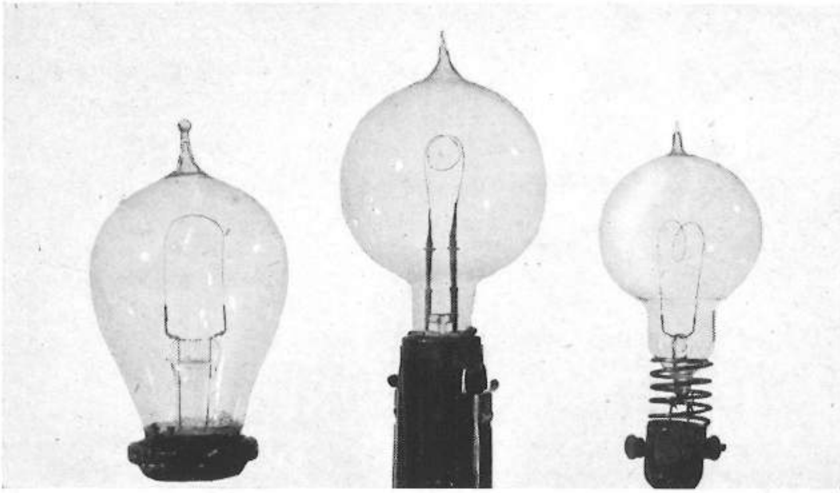


Swan's first incandescent carbon-filament lamp. 1878

materials heated in this way. Prominent among experimenters were Davy, who obtained incandescent light for very brief periods from a number of different materials in 1802, and Grove and de Moleyns, who made lamps with platinum filaments in 1840. Their failure to produce a lamp which would give light for a reasonable length of time is chiefly due not to a lack of skill or perseverance, but the lack of any means of preventing rapid oxidisation of the filament. Incandescent metal or carbon will oxidise, or burn, if there is any oxygen with which it can combine; and as air contains oxygen it must therefore be evacuated from the bulb as completely as possible. None of the suction pumps available to these men was good enough for the purpose, a sufficiently high degree of vacuum being unobtainable until the Sprengel air pump made its appearance in 1875. From that year onwards developments were rapid.

Working quite independently but on parallel lines, Swan in England and Edison in America both produced practical lamps in 1878. In point of fact Swan was probably the first to do so, but he was never in a hurry to patent his processes and may thus have lost much of the credit due to him.

The first practical lamps were cigar-shaped, the current-carrying lead passing through the glass at each end being connected inside the evacuated bulb to a thin strip of carbonised paper or thread, for which the carbonised bamboo fibre was substituted in 1880. Though a high vacuum was



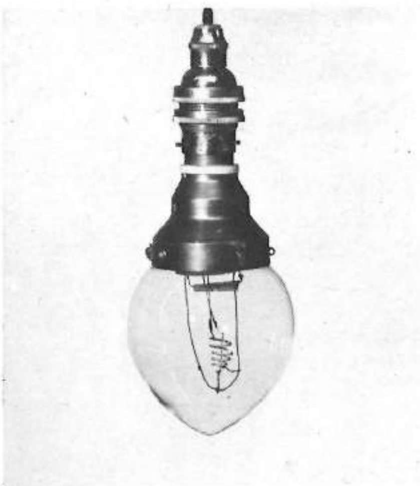
Three early carbon lamps with various types of lampholder

obtained before the lamp was sealed, contamination and burning of the filament still occurred and Swan realised that it was due to the emission of trapped gases from the filament when heated. He therefore continued the pumping process while the filament was glowing brightly, thereby improving the durability of the lamp.

In order to prevent leakage there must be an absolutely air-tight metal-glass seal at all temperatures at the point where the leads enter the lamp, and to obtain this a metal must be used which expands at the same rate as the surrounding glass. Platinum was the only such metal available in early days, a fact which may have been partly responsible for the then high cost of lamps.

In 1893 improved filaments were made by squirting a solution of cellulose through a round die, and by carbonising the thread obtained, filaments of any desired length or diameter could be produced. It is interesting to note that this process also led to the founding of the great artificial silk industry of to-day.

In 1904–5 squirted carbon filaments were further improved by a process which gave them greater uniformity of diameter and a glassy surface which, taken in conjunction with their modified electrical characteristics, caused them to be known as "metallised carbon" filaments. No major improvements in the manufacture of carbon lamps has been made since that time.



Nernst lamp, showing the heater running through the centre of the filament spiral

NERNST AND EARLY METAL FILAMENT LAMPS

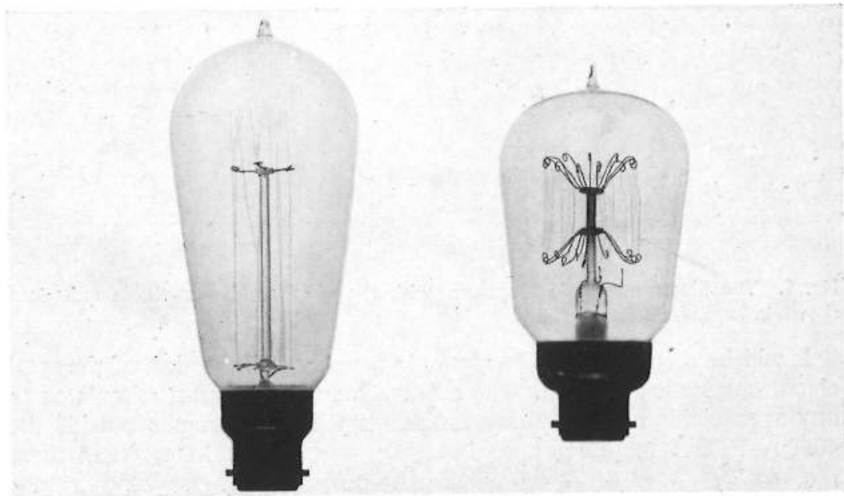
The first British patent for a Nernst lamp was taken out in 1897. Nernst employed a squirted filament made of oxides used in the Welsbach incandescent mantle, these oxides becoming conductors of electricity at high temperatures. In order to attain the necessary temperature a separate heater wired in parallel with the filament had to be included in the lamp, the heater automatically cutting out when the required temperature was reached. The oxide filaments were electrically unstable, however, and had to be run in series with a ballast resistance, which reduced the efficiency of the lamp as a whole, although it was still a great advance on the carbon lamp in this respect. The life of the lamp was about 900 hours on A.C. and 300 hours on D.C. and it would undoubtedly have had very considerable success had not new types of metal filament lamps been developed very rapidly at about the same time.

Lamps with an Osmium filament appeared in 1902. They had a life of about 500 hours, with extremely good candle-power maintenance, but they were not made for voltages greater than 77 volts. They were also extremely fragile, and cost about 9*s*. each, despite which they were used very largely on the Continent until about 1905.

In that year the tantalum lamp was put on the market. This was the first lamp employing a drawn wire and therefore led to a great improvement in the uniformity of filament production as compared with filaments produced by a squirted process, but the length of wire required for a lamp running on ordinary mains voltage was about 700 mm. This meant abandoning the old spiral filament formation, and the adoption of the now familiar squirrel cage method of winding the wire on supports held in a central glass rod. The tantalum lamp was slightly less efficient than the osmium lamp but was remarkably strong. While not very satisfactory on A.C. owing to recrystallisation of the filament it was extensively used for traction lamps until about 1914 when it was superseded by lamps with a drawn tungsten filament.

About 1906, filaments of tungsten were made by a process similar to that used for the production of carbon filaments. Finely divided tungsten powder was mixed with a starch or dextrin binder and squirted through a die, the resultant thread being sufficiently strong to withstand subsequent drying, forming and purifying processes, but the finished filament, though more efficient than any of its predecessors, was still extremely brittle. It was not until 1909 that a process was discovered for making tungsten ductile, so that it could be drawn into strong tough wire of the required size.

It is at about this point that the modern lamp era can be said to begin. In the previous 20 years or so, the brilliant and painstaking efforts of individual scientists had at last given us a source of light which was an enormous advance on anything produced in the thousands of years that went before. They gave us light with no flame, fumes, smoke or smell; light that could be controlled from far or near, with no fuel to be handled, no burner to clean and no wick to trim. All honour to them, working as they did with tools and materials which we should call crude by modern standards.



An early tungsten lamp with squirted filament beside, on the right, a tantalum lamp

NATURE OF LIGHT

ELECTRO-MAGNETIC RADIATIONS

LIGHT, HEAT, RADIO WAVES, X-RAYS and other electro-magnetic radiations are essentially similar in that they all travel through space without any apparent means of conveyance at 3×10^{10} cms. (186,000 miles) per second.

It is convenient to consider that the radiations move outwards from the point of propagation in the same way as ripples move from the point of disturbance in a pool. The ripples move outwards though the only actual movement of the water itself is vertically up and down. Similarly, light, heat, etc., may, for the purposes of this explanation, be considered as wave-motions, though it is difficult to comprehend a wave-motion unless there is something for the wave to move in.

Since all the electro-magnetic radiations travel at the same speed, it will be apparent that if the crests and troughs are close together (i.e. if the wavelength is short) a large number of them will pass a given point in a given time, or in other words the *frequency* is high; but if the wavelength is long, the frequency will be low. The physical and physiological effects of the radiations depend upon their wavelength (or frequency) and the names given to the various ranges of radiation are shown below.

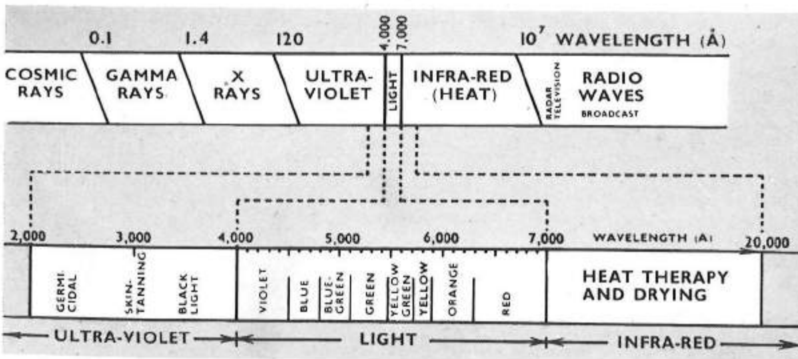


Fig. 1. The Electro-magnetic Spectrum, with the visible and near-visible radiations shown in expanded form beneath

It will be seen that light covers only a very small fraction of the total electro-magnetic spectrum. The average human eye is not stimulated to any appreciable extent by any radiations with wavelengths outside the 4000 Å–7000 Å band * (approximately); wavelengths longer than these

* Å = Angstrom unit, a wavelength of one hundred-millionth of a centimetre.

give us the sensation of heat and the possibility of radio communication, while the shorter waves give us, among others, ultra-violet rays (used for a variety of purposes), X-rays and cosmic rays.

A generator of light would be most efficient if it could be made to produce light only, but at present there are no known light sources, either natural or artificial, which do not also generate heat to a varying degree. As lamp development continues, so the quantity of light generated is increased with a consequent reduction of heat, but it is improbable that really "cold" light will be obtainable, at least in sufficient quantity for practical use.

Ultra-violet radiations, though invisible, can be used to produce light as explained in pages 21–23 ; it is indeed certain that before many years are passed, generation of light by this means will have become as commonplace as the use of filament lamps of to-day.

COLOUR OF LIGHT

The colour sensation received by the eye depends on the wavelength of the light. The boundary between one colour and the next is naturally indefinite, for the colours merge into one another and it is impossible to say, for instance, where orange light ends and red begins; but for convenience a series of arbitrary divisions are generally accepted as shown in Fig. 1.

Light which the eye recognises as "white" can be split up into two or more lights of different colours, and a "white" surface is one which reflects all colours of light in the same proportion as they are present in the incident light. "Painting" with light is an additive process, and as more of each of the three primary colours (red, blue, green) are mixed together the light becomes whiter and brighter; but painting with pigments is a subtractive process by which mixture of colours leads to a darker result.

There is only one way of obtaining coloured light from an original white light, i.e. by absorbing to a greater or less degree all the unwanted constituents of the white light. Usually this is done by means of a coloured gelatine or glass filter or by colouring a lamp bulb, but in most cases the selectivity of the filter is not high and some unwanted colours are also passed, e.g. a yellow-sprayed lamp will give a little orange and green light besides the yellow.

A coloured material seen under white light appears coloured because it reflects that colour of light much more strongly than the other colours which it absorbs, e.g. a piece of blue paper will reflect blue light strongly, violet and green weakly, and other colours not at all. Thus, if a blue paper is seen by the light of the yellow-sprayed lamp, it tends to appear greenish

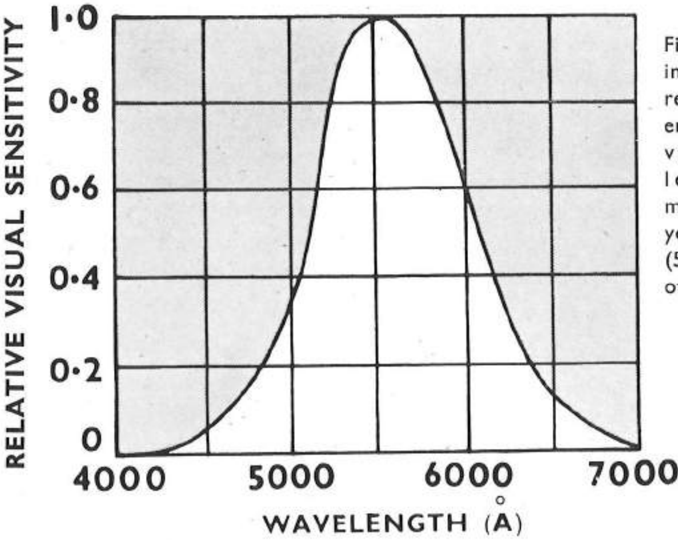


Fig. 2. The curve indicates the eye's response to equal energy of light at various wavelengths. It is more sensitive to yellow-green light (5550 Å) than to other colours

as green is the only colour present in the light which the paper is able to reflect. It is evident that the apparent colour of objects may vary according to the nature of the lamp illuminating them and in extreme cases the natural colour may be entirely obscured.

EYE RESPONSE

The average human eye is not equally sensitive to all colours of light. The curve above shows how the average eye is stimulated far more strongly by yellow light than by violet, blue or red. This means in practice that yellow colours in general appear relatively bright when white light falls on them, and that lamps which give yellow light only tend to be more efficient in their own class than lamps giving any other colour.

CONTINUOUS AND DISCONTINUOUS RADIATION

When a solid body is heated to incandescence the electrons are violently agitated and constantly collide with their neighbours. Some of the energy resulting from these collisions is radiated from the hot metal and due to the relatively close packing of the individual atoms in a solid body the energy will appear as a continuum characteristic of the temperature of the radiating body and not characteristic of the nature of the individual atoms. The result is a confused radiation which is smoothly distributed over a wide band of wavelengths (Fig. 3). Some of the radiations may be in the visible band but the greater part will be in the infra-red (heat) band.

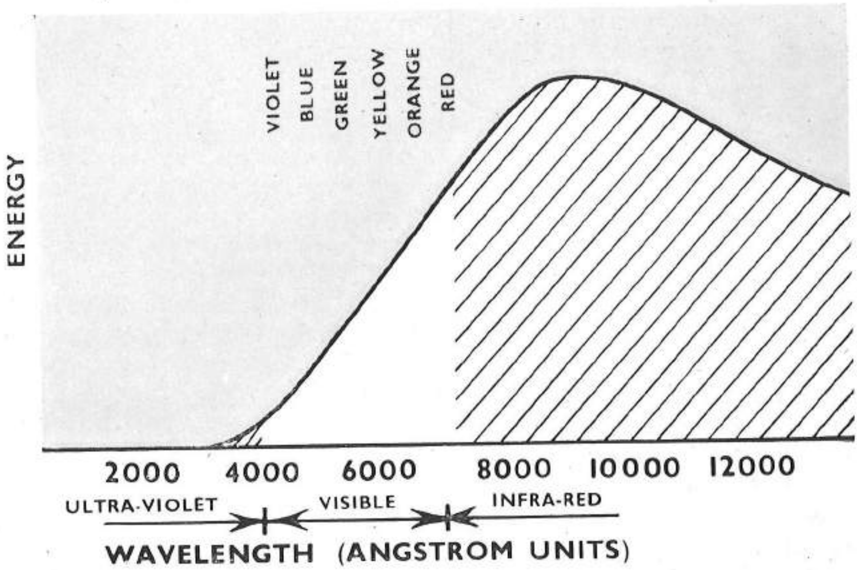


Fig. 3. Continuous spectrum of a filament lamp. There is a large proportion of heat (infra-red) radiation compared to light

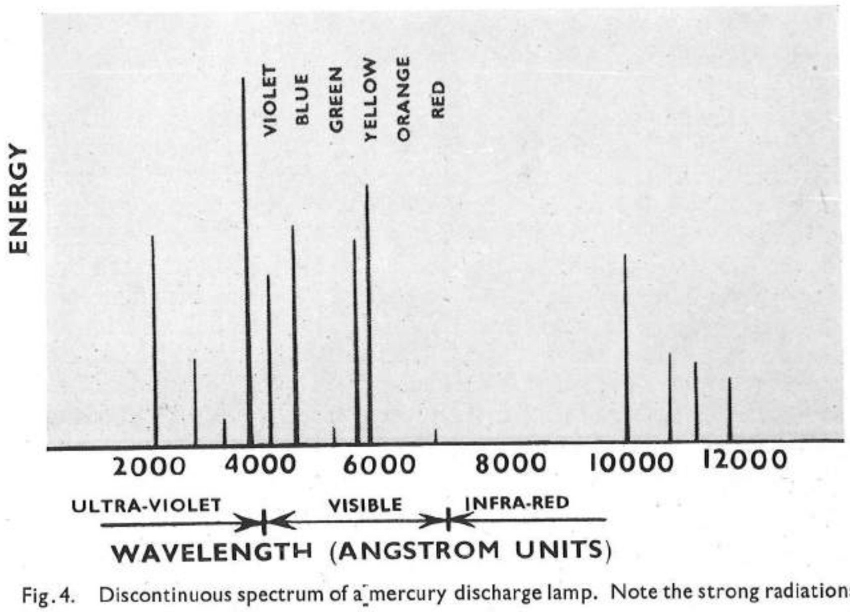


Fig. 4. Discontinuous spectrum of a mercury discharge lamp. Note the strong radiations in the ultra-violet region

Although the radiation is more intense at the long wave (red) end of the visible spectrum than at the short wave end, the radiation is continuous throughout the whole band and if the metal is sufficiently hot some light is produced at every wavelength within that band.

An "excited" gas or vapour behaves in a different manner. In its excited state it contains numbers of electrons which, due to collision with other electrons, have been forced into unnatural orbits round their parent atoms. They quickly return to their normal orbits, but in so doing give up the energy they absorb in collision, and at low vapour pressures this energy appears as a radiation at one or more of a series of fixed and definite wavelengths. Nothing one can do will alter these wavelengths (except that we may be able to broaden the individual radiations to embrace a narrow band of wavelengths) though by varying conditions of temperature and pressure the proportion of energy radiated at each wavelength can be varied. In between those wavelengths there are blank spaces at which there is no radiation at all (Fig. 4).

Thus the spectrum of a low-pressure discharge lamp consists of a number of isolated lines and is quite dissimilar from the continuous spectrum of an incandescent body such as a lamp filament. There is evidence, however, that at high vapour pressures certain electric discharge lamps are possible which combine the effects of the broadening of isolated lines with the continuous spectrum corresponding to an incandescent body.

LUMINOUS EFFICIENCY

The luminous efficiency of lamps is expressed in terms of lumens per watt, i.e. the rate of flow of light per unit of electrical power consumed. In theory it would be possible to generate white light at an efficiency of 250 l/w. if all the electrical energy were transformed into light and none into heat or other unwanted radiations; and monochromatic yellow-green light (5550 Å) could reach an efficiency of 625 l/w. under similar conditions. But though we can produce light electrically more efficiently than by any other method, we have a long way to go before reaching such figures. The practical and physical limitations imposed by the materials we have to use make it impossible at present to construct filamant lamps with an efficiency substantially greater than 20 l/w. if lamp life is to be prolonged, while discharge lamps reach 70 l/w. or slightly more. Nevertheless there is some justification for pride in the improvement in lamp efficiency which has taken place throughout the last 60 years. Finality has by no means been reached and further advances can be expected in the future.

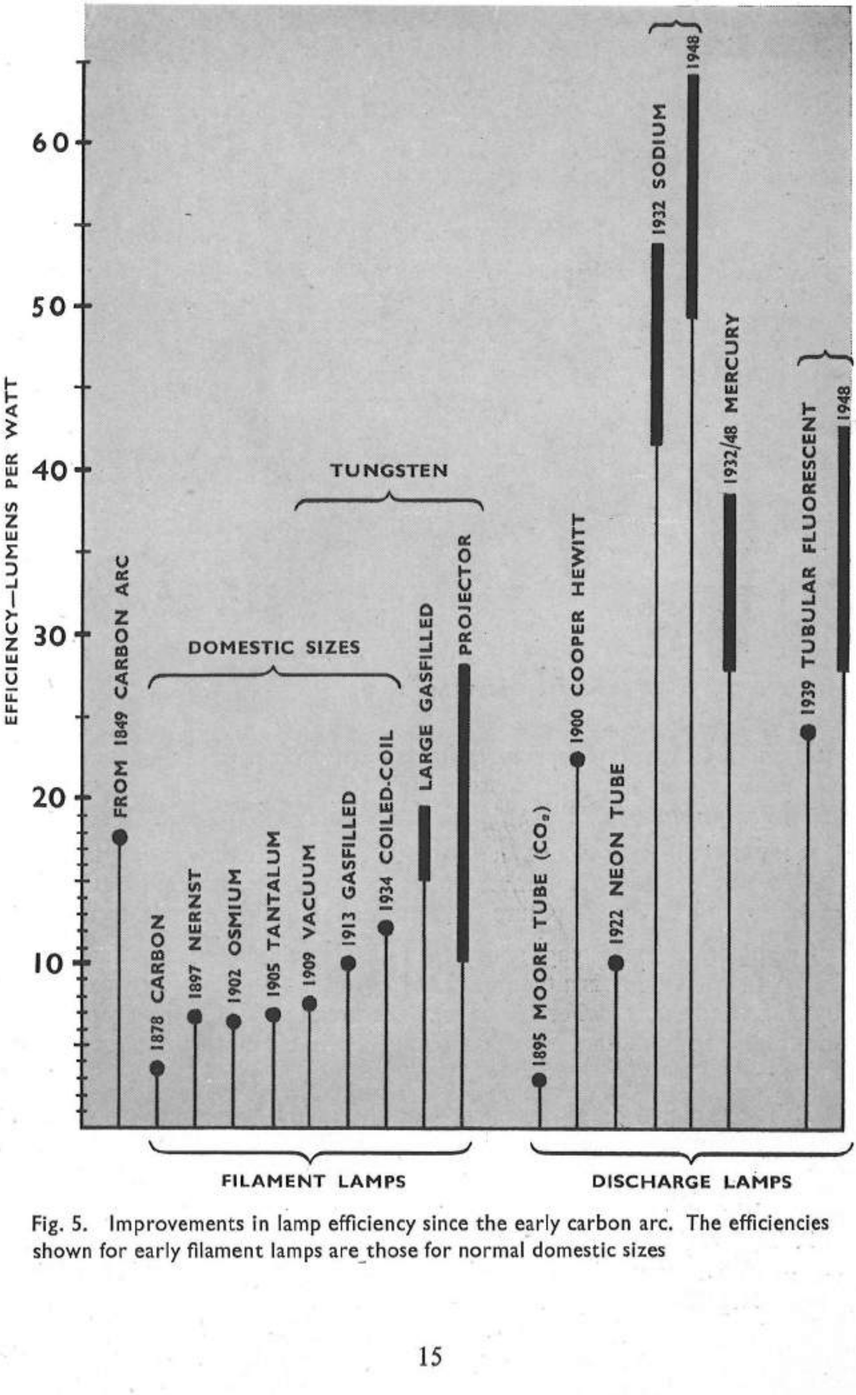


Fig. 5. Improvements in lamp efficiency since the early carbon arc. The efficiencies shown for early filament lamps are those for normal domestic sizes

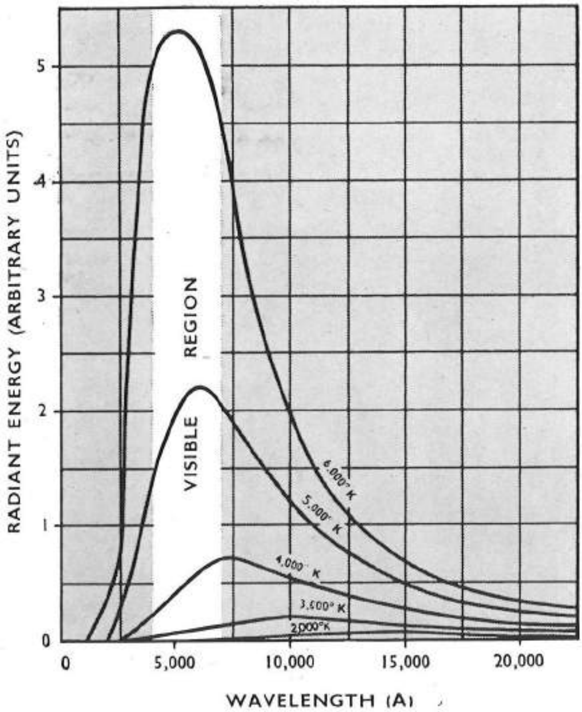


Fig. 6. The relative energy radiated at various wavelengths by a "black body" at five different temperatures

PRODUCTION OF LIGHT

Temperature Radiation

ANY HOT BODY WILL RADIATE ENERGY over a wide band of wavelengths, the amount radiated at any particular wavelength being determined by the nature of the material and its temperature.

The diagram on this page shows the radiation characteristics of a "black body" (a black body is a theoretically ideal radiator closely approximated by an incandescent carbon filament). The area under the curve represents the total energy radiated and examination will establish three important facts:—

1. The radiated energy increases rapidly as the temperature is raised. Stefan has shown that the energy radiated is proportional to the fourth power of the absolute temperature (centigrade temperature $+ 273°$).
2. The wavelength of maximum radiation decreases as the temperature rises. Wien has shown that the wavelength of maximum radiation $\times$ absolute temperature is constant.

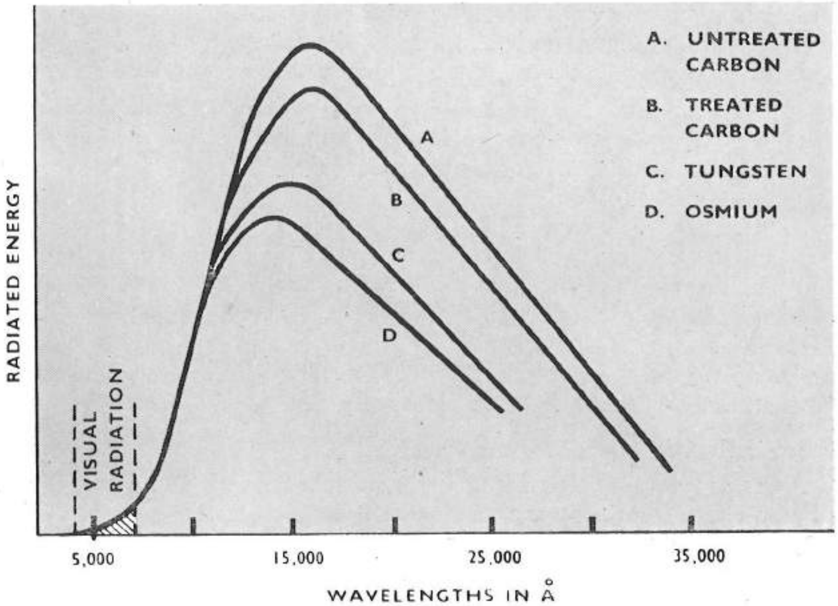


Fig. 7. Wavelength distribution of radiant energy from various materials at the same temperature

3. The proportion of the total radiation which is emitted within the visible range increases as the temperature is raised.

It will be evident that the luminous value of the curves cannot be assessed without taking into account the response of the eye (Fig. 2) and each ordinate of Fig. 6 should be multiplied by the corresponding ordinate of Fig. 2, which will have the effect of modifying the luminous advantage obtained from higher temperatures. In fact at 2000° absolute (2000 Kelvin) a temperature rise of 20° C. will only increase the total radiation by 4 per cent., but will increase the light output by 15 per cent.

No actual substance has the radiation characteristics of a black body, most materials having radiating properties which depart considerably from the ideal. Fig. 7 shows the energy distribution of some of these "selective radiators" which are being or have been used for making lamp filaments. The materials shown are operating at the same temperature and the total visible radiation is the same in each case, but it will be seen that the total energy radiated is least in the case of Osmium, a little more with Tungsten and most with untreated Carbon. At first sight, therefore, it appears that Osmium would be the best material to use as it dissipates (and requires) less energy to provide a given quantity of light.

Osmium, however, has a melting point of about 2500° C., whereas the melting point of Tungsten is about 3400° C. and the luminous efficiency gained by employing Tungsten at a higher working temperature far outweighs the loss due to its being an inferior radiator.

If these were the only considerations governing the choice of filament material, Carbon might be supremely suitable as its melting point is very high, but it cannot be operated satisfactorily at temperatures above 1850° C. on account of rapid evaporation which would soon destroy the filament. Manufacturers thus have to search for a conductor having a high melting point and a low rate of evaporation, with the necessary mechanical properties to enable filaments to be shaped into suitable forms of sufficient strength to withstand ordinary (or sometimes particularly arduous) service. Tungsten is almost universally used for this purpose at present, and will probably be so used in the future.

Electric Excitation of Gases and Vapours

A gas or vapour enclosed in a discharge tube consists of many millions of atoms each comprising a central positively charged *nucleus* round which a number of negatively charged *electrons* revolve. In their normal state, these charges balance each other and the atom is electrically neutral. Due to the action of some agency such as cosmic radiation received from outer space, a very small proportion of electrons become temporarily detached from their parent atoms. These electrons quickly recombine with nuclei, but others are constantly being formed so that some free ions are always present.

If a voltage is applied to the ends of the tube, the detached electrons (negative ions) will drift towards the positive pole of the battery, while the atoms which are lacking an electron (and therefore are positively charged ions) will drift towards the negative pole. This drift constitutes a flow of current, but at low voltages the current will be so microscopic that it can be ignored.

As the voltage is raised the ions gather more speed, and when they strike atoms in their path, as they are bound to do from time to time, the collision becomes more violent. Below a certain critical voltage, these collisions are elastic and the atoms and electrons rebound in the same manner as billiard balls; but when a critical voltage is reached, the force of collision is sufficient to displace an electron from the bombarded atom and force it temporarily into an unnatural orbit. In this condition, the gas is said to be "excited" (see page 14) and may emit visible light of a colour characteristic of the gas.

It is impracticable to control the voltage applied to the lamp so that this critical stage is reached but not passed. One of the electrons, for instance, may have been unusually fortunate in avoiding collisions and will have travelled an abnormal distance, accelerating all the time, before it eventu-

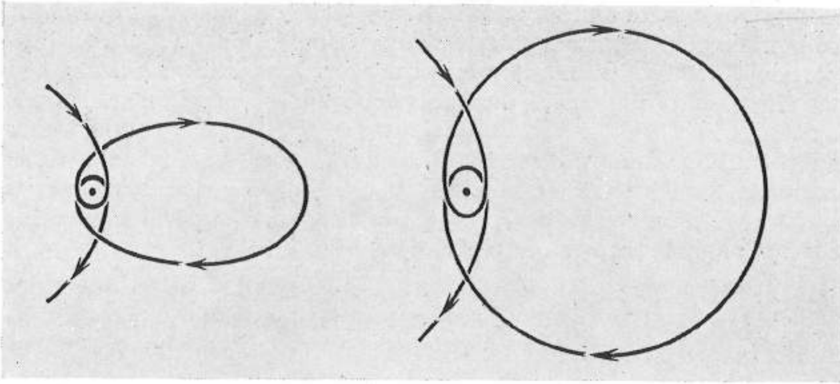


Fig. 8. Simplified diagram of a sodium atom showing the orbit of an electron. LEFT: In the normal state. RIGHT: In the first excited state

ally strikes an atom with a force sufficient not only to displace an electron from its normal orbit but to expel it altogether. When this happens the displaced electron and the atom minus its electron start to move under the influence of the voltage, each making more collisions which may form new ions every time, and so on with snowball effect.

In this state the gas is said to be *ionised*, and it will be apparent that the current now tends to grow of its own accord, and unless it can be controlled will eventually reach such a value that the tube will burst. Also, it will be seen that a higher voltage is necessary to ionise the gas and start an appreciable current flow than to keep it flowing once started. On A.C. supplies an inductance of one form or another is normally employed to limit the current and provide the correct lamp wattage. In a few cases, resistances are used, but these consume more power than an inductance (choke or transformer). On D.C. supplies a resistance must be used.

Discharge lamps which operate normally with a low internal pressure will "strike up" immediately the circuit switch is closed, but the lamps which build up a considerable internal pressure when alight (e.g. high-pressure mercury lamps) cannot re-strike after being switched off until the lamp cools and the pressure falls. The chief reason for this is that when under pressure the atoms comprising the gas or vapour filling are packed tightly together and electrons therefore only travel a comparatively short distance before a collision occurs. In these short distances they do not attain enough speed to cause an ionising collision, but as the vapour cools and the pressure falls, the atoms become more widely spaced, giving the electrons more room to generate the necessary speed.

Variation of the pressure within the tube will not alter the wavelengths at which radiation takes place but it will have the effect of increasing the strength of radiation at some wavelengths while reducing it at others. It so happens that as the pressure of mercury lamps is raised, a greater proportion of the total radiation takes place within the visible spectrum, and the alteration of the relative strengths of the individual visible radiations makes the light whiter; thus we obtain greater light efficiency and a whiter light, both desirable objectives. But at high pressures the ultra-violet radiation, though present, is relatively subdued, and if we require quantities of ultra-violet for any purpose, we use a low pressure lamp which generates U.V. strongly but is weak in visible light.

A discharge in sodium vapour, on the other hand, gives most visible light at low pressure, and there would be no luminous advantage in raising sodium lamp pressures because the efficiency would actually decrease.

To be suitable for use in a discharge lamp, a gas or vapour must have the following characteristics :—

(1) At practicable pressures it must emit a reasonable proportion of its energy within the visible spectrum (or in the U.V. spectrum when fluorescent effects are desired).

(2) It must give a colour of light (or wavelength of U.V.) acceptable for the purpose in view.

(3) It must not subject the glass or metal parts of the lamp to chemical attack.

(4) It must not "clean-up" i.e. disappear from the core of the tube through being trapped against the glass walls by evaporated material from the electrodes.

(5) It must not decompose under the action of the discharge.

(6) The voltage necessary both to start and to maintain the discharge should preferably be low.

(7) In the case of a vapour, the vapour pressure must be appreciable at temperatures below the softening point of the bulb.

These requirements leave us with a number of possible gases and vapours from which to choose.

Gases	*Colour of Light*
Neon	red.
Hydrogen	pink.
Helium	ivory.
Nitrogen	buff.
Carbon dioxide	daylight white.
Argon Krypton Xenon	not generally used alone but usually in conjunction with other gases or vapours.

Vapours	*Colour of Light*
Mercury ...	blue to white according to pressure.
Sodium ...	yellow.
Cadmium	greenish blue.
Zinc ...	greenish blue.
Thallium	green.
Magnesium	grass green.

It would seem attractive to mix, say, mercury, neon and sodium within a single discharge tube and thus blend the colours of the individual discharges (blue-green; red; yellow, respectively) in suitable proportions to give a more or less white light. Unfortunately, this cannot be done in practice as the radiation from the gas or vapour having the lowest critical voltage (page 18) becomes strongly predominant.

Luminescence

Luminescence is the collective term used to denote the emission of light other than the temperature radiation of a hot body such as a lamp filament. It may be caused either by electrical emission, chemical reaction, living organisms or by the action of light or some similar radiation.

A luminescent body may be either (1) *Phosphorescent* or (2) *Fluorescent*.

(1) *Phosphorescence*. Certain substances, while activated by light or similar radiation, absorb some of the light energy thus reaching them and release it again both during activation and subsequently over a considerable period of time. This property may be useful for reducing "flicker" from some types of lamp working on A.C. supply.

(2) *Fluorescence*. A fluorescent material also absorbs some of the energy reaching it but re-emits some of this energy in the form of light only during the time it is exposed to the exciting radiation. Fluorescent materials obey the following rules:

(*a*) Each fluorescent substance is only stimulated by exciting rays lying within definite limits of wavelength, depending on the substance in question.

(*b*) The spectrum of the emitted fluorescent light is continuous over a definite band of wavelengths, whether the exciting rays have a continuous or discontinuous spectrum.

(*c*) If fluorescence occurs the colour of the emitted fluorescent light is independent of the nature or wavelength of the exciting rays.

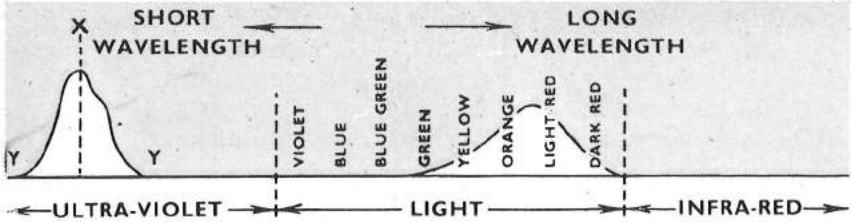


Fig. 9. A particular fluorescent material will respond to any radiation in the ultra-violet waveband YY, but most strongly if the stimulus is concentrated at X. Whatever the wavelength of the stimulating radiation, the fluorescent light will remain the same colour

(*d*) Over a wide range the amount of fluorescent light emitted is proportional to the strength of the exciting rays, e.g. twice the stimulation will give twice the effect.

(*e*) The emitted fluorescent light is of longer wavelength than the exciting rays (Stokes Law. This is not strictly true in all cases but is generally borne out in practice).

In fact the mechanism of fluorescence may be likened to that of an ordinary step-up transformer, but in this case wavelengths are transformed instead of voltages (Fig. 9). The strength of the emitted light will in each case depend both on the strength of the exciting rays and on how closely their wavelength(s) correspond to that of the peak of the absorption band.

Fluorescent lamps used in lighting practice may be conveniently divided into two main groups:—

(1) Those in which the fluorescent material is excited by long wavelength U.V., i.e. of the order of 3000–4000 Å. These materials are employed outside the discharge tube itself—either on the inside surface of the outer glass envelope of the lamp, or are incorporated in the paints, etc., used for decorating a surface to be irradiated by a "black" lamp. (Page 85.)

Most organic substances fluoresce to some extent, but deliberate fluorescent effects can be most strongly produced by using activated inorganic materials (i.e. materials containing a minute trace of a metallic "impurity" such as manganese. Zinc sulphide, for instance, will fluoresce in all colours from blue to red depending on the activator employed.

(2) Those in which the fluorescent powder is excited by short wave U.V., i.e. below 3000 Å. Since the arc tube of such a lamp is at a low temperature, fluorescent powders are chosen which are most resistant to chemical attack by the ionised mercury vapour and they

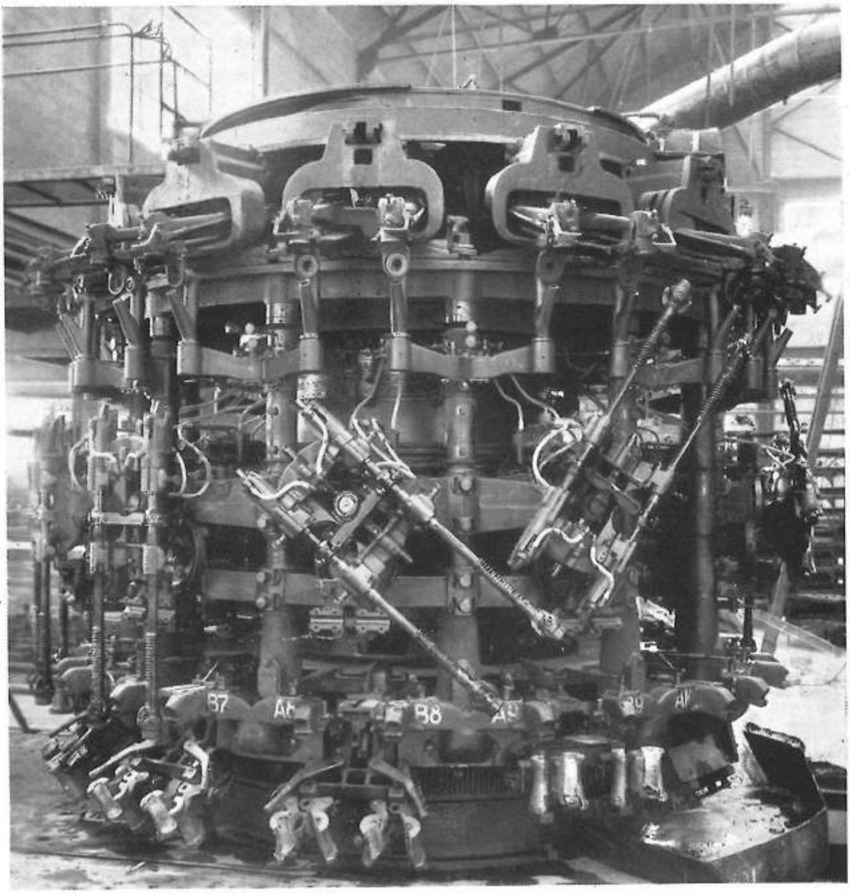
are then placed inside the actual discharge tube. The fluorescent materials which absorb the U.V. and the glass walls which are opaque to U.V. of these wavelengths thus form a double barrier against the passage of dangerous radiations, and lamps designed for ordinary lighting purposes are perfectly safe to use.

Typical fluorescent substances in this class are:—

Cadmium Phosphate, Chlorophosphate or Borate	Red
Zinc Beryllium Silicate	Orange or Yellow
Zinc Silicate	Green
Magnesium Tungstate	Blue
Uranium Dioxide (dissolved in glass) ...	Green or Canary
Calcium Halophosphate	White and near-White

By mixing these and other preparations in suitable proportions it is technically possible to obtain a very wide range of colours of fluorescent light.

As far as E.L.M.A. members are concerned, the Zinc Beryllium Silicate powders have been abandoned for general use for a long while in favour of the Halophosphates.



A Westlake machine capable of blowing 100,000 identical lamp bulbs per day

MODERN LAMP MAKING

THE MAJORITY OF ELECTRIC LAMPS for general use are mass-produced by machines expressly designed for the purpose, and by operatives specially trained in his or her particular process, working in a building exactly adapted to accommodate the flow and storage of the raw materials and finished goods.

At one time, some years ago, the term "mass-produced" had come to be almost synonymous with "cheap and nasty", probably because a mass-produced article has no individuality, each being indistinguishable from its neighbour. This characteristic may be very undesirable for articles of a personal nature, but it is exactly what is required of articles of general utility such as electric lamps which must be interchangeable, are required in vast numbers, and must be at a price within the reach of all.

Many tens of millions of electric lamps are needed in the British Isles every year. Were the most popular types to be made by hand, not only would the performance of individual lamps vary far more than would be acceptable to critical users, but the supply would fall far short of the demand. To give a single instance, a skilled operator working by hand can seal the filament into a lamp bulb at a rate of about 20 per hour, but each machine at present used can perform this operation about 1000 times per hour as only part of its duty.

Skilled craftsmen can—and for certain types of lamps, do—make good lamps by hand in small numbers, but if the demand justifies their use machines under proper supervision and control can produce far larger quantities of better and more uniform lamps at a cheaper rate, depending partly on the extent to which they can be concentrated entirely on one particular product. In the ideal mass production plant, only one absolutely standardised article is made, but in the case of electric lamps there is an obvious need for various sizes and types to cater for different requirements. and for various voltage ratings to suit the voltage of the electric supply in all districts.

A plant designed to produce ordinary lamps for general lighting service at voltages between 200 and 260 v., in sizes from 15–100 watts and in two bulb finishes therefore has to deal with not only one, but with eighty-four different types of product—and that still leaves out of consideration all voltages below 200 v., all wattages above 100 w., and all special markings or caps that may be demanded by customers. Small wonder then that the lamp manufacturers would welcome standardisation of supply voltage throughout the country, and that when approached to make a dozen or two of yet another style or type of lamp their attitude is likely to be "Yes, if we must, but we would greatly prefer you to make do with a standard type"; for a non-standard lamp is not only relatively expensive in itself but also tends to force up the price of the regular article.

GLASS MAKING

Many of the glass parts of a lamp run at high temperatures, and it is important that under these conditions strains are not set up, causing cracking or fracture of these glass parts. The glass must therefore be of high quality manufacture; but since molten glass attacks and tends to absorb most things with which it comes into contact, this entails very careful control of the entire process of glass making, including apparently unimportant details such as the composition of the fire-blocks forming the sides of the melting and mixing tanks. Commercial quality glass is by no means good enough for lamps.

A number of those shapes and sizes of bulb not in very great demand are still blown in the time-honoured way by skilled craftsmen, but all bulbs for the popular sizes of filament lamps for general lighting service are blown automatically by machines which can each produce some 100,000 identical bulbs per day continuously for as long as may be required. The full potential output of a few such machines is so far ahead of present-day demand that the sensible and obvious course is adopted—the associated manufacturers draw their bulb supplies from a central pool instead of each having to buy costly machines and run them intermittently (and therefore uneconomically).

These machines draw a measured quantity of glass from the furnace, blow it to shape and give it a high polish, after which the bulbs are annealed to relieve strain and the rough edges of the neck are trimmed. Then, if they are to be pearl lamps, they are internally sprayed twice with hydrofluoric acid, the first treatment etching the glass and leaving it with a rough inside surface which breaks up the light rays and diffuses the light, and the second treatment re-toughening the glass which has been made brittle by the etching.

The various sizes of glass rod and tube used are produced by machines, but the accuracy with which a desired diameter of tube can be made is at present not nearly so great as in the case of metal products. Therefore the rod and tube are gauged into batches of the desired diameters for use on the various lamp-making machines, which are then adjusted to accept the materials available.

The type of glass suitable for filament lamps may be entirely unsuitable for parts of electric discharge lamps in which gases or metallic vapours are contained at high temperatures. Sodium vapour, for instance, attacks ordinary glass and therefore the discharge tubes of sodium lamps have to be constructed of sodium-resistant glass. In many types of mercury discharge lamp the energy of discharge is concentrated in a small tube which attains a temperature too great for ordinary glass to withstand, and quartz or special heat-resisting glass has to be used instead. Special envelopes are also necessarily employed where it is required to permit the passage of certain wavelengths of ultra-violet radiation, to which ordinary glass is opaque, or nearly so.

In addition to the problem of producing the right kind of glass in the right size, there is also the problem, dealt with in LEAD-IN WIRES (p. 31),

of sealing into the glass the various current-carrying leads and supports necessary for the proper functioning of the lamp.

FILAMENT MANUFACTURE

The production of practically pure tungsten metal from the ore *wolfram* necessitates a long and complicated chemical treatment with which it would be out of place to deal here, but the process eventually produces a fine grey metallic tungsten powder over 99·9 per cent. pure.

In the first decade of this century much difficulty was experienced in making this powder cohere so that a filament could be formed from it, but in 1909 a method of treatment was devised by which it was rendered ductile and could be drawn through dies to the required diameter. This method, which is still used, may be outlined as follows:—

The tungsten powder is placed in a mould some 16 ins. long by $\frac{3}{8}$ in. square section, and is subjected to hydraulic pressure of many tons per square inch. This makes the powder stick together sufficiently to permit careful handling (in the same manner as foundry sand can be moulded). A very heavy electric current is then passed through it for a few moments in an atmosphere of hydrogen, having the effect of fusing the various particles together to form a more or less solid bar. The "sintered" bar is then put into a furnace and when hot is beaten on all sides ("swaged") by a series of rotating hammers so that it gradually becomes thinner and longer until it has reached such dimensions that it can be handled by wire-drawing machinery. In the final stages it is drawn through a series of diamond dies of diminishing size until the required diameter is reached, by which time the original 16-in. "slug" has been extended to a length of several miles.

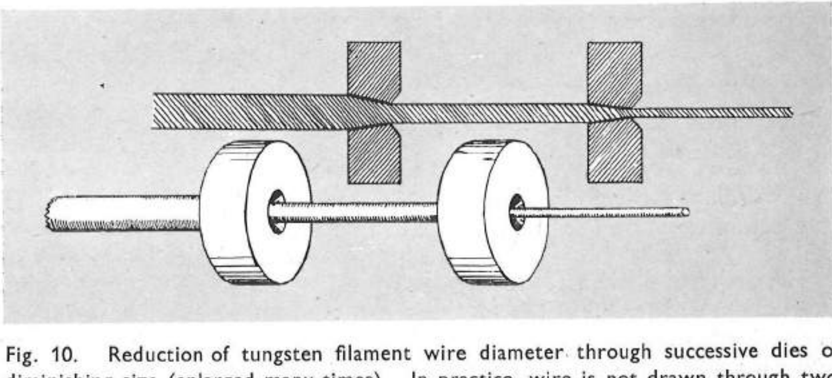


Fig. 10. Reduction of tungsten filament wire diameter through successive dies of diminishing size (enlarged many times). In practice, wire is not drawn through two dies simultaneously

The extreme accuracy required in filament manufacture may be illustrated by a few figures.

The filament of most types of lamp is formed into a single coil or coiled coil which must maintain its strength and rigidity even when heated to temperatures exceeding 2500° C. This requires, among other things, very careful control of the grain size of the original tungsten powder, the bulk of which should have a diameter varying between one and two thousandths of a millimetre, but if there is too great a proportion of the smaller sizes the wire will be unsatisfactory. Samples of every batch of powder must therefore be taken, the actual grain sizes measured and the size distribution discovered, for which photomicrography and subsequent projection on to a screen are used.

Filaments for the sizes of lamps most commonly used range from 0·0006 to 0·002 in. in diameter, and if lamps are to have the long and uniform life the user now has a right to expect from them, the filaments must be very accurately round and must not have local variations in diameter as great as 1 per cent., i.e. a variation of only ten millionths of an inch will not be permissible in some cases.

Not only must filament wire have a uniform diameter throughout its length, but the dies are required to produce wire of the same diameter regularly over long periods of time. Dies for the smallest filaments (15 w. high voltage) must therefore be maintained perfectly round and with a size tolerance not exceeding 2 per cent.; even then it is the practice in highest quality manufacture to make adjustments, in later stages of filament coiling, for those filaments whose diameter is near the upper or lower limit of tolerance.

FILAMENT COILING

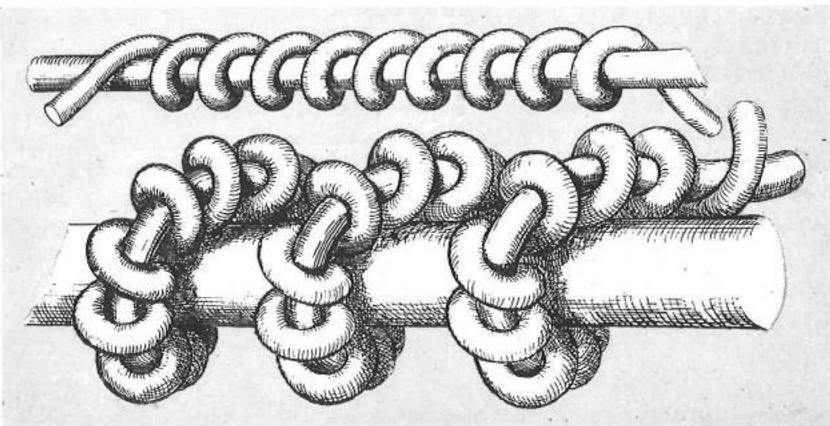
The internal diameter of coiled filaments must be very accurately controlled. It is found that the diameter of the mandrel on which the filament is coiled is most exactly determined by weighing a known length, and therefore precise knowledge of the density of the material is necessary. So also is knowledge of its hardness, for a filament helix which cuts into the mandrel would be shorter than one which did not. Accuracy in mandrel diameter is no less important than filament diameter, since it has as great an effect on the performance of the lamp.

The designed distance between adjacent turns of a coiled filament varies from about 0·3 to 0·6 of the wire diameter, and the permissible variation in spacing is only of the order of 1 per cent., i.e. about 5 millionths of an inch for a 40 w. high voltage lamp. It will be readily understood, therefore, that in the filament coiling machine both the tension of the filament wire

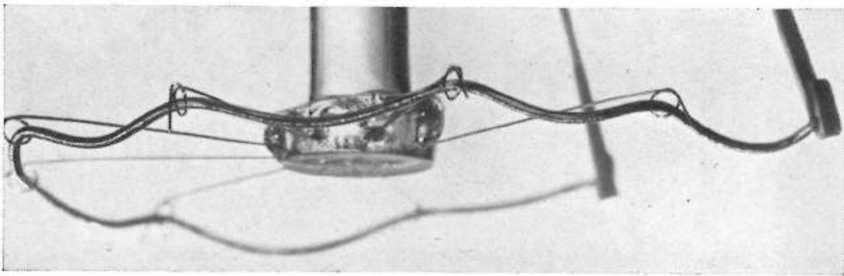
Magnified view of a filament coil which has become distorted in use. A similar degree of non-uniformity in a filament coil to be mounted in a new lamp would ensure immediate rejection

as it is wound on the mandrel, and the speed with which the mandrel moves along must be kept absolutely constant, otherwise relatively wide variations in the pitch of the coiling may result. Even a slight excess of hardness in one tooth of a gear-wheel will result in erratic running sufficiently serious to make the difference between a satisfactory filament coil and an unsatisfactory one.

When coiled-coil filaments are required, the primary coil together with the mandrel on which it is wound is coiled round another and larger mandrel about twice the diameter of the primary coil. Both mandrels are subsequently removed by dissolving in acid after the filament has been cut into suitable lengths. The care with which the highly complicated but unsupported double spiral must be handled will be appreciated when it is realised that though the individual turns of either coil are far too small to be distinguished by the naked eye, yet microscopically small displacement



TOP: Primary coil wound round the mandrel. BOTTOM: Primary coil and mandrel wound round a secondary mandrel to form a cored coiled-coil. The cores are subsequently dissolved



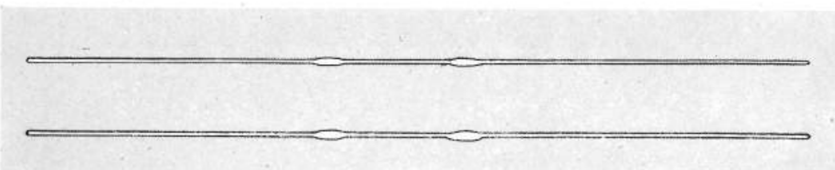
With the lamp in the cap-up position, the filament lies on the single-wire portion of the support loops

which might make one turn touch its neighbour must be avoided, otherwise the effective length of the filament will be reduced and the lamp will be over-run and therefore fail early.

Both before and after the mandrel has been cut and dissolved, the filament coils are subjected to a heat treatment to prevent excessive sag and movement of the filament during the life of the lamp. The coils are fed into a furnace through which hydrogen is flowing and the temperature attained may be up to 1800° C. depending on the type of coil being produced. This operation requires careful control, as excessive heat treatment will cause the filaments to become undesirably brittle.

FILAMENT SUPPORTS

The molybdenum wires which support the filament within the lamp have some effect on its performance. A sufficient number of supports must be provided to prevent the filament from sagging when very hot, for sagging would stretch and open out the coil and result in a reduction of light output. On the other hand, each support acts as a conductor drawing away heat, therefore too many of them would cool the filament and again result in a loss of light. Thus there is a tendency to reduce the number of supports as chemists and physicists produce tungsten wire more able to retain its shape at high temperatures.



Lead-in wires. The centre part, between welds, is made of composite wire round which the glass is pressed to form an air-tight seal

Even the shape of the support loops through which the filament runs is important. Loops must be almost closed in order to retain the filament whichever way up the lamp is burned, but filament lamps for ordinary lighting service are designed to be burned cap-up. The loops are therefore so arranged that when burned in the cap-up position the filament rests only on the single-wire portion of each loop. When the lamp is turned on its side or upside down, part or parts of the filament must come in contact with the double-wire part of the loop, thus short-circuiting one or more sections of filament and somewhat reducing lamp life.

LEAD-IN WIRES

Where the lead-in wires, which carry the current from the outside to the inside of the lamp, pass through the glass they must make a completely airtight seal at all temperatures. They must therefore have the property of being wetted by the molten glass and must also have the same coefficient of expansion with temperature as the glass, for otherwise when heated they would either burst the glass seal, or would expand less than the glass, leaving a small gap through which air could pass. Platinum has this characteristic and was, in fact, used for this purpose in early lamps, but its very high price prevents its continued use.

No other single metal has the required physical and electrical characteristics and a composite wire has to be made up. This generally consists of nickel-iron wire with a copper sheath, the proportions of the metals being so arranged that when drawn to the required size the overall coefficient of expansion equals that of glass.

Economic considerations demand that this composite wire be kept short, and the length is usually limited to that of the glass "pinch". Inside the lamp the wires connected to the filament are usually nickel, while the connection to the cap is a copper wire. Thus from the cap to the filament there is a "3-part" lead (copper—composite wire—nickel) and these wires are fabricated on automatic machines which cut the components into desired lengths, and hold the pieces for a short interval in hydrogen flames where the welds are made. The same machine also flattens the end of the nickel wire, and turns it over in the form of a small hook, ready for receiving the end of the filament.

When a coiled-coil lamp fails through filament breakage whilst alight there is a possibility of the gas filling becoming ionised and therefore capable of carrying a large current sufficient to shatter the lamp. In order to avoid this a fuse, so designed that it will blow immediately ionisation occurs, is incorporated in the lead-in wires, thus avoiding lamp breakage and replacement of circuit fuses. The automatic machines which fabricate the lead-in wires also seal the fuse into a short length of glass tube for protection.

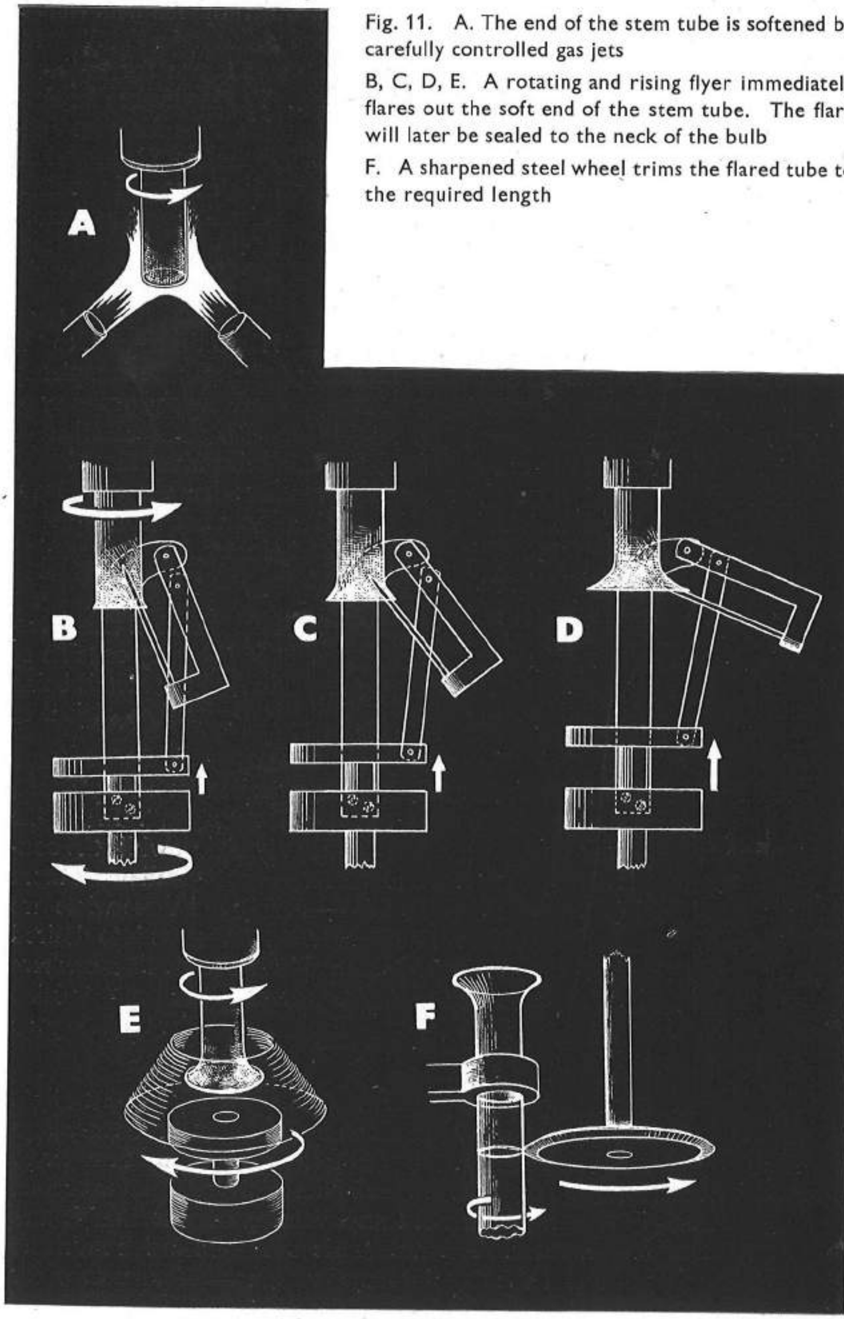


Fig. 11. A. The end of the stem tube is softened by carefully controlled gas jets

B, C, D, E. A rotating and rising flyer immediately flares out the soft end of the stem tube. The flare will later be sealed to the neck of the bulb

F. A sharpened steel wheel trims the flared tube to the required length

STEM MAKING

The next step is the manufacture of the "stem", or glass and lead-in wire assembly on which the filament will be mounted. The stem consists of four parts: (1) a glass stem tube, one end of which is flared out to form a surface for sealing to the glass bulb, (2) a glass exhaust tube through which, after sealing, the lamp is first evacuated and then filled with the appropriate gas, (3) a glass rod or cane, which will carry the molybdenum filament supports, and (4) the lead-in wires.

These four components are fed automatically from hoppers into a machine which heats the stem tube until it collapses around the lead-in wires, and a small clamp completes the airtight pinch. At the same time, the ends of the exhaust tube and cane are heated and welded to the stem tube, and a puff of air is forced through the exhaust tube to blow a hole in the side of the "pinch" to form a connecting passage between the exhaust tube and the interior of the bulb.

FILAMENT MOUNTING

This operation is also performed automatically. The filaments are laid out on a tray from which they are picked up one at a time by a vacuum chuck and fed into the loops of the lead-in wires where they are clamped into

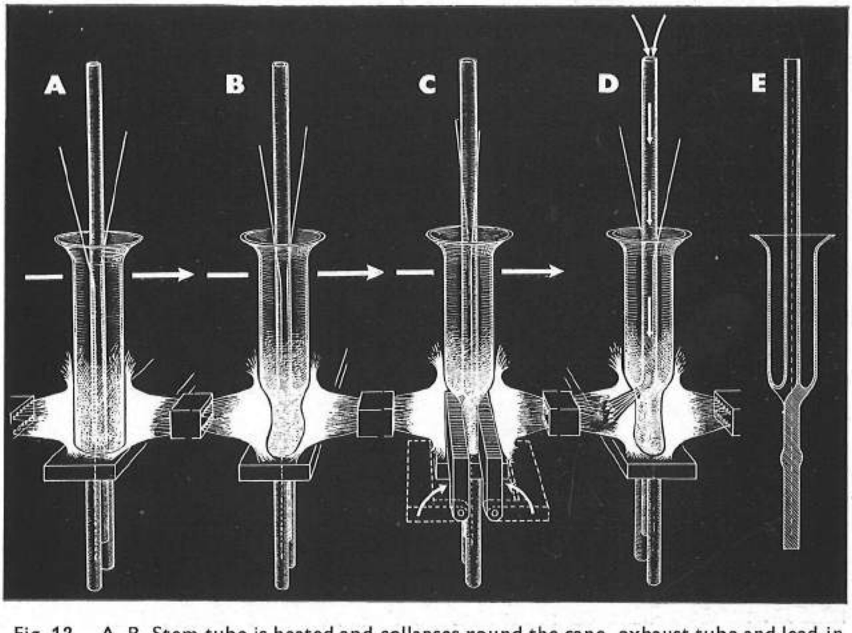


Fig. 12. A, B. Stem tube is heated and collapses round the cane, exhaust tube and lead-in wires. C. Clamp completes the seal at the "pinch". D. Air is blown through the exhaust tube to clear a passage as at E

place. On the same machine the end of the glass cane is softened, the molybdenum filament supports inserted, and their ends wrapped round the filament.

SEALING

The mounted stem is fed up the neck of a glass bulb, and gas jets adjusted to fuse the flared end of the stem tube to the bulb neck. Careful adjustment of jets is necessary to prevent excessive strain in the glass.

PUMPING

Both vacuum and gasfilled lamps must have the air extracted from the bulb to leave the highest commercially obtainable vacuum, for any trace of

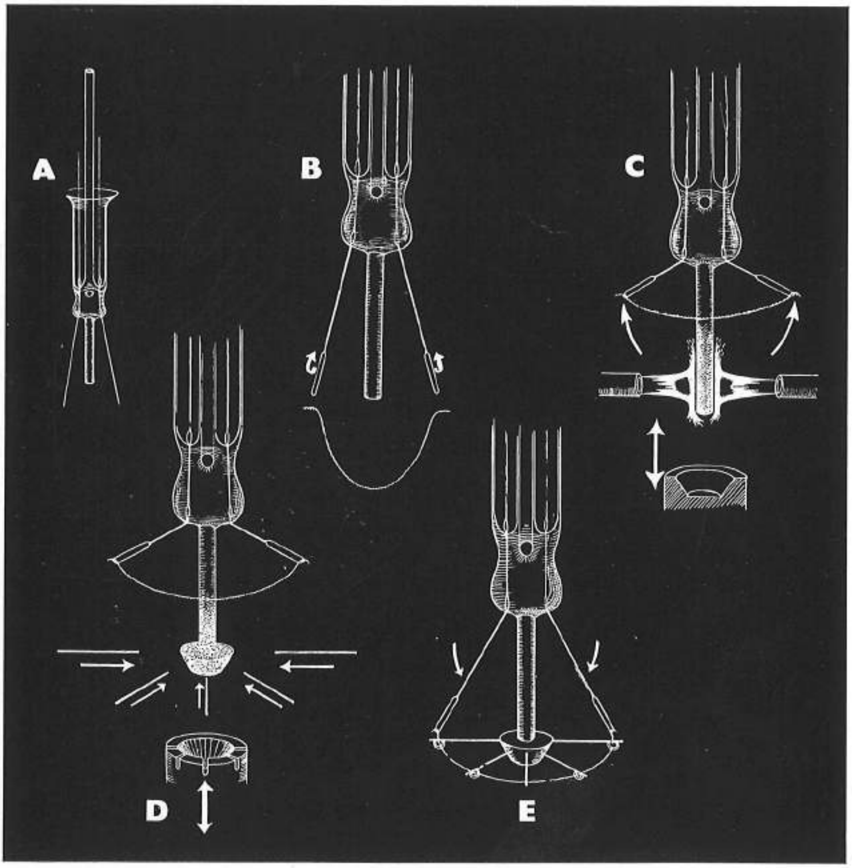
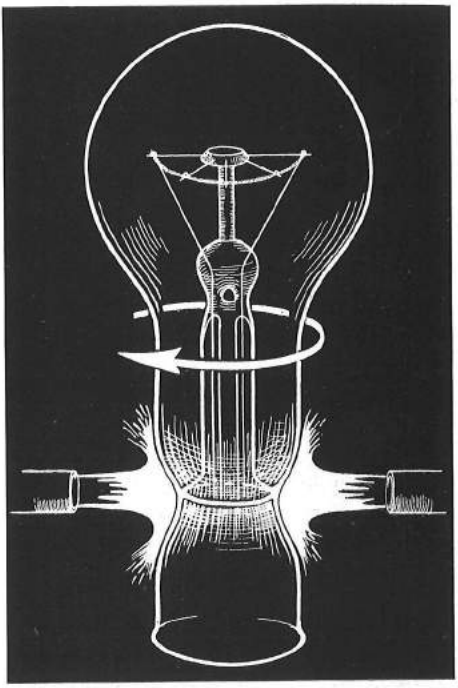


Fig. 13. A. Stem. B. Formation of filament clamps. C. Filament clamped at ends. Cane heated and formed to shape. D, E. Supports inserted and looped round filament

Fig. 14. Welding the flared end of the stem tube to the neck of the bulb. The part below the weld is later trimmed off



oxygen remaining in the bulb would combine with the incandescent filament and the tungstic oxide so formed would volatilise on to the bulb, causing a yellowish white deposit. Pumps commonly used for this purpose are in continuous use and produce bulb pressures of the order of $\frac{1}{100000}$ millimetre of mercury.

Even such a high degree of vacuum does not entirely extract all the undesirable oxygen, which would combine with the tungsten filament, causing it to burn and thus have a short life. In order to eliminate this trace of oxygen, the filament is dipped in a liquid containing finely divided phosphorus in suspension. This phosphorus remains on the filament until after the lamp has been exhausted; the lamp is then lit up and the phosphorus burns in the oxygen which is present, effectively removing it.

Gasfilled lamps for general lighting service are filled with an argon-nitrogen mixture immediately after they have been exhausted of air. One of the major requirements of this gas is that it should be ultra-dry, for if a single drop of moisture found its way into a container large enough to fill half a million lamps all of them would fail early.

The lamps are fed into a heated tunnel to drive out occluded gases and moisture from the lamp. Whilst still in the tunnel, lamps are evacuated, flushed out with gas, and re-evacuated. They are then cooled as quickly as possible and filled with the appropriate gas. It is essential to cool as much as possible before filling in order to obtain as high a pressure of gas in the bulb as possible (about 600 mm.). After filling, the exhaust tube is sealed off in a small flame.

The quality of gas filling is assessed by passing a high-frequency discharge through the lamp, the colour of the resultant glow indicating the presence or absence of impurities.

CAPPING

The cementing of the cap to the bulb is a minor mechanical operation, but if faulty, can cause a great deal of annoyance and danger. When new, the cement must withstand a torsion test of 25 or 45 lb. ins., depending on the type of cap used, and must retain a firm joint between the glass and brass despite continual rapid heating and cooling when the lamp is in use, and also when used in high temperatures which may be encountered in ordinary practice, as in a boiler room. A system by which the cap is mechanically fixed to the glass without the aid of cement has been developed for some lamps operating at high temperature; projections in the cap interlock with recesses in the glass seal, and once fitted the cap cannot be removed without breaking the glass.

In general, projector type filament lamps are required to operate with the plane of the filament exactly at right angles to the line of projection. In order to save trouble when renewing a lamp, and to ensure that the lamp is inserted in its correct position even when replaced by unskilled labour, a prefocus cap is often used.

STATISTICAL CONTROL

Statistical methods of quality control are fully employed in a first-class lamp factory. At all stages in manufacture, samples of the product are constantly being removed for test and analysis, so that an up-to-date record of the precision attained throughout the works is under constant review. Statistical analysis of these results also shows whether the individual samples are closely grouped round the designed target figure, or whether they are beginning to spread, indicating an undesirable loss of control at some stage. Further, constant analysis of the results gives early warning of a tendency to develop a "drift" in one direction or the other, i.e. filament grain size, or coil pitch, or some other essential detail may be tending to increase or decrease, though still well within the limits of tolerance, and early knowledge of this tendency, coupled with long experience which indicates the probable root of the trouble enables it to be corrected before it has developed to such an extent that the finished product may have to be rejected. This continual testing is of course somewhat expensive, but is fully justifiable since it is the only possible method of guaranteeing satisfactory service when the lamps eventually reach the open market. Users would soon find that a reduction of lamp price made possible by skimped testing routine would be an expensive economy.

GENERAL

Although filament type electric lamps are now so common that they are generally regarded as ordinary everyday articles, it will be appreciated from the foregoing sections that their manufacture requires—or should require—a degree of accuracy and control far higher than most commercial products, since microscopic inaccuracies can make relatively large differences to the performance of finished lamps.

The period of experiment and improvisation in the manufacture of ordinary lamps for general lighting service is now over, though research is still energetic and continuous. After more than sixty years of lamp development, however, the buyer and user of a lamp has a right to expect that it shall perform in a manner not only satisfactory in itself, but also practically identical with that of a similar lamp bought at a different shop on a different date.

Three of the qualities demanded from a good lamp are that it should deliver as much light as possible with the least consumption of current, and for the longest possible time; but the light output and life of lamps are interdependent, e.g. a photoflood lamp is deliberately made to give a great quantity of light for only a few hours, yet its quality may be just as high as that of an ordinary lamp made to give less light for many hundreds of hours. Uniformity of performance is therefore a very important factor in customer satisfaction, and the efforts of lamp manufacturers of repute are constantly directed towards achieving ever greater uniformity of product, whilst at the same time making full use of technical advances which permit the other lamp qualities to be improved.

Even with the best interests of light users at heart, individual manufacturers might come to very different conclusions regarding desirable lamp life and efficiency, and there might therefore be a very wide variation in performance between similar lamps made by X and Y, e.g. both brands might be of first-class quality, but X's might have a life of, say, 1200 hours with an efficiency of 12 lumens per watt, whereas Y's had only half the life with a corresponding increase in efficiency. Thus there is a need for an impartial advisory body to decide a minimum standard of life, efficiency and other qualities which, if adhered to or improved upon, will result in lamp performance satisfactory to the great majority of users.

The British Standards Institution undertakes this work, and the appropriate B.S. Specification (No. 161 for tungsten filament lamps for general lighting service) is the lamp manufacturers' Bible. It can be quite definitely stated that lamps which fail to comply with the *current* specification (and it is revised from time to time as may be justified by conditions) are either of such poor quality or so uncertain in performance that they are no credit to their maker and of very doubtful value to the purchaser; even lamps which just succeed in passing the lower limits of the specification can only be classed as very ordinary, for the best quality lamps are and always have been kept well ahead of the specification in force for the time being.

This would, of course, be an easy matter to arrange if the lamp manufacturers controlled the provisions of the specification, but in fact they do not and cannot. The committee of about twenty people which draws up a specification includes not only representatives of lamp manufacturers but also those of Government departments and large groups of lamp users, such as railways, shipping companies, large industrial and commercial groups, and so on. The Committee has to decide, among other things, what lamp life and efficiency will enable the greatest number of users to obtain their light most economically, and this obviously entails consideration of the average cost of electricity for lighting throughout the country.

MODERN FILAMENT LAMPS

DEVELOPMENT

THOUGH OF CONSIDERABLE HISTORICAL INTEREST, most of the various advances in lamp manufacture from 1878 up to 1911 were of no more than temporary value since they concerned the use of different processes and filament materials, etc., which were themselves rapidly superseded by others. In 1911, however, a satisfactory means of drawing metallic tungsten into a fine wire was invented, and modern lamp development can be said to date from that year.

Though the drawn wire tungsten filament vacuum lamp was a considerable advance on anything that had been commercially produced before, it still had a very limited luminous efficiency if run at a temperature low enough to give a satisfactorily long life. Furthermore, in common with other vacuum lamps, the glass bulb tended to "blacken" after a period of burning, thus obscuring some of the light generated by the filament.

Apart from mechanical fracture, the life of a given filament is dictated by the temperature at which it is run. However much care is taken in manufacture, it is impossible to produce a filament exactly uniform in diameter throughout its length, and there is bound to be a spot somewhere of very slightly less thickness than the remainder. Since every part of the filament is carrying the same current, this thin spot will also become the hottest spot, as the current density here will be at its maximum.

The hot spot is also a weak spot, and the weight of the filament is liable to create a slight tension which pulls out the wire, making it ever thinner and hotter, and so on with snowball effect. "Evaporation" of the filament material also tends to occur at high filament temperatures, i.e. minute particles of filament material are constantly being shot out from the body of the metal, in much the same manner as steam or vapour is given off by simmering water. More of these particles are expelled from the hot spot than from anywhere else, still further reducing its diameter, leading to still greater rate of evaporation, and so on. Thus the effects of tension and evaporation both tend to shorten lamp life, and the higher the average temperature of the filament the more rapidly will the effects become disastrous. In other words, over-running a filament lamp drastically shortens its life, and is not therefore a generally satisfactory method of obtaining more light.

The rate of evaporation of the filament, however, is dependent on the external pressure exerted on it (cf. water under pressure has a higher boiling point than when in vacuo). In the vacuum lamp the pressure on the filament is zero, or very nearly so, and the rate of evaporation is at a maximum. If therefore an inert gas, which will not attack the filament or other parts of the lamp, is inserted in the bulb, its pressure should result in a slowing down of the evaporation so that the filament could be designed to run at a rather higher temperature without any ill effects. Nitrogen or argon, or a mixture of the two, are suitable gases to use for general lighting service lamps, since they can be extracted from the air at reasonable cost and have a moderate density sufficient to effect a considerable reduction in filament evaporation. In cases where maximum efficiency is required, and cost is of secondary importance (as, for instance, in miners' cap lamps) krypton gas may be used, as its greater density permits higher filament temperature, but its cost and the difficulty of handling it preclude its use for ordinary lamps at present.

If a vacuum lamp with a "straight" filament formed into the shape of an open cage were to be filled with gas, the wire, though heated by the passage of current through it, would at the same time be cooled by the gas which circulates within the bulb, passing on its heat to the glass walls which dissipate it by radiation or convection. This cooling effect would be so pronounced that the filament barely glowed except near the top of the bulb where the gas is hottest. The principle of gas filling in fact seemed to offer little hope of success.

Examination of the flow of gas round and past a hot wire, however, showed that in contact with the wire was a thin layer of gas which remained almost stationary, and no appreciable gas movement occurred within a very small distance from the wire surface. If the filament is coiled into a very tight spiral, the stationary layers round adjacent coils tend to interlock, denying free passage of the gas through the coil. Heated gas therefore tends to flow round the outside of the filament spiral, which, in effect, becomes a relatively short thick cylinder from the outside surface of which gas can carry away heat. It will be apparent that the cooling surface thus presented to the gas is very much less in area than that of the total length of uncoiled filament, and heat loss to the gas is reduced accordingly, so that equal input wattage will produce higher filament temperature, or equal temperature is reached with less wattage, as may be required.

The relative cooling effect with a closely or loosely coiled spiral is well illustrated by an ordinary electric fire with a damaged heating element. The closely coiled sections run at a high temperature, while sections where the spiral is stretched are comparatively cool.

Gas filling, introduced in 1913, is not necessarily advantageous with all coiled filament lamps. The diameter of the filament is the limiting factor, for with wire of the finest diameter the surface area is so large in comparison with its mass that even close coiling cannot prevent a loss of heat to the gas (i.e. waste of energy) which cannot be counterbalanced by the energy saved by operating the filament at a higher temperature (see page 16) Thus lamps for general lighting service are gas-filled only in sizes from 40 w. upwards (25 w. in the 100–130 v. range) though mass production procedure also requires the smaller sizes to contain coiled filaments.

The "pipless" lamp was produced in 1922. Previously, the lamp was exhausted through a hole in the end of the bulb, which was subsequently sealed by fusing together the edges of the hole to form a small pip, which was not only unsightly but also liable to catch on things and be snapped off. Nowadays the lamp is exhausted and the gas admitted through a hole automatically blown in the "pinch" and a smoothly rounded bulb shape is obtained, improving both the appearance and the handling properties of the lamp.

Coiled coil lamps were first introduced in 1934. The second coiling of the already coiled filament is a logical step to reduce still further the loss of heat to the gas and results in an increase of luminous efficiency ranging up to 20 per cent., but the principle is not applicable to all sizes of gasfilled lamp, for—

(*a*) The filament diameter must be large enough to give the mechanical strength necessary to retain its shape when hot.

(*b*) The gain due to coiled coiling is progressively reduced as filament diameter is increased.

These considerations limit the value of coiled coiling to the 40–100 w. range of lamps for general lighting service, but coiled coil filaments are sometimes used elsewhere, e.g. in projector lamps primarily to reduce filament area.

It should be understood that the increase of light from a coiled coil lamp is not due to a rise in filament temperature. Other things being equal, the reduced loss of heat to the gas would result in the filament becoming hotter, but that cannot be permitted as the lamp life would be shortened. Therefore the filament is made a little longer to put more resistance in circuit and thus bring the temperature back to normal. This, however,

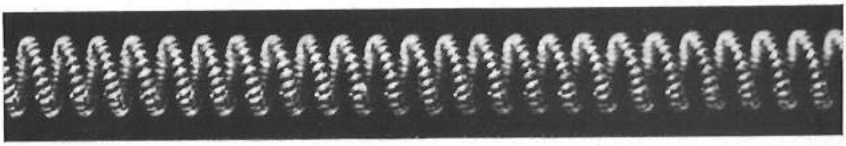


Fig. 15. Micro-photograph of a coiled-coil filament. Note the absolute uniformity of both primary and secondary coils

also reduces the wattage, but as it is desirable to retain the standard range of wattages the filament is also made a little fatter to bring the wattage up to normal. Thus a coiled coil lamp has a slightly longer and fatter filament than a single coil lamp, and the extra light is obtained from the resulting larger area of incandescent surface.

TECHNICAL

GENERAL SERVICE LAMPS

DETAILS OF BULBS

Bulbs for all sizes of lamps used for general lighting service are now usually made from soda lime glass formed by fusing a mixture of soda ash, lime and sand, which can withstand the temperatures normally attained in this class of lamp. Special glasses are used for some other types.

Bulb Finish

General lighting service (G.L.S.) bulbs are normally obtainable in two styles:—

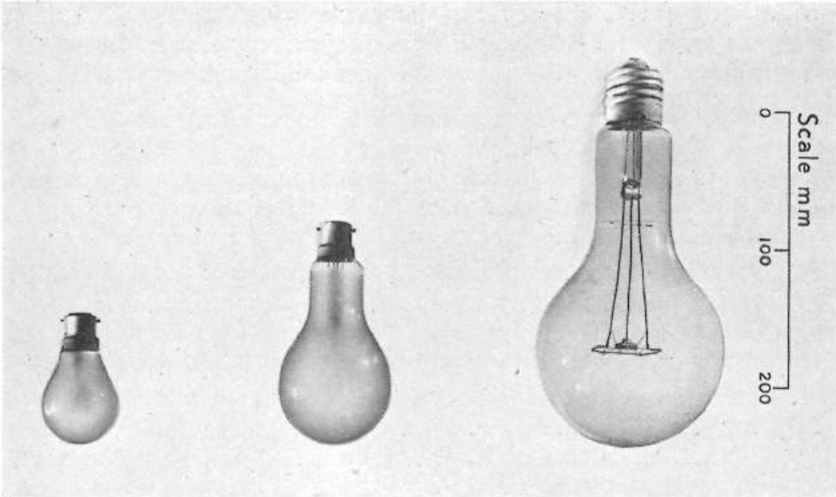
1. Clear glass.
2. "Pearl".

Clear Bulbs

These have a smooth inside and outside surface, and absorb the least possible quantity of light, but do not modify the brilliance of the filament, which can be clearly seen. In sizes below 200 w., where lamps are likely to be mounted below medium height, it is generally preferable to use a pearl bulb in order to reduce glare and eliminate or soften the hard shadow effect received on walls and ceiling caused by the abrupt cut-off of light at certain angles, depending on the nature of the lighting fitting in which the lamp is housed.

Pearl Bulbs

The only difference between the pearl and the clear bulb is that the former undergoes two internal acid-spraying processes to roughen the inside surface of the glass, and thus form countless minute prisms which each refract the light in a different direction, creating a degree of diffusion which conceals the brilliant lamp filament, the light appearing to come from a bright patch on the bulb surface. This diffusion is not accompanied by any appreciable loss of light.



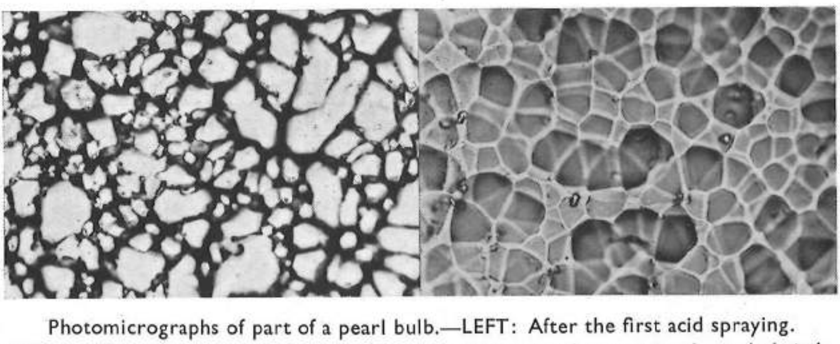
Three representative sizes of G.L.S. lamp; 15, 150 and 500 w. The smallest is a vacuum lamp, the others gasfilled

Pearl lamps have a smooth exterior surface which does not collect dust and dirt. They are standard up to and including 150 w., and can be obtained * in other sizes.

Effect of bulb finish on light control

Precise control of light by optical means can only be obtained from a light source of small effective dimensions. Control by mirror or lens used in conjunction with a clear gasfilled lamp can be sufficiently accurate for everyday purposes, but substitution of a pearl lamp will inevitably broaden the distribution of light and may make the controlling apparatus ineffective.

* Under normal conditions.



Photomicrographs of part of a pearl bulb.—LEFT: After the first acid spraying. RIGHT: After the second acid spraying to re-toughen the glass previously made brittle.

Accurate beam control from clear lamps may cause streaks or striations to appear on a lighted surface; if this is objectionable, pearl lamps will often be found to avoid this effect while maintaining sufficient control.

In designing lighting installations, certain mandatory requirements* concerning the maximum brightness of a light source, and the angle at which a fitting cuts off the direct light from the source, may have to be met. In the latter respect the position of the light source, within the fitting is generally taken as the geometrical centre of the filament for both clear and pearl lamps.

Colouring

The colour of light emitted may be modified by:—

1. *Colour Spray*. A coloured medium is sprayed on to the outside of the bulb. Standard colours include Blue, Green, Amber, Red and White. All colours are available† up to and including 200 w., and White also in larger sizes.
2. *Varnish*. Various colours of heat-resisting varnish may be applied to the bulb, but this treatment is not to be recommended for other than temporary lighting, since the varnish is liable to scratch and peel off.

Absorption of light by colour media

All the above methods of obtaining coloured light depend upon absorption by the media of unwanted colours. This wasteful process necessarily results in a reduction of light output varying in extent with different colours.

The table below gives the approximate transmission factor of the colour media employed, and the relative wattage of colour sprayed lamps that must be installed to give as much light as a clear lamp.

Colour	Approximate transmission factor (per cent.)	Relative wattage required (clear lamp taken as 1)
White	70	1·5
Blue	2·5	40
Green	20	5
Amber	50	2
Red	6	17

* E.g. Factories (Standards of Lighting) Regulations, 1941.

† Under normal conditions.

Bulb Shape

Two main factors control the shape of gasfilled lamp bulbs for G.L.S. lamps:—

1. Good appearance.
2. Adequate cooling of the heated gas without raising the temperature of the glass or cap cement beyond its safe working limit. With the lamp in the pendant position the natural flow of hot gas is such that the solid matter evaporated from the filament is carried up to the neck of the bulb and deposited there, where it has no ill effect. If the lamp is used in other than the pendant position the greatest blackening will appear vertically above the filament, where it may absorb a considerable proportion of the generated light. In larger sizes of lamps a mica disc is inserted in the neck of the bulb to give the "pinch" wires and cap assembly additional protection from heat.

CAPS

The types of cap most commonly used in this country for other than projection purposes are as follows:—

1. Standard Bayonet (B.C.)
2. Small Bayonet (S.B.C.)
3. Goliath Edison Screw (G.E.S.)
4. Edison Screw (E.S.)
5. Small Edison Screw (S.E.S.)
6. Miniature Edison Screw (M.E.S.)

Dimensions of these and other caps will be found on pages 147–8. For general lighting service lamps the caps used are B.C., E.S. and G.E.S.

B.C. caps make lamp replacement and removal easy, and allow lightly loaded spring plungers in B.C. lampholders up to current values of about 1·5 amps. At greater current values the lamp-holder springs may fail owing to overheating, and for the sake of uniformity among the various voltage ranges B.C. caps are fitted as standard to all G.L.S. lamps up to and including the 150 w. size. E.S. caps are fitted to 200 w. lamps. The larger sizes, from 300 w. upwards, are fitted with G.E.S. caps which provide adequate electrical contact surface and are of sufficient diameter to give mechanical support to the large bulb.

The design of the caps, and the method of attachment to the bulbs, enables them to withstand the torsion test specified in British Standards Specification 161, i.e. 25 lb. ins. for B.C. and E.S. caps, and 45 lb. ins. for

G.E.S. caps. The cap cement will safely withstand a working temperature up to 140° C.

The insulation resistance between the current-carrying leads and the shell of a B.C. cap is more than 50 megohms in order to comply with I.E.E. wiring regulations. In the case of E.S. and G.E.S. caps insulation resistance cannot apply as the parts are connected within the lamp, but the design of the lampholder ensures that safety regulations are not contravened.

FILAMENT FORMATION

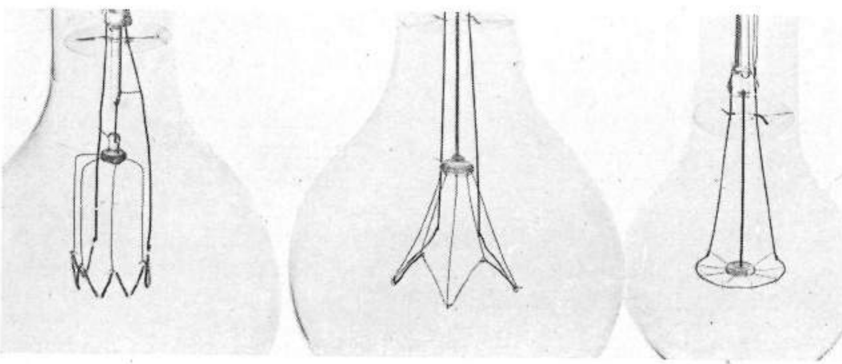
Most G.L.S. lamps have a wreath filament but where the length of filament is too great to be accommodated in one plane, it takes the form of a multiple V or M.

FILAMENT SUPPORTS

In most G.L.S. lamps the filament is welded or clamped at each end to the lead-in wires, which from the "pinch" to the filament are made of copper for vacuum lamps, and nickel for gasfilled lamps.

The central parts of the filament are supported by molybdenum wires inserted into the "stud" at the end of the central glass rod, the other ends of the wires being bent into a hook or loop through which the filament passes. Molybdenum is used because it can withstand the high filament temperature without vaporising, and has sufficient elasticity to absorb shocks.

Each of these wires causes local cooling of the filament and a reduction of light output. The number employed is reduced to a minimum consistent



Filaments used in general service lamps.—LEFT and CENTRE: Multiple V or M. RIGHT: Wreath filament with adequate mechanical support of the filament. The permissible length of filament between supports depends on its strength to resist tension and sagging, and this in turn depends upon the molecular structure and heat treatment of the filament both before and after coiling. The very greatest care is therefore devoted to these matters during filament manufacture.

LUMINOUS OUTPUT

In the table (overleaf) columns 3 to 8 are derived from B.S.S. 161 (1940 edition), whereas columns 9 to 11 give the average lumen output throughout life of normal high-quality pearl or clear lamps. This "average throughout life" figure should be used in designing lighting installations, coupled with a maintenance factor (usually assumed to be 0·8) to allow for depreciation of light output due to deterioration of external transmitting and reflecting media caused by the collection of dust, etc., between normal maintenance operations.

It will be seen from columns 6 to 11 of the table on the next page that normal high-quality lamps consistently give some 6 per cent. more light throughout life than is required by B.S. Specification. If a lower quality lamp, which nevertheless just complied with the Specification, were overrun in order to make it give as much light as the best quality lamp, its life would be reduced by about 20 per cent. and its wattage increased by about 2 per cent.

ELECTRICAL CHARACTERISTICS

Over the normal range of operating voltages likely to be encountered in practice, the properties of gasfilled lamps vary approximately according to the formulae below, the normal value in each case being printed in capitals.

$$\frac{\text{VOLTS}}{\text{volts}} = \left(\frac{\text{LUMENS}}{\text{lumens}}\right)^{0\cdot3} = \left(\frac{\text{WATTS}}{\text{watts}}\right)^{0\cdot7} =$$

$$\left(\frac{\text{LUMENS PER WATT}}{\text{lumens per watt}}\right)^{0\cdot5} = \left(\frac{\text{AMPS}}{\text{amps}}\right)^{2} = \left(\frac{\text{OHMS}}{\text{ohms}}\right)^{2} = \left(\frac{\text{life}}{\text{LIFE}}\right)^{0\cdot075}$$

e.g. To find the current taken by a 230 v. 100 w. lamp burning on a 200 v. supply:

$$\text{Normal current} = \frac{100}{230} = 0\cdot435 \text{ amps.}$$

From the equation above,

$$\frac{\text{VOLTS}}{\text{volts}} = \left(\frac{\text{AMPS}}{\text{amps}}\right)^{2} \text{ or } \frac{230}{200} = \left(\frac{0\cdot435}{\text{amps}}\right)^{2}$$

from which the current may be found to be 0·4 amps. approx. The family of curves given in Fig. 16 enable quick approximations to the various

Watts	Bulb finish (P=Pearl) (C=Clear)	B.S.S. Nominal Initial Output (lumens)			B.S.S. Minimum Average throughout life (lumens)			Normal High-Quality Lamps Average throughout life (lumens)		
		Single-coil 110 v.	Single-coil 230 v.	Coiled-coil 230 v.	Single-coil 110 v.	Single-coil 230 v.	Coiled-coil 230 v.	Single-coil 110 v.	Single-coil 230 v.	Coiled-coil 230 v.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
15	P or C	140*	120*	—	126*	107*	—	133*	113*	—
25	P or C	240	220*	—	215	195*	—	228	206*	—
40	P or C	470	340	415	423	312	367	449	330	389
60	P or C	790	600	700	716	551	627	759	584	665
75	P or C	1060	810	930	944	740	833	1000	785	883
100	P or C	1500	1200	1340	1319	1094	1197	1400	1160	1270
150	C	—	2090	—	—	1857	—	2230	1970	—
200	C	—	2880	—	—	2572	—	3090	2725	—
300	C	—	4690	—	—	4176	—	4950	4430	—
500	C	—	8410	—	—	7485	—	8950	7930	—
750	C	—	13500	—	—	12022	—	14270	12740	—
1000	C	—	18900	—	—	16800	—	19640	17800	—
1500	C	—	30100	—	—	26775	—	30220	28380	—

* Vacuum lamp.

Data in Columns (2) *to* (8) *based on B.S.S.* 161, 1940 *edition.*

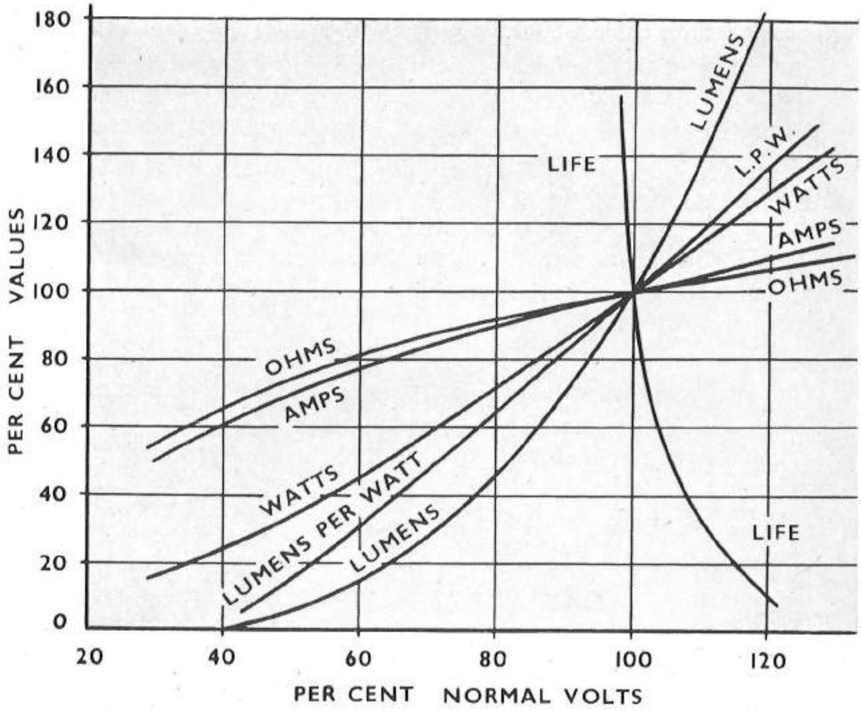


Fig. 16. Family of curves giving a general indication of the characteristics of gasfilled G.L.S. lamps on varying mains voltage

values to be found, but should not be regarded as strictly accurate for any particular class or voltage of lamp.

It should be noted that over-volting a lamp in order to obtain increased efficiency and light output results in seriously shortening lamp life. Conversely, increased lamp life obtained by under-volting results in seriously reduced light output without a corresponding reduction in lamp wattage; in other words, current is being used wastefully and uneconomically. Deliberate over- or under-running of lamps is therefore not to be recommended save in exceptional circumstances and for a specific purpose. Long wiring runs with conductors of inadequate size are a frequent cause of lamps receiving less than their rated voltage.

To give an example: It is desired to replace two 300 w. lamps in an old installation by two 500 w. lamps in the same positions. Lamps are to be burned 1000 hours per annum; supply is at 230 volts; lamps are 180 ft. distant from the switchboard and are connected thereto by 1/0·036 cable (0·001 sq. in. area); current is supplied at £10 per kW. installed plus $\frac{1}{2}$*d.* per unit. Will the existing wiring be satisfactory?

Total length of cable, 360 ft.	
From cable-makers tables, resistance of this length of old cable	$= 2 \cdot 88$ ohms.
Normal current taken by the 500 w. lamps = $\frac{2 \times 500}{230}$	$= 4 \cdot 35$ amps.
Volts drop at lamp caps with old cable = $4 \cdot 35 \times 2 \cdot 88$	$= 12 \cdot 5$ volts.*
Percentage of normal volts remaining at lamp caps = $\frac{230 - 12 \cdot 5}{230}$	$= 94 \cdot 6\%$.
From curves above, wattage of lamps . .	$= 92\%$ of normal.
The consumer also pays for the wattage lost in the old wiring = $12 \cdot 5 \times 4 \cdot 35$ . . .	$= 54$ watts.
Total wattage $\left(\frac{92}{100} \times 2 \times 500\right) + 54$ . .	$= 974$ watts.
Annual cost—£10 + 974 × ½*d.* . . .	= £12 0*s.* 7*d.*
From curves on previous page, light output of lamps	$= 82\%$ of normal.

Re-calculation on similar lines shows that if the old cable were replaced by 3/0·036 cable, the results would be:

Annual cost	£12 1*s.* 7*d.*
Lighting effect	93 % of normal.

It will be seen that, in this instance, retention of the old wiring would result in an apparent saving of one shilling, but at the same time it will be responsible for the loss of some 12 % of the light which would be available with adequate wiring. As the value of the light so lost is over twenty-five shillings the old wiring is too expensive to retain.

Even though a reduced voltage at the lamps will make them last longer, it can be shown that inadequate wiring invariably causes an economic loss. In effect, the lighting user pays more for inadequate wiring than he would have to pay for wiring of the correct size.

LUMEN MAINTENANCE

The initial light output of general service gasfilled lamps is approximately 5 per cent. above the "Average throughout life" figure shown on page 48, and the output at the end of life some 5 per cent. below. Through-

* A slight re-calculation should be made owing to the reduced current taken by the under-run lamps, but it is omitted here to avoid complicating the example. The correct figure is about 12·3 volts.

out life there is thus a steady gradual diminution of light until at the end of 1000 hours the light output is still approximately nine-tenths of the original. Changes in wattage and current taken by the lamp are so small as to be negligible.

The above figures refer only to clean lamps burned in the proper (cap up) position. Burning lamps in other positions will result in interior blackening of the bulb over an area situated vertically above the filament, and the semi-opaque metallic film so formed will reduce light output to a greater extent than when the blackening is in the neck.

The absorption of light by dust and dirt on the lamp is usually greater than one might expect from casual inspection of the bulb. A film of dirt which may not be noticeable on a lighted lamp a short distance away may be causing as much as 20 per cent. loss of light.

LAMP LIFE

Though rigid control of manufacturing processes results in ever-increasing uniformity of life, absolute uniformity is unobtainable. In practice it is found that if lamps are burned at their rated voltage the percentage remaining alight after a given period is approximately as shown in Fig. 17. Failures before 500 hours are uncommon, but from about 700 hours onward they occur at an increasing rate until half the batch is

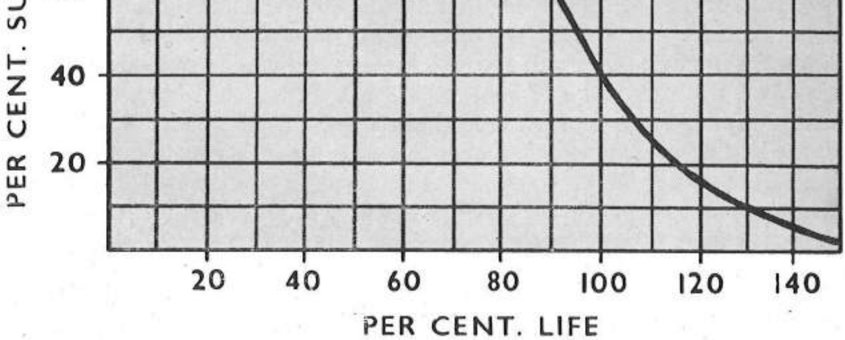


Fig. 17. Survivor curve for G.L.S. lamps run under normal operating conditions at rated voltage. A few fail early, most fail at or around rated life.

burned out. Thereafter failures again become less frequent until there remain a very few with exceptionally long lives. It will be seen that the great majority of lamps burn out close to their rated life of 1000 hours, and the average life of a batch is 1000 hours or slightly longer.

The fact that the only way of ascertaining the life of a particular lamp is to test it to destruction is the reason for responsible manufacturers declining to guarantee the life of any particular lamp. The claim they make, and can substantiate, is that a batch of lamps selected and tested according to the provisions of B.S.S. 161 will pass that test, and that the variation between the lives of individual lamps within the batch will not exceed the specified figure.

A manufacturer who guarantees the life of *each* lamp must either be aware that his lamps have a relatively low efficiency, or believes that the public will not, in general, claim replacements to which they are entitled.

BRIGHTNESS

The brightness of a lamp is a measure of the light emitted per unit projected area of the filament, or of the whole or part of the bulb when a diffusing bulb is used.

The greater the degree of light control desired, the more necessary is it to use a light source of small physical dimensions and consequent high brightness, but extreme lamp brightness is one of the factors contributing to glare and discomfort. In general, the larger sizes of lamps are mounted at considerable heights well out of the normal line of sight, and should not be troublesome in this respect if installed in appropriate reflectors giving a degree of screening or diffusion. The smaller sizes, from 150 w. downwards, are more generally used singly or in groups for domestic and other interiors with limited ceiling height, in which a reduction of brightness of lamp, if visible, or of the fitting makes a disproportionate increase in comfort. Pearl lamps are therefore recommended for almost all such applications, for in addition to reducing brightness the diffusing bulb also softens shadows, avoids streaks of light on the ceiling and elsewhere, and practically eliminates the sharp change in brightness often noticeable on walls at the level where the top of an open diffusing fitting begins to obstruct the light from a clear lamp. Clear lamps are however recommended for those situations where sparkle or glitter is specially required, as for the display of some classes of jewellery, cut glass, etc.

The brightness of clear gasfilled lamps up to 200 w. for general lighting service ranges from about 2500 to 4350 candles/in.^{2}, according to size. In pearl lamps the size and brightness of the apparent luminous patch on the bulb surface varies with the angle of view, but the maximum brightness of the patch may be taken as 40 candles/in.^{2} for the 40 w. lamp, increasing to 130 candles/in.^{2} for the 150 w. lamp.

STANDARD VOLTAGES

Tungsten filament lamps for general lighting service are at present made for the following voltages. Due to abnormal manufacturing difficulties some of the intermediate voltage steps previously covered have had to be abandoned temporarily.

Voltage	Wattage	Voltage	Wattage
25, 35, 50, 55, 60, 65, 75	15, 25, 40, 60, 100	150	As 100–130 v. range, except 75 w.
100, 110, 120, 130	15, 25, 40, 60, 75, 100, 150, 200, 300, 500, 750, 1000, 1500	200, 210, 220, 230, 240, 250, 260	As 100–130 v. range.

STARTING CHARACTERISTICS

At the instant of starting the filament is cold and has a very much lower ohmic resistance than when heated to its normal operating temperature. Thus, momentarily, a relatively large current flows, but is rapidly reduced to normal as the filament heats and its resistance rises.

The proportion of excess current, and time taken to reach stable conditions, depend on the wattage and voltage of the lamp (Fig. 18). As a general rule, the starting current of lamps is up to 14 times the normal running current. The time taken to reach nearly full brightness depends on wattage and type; for example a 230 v. 500 w. gasfilled lamp reaches 90 per cent. of full brightness in $\frac{1}{5}$ second, and a 230 v. 25 w. vacuum lamp in about $\frac{1}{50}$ second.

The momentary excess current persists for too short a time to operate any ordinary circuit breakers or fuses, and is generally ignored by switch manufacturers, since switches are more likely in this instance to fail by repeated *breaking* of a circuit than by *making* a circuit carrying heavier current.

It is commonly supposed that switching on a lamp is relatively expensive in current and is best avoided by leaving a lamp burning continuously instead of switching it on and off when it is only required intermittently. Inspection of the curves above shows this to be a fallacy, especially as repeated switching has a negligible effect on lamp life.

LAMP CURRENT AND RESISTANCE

The table opposite gives the normal current and *hot* lamp resistance of lamps complying exactly with their rated wattage. Current figures (amps.) are printed in bold, resistance (ohms) in *italics*.

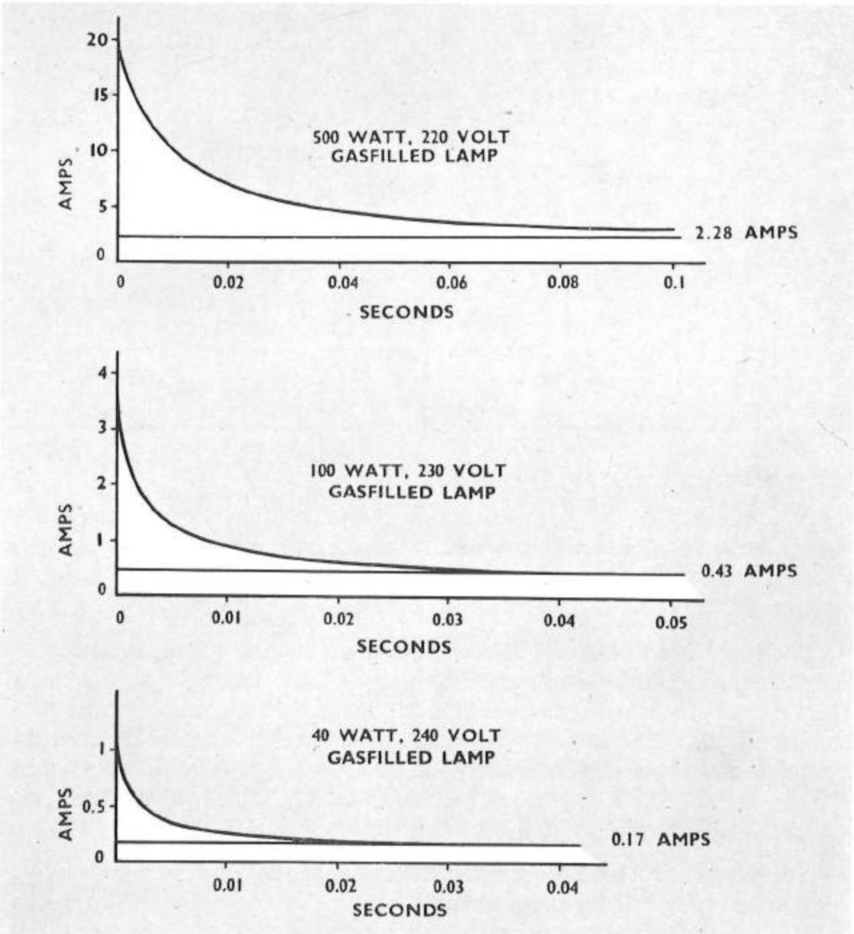


Fig. 18. At the instant of switching on, filament lamps pass excess current for a very brief period while the filament becomes hot

NORMAL **CURRENT**/*Resistance* VALUES OF LIGHTED LAMPS

Rated Watts	RATED LAMP VOLTAGE 100	110	120	130	200	210	220	230	240	250	260
15	**0·15**/*667*	**0·14**/*805*	**0·12**/*962*	**0·11**/*1125*	**0·075**/*2670*	**0·071**/*2950*	**0·068**/*3230*	**0·065**/*3500*	**0·063**/*3830*	**0·06**/*4160*	**0·058**/*4500*
25	**0·25**/*400*	**0·23**/*484*	**0·21**/*576*	**0·19**/*676*	**0·13**/*1600*	**0·12**/*1770*	**0·11**/*1930*	**0·11**/*2110*	**0·1**/*2300*	**0·1**/*2500*	**0·096**/*2700*
40	**0·4**/*250*	**0·36**/*302*	**0·33**/*361*	**0·31**/*422*	**0·2**/*1000*	**0·19**/*1105*	**0·18**/*1210*	**0·17**/*1320*	**0·17**/*1440*	**0·16**/*1560*	**0·15**/*1690*
60	**0·6**/*167*	**0·55**/*201*	**0·5**/*240*	**0·46**/*282*	**0·3**/*667*	**0·29**/*736*	**0·27**/*806*	**0·26**/*881*	**0·25**/*960*	**0·24**/*1040*	**0·23**/*1125*
75	**0·75**/*133*	**0·68**/*161*	**0·62**/*192*	**0·58**/*225*	**0·37**/*533*	**0·36**/*589*	**0·34**/*645*	**0·33**/*706*	**0·31**/*767*	**0·3**/*832*	**0·29**/*900*
100	**1·0**/*100*	**0·91**/*121*	**0·83**/*144*	**0·77**/*169*	**0·5**/*400*	**0·48**/*442*	**0·45**/*484*	**0·43**/*529*	**0·42**/*576*	**0·4**/*625*	**0·38**/*676*
150	**1·5**/*66·7*	**1·36**/*80·5*	**1·25**/*96·2*	**1·15**/*112·5*	**0·75**/*267*	**0·71**/*295*	**0·68**/*323*	**0·65**/*350*	**0·63**/*383*	**0·6**/*416*	**0·58**/*450*
200	**2·0**/*50*	**1·82**/*60·5*	**1·67**/*72*	**1·54**/*84·5*	**1·0**/*200*	**0·95**/*221*	**0·91**/*242*	**0·87**/*264*	**0·84**/*288*	**0·8**/*312*	**0·77**/*338*
300	**3·0**/*33·3*	**2·73**/*40·3*	**2·5**/*48*	**2·31**/*56·4*	**1·5**/*133*	**1·43**/*148*	**1·36**/*161*	**1·3**/*176*	**1·25**/*192*	**1·2**/*208*	**1·15**/*225*
500	**5·0**/*20*	**4·55**/*24·1*	**4·17**/*28·8*	**3·85**/*33·8*	**2·5**/*80*	**2·38**/*88·5*	**2·28**/*96·7*	**2·18**/*106*	**2·08**/*115*	**2·0**/*125*	**1·92**/*135*
750	**7·5**/*13·3*	**6·82**/*16·1*	**6·25**/*19·2*	**5·77**/*22·5*	**3·75**/*53·3*	**3·57**/*58·9*	**3·41**/*64·5*	**3·26**/*70·6*	**3·12**/*76·7*	**3·0**/*83·2*	**2·88**/*90*
1000	**10**/*10*	**9·09**/*12·1*	**8·34**/*14·4*	**7·69**/*16·9*	**5·0**/*40*	**4·76**/*44·2*	**4·55**/*48·4*	**4·35**/*52·9*	**4·16**/*57·6*	**4·0**/*82·5*	**3·84**/*67·6*
1500	**15**/*6·67*	**13·64**/*8·05*	**12·5**/*9·62*	**11·54**/*11·25*	**7·5**/*26·7*	**7·15**/*29·5*	**6·72**/*32·3*	**6·52**/*35*	**6·26**/*38·3*	**6·0**/*41·6*	**5·78**/*45*

PROJECTOR LAMPS

CLASSIFICATION

Projector lamps are available in a number of types for various purposes, and are classed as follows—

Class A.1—Up to 1000 w., with cylindrical bulbs. Must be burned vertically with the cap downwards. These have a very high efficiency and an objective life of 25 or 50 hours according to type. When used in slide lanterns, cinema projectors, etc., they can be brought close to a short-focus condenser which will then transmit a large proportion of the lamp light.

The bulbs are relatively small in diameter, and in some cases, in order to avoid excessive heating of the bulb by the filament, the lamps must be burned in an air stream, or forced draught ventilation, of sufficient strength to keep bulb temperature below 500°C. For cinema projection purposes the top of the lamp is blackened to absorb stray light.

Class B. 1—Up to 1000 w., with round bulb. These lamps have a concentrated bunched filament and are suitable for use in floodlights and for stage lighting purposes where long life (800 hours) is a primary consideration. They can be burned at any angle except within 45° of the cap-up position.

Class B. 2—As Class B. 1 but with pear-shaped bulbs and suitable for burning in any position.

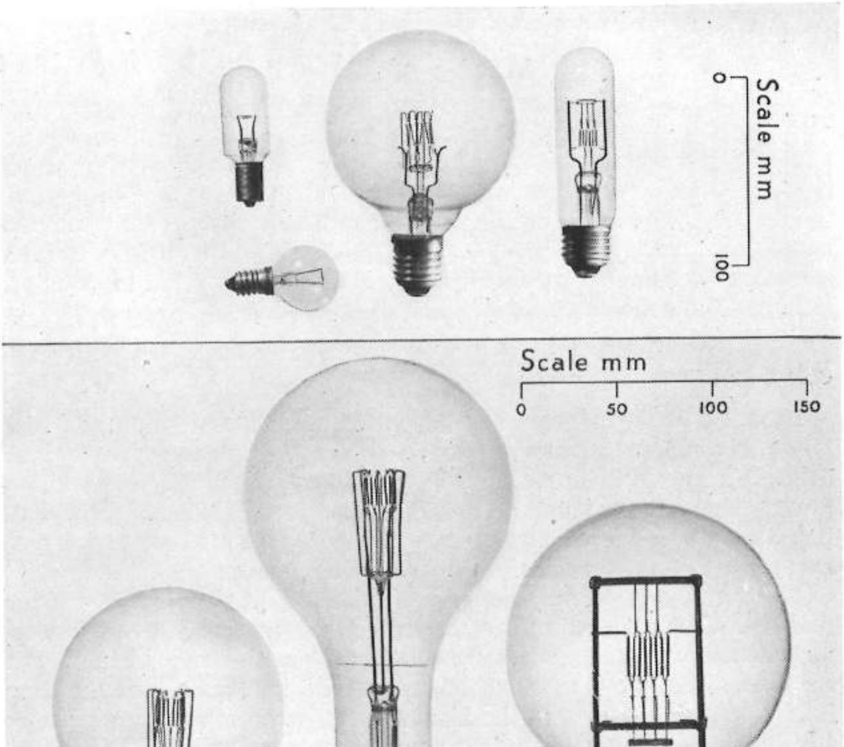
Class E.—Of 500 w., with a round bulb, designed especially for episcope and epidiascope projection. Must be burned within 45° of the vertical position with cap downwards. Life 100 hours.

Class F.—Low wattage lamps with round or tubular bulbs, operating on voltages up to 12 v., and specially designed for micro-projection purposes, e.g. home cine-projectors, sound recording, microscope illumination, etc. Life 100 hours or less, according to type.

Class G.—Low voltage tubular "exciter" lamps for sound reproduction. Life 100 hours.

Studio Lamps—Up to 5000 w., in round bulbs, with concentrated filament, designed for the lighting of film studios. Objective life 100 hours. In addition, lamps of short life are made at colour temperature 3400° k. for colour film purposes.

Tubular Line—Lamps up to 2000 w., in tubular bulbs designed for horizontal burning. The straight-line filament arranged along the axis of the tube enables a very accurately controlled fan-shaped beam



Representative Projector Lamps.—TOP: Upper: Class G. 75 w. exciter. Lower: Class F, 24 w. Centre: Class E, 500 w. epidiascope. Right: Class A1, 300 w. MIDDLE: Left: Class B1, 1000 w. Centre: Class B2, 1000 w. Right: Studio, 2000 w. BOTTOM: Line filament, 2000 w.

of light to be projected from a parabolic trough-shaped reflector such as is used for floodlighting. Life up to 1000 hours.

BULB SHAPES

The bulb shapes adopted in all cases are designed to avoid overheating (and consequent failure) of the glass, while at the same time being kept small enough to be used efficiently in the optical apparatus for which the lamp is required. It will be understood that burning the lamp in other than the proper position may divert the normal flow of hot gas in the interior, resulting in overheating and softening of other internal glass parts.

CAPS

Though a variety of screw and bayonet caps are still fitted to projector lamps, especially in the smaller sizes, it is very desirable to ensure that the filament is always in correct relationship with the optical system without having to rely on the judgment or skill of the operator to make it so. This object may be achieved by fitting the lamp with a prefocus cap which, according to type, contains one or more slots, grooves or other features which engage with corresponding projections in the lampholder, and are designed so that the lamp cannot be inserted wrongly. In the optical apparatus in which these lamps are used the position and orientation of the holder is fixed by the manufacturer, and the prefocus cap on the lamp is also fixed in relation to the filament; thus lamp replacements can be fitted with absolute certainty that no adjustment is required.

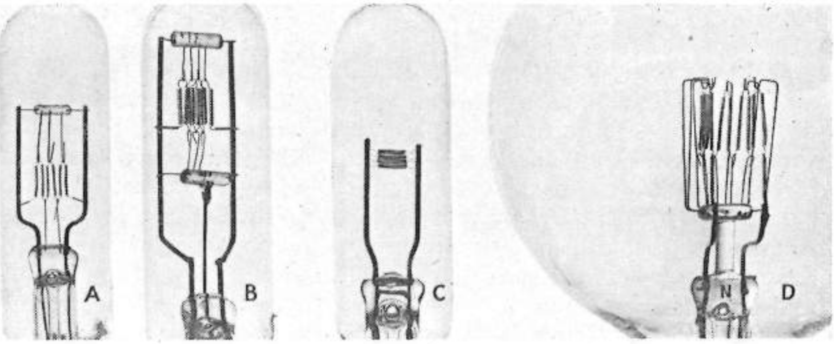
Some of the larger projector lamps, such as are used for cinema studios, are not fitted with any cap, the internal supports being connected to two heavy external metal contact plugs to which the circuit wiring is clamped. These "bi-post" contacts are pushed right home into the sockets of a fixed holder, the whole assembly then being rigid and effectively prefocussed.

FILAMENT FORMATION

(i) *Grid filaments.* These are employed where the source must be very concentrated, with the maximum light output in one particular direction (as in optical lanterns and cinema projectors).

The filament is generally arranged in M or multiple-M formation with the limbs substantially vertical and all lying in a plane parallel to the condenser lens of the optical system.

In the *Monoplane* grid filament, the limbs of the filament are in a single plane and a spherical mirror is usually employed behind the lamp in order to reflect back through the filament formation the light going in a rearward direction. This mirror is so adjusted



Projector lamp filament formations.—A. Monoplane grid. B. Biplane grid. C. Solid source. D. Bunch

that the reflected images of the limbs appear in the spaces between the actual limbs, thus giving in effect an almost "solid" rectangular source.

In the case of *Biplane* grid filaments the limbs are arranged in two parallel planes, one close behind the other and with the limbs in the second plane staggered in relation to those in the first, thus giving a similar effect to a monoplane grid with mirror.

(ii) *Solid source filaments.* In a comparatively open "grid" assembly the gas filling of the bulb inevitably has a greater cooling effect on the outside limits, and on the ends of the limbs, than on the central portions of the filament. One way of counteracting this is to mount all the limbs in a single plane, each limb being parallel with and touching its neighbour throughout its length. By this means a higher average filament temperature and a more uniformly bright compact source can be obtained.

(iii) *Bunch filaments.* Where a lamp is required to be used in conjunction with a parabolic mirror to give a near-parallel beam of light (as in a long-range floodlight) the filament must be concentrated into as small a volume as possible and should be arranged to give approximately equal light intensity in all directions.

In class B.1 and B.2 projector lamps a "bunch" filament is used. This consists of coiled tungsten wire bent into multiple V's or M's arranged vertically in a ring, so as to form a hollow cylinder of small dimensions.

Details of performance, dimensions, etc., of Gasfilled Projector Lamps will be found on page 131.

MISCELLANEOUS FILAMENT LAMPS

In 1939 electric lamps were available in an enormous range of types and sizes designed to cater for every likely (and not a few unlikely) needs of the public. During the war the heavy demands of the Services for special types of lamps, and the need to concentrate the remainder of plant capacity on the maintenance of the most vitally important lamps for industrial and public use made it necessary to discontinue, for the time being at least, the manufacture of several thousand of those types and sizes without which the nation could still survive, though at some inconvenience. Had the supply of some of the remaining types of lamps been interrupted for any appreciable time, industry would have been paralysed and disaster would have followed.

At the time of writing, war conditions still exist to some extent. The available labour and materials must necessarily still be devoted to supplying the most important demands, and only a few of those types of lamps which disappeared during the war have yet made their reappearance. Others will doubtless do so in due course, though not necessarily in exactly the same form as previously. Throughout this section a clear indication is given as to which lamps are available now, and which have been in the past, though as the size of this book must be limited the list is by no means complete. Furthermore, "available" does not necessarily mean "immediately available", for some of the types mentioned are being made only in very limited quantities as yet.

ARCHITECTURAL TUBULAR LAMPS

These are vacuum lamps containing a line filament mounted centrally in the tube and extending to within a very short distance of each end of the lamp. Lamps may thus be butted together to form continuous lines of light.

Internal connections are taken out to two pegs, one near each end of the lamp, which are a press fit into spring holders. These holders are sufficiently long to receive also the sealing "pip" of the lamp, which is in line with the pegs and very close to one of them; the pip is thus protected from accidental damage in use.

The opal glass type is generally preferred by users, as it reduces glare to a minimum. (Opal glass, which is a mixture of clear glasses of different refractive indices and with very carefully controlled grain size, achieves almost perfect diffusion of light by an effect similar to that of minute gas bubbles when health salts are stirred in water. When unlighted, it appears white.)

The efficiency of the white opal lamps is of the order of 5 lumens per watt (7 L/W. for clear lamps) and their brightness about $1\frac{1}{2}$ candles/in.^{2}. This is not high by modern standards, but the low brightness (in opal or

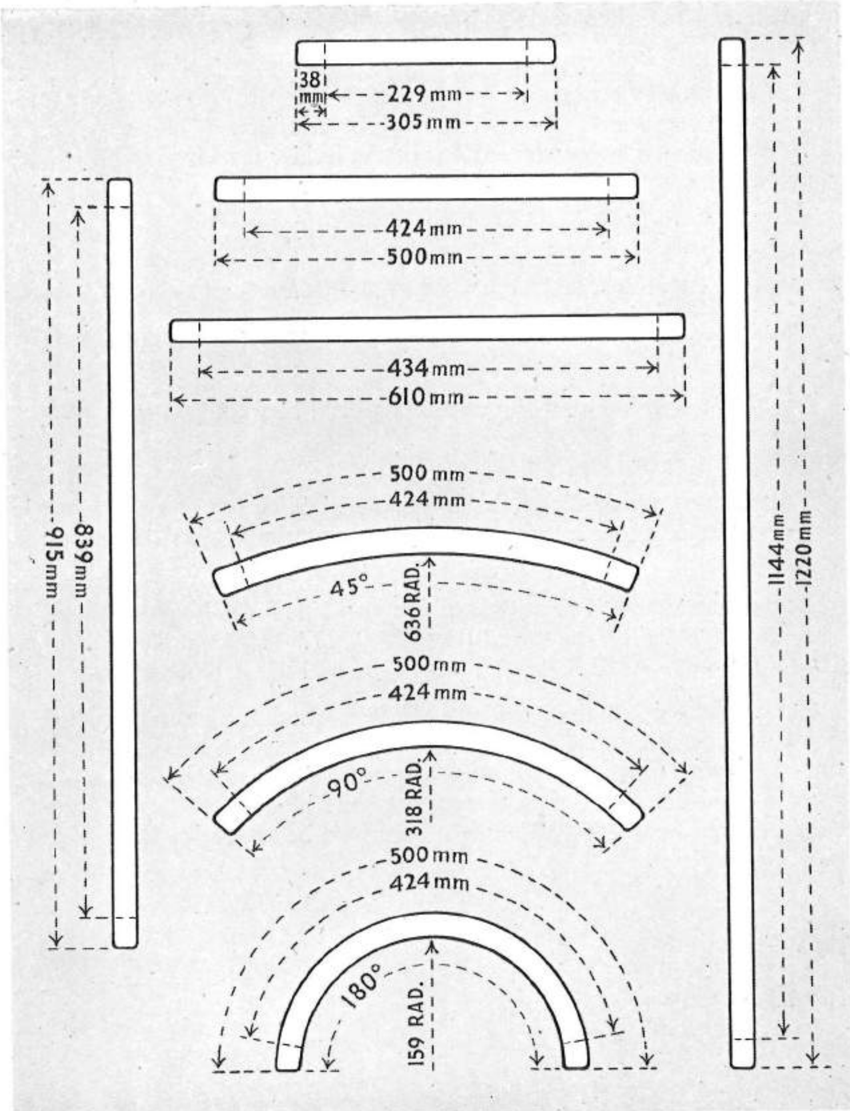


Fig. 19. Dimensions of standard architectural lamps. Overall lengths of straight lamps are approximately 12, 20, 24, 36 and 48 inches. Curves are one-eighth, one-quarter, and one-half of a circle

coloured types) makes the lamps very acceptable where the decorative aspect is as important as the utility value of the light, e.g. in hotels and restaurants, for displays and domestic applications (particularly for lighting at mirrors).

The lamps may be burned in any position, but great care is advisable when removing a lamp from its holders for cleaning. If one end is lifted too far before the other end is clear of the holder the leverage so exerted may be quite sufficient to loosen the peg cap or break the glass.

Previously all lamps were available for the 200–250 v. range, and those up to and including 24 ins. (nominal) in length also for 100–130 v. At present the 100–130 v. range is limited to lengths *less* than 24 ins. (nominal).

Bulb finish available now: clear, white opal, or sprayed white, red, blue, green, amber.

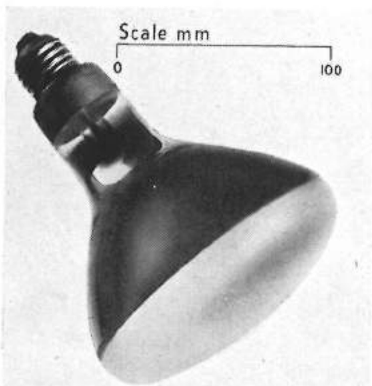
Details of Architectural Tubular Lamps will be found on page 140.

REFLECTOR SPOTLIGHT LAMPS

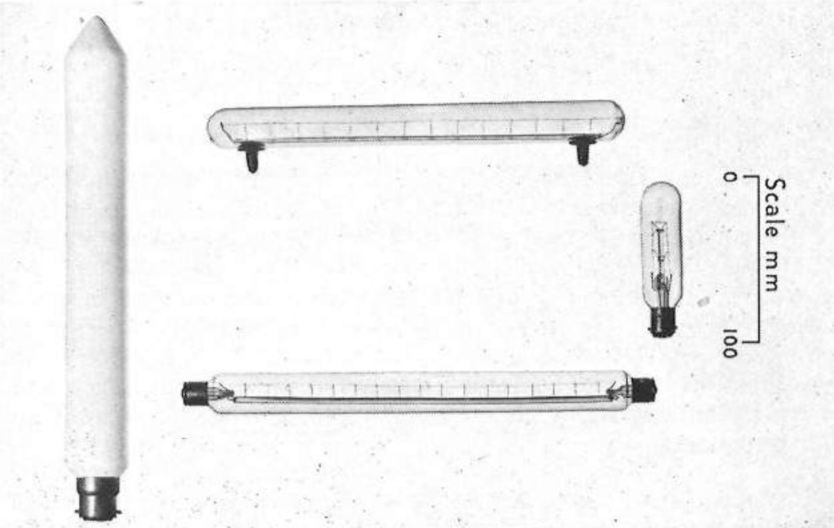
These lamps are designed chiefly for the highlighting of small areas in shop windows, shop interiors and other situations where emphasis is required.

Lamps are rated at 150 watts, and are available for voltages of 110, 210, 230, 240 and 250. The overall length is 177 ± 6 mm. and diameter $126 \pm 1 \cdot 5$ mm. An E.S. cap is fitted. Nominal life is 1000 hours.

The upper part of the gasfilled bulb is internally mirrored and has a parabolic contour so as to project a large proportion of the light in a direction away from the cap, while the end of the bulb is flattened and given a satin finish to soften the edges of the illuminated "spot" and to eliminate any streakiness that might otherwise be apparent.



150-watt reflector spotlamp with internal mirror and lightly frosted front to prevent striation



LEFT: Vacuum tubular lamp. UPPER: Clear "maxtrip" tubular. LOWER: Clear double-capped tubular. RIGHT: "Morse" tubular

As the mirrored surface is not exposed to atmospheric pollution or accidental scratching, it retains its reflecting property almost unimpaired to the end of life.

SINGLE-CAPPED VACUUM TUBULAR LAMPS

At the present time the only lamps of this description generally available are as follows:—

Wattage	Voltage	Dia. mm.	Overall Length mm.	Cap	Finish	Lumen Output (approx.)
25	50, 60, 65, 75, 110, 120, 210, 220, 230, 240, 250, 260	25 ± 1	86 ± 3 92 ± 3 94 ± 3	B.C. S.B.C. S.E.S.	Clear	185
40 60	As above except 50–75 v.	38 ± 1	302 ± 3	B.C. or E.S.	Opal or opal-ised	240 360

The 25 w. lamp is sometimes preferred for signs or for local lighting applications where space is very limited.

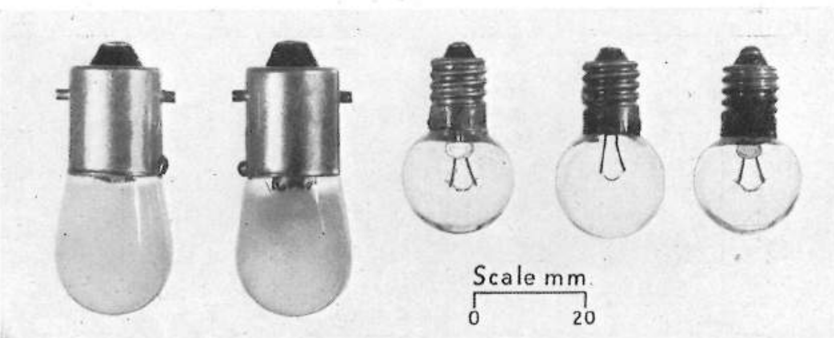
DOUBLE-CAPPED CLEAR VACUUM TUBULAR LAMPS

These have straight 25 m/m. (1 in.) diameter bulbs with the filament supported centrally. Complying with B.S.S. 555, the luminous efficiency is approximately 8 lumens per watt.

These lamps have been, and are, used largely for the illumination of showcases and pictures, and in other positions where a moderate amount of light is required from a lamp of small diameter up to 12 ins. long. Being of fairly low efficiency they require a comparatively large wattage to provide a given amount of light and generate a fair quantity of heat per lumen of light, and are likely to be superseded by tubular fluorescent lamps in positions where the available length is sufficient for the installation of the latter, especially where coolness is important, or in cases where a high electricity tariff and long hours of burning favour the economics of the fluorescent alternative.

Lamps are fitted with a centre contact (S15s) cap at each end, except those lamps marked* in which peg contacts at the side are used.

Length (mm.)	Wattage	Nominal Lumen Output
221	30	230
284	30	230
284	60	510
*252	30	—
*252	60	—



Five standard miners' lamps. LEFT: Hand lamps. RIGHT: Cap lamps. All are Krypton-filled to give maximum luminous efficiency

MINERS' LAMPS

Though mains lighting is being installed in an increasing number of British mines, battery-operated cap lamps and hand lamps are still necessary at the coal face. Lighting equipment actually carried by the miner must be as small and light as possible, but the dirty surroundings make it specially important that the small wattage available be used to convert electricity into light as efficiently as possible.

Up to the recent past the manufacturers specialising in mines lighting apparatus have used a variety of battery sizes and reflector arrangements which required 53 different types of lamp bulbs, filament formations and sockets based on the requirements of B.S.S. 535, but it would obviously be in the public interest to reduce the number to a more rational figure. It is hoped that the Ministry of Fuel and Power will agree to standardisation of the following five lamps.

Type	Nominal Volts	Amps.	Bulb finish	Cap
Cap	3·6	1·0	Clear	M.E.S.
Cap	4·0	1·0	Clear	M.E.S.
Cap	4·8	0·8	Clear	M.E.S.
Hand	2·5	1·75	Pearl	S.C.C.
Hand	4·0	1·0	Pearl	S.C.C.

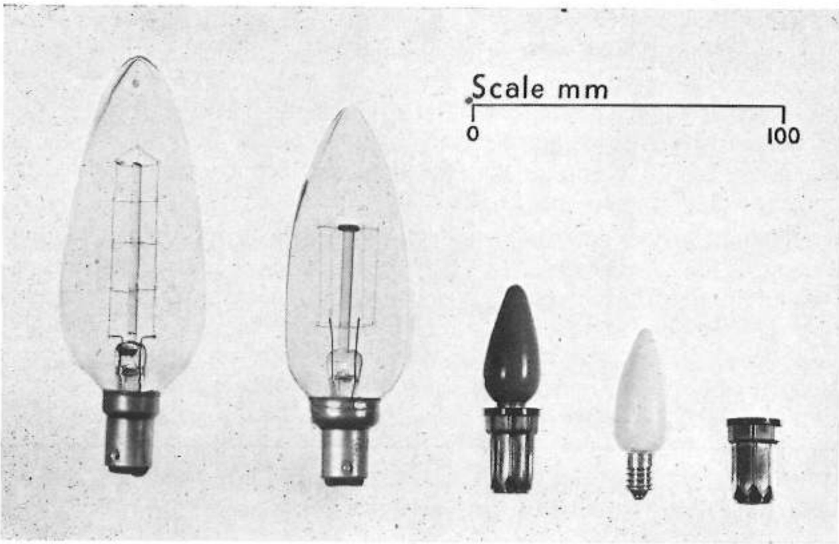
These lamps all comply with the appropriate section of the Coal Mines (Lighting) General Regulations, 1947.

The necessity of obtaining the highest possible luminous efficiency from these small lamps, even though at some extra cost, requires Krypton to be used in place of Argon for the gas filling. Krypton has a higher density and lower specific heat, and thus permits higher filament temperatures to be achieved with less loss of heat to the gas, resulting in increased luminous efficiency.

In low-voltage lamps such as these, the voltage generated by the thermo-electric effect at the points where the tungsten filament is attached to the nickel supports may be appreciable in relation to nominal lamp voltage, and can change light output by as much as 5 per cent. Internal connections are therefore always arranged so that the generated voltage assists the applied voltage when the lamp is used in its normal position.

DECORATION LAMPS

For decorating Christmas trees and for festive occasions, special sets of ready-wired clear or coloured lamps are available. The sets comprise either 12 or 16 low-voltage lamps wired in series for 200/260 v. supplies.



LEFT: Clear decoration candle lamps. RIGHT: Christmas tree lamp. Note how the screw cap is well protected by the holder

It will be apparent that if one lamp fails the whole set is extinguished, full mains voltage appearing at the lampholder containing the burned-out lamp. For that reason the flexible wire used is of good quality and deep-skirted S.E.S. lampholders are fitted to provide adequate protection against shock. Many of the foreign decoration lamp sets previously available used very poor flex and left part of the "live" holder or lamp cap exposed, with very serious risk to the user, particularly where children were concerned.

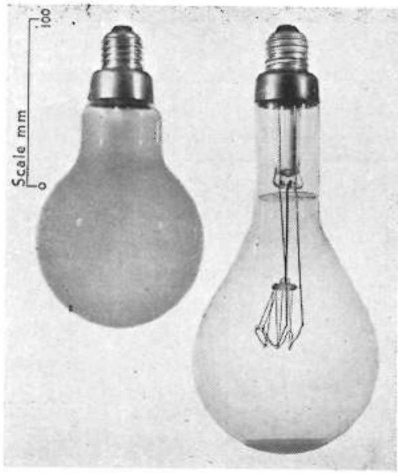
In the event of failure, it is recommended that each lamp be withdrawn and tested on an ordinary 4½ v. dry battery until the faulty lamp is found.

Clear vacuum candle lamps, popular for certain styles of domestic and commercial interiors, are available for standard voltages above 50 v. as follows:—

Watts	Overall Length (mm.)	Bulb Dia. (mm.)	Standard Cap
25	114 ± 5	38 ± 1	B.C.
	116 ± 5	38 ± 1	S.B.C.
40	135 max.	46 max.	B.C.
	133 max.	46 max.	S.B.C.

The luminous efficiency of these candle lamps is approximately 8 lumens/watt and the average life 1000 hours.

LEFT : 500 w. photographic lamp
RIGHT : 400 w. enlarger lamp with the end of the bulb frosted



PHOTOGRAPHIC AND ENLARGER LAMPS

For photographic purposes lamps are required which give the greatest possible light output per watt, even though this entails severe sacrifice of life. Photoflood lamps operate at exceptionally high efficiency and give a whiter light than ordinary gasfilled lamps. All have pearl bulbs and a fuse fitted within the cap.

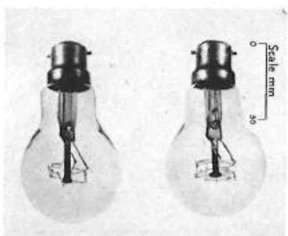
In enlarger lamps the aim is to obtain a source of high brightness and large area. The lamps have a lower efficiency and longer life than Photoflood lamps.

Details of these lamps will be found on page 140.

Manufacturers of well-known photographic apparatus can give general guidance as to the most satisfactory way of using these lamps with various subjects, lens apertures, film speeds, etc.

SERIES-BURNING TRACTION LAMPS

For various public transport vehicles where the voltage of supply may be of the order of 600 v. (for which it is impracticable to make low wattage



LEFT: Series-burning traction lamp. RIGHT: Rough-service lamp filament lamps) it is convenient to run several lamps of normal rated voltage in series. Series-burning lamps with clear or pearl bulbs are specially designed for this purpose. It is of course essential that all lamps on any one circuit should be of the same current rating. Series-burning traction lamps are made to comply with B.S.S. 867.

Standard Lamp Voltages	Nominal Watts	Cap	Rated Amps.	Bulb Dimensions mm.	Type
100, 110, 120, 130	40	B.C. or	0·35	60×110	Vacuum or Gasfilled
	60	E.S.	0·52	65×117·5	Gasfilled
40	40*	E.S.	1·0	60×110	Gasfilled
	60*	E.S.	1·5	65×117·5	Gasfilled
50	40*	E.S.	0·8	60×110	Gasfilled
	60*	E.S.	1·2	65×117·5	Gasfilled

Lamps marked * are fitted with a fusible cut-out which short-circuits the lamp immediately it fails, thus leaving other lamps on the same series circuit alight.

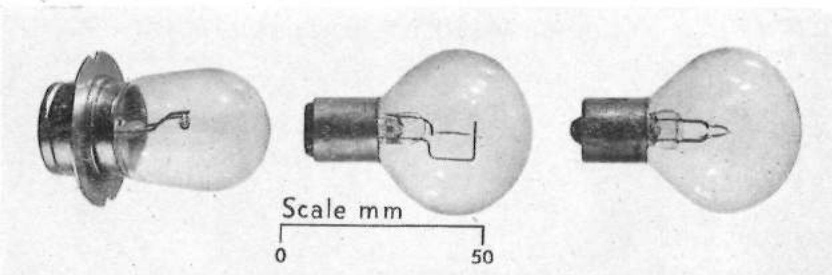
ROUGH SERVICE LAMPS

Where conditions of vibration are thought likely to lead to early lamp failure, three alternatives are open to the user:—

(1) To fit anti-vibration lampholders and continue to use ordinary lamps.

(2) To use rough service lamps.

(3) To transform to a lower voltage and thus take advantage of a shorter and thicker filament.



Motor car headlamps. LEFT: Prefocus. CENTRE: Line filament. RIGHT: V Filament

Despite very considerable experience with vibration troubles, lamp manufacturers agree that it is generally impossible to state, without trial, which alternative is likely to be the best solution in any particular case, since so much depends on the nature of the vibration or shock-producing agency and the foundation upon which it works.

In rough service lamps the filament is spiralled and retained in position by a greater number of supports than in lamps for general lighting service. The filament is also designed to operate at a slightly lower efficiency in order to increase mechanical strength. Lamps are of the vacuum type, with clear bulbs marked "R.S."

Standard Voltages	Watts	Cap	Bulb Dimensions mm.	Approx. Initial Efficiency (230 v.) (Lumens/watt)
110, 120, 210, 220, 230, 240, 250	40	B.C. or E.S.	60×110	7·5
	60		$65 \times 117{\cdot}5$	8·5

MOTOR CAR HEADLAMPS

Though a point source of light and a truly parabolic reflector are, in theory, required for projecting a parallel-sided beam of light, this arrangement would not be suitable for a motor headlamp since a certain amount of sideways and downward spread of the beam is required. It would also be impossible to obtain in practice, since the light source must have some dimensions even though small, and since ordinary manufacturing conditions do not permit a perfect parabolic mirror to be produced. Neither can exact location of the light source at the focus be guaranteed.

The practical ideal is a very bright, compact light source situated at the effective focus of a mirror as accurately shaped as possible, but which nevertheless results in a slight spreading of the beam. Further spreading, if desired, can then be effected by means of the front glass of the lamp housing.

It is only those portions of the lamp filament at, or very near to, the effective focus of the mirror which give any useful forward light. Thus it is essential that the filament dimensions shall be as small as possible. Coiled filaments are universally employed, and it is apparent that the closer the coiling, the more of the filament that is effective. It is in that respect that low-quality headlamps usually fail, for the coiling is often so open as to lower the temperature of the whole filament (page 40) as well as to make only a very small portion of it effective.

In the past, lamp focussing was carried out by moving the lamp, or its holder, backwards or forwards in relation to the mirror. A recent development, now being adopted by many car manufacturers, is that the lamp is fitted with a prefocus cap which is gripped rigidly by an appropriate holder in the headlamp housing, thus ensuring accurate focus at all times, no adjustment being possible. This arrangement, of course, necessitates much more accurate location of the filament with respect to the cap than formerly—in fact, an accuracy within ½ millimetre.

Lamps rated at 6 or 12 v. are made to operate satisfactorily at voltages of the order of 6½ and 13½ v. respectively, in order to allow for the effect of battery charging whilst the engine is running. It should be noted that 6 v. lamps, due to their higher current rating, are far more affected than 12 v. lamps by faulty or inadequate wiring. For instance, it may even be found that with seriously inadequate wiring the substitution of 6 v. 36 w. lamps for 6 v. 24 w. lamps causes an actual reduction of light output, due to voltage drop in the leads.

A filament shaped into the form of a V can be located so that practically all of it is at the effective focus, but should it be out of focus, it is very ineffective. A line filament, on the other hand, though theoretically not so effective as the V, can be slightly out of focus without any great loss in performance. Most single-filament headlamps can be obtained with either line or V filament.

Double filament headlamps contain two separate V filaments, one for normal driving, and the other offset in both the vertical and horizontal planes so as to give a dipped and swivelled beam. Both filaments are of the same wattage.

Headlamps are made to comply with B.S.S. 941 (at present under revision), which gives details of the following lamps. Other sizes are also available.

Rating		Overall Length (mm.)	Bulb Dia. (mm.)	Light Centre Length (mm.)	Filament Shape	Standard Cap
Volts	Watts					
6	24	56 ± 4	38 ± 2	28·5 ± 1	V	B15s/17
6	24/24					B15d/17
6	36					B15s/17
12	36					B15s/17

SIGN LAMPS

Though electric signs are normally made in a variety of styles and sizes, their legibility and effectiveness usually depend upon each individual limb of a letter sign, or each line of a drawing, appearing to be evenly bright along its length. This generally calls for the use of a relatively large number of lamps spaced close together, each lamp being of low wattage for economical operation and to avoid dazzle. Sign lamps are also used as indicators for a variety of purposes, e.g. in switchgear, cooker control panels, etc.

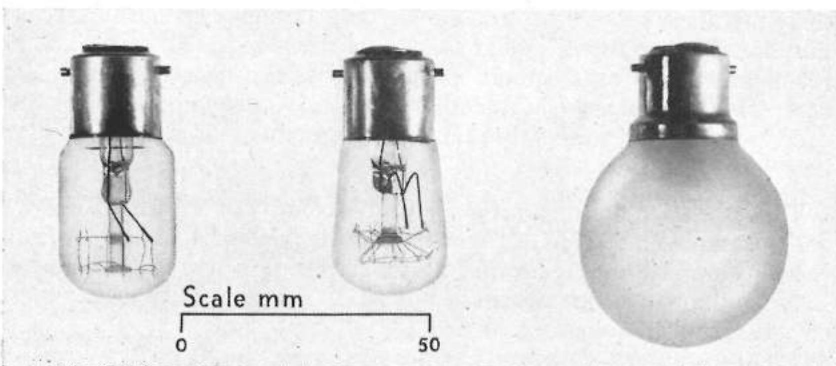
The standard 15 w. pygmy sign lamp (vacuum) is available as listed below. Nominal average life is 1000 hours.

Standard Voltages	Dimensions (m/m)		Cap	Colours
	Dia.	Overall Length		
25, 50, 60, 65, 75, 110, 130, 150, 210, 230, 250	28±1	56±3 58±4 62±3 64±3	B.C. E.S. S.B.C. S.E.S.	Clear, or outside sprayed in white, red, blue, green or amber.

The approximate luminous efficiency of the 230 v. clear sign lamp is 6·5 L/W.

SWITCHBOARD INDICATOR LAMPS

Switchboard indicator lamps are required to have a long life and sometimes to operate under conditions of shock. High efficiency is of secondary importance to robustness and reliability.



LEFT: Pygmy sign lamp. CENTRE: Switchboard indicator lamp. RIGHT: Bus lamp

A clear lamp with dimensions similar to the sign lamps (B.C. cap) shown overleaf is available in two ratings (*a*) for the 100–130 v. range, (*b*) for the 200–260 v. range. One lamp covers each range, and wattage is not marked as it would vary according to the voltage applied.

The light output of these lamps is of the order of 50 lumens at 230 volts.

TRAIN AND BUS INTERIOR LAMPS

Train and bus lamps must be robust to withstand severe vibration, and of low voltage since they operate from a battery. Gasfilled lamps complying with B.S.S. 555 are listed below, and some additional ratings are also available. Lamp life is 1000 hours.

Type	Volts	Watts	Overall Length (m/m.)	Bulb dia. (m/m.)	Average Initial Efficiency (L/W.)	Standard Cap	Bulb Finish
Train	24	15 20 30	68±4	49±2	10·0 10·4 11·0	B.C.	Pearl or Clear
Bus	12	12	68±4	50±1	10·4	B.C.	Pearl or Clear

FILAMENT LAMPS FOR SPECIAL PURPOSES

The types of filament lamps dealt with in the preceding sections are those which members of the general public are most likely to use, but there are many other types and sizes which, though essential for special purposes, are not the particular concern of the man-in-the-street. Lamps for lighthouses, for telephone switchboards, for railway signals, for aeroplanes and ships—these and others are vitally important for the orderly progress of society, but can receive no more than passing mention here.

The largest lamp at present made in this country is rated at 10,000 w., and measures 22 × 11½ ins.; the smallest, the size of a grain of wheat, is a tiny miracle of engineering which fits inside a surgical instrument. Between these two extremes are lamps which can be used to meet almost any reasonable requirement.

ELECTRIC DISCHARGE LAMPS

HISTORICAL

ELECTRIC DISCHARGE TUBES GIVING A SMALL quantity of light and other radiations are historically older than filament type lamps, but the production of light was not the chief aim of early experimenters, who were more interested in studying the manner in which a partial vacuum conducted electricity. The difficulty of obtaining a reliable source of high potential and a high degree of vacuum in imperfect tubes were serious handicaps up to the middle of the nineteenth century, but from about 1800 onwards, scientists began to take an interest in the production of light by these means. Sir Humphry Davy showed that discharges in different gases and vapours would give various colours of light, and Fraunhofer and Wollaston examined the light from discharges spectroscopically, showing that its nature differed from that of sunlight or familiar kinds of light depending upon incandescence.

Michael Faraday began a systematic study of luminous discharges in 1838, and his experiments and demonstrations aroused great interest. Among other phenomena, he showed that the light output may not be uniform throughout the length of the discharge, but that dark spaces may occur. His name is still associated with the dark space near the cathode of a discharge lamp operating at a low pressure.

Ruhmkorff's induction coil (1851), which was a powerful source of high potential, and the skill of Geissler, the glassblower of Jena, in making up tubes in a variety of spectacular and attractive forms gave further impetus to investigations, but it was not until the last few years of the century that Moore began research on the value of electric discharges as illuminants.

The first large-scale commercial lighting installation was erected at Newark, U.S.A., in 1904, and consisted of a Moore tube 180 ft. long powered by a high-voltage transformer in place of an induction coil. Shortly afterwards this was followed by the installation of similar tubes in the courtyard of the Savoy Hotel and elsewhere in this country. Most of the early tubes were filled with carbon dioxide, giving a nearly white light, or with nitrogen, which gave a buff or golden colour, and had to be fitted with an automatic replenishing device in order to compensate for the loss of gas within the tube due chiefly to trapping of the gas against the walls of the tube after a period of use.

Fractional distillation of air enabled various chemically inert gases such as neon, krypton, argon and helium to be produced. These gases do not "clean up" readily, and tubes filled with them do not require periodic replenishment.

Neon proved particularly satisfactory as a source of red and orange light. Neon-filled high-voltage tubes were commercially produced in 1896, and their attractive appearance and relatively high luminous efficiency made them very suitable for advertising purposes. Similar tubes with additional mercury filling gave a bluish light.

Cooper Hewitt and Arons devised special starting gear which enabled tubes filled with mercury or mercury vapour alone to be run on comparatively low voltage, but the colour of the light was unsatisfactory for general purposes owing to the almost complete absence of red rays. Numerous attempts were made to correct this deficiency, notably by Wolke, who added cadmium to the contents of the tube, but the means of producing a fully satisfactory and simply operated mercury lamp of high efficiency did not become apparent until the 1930's.

From the electrical point of view, the later improvement of electric discharge lamps has been a matter of technical advancement rather than of discovery of new scientific principles. In particular, it is the development of special types of electrodes capable of carrying relatively large currents and operating at low voltages which has enabled discharge lamps to become objects of everyday use.

Progress since 1932 has been spectacular and rapid. Mercury and sodium lamps operating on mains voltage were commercially produced in 1933; partial colour correction of mercury lamps was achieved by utilising a fluorescent-coated outer bulb in 1937; modern mains-voltage tubular fluorescent lamps followed in 1939 and have been progressively improved in light output, life and every other quality since then, with further improvement doubtless to come. Parallel with all this, in spite of the interruption caused by the war years, other discharge lamps have been developed for special purposes; high pressure compact sources of light for projection purposes; flash tubes for stroboscopes and photography; high-tension fluorescent tubes; ultra-violet and glow lamps and a host of others for special purposes.

Research and development go on, and in future, as in the past, the benefit will be passed to the public.

TECHNICAL

The potential necessary to maintain an electric discharge through a gas or vapour may be conveniently divided as follows:—

1. The potential necessary to make the current flow into the gas or vapour from the metallic electrode acting for the time being as a

cathode (i.e. connected to the negative pole of the supply). The magnitude of this "cathode fall" is greatly dependent on the nature and condition of the electrode.

2. The potential necessary in the remainder of the discharge column (the "positive column" as it is called). The potential drop per unit length of the positive column is nearly uniform.

Of these two, the cathode fall is practically useless for the production of light or any other required radiation, and merely results in the generation of heat. The potential drop in the positive column, however, is useful in that, for a given value of current, it determines the wattage dissipated in this part of the discharge, and hence the light output. It is thus apparent that if a lamp is to be efficient, the potential drop in the positive column must be large in comparison with the cathode fall.

Fig. 20 (left) illustrates how the potential (full line) may fall in a lamp with simple metallic electrodes. The whole area under the sloping line is a measure of the wattage of the lamp, but the only useful wattage is indicated by the area above the dotted line, the remainder being wasted at the cathode. If the cathode fall can be reduced, (right) the wattage usefully employed will be a greater proportion of the whole than formerly. In other words, lamp efficiency will have been increased.

With plain or tubular metallic electrodes such as are universally employed for "cold cathode" lamps, the cathode fall is considerable, and short lamps therefore tend to be relatively inefficient. Cold cathode lamps, therefore, are generally made of considerable length, and thus require a high-tension source of supply. It follows that for a given lamp wattage the lamp current is low.

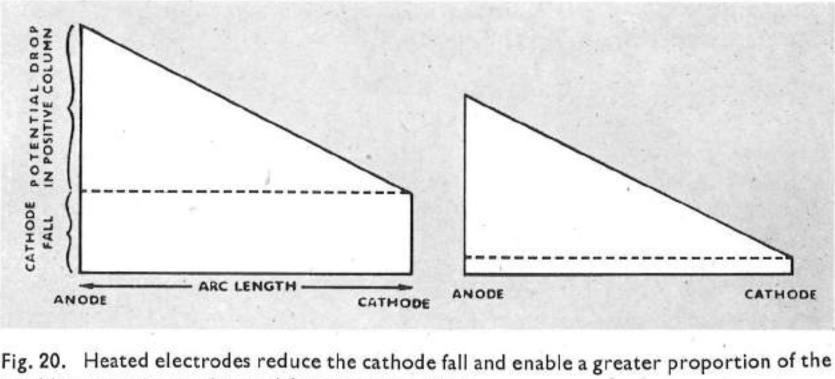
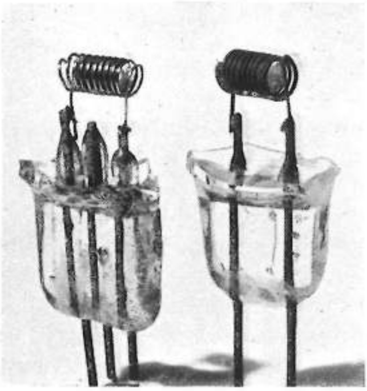


Fig. 20. Heated electrodes reduce the cathode fall and enable a greater proportion of the total lamp wattage to be used for generating light



Typical electrodes for hot-cathode lamps. Each contains a pellet of electron-emitting material

If a discharge lamp is to be worked by ordinary mains voltage of about 230 v., the actual voltage appearing at the lamp cap will be very much less (see page 19. In the case of high pressure mercury lamps, for instance, lamp voltage may be about 140 v.). With only this very limited lamp voltage available, the cathode fall must obviously be reduced as much as possible in order to leave a reasonable "useful" potential drop for the positive column. Furthermore, if the lamp is to have a high light output, its wattage must be kept up, and therefore the current flow must be appreciable.

Neither of these requirements can be met by simple metallic electrodes operated cold, since the cathode fall is high and they are incapable of handling a medium or large current without becoming damaged. It has been found, however, that if the operative part of an electrode consists of a pellet or a coating of special alkaline earth oxides, which is heated by one means or another, relatively high current can be handled without damage and with considerably reduced cathode fall (Fig. 20). Mains voltage operation of short discharge lamps of moderate or high wattage rating thus becomes a practical possibility.

MAINS VOLTAGE MERCURY LAMPS

Mains voltage mercury discharge lamps are classified as follows:—

All have the prefix M, followed by

A	indicating	glass envelope loaded above 10 watts/cm. of arc length
B	,,	quartz envelope loaded below 100 watts/cm. ,, ,, ,,
C	,,	glass envelope loaded below 10 watts/cm. ,, ,, ,,
D	,,	quartz envelope with forced liquid cooling.
E	,,	quartz envelope loaded above 100 watts/cm. of arc length

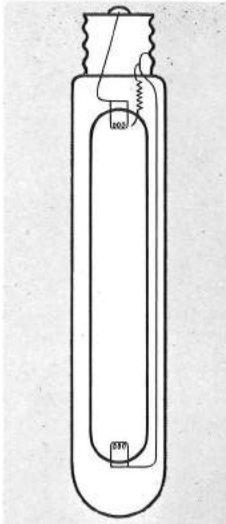


Fig. 21. Simplified diagram of the internal arrangements of a mercury lamp type MA. A similar arrangement is used for type MB

The letter F indicates that a fluorescent outer bulb is used, T that an incandescent tungsten filament is incorporated, and W that the outer bulb is made of Wood's glass.

The normal burning position is indicated by the suffix:—

/V	indicating	vertical, cap up
/D	,,	vertical, cap down
/H	,,	horizontal
/U	,,	any position

Thus MCF/U indicates a low-pressure mercury lamp with a fluorescent bulb which can be used in any desired position; MA/V indicates a high pressure mercury lamp with non-fluorescent bulb, which must be burned vertically, cap up.

The essential parts of a mains voltage mercury lamp (types MA or MB) are depicted in Fig. 21. Differences of detail occur with different types but all contain the following items:—

1. An inner discharge tube made of glass or quartz suitable to withstand the temperatures and pressures obtained, and filled with a small quantity of mercury vapour, with a little argon to assist starting.
2. An outer bulb, the space between this and the inner tube being at reduced pressure in order to conserve heat.

3. Two main electrodes, one at each end of the inner tube, generally constructed of coiled tungsten wire coated with, or enclosing a pellet of, alkaline earth oxides. The ends of the inner tube are often silvered to facilitate evaporation of mercury from the electrodes.

4. A plain metallic starting electrode, situated very close to one of the main electrodes but connected *via* a high resistance to the electrode at the other end.

5. A suitable cap.

When the lamp is first switched on, the mains voltage is generally insufficient to initiate a discharge between the main electrodes, but full mains voltage appears also across the narrow gap between the starting electrode and one of the main electrodes. At this point the potential gradient (volts per cm.) is sufficiently high to start a discharge in argon, and the degree of ionisation thereby effected enables the discharge between the main electrodes to take place. The argon discharge warms the tube and its contents, gradually vaporising the mercury until, in the fully run-up condition of the lamp, the mercury is completely vaporised. Early in the running-up period the argon discharge gives place to a discharge in mercury, and when the lamp is fully run up the effect of the argon filling is insignificant.

Once it has started the lamp, the starting electrode has no material effect on performance, since the current through it is limited by the high series resistance (usually about 50,000 ohms).

THE CHOKE

In common with all other kinds of discharge lamps, a device must be connected in circuit to limit the discharge current to the correct value (page 19). On A.C. supplies a choke is used for this purpose (Fig. 22) and, if correctly designed, limits lamp wattage within about 2 per cent. of rated value. In order to provide stable running conditions it should

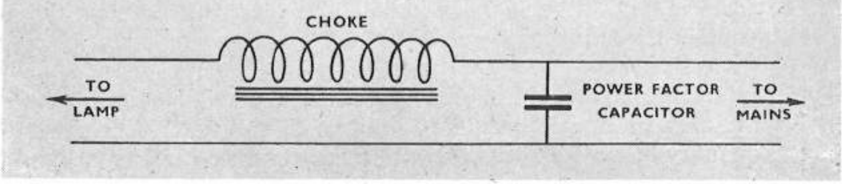


Fig. 22. Circuit diagram for mercury lamps types MA and MB. Note that the power factor capacitor must be on the mains side of the choke

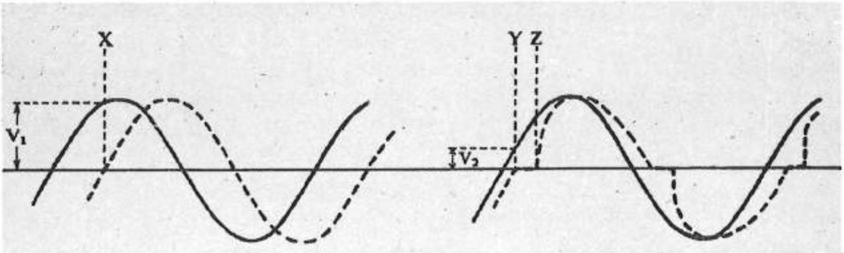


Fig. 23. LEFT : Normal phase relationship of mains voltage (full line) to lamp current (dotted) in a discharge lamp. RIGHT : Too high a power factor of the lamp-choke combination results in a distorted current wave form and increased flicker

absorb a voltage equal to more than half that of the supply mains.* The reason for this may be understood by considering Fig. 23 showing curves of mains voltage and lamp current on 50 cycle mains.

In the case of a filament lamp operating on a 50 cycle supply, the filament retains much of its heat during instants when the current cycle passes through zero, and this thermal inertia smooths out what would otherwise cause an appreciable cyclic variation in light output. With discharge lamps, however, the arc is actually extinguished as the current falls to zero each half cycle, and the light is consequently extinguished. In order to avoid obvious flicker, it is essential to arrange that the arc strikes again immediately; but for this to happen there must be sufficient mains voltage at that instant (at the point of zero current, mains voltage and lamp voltage are equal and in phase with each other).

If the choke is correctly designed (Fig. 23 (left)) the lamp current will lag behind mains voltage by an angle such that at the point (X) of zero current there is already a sufficient voltage (V_1) to start the discharge in the opposite direction. If it is badly designed (possibly in a misguided attempt to improve power factor) there may only be an insufficient voltage (V_2 in Fig. 23 (right)) available at zero current, and the discharge remains extinguished until point Z is reached at which the available voltage becomes sufficient. The prolonged "out" periods would cause a very noticeable flicker and distort the current waveform.

Considerations of efficiency dictate that lamps be designed to operate at as high a voltage as possible, but too high a lamp voltage would result in lamps being extinguished by a small fall in mains voltage, such as may occur from time to time. In general, it may be said that lamps are designed to withstand a sudden mains voltage drop of about 30 v. without being extinguished thereby.

* More than half the supply voltage remains available for the lamp, owing to the phase displacement of voltage in component parts of the circuit.

It is essential to use a choke of the correct rating, otherwise the lamp will be either under- or over-run, with consequent ill-effect on its performance, particularly as regards life. Under ordinary conditions, the choke selected should have a voltage rating corresponding to the average mains voltage under load conditions.

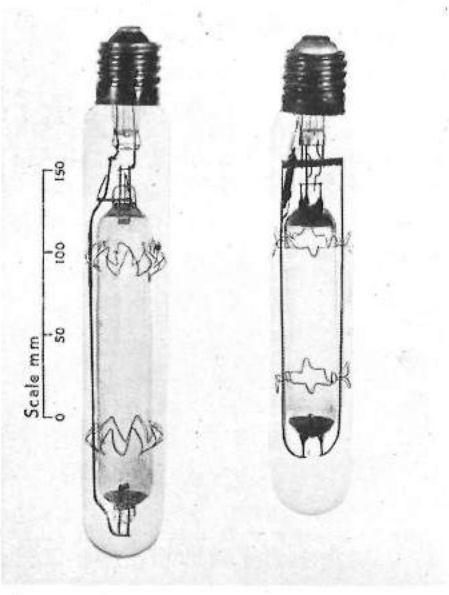
Discharge lamp stabilisation can also be achieved by means of series capacitors with some choke impedance to keep the current wave-form a reasonable shape. (If the current wave-form is allowed to get too badly distorted the lamp electrodes will disintegrate early in life). A leading power factor is obtained.

POWER FACTOR CAPACITOR

Though the apparent power factor of the lamp itself is nearly unity, the inclusion of a choke in the circuit reduces the overall power factor to an unacceptably low figure. This is normally corrected to a higher value by connecting a suitable capacitor across the *MAINS* (not across the lamp). In a multi-lamp installation it may be more convenient to correct power factor by a suitable number of bulk capacitors, but care should be taken to ensure that over-correction does not occur if only part of the installation is in use.

TYPE MA LAMPS'

These consist essentially of a hard-glass discharge tube centrally supported in an outer glass envelope. Both glasses are opaque to ultra-violet



Mercury lamps type MA. LEFT: 400 w. RIGHT: 250 w. Various kinds of spring supports are used to maintain the inner tube central in the outer radiations having any harmful effect. Such radiations may be generated in small quantities in the discharge, but are completely absorbed within the lamp. The time required to reach full brightness from cold is about six minutes and the vapour pressure within the discharge envelope is then about one atmosphere.

MA/V lamps, unless specially designed, must be burned vertically, cap up,* or very nearly so, in order to maintain the discharge arc centrally within the tube. Were the lamp to be tilted to a near-horizontal position, convection currents would carry the centre part of the arc upwards until it touched and overheated the glass. If it is desired to burn a lamp horizontally (as in street lighting lanterns) this may be done either by using an MA/H lamp which operates at a slightly lower efficiency than the MA/V, or by using a lamp with the arc maintained centrally by means of a magnetic device. The magnetic leakage flux from a special choke may be used for this purpose, or alternatively a small magnetic deflector consisting of an iron core wound with wire carrying the lamp current. Either device will raise the overall power consumption of the circuit by a few watts.

The electrodes are similar in construction to those shown on page 76. No pre-heating circuit is required, and they are kept heated by the action of the discharge while the lamp is alight. The act of starting, however, causes more loss of "active" material from the electrodes (by sputtering and mechanical disintegration) than a period of normal burning, and lamps which are only burned for short periods at a time must therefore be expected to have shorter lives than normal. Since the running-up period is several minutes, however, these lamps are unlikely to be used in situations where a light is only required for brief intermittent periods, and variation of lamp life with switching is not a matter of major importance.

Should a lamp be switched on soon after a former period of burning, it will not re-strike until the discharge envelope has cooled sufficiently for the vapour pressure to fall to a low value. No harm will be done to the lamp by leaving the switch in the "on" position.

At the instant of striking from cold, the purplish colour of the argon discharge is apparent, but almost immediately the colour changes to blue-green as the discharge in mercury becomes effective. At first, the discharge fills the inner tube, but during the run-up period the arc becomes progressively narrower and brighter until it appears as a thin cord stretched between electrodes. The outer limit of the arc is usually defined as the point where the brightness has fallen to one-tenth of the maximum in the centre. The arc of both the 400 w. and 250 w. MA/V lamps has a maximum

* Lamps for vertical burning, cap down, may also be obtained. These have the discharge tube reversed end for end.

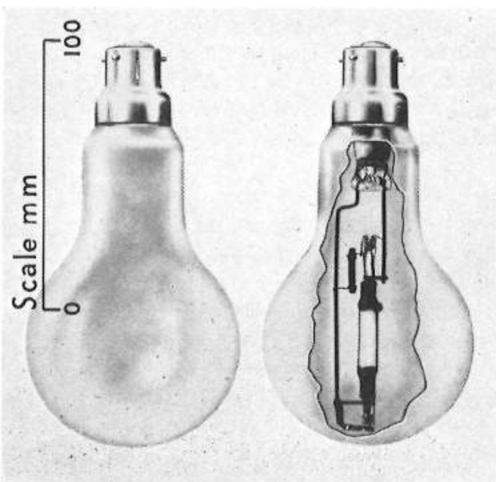
brightness of about 1000 candles/in.^{2}, with an effective average of about 750 candles/in.^{2}. Arc width is about $\frac{1}{2}$ in. in the 400 w. lamp and $\frac{3}{8}$ in. in the 250 w.

The principal radiations emitted by MA lamps in the visible band of wavelengths are at 4047 Å (violet), 4358 Å (blue-violet), 5461 Å (yellow-green), 5770 and 5791 Å (both yellow). The blue-violet and yellow-green lines are predominant, and there are also a number of weak radiations at other wavelengths, but these, including a small amount of continuous-spectrum radiation from the hot electrodes, are not sufficient to affect the overall colour of the light materially. This is best described as being blue-white or blue-green, though the apparent colour depends on a number of extraneous factors such as the colour of nearby lights and surroundings.

Ordinary MA lamps emit only some 1 per cent. of red light (compared with 15 per cent. of red in natural daylight). A few per cent. of extra red light can be obtained by adding a small quantity of cadmium to the contents of the discharge tube, but the lamp operates at a substantially lower luminous efficiency.

TYPE MB LAMPS

Mercury lamps of relatively low wattage are required for a number of industrial and street lighting purposes, but were an MA lamp to be made in a size to consume only about 100 w. the luminous efficiency would be unacceptably low (below 25 lumens per watt average throughout life, compared with 36 L/W for the 400 w. lamp).



Normal and cut-away views of a mercury lamp type MB. The starting resistor can be seen above and to the left of the discharge tube

In order to obtain higher efficiency it is necessary to increase the electrical loading per unit length of arc and the vapour pressure. The discharge envelope in MB lamps is therefore made much shorter than in type MA, but this results in a temperature rise which hard glass cannot withstand. Quartz must therefore be used, and its refractory nature enables the tube diameter to be reduced also, thus making a very compact source. The vapour pressure when fully run up is of the order of 10 atmospheres.

The starting arrangements for the MB lamps are similar to those for type MA, but only about 3 minutes are required to reach full brightness. In its fully run-up condition the arc brightness is of the order of 5000 candles/in.^{2}, which is much too high a value to be tolerable if exposed to view. In MB/V lamps the outer bulb is therefore pearled, and the light appears to be emitted by a patch on the bulb surface having a maximum brightness of the order of 60 candles/in.^{2}.

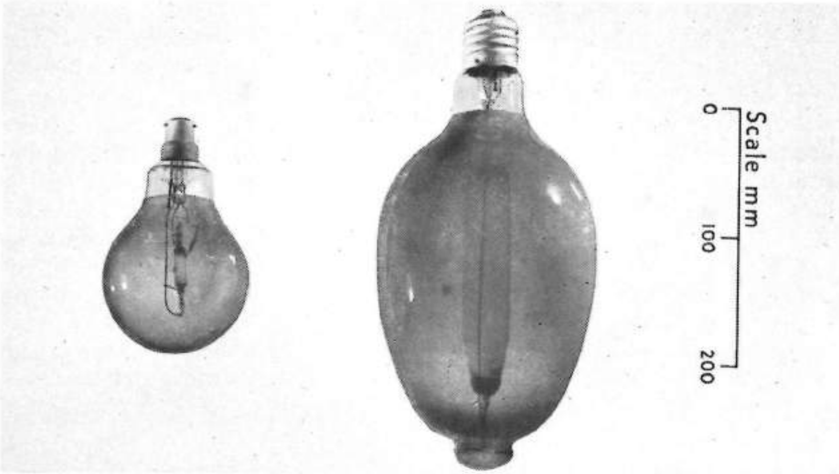
It is important to note that *no attempt should be made to use any type MB lamps if the outer bulbs are broken.* Certain harmful short-wave ultra-violet radiations are generated within the discharge, and are readily transmitted by the quartz discharge envelope, but are normally completely absorbed by the outer glass bulb. Should a part or the whole of this bulb be missing, these radiations may have a marked therapeutic effect, and in particular are liable to affect the eyes.

The pearl bulbs of MB/V lamps have the same dimensions as either 150 w. or 200 w. gasfilled lamps, and one might be mistaken for the other. In order to prevent an MB lamp being inserted in an ordinary B.C. lamp socket (with no choke in circuit) the B.C. caps of these lamps are fitted with three pins at angles of 135°/135°/90°. MB/V lamps are designed to be burned vertically, cap up, but burning them in other positions has no appreciable effect on their performance.

Due to the higher vapour pressure employed, the longer-wave visible radiations emitted tend to be strengthened in comparison with the shorter wavelengths. MB/V lamps thus give slightly more red light than MA/V lamps, and the light appears a little whiter.

TYPES MAF AND MBF LAMPS

Some 3 to 4 per cent. of the electrical energy supplied to MA and MB lamps is converted by the discharge into long-wave ultra-violet radiation which passes through glass, is invisible and therefore normally wasted. This radiation, however, may be used to stimulate fluorescent materials which then, if carefully selected, emit a colour of light complementary to that of the discharge itself, thus effecting a degree of colour correction. This principle is followed in MAF/V and MBF/V lamps.



Mercury lamps with fluorescent bulb.—LEFT: 80 w. type MBF. RIGHT: 400 w. type MAF in isothermal bulb

In the case of MAF/V lamps, zinc and zinc-cadmium sulphide powders which fluoresce with an orange colour are chosen. These cannot be placed within or in contact with the discharge envelope on account of the high temperatures reached, but they are deposited on the inside surface of the outer bulb. The latter is enlarged in order to reduce powder temperature still further, either in cylindrical (tubular) form or, for maximum efficiency,

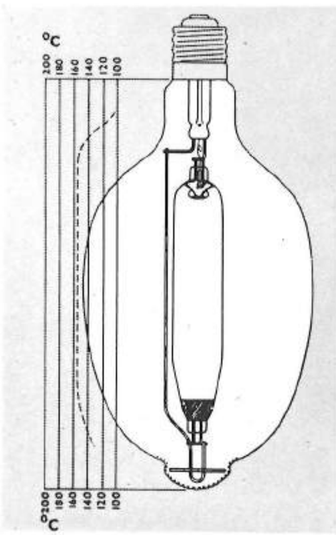


Fig. 24. Over the greater part of the isothermal bulb surface the temperature is substantially even

in conical (isothermal) form designed to give as uniform a temperature over its surface as possible.

The fluorescent powders used in the MAF/V lamp are yellowish in appearance, and therefore tend to absorb some of the blue light emitted by the discharge. To counteract this, a little cadmium is added to the content of the discharge envelope; this has the effect of increasing the proportion of blue light generated (and also increasing the proportion of red slightly) but does so at the expense of the total light output, which falls by some 12 per cent. The amount of blue light absorbed by the powder is balanced by the amount of orange light obtained by fluorescence, the two sources of light combining to give an overall result containing some 5 per cent. of red light (against 1 per cent. for MA lamps) representing a considerable improvement in colour quality deemed, for some industrial purposes, to be worth the small sacrifice in luminous efficiency.

The brightness of the Isothermal bulb varies over its surface. At a distance of 1 in. from the bottom of the lamp the brightness is of the order of 10 candles/in.^{2} and approximately 15–20 candles/in.^{2} at a distance of $2\frac{1}{2}$ ins. from the bottom; the maximum brightness, near the centre of the bulb, is of the order of 300 candles/in.^{2}.

In MBF/V lamps the mercury discharge, due to the higher vapour pressure, generates initially more red light than MA lamps, and the degree of colour correction required is therefore not so great. The additional blue light required to offset the blue absorbed by the yellow powder may be obtained by adding a blue-fluorescing component to the mixture of fluorescent powders, thus avoiding the necessity of inserting cadmium into the discharge envelope. As a result, MBF/V lamps operate at the same luminous efficiency as corresponding MB/V lamps, the overall colour of light being similar to that of the MAF/V.

For MBF/V lamps the outer bulb is retained in pear shape, but enlarged to reduce the temperature of the powder. The relatively large size of the 125 w. lamp makes it necessary to fit a G.E.S. cap in order to obtain the required mechanical strength.

The warning on page 83 about using lamps with broken outer bulbs applies also to MBF/V lamps.

TYPE MBW ("BLACK") LAMPS

These lamps are intended primarily as sources of long-wave ultra-violet radiation capable of exciting fluorescent materials placed outside the lamps. They have found many applications in industrial and commercial fields, and to some extent for decoration and display.

A "black" lamp, type MBW/V, with special bulb to absorb light but permit the passage of ultra-violet

The lamp is identical with the corresponding wattage of MB/V lamp except for the cap and the bulb, which is made of Wood's glass. This is a special deep violet-blue preparation containing nickel and cobalt, which appears black when unlighted and almost entirely absorbs the visible light emitted by the mercury discharge; in fact, only some 0·01 per cent. of the input energy is radiated in the visible waveband. Wood's glass, however, is relatively transparent to long-wave ultra-violet and freely passes the 3654 Å radiation generated by the discharge. Some 3 per cent. of the input energy is radiated by the lamp at this wavelength, but the glass is practically opaque to mercury radiations at shorter wavelengths, which for practical purposes may therefore be ignored.

When looked at directly these lamps cause misty or blurred vision, due to fluorescence of parts of the eye, and it is therefore desirable to screen the lamps so that direct view is avoided, just as one would screen ordinary MB lamps. They have no other effect on human beings.

MBW/V lamps are available in the 125 w. size with a 3-pin B.C. cap and a bulb size corresponding to the 125 w. MB/V lamp. They are designed for vertical burning, cap up, but may be used in other positions without appreciable effect on their performance.

The performance, dimensions, etc., of MA and MB lamps will be found on page 141.

CHARACTERISTICS OF TYPES MA AND MB LAMPS

STARTING CHARACTERISTICS

Figs. 25 and 26 show how the light output and electrical characteristics of 400 w. MA/V and 125 w. MB/V lamps vary during the run-up period. The curves for 250 w. lamps are very similar to those for the 400 w., and

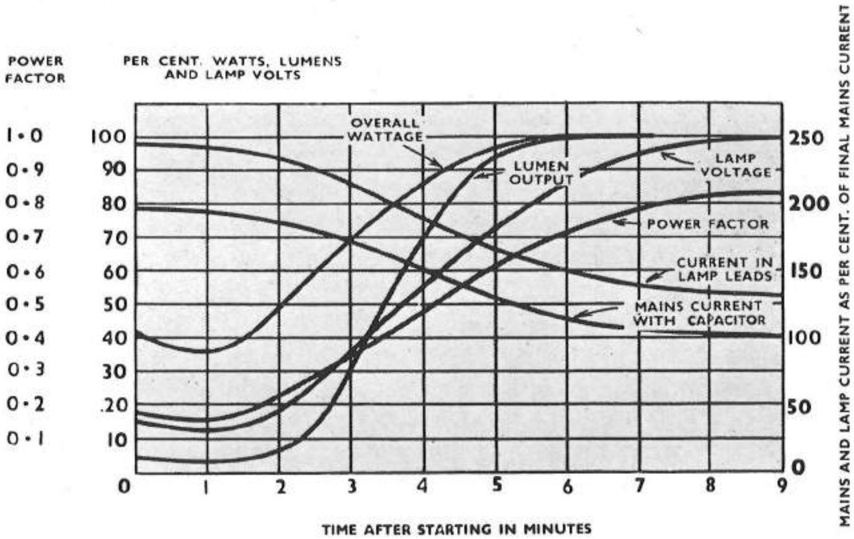


Fig. 25. Starting characteristics of mercury lamps. ABOVE: 400 w. type MA. BELOW: Fig. 26. 125 w. type MB. The curves for 250 w. MA and 80 w. MB are similar

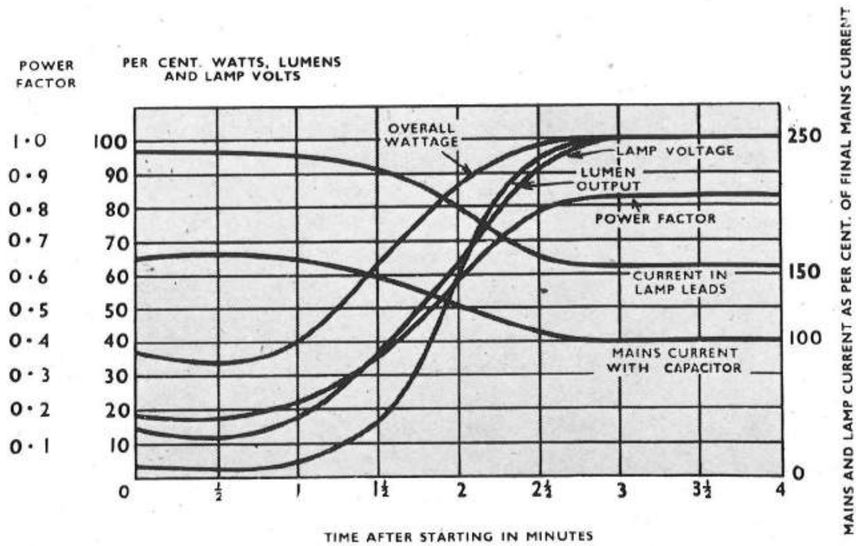


Fig. 26. Note that in each case the lamp current, whether power factor capacitors are used or not, is the same as the mains current without capacitors

the 80 w. similar to the 125 w. curves. Curves for MAF/V and MBF/V lamps are also in very close agreement with those shown.

Points of special interest are:—

(*a*) The time taken to reach stable conditions may vary slightly with ambient temperature, or if the lamp is restarted before having cooled completely after previous burning.

(*b*) The lamp current, whether power factor correction is employed or not, is the same as mains current without power factor correction.

(*c*) Starting current in the mains may reach a value double that of the running current.

(*d*) Lamp voltage rises as lamp current falls.

(*e*) Occasional instances have been reported where a circuit-breaking device in the neutral of a three-phase installation has operated soon after switching on. Due to the changing power-factor of the circuit during run-up, it may happen that if the separate phases are switched on one after the other at intervals of some three minutes the installation becomes rather more out of balance than might be expected; but if all phases are switched together, or nearly so, no trouble of this nature should be experienced.

ELECTRICAL CHARACTERISTICS

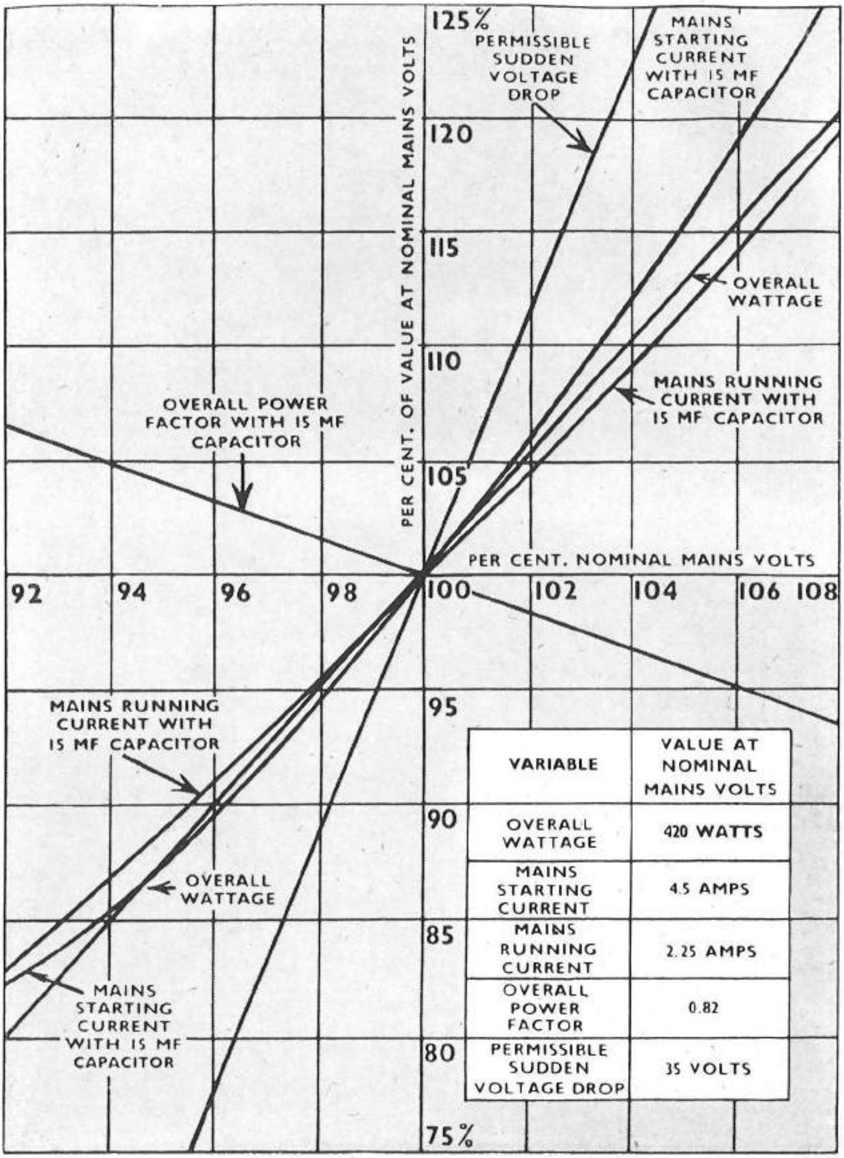
Figs. 27 and 28 show the electrical characteristics of MA and MB lamp circuits, both fluorescent and non-fluorescent, when equipped with appropriate power-factor correction capacitors on 230 v. mains.

LAMP CHARACTERISTICS

Figs. 29 and 30 show the change in lamp wattage, luminous efficiency and lumen output of types MA and MB lamps, both fluorescent and non-fluorescent, as actual mains voltage is varied above or below the nominal value.

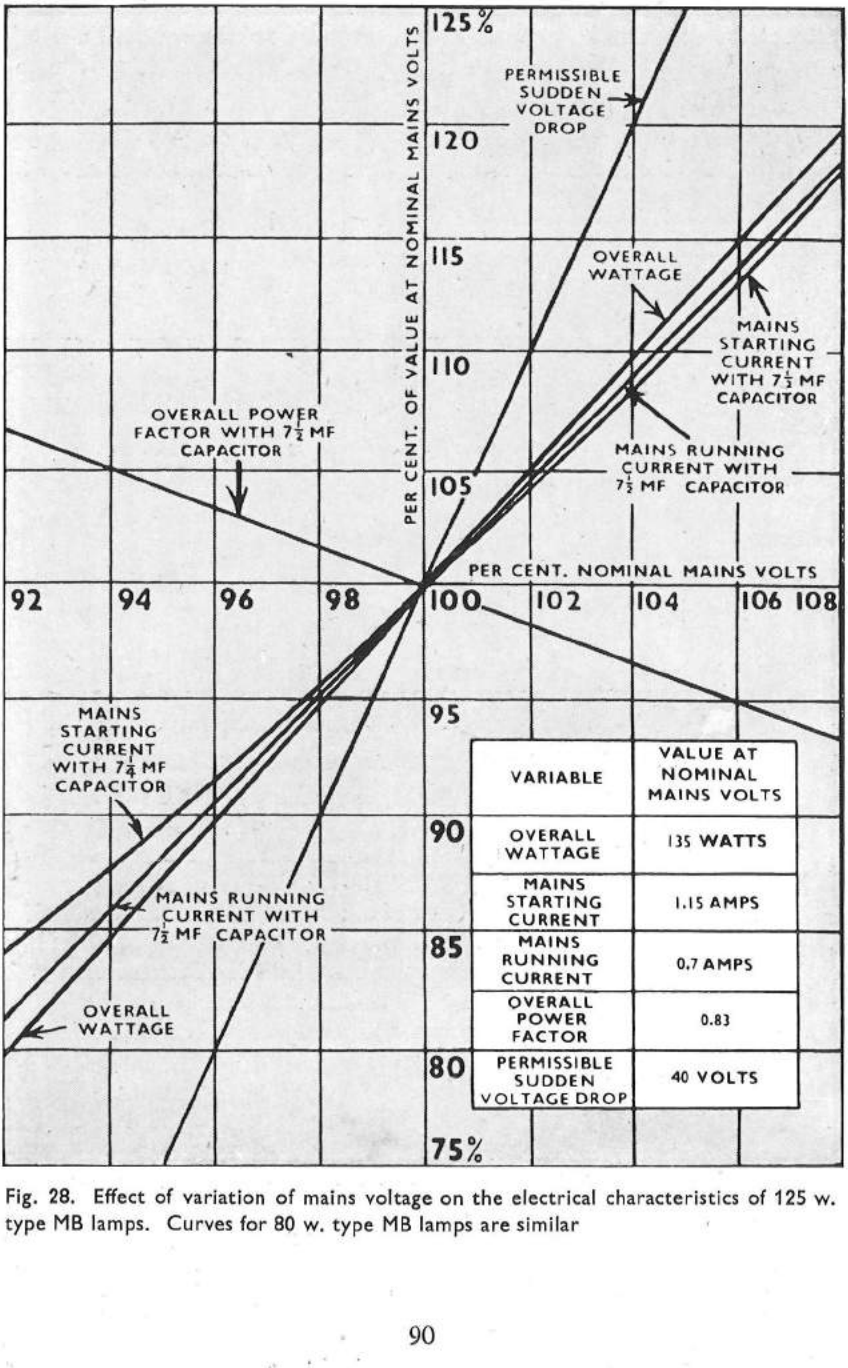
POWER FACTOR CORRECTION

Owing to the fact that the lamp current wave is non-sinusoidal it is not generally possible to correct the power factor of the circuit to unity, but as capacitor values are increased, the lagging power factor rises to a maximum of about 0·97 and then changes to a leading power factor and decreases.



VARIABLE	VALUE AT NOMINAL MAINS VOLTS
OVERALL WATTAGE	420 WATTS
MAINS STARTING CURRENT	4.5 AMPS
MAINS RUNNING CURRENT	2.25 AMPS
OVERALL POWER FACTOR	0.82
PERMISSIBLE SUDDEN VOLTAGE DROP	35 VOLTS

Fig. 27. Effect of variation of mains' voltage on the electrical characteristics of 400 w. type MA lamps. Curves for 250 w. type MA lamps are similar



VARIABLE	VALUE AT NOMINAL MAINS VOLTS
OVERALL WATTAGE	135 WATTS
MAINS STARTING CURRENT	1.15 AMPS
MAINS RUNNING CURRENT	0.7 AMPS
OVERALL POWER FACTOR	0.83
PERMISSIBLE SUDDEN VOLTAGE DROP	40 VOLTS

Fig. 28. Effect of variation of mains voltage on the electrical characteristics of 125 w. type MB lamps. Curves for 80 w. type MB lamps are similar

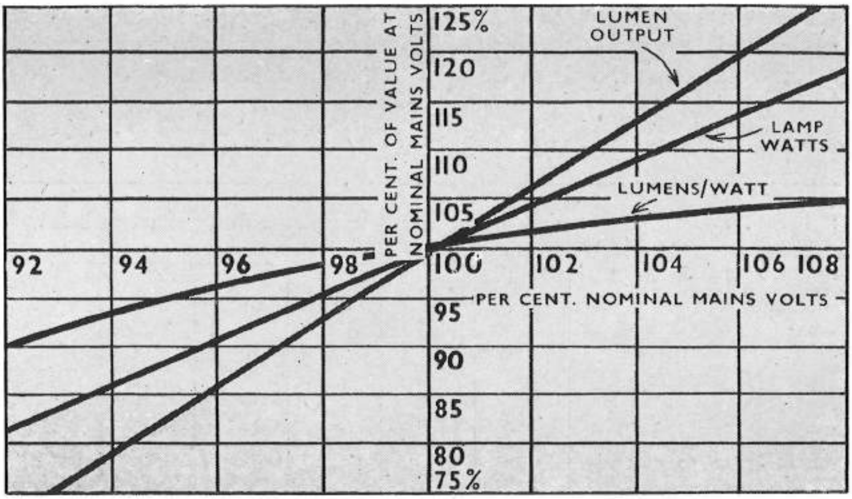


Fig. 29. Effect of variation of mains voltage on the lamp characteristics of 400 w. and 250 w. type MA lamps

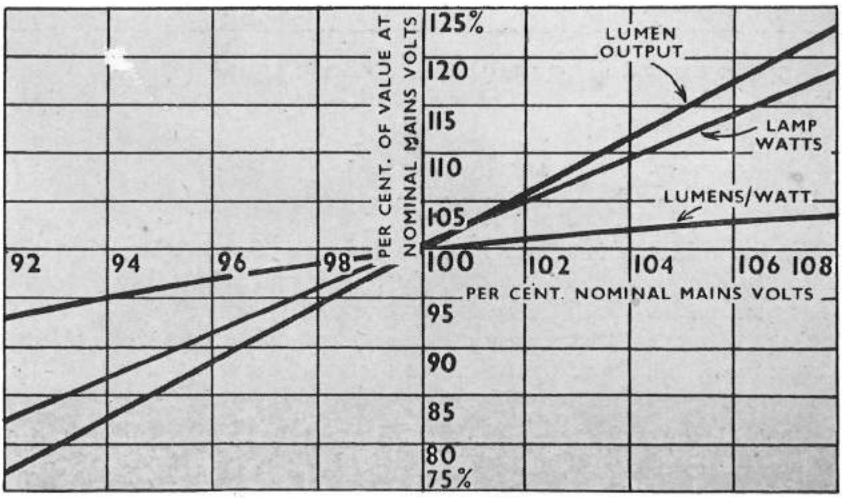


Fig. 30. Effect of variation of mains voltage on the lamp characteristics of 125 w. and 80 w. type MB lamps

A leading power factor is disliked by supply authorities and also requires a large capacitor. Generally a lagging power factor of about 0·8–0·85 is acceptable to all parties concerned, and may be obtained by connecting across the mains a capacitor of the value shown in the Table below.

Capacitor Values for Power Factor Correction

Lamp Watts	Mains Voltage	Capacity (mfd.) to give the Power Factors below					
		0·7	0·75	0·8	0·85	0·9	0·95
80	200–220	5·0	6·0	7·0	8·0	9·0	10·5
	230–250	4·0	4·5	5·5	6·5	7·5	9·0
125	200–220	7·0	8·5	10·0	11·5	13·0	15·5
	230–250	4·0	5·5	7·0	8·0	9·5	11·0
250	200–220	10·0	12·5	15·0	18·0	21·0	24·5
	230–250	7·0	9·0	11·0	13·5	16·0	19·0
400	200–220	12·0	16·5	20·5	24·5	29·5	35·5
	230–250	8·0	10·5	14·0	17·5	21·5	25·5

Capacitors used for power-factor correction are usually fitted with a high-value internal resistor which allows the charge to leak away when the circuit is switched off.

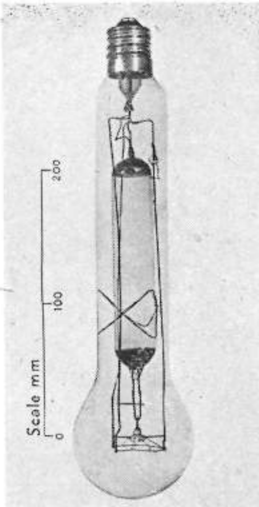
TYPE MAT LAMPS

Earlier reference has been made to the lack of red light emitted by mercury lamps, which emit violet, blue, green and yellow light strongly. Tungsten filament gasfilled lamps, on the other hand, give an excess of red light (compared with natural daylight) but emit progressively weaker radiation of colours of light towards the short-wave (violet) end of the spectrum. The two types of lamp are therefore to some extent complementary, and a combination of the two into a single bulb was successfully effected in 1935.

Mercury-tungsten (MAT/V) lamps consist essentially of the following components:—

(*a*) A hard-glass discharge tube similar in principle to that of MA/V lamps, including the starting electrode and resistor.

Type MAT/V lamp containing within the same outer bulb a mercury discharge tube and a tungsten filament, the latter exercising the necessary current control



(*b*) A coiled tungsten filament, part of which can be short-circuited by (*c*).

(*c*) A thermally operated bi-metal switch contained with the filament in an outer bulb which is filled with inert gas.

The lamp circuit diagram is shown in Fig. 31. When the lamp is switched on from cold, the bi-metal switch contacts are open, and current flows through the discharge path and the whole of the filament in series with it; filament dimensions are so arranged that lamp current is thereby limited to an appropriate value during this early stage of run-up.

As the mercury discharge builds up, the heat of the discharge plus the hot gas rising from the filament raise the temperature of the bi-metal strip sufficiently to bend it towards its contact and thus short-circuit part of the filament, the portion remaining in circuit being such that the requirements of the discharge in its fully run-up condition are satisfied.

Compared with ordinary mercury lamps, the mercury-tungsten lamp has three obvious advantages: since current limitation is secured by the filament within the lamp, no external apparatus such as a choke and capacitor are required; the colour rendering properties of the lamp are very considerably better, the red content of the light having been raised to approximately 8 per cent. (from 1 per cent.); and a fair quantity of light (chiefly from the filament) is obtained immediately the lamp is switched on from cold.

On the other hand, the luminous efficiency of the mercury-tungsten lamp is lower than that of ordinary mercury lamps of comparable wattage,

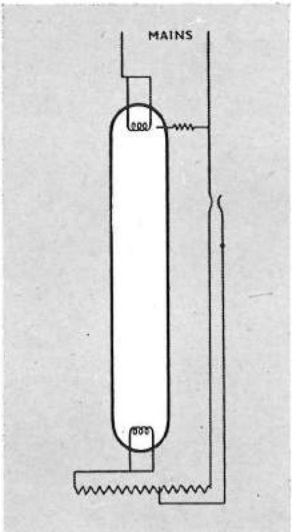


Fig. 31. Circuit diagram of a type MAT/V lamp, showing the starting electrode and the bi-metal switch short-circuiting part of the filament

though still higher than that of comparable gasfilled lamps. Also, the unusual length of some of the lamps almost certainly makes it necessary to use specially deep fittings to exert the required anti-glare control and to ensure a good colour-mix of the light before reaching the working plane.

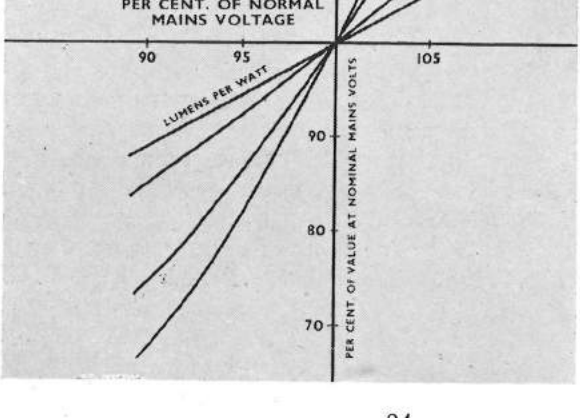


Fig. 32. Approximate lamp characteristics of the 500 w. type MAT/V lamp on varying mains voltage

MAT/V lamps *must* be burned vertically, cap up, or nearly so. As with ordinary mercury lamps, the discharge will not re-strike until the lamp has cooled after previous burning, and until the discharge strikes no current passes through the filament.

The 500 w. lamp may be obtained for use on D.C. supplies.

Details of MAT/V lamps will be found on page 142.

The lamp characteristics on varying mains voltage are shown graphically in Fig. 32.

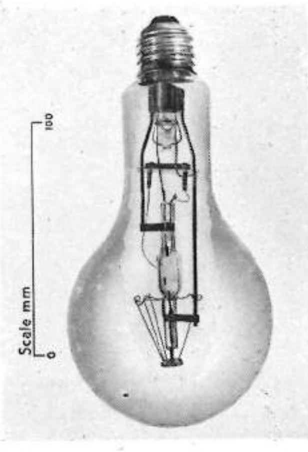
TYPE MBT LAMPS

These lamps are essentially similar to Type MAT lamps described above, but a small quartz discharge tube is employed, and a thermal switch is not necessary.

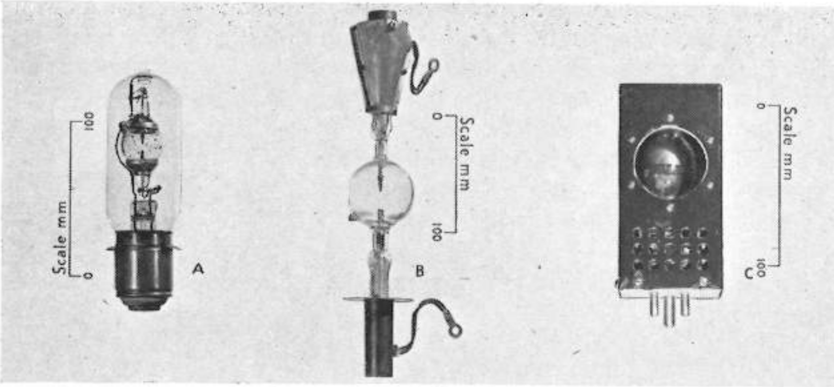
The lamp can be substituted in an industrial type reflector for a gasfilled lamp having similar bulb dimensions without altering the cut-off properties of the reflector, and the pearl outer bulb ensures a good blend of the two colours of light.

The MBT/V lamp of 200 w. should be burned vertically, cap up; the MBT/U lamps of 160 and 250 w. may be burned in any position.

Details of MBT lamps will be found on page 142.



Cut-away view of a 160 w. type MBT/U blended-light lamp



Three compact-source mercury lamps, type ME. LEFT: 500 w. CENTRE: 2500 w. RIGHT: 250 w., in metal box with window

TYPE ME LAMPS

In these lamps the source of light is a very short intensely bright arc between solid tungsten electrodes contained in a spherical quartz bulb which requires no artificial cooling. They are therefore very suitable for projection purposes.

ME lamps are in general suitable for operation on either A.C. or D.C. supplies with appropriate current-limiting equipment, though some are for D.C. operation only. When used on A.C. a special choke is required, e.g. the choke for a 250 w. MA lamp will *not* be suitable for the 250 w. ME owing to the different lamp characteristics.

In view of the high pressure developed, these lamps should only be operated within a protective housing to avoid any possible risk from fracture of the bulb. The 250 w. lamp is available with either a glass or

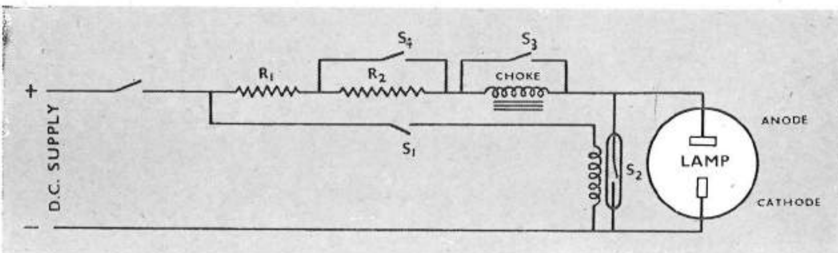


Fig. 33. Typical circuit diagram for a large type ME lamp. For starting, S_2 and S_4 are closed. Closing S_1 opens vacuum switch S_2, inducing in the choke a voltage impulse to start the lamp. S_3 is then closed. For simmering, S_4 is opened, bringing R_2 into circuit

metal jacket, the discharge bulb in the latter case being mounted in a box having a glass window through which the light is emitted; no additional protective housing is required for this type.

Of the larger sizes, only the 500 w. lamp has an outer bulb. It is therefore convenient with lamps over 500 w. to use a double-ended construction which allows leads to be taken from each end of the lamp to a sufficient distance from the arc to keep terminals at a reasonable temperature.

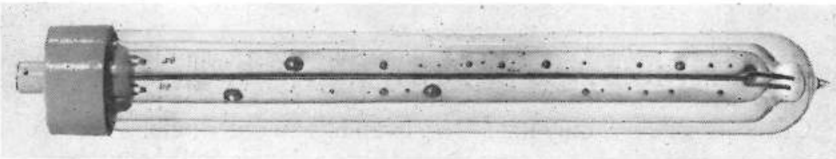
Several unusual technical problems peculiar to these lamps have had to be solved. In the first place, means have had to be found of keeping the arc absolutely steady between electrodes, for where the arc dimensions may be only of the order of $3 \cdot 75 \times 1 \cdot 5$ millimetres any slight movement would have a serious effect on the steadiness of the beam projected by an optical system. Secondly, a new technique of sealing-in has had to be developed since normal seals would not carry the heavy current required by these lamps, and the usual method is to use multiple molybdenum foil which can be sealed directly into quartz and will safely carry up to 10,000 amps. per sq. cm. of cross section.

A third difficulty lies in choosing a suitable bulb diameter and thickness. Too small a bulb would weaken through over-heating and burst under the vapour pressure developed (about 25 atmospheres in the small sizes, less in the larger); too large a bulb would be mechanically weak in relation to the internal pressure even though it remained relatively cool; and though in theory it is possible to strengthen such a bulb by increasing wall thickness, in practice it is found that with too thick a wall thermal stresses are set up during fabrication or operation of the lamp and would probably lead to rupture. A wall thickness of the order of 5 mm. is found generally satisfactory for the larger sizes.

The lamp takes 10 minutes or more, according to size, to reach full brightness, and the normal cooling period must elapse before it can restrike after being switched off when hot. In the case of the larger sizes such as are used in cinema spotlights, this delay would be undesirable and can be avoided by keeping the lamp "simmering" (i.e. running at much reduced power) while it is not required for use.

Fig. 33 shows a circuit arrangement adopted for one of the large ME lamps.

Since the lamps are intended for projection purposes, arc size and brightness are the factors of importance optically, and are tabulated on page 143. In type MEC lamps some cadmium, or cadmium and zinc, in addition to mercury are inserted, the resultant colour-corrected light having a red content of some 10 per cent.



Sodium lamp (type SO/H) in a detachable vacuum jacket. The droplets of metallic sodium must be well distributed throughout the length of the U-shaped discharge tube

SODIUM LAMPS (TYPE SO/H)

Sodium discharge lamps consist of the following essential features:—

1. A discharge tube made of special glass, containing metallic sodium and a little neon.
2. An electrode sealed into each end of the discharge tube.
3. A double-walled vacuum jacket serving as an outer bulb.
4. Cap, internal connections and supports.

An electric discharge in sodium at low vapour pressure emits luminous radiation which, for practical purposes, may be regarded as being concentrated in two lines at 5890 Å and 5896 Å. These two lines are, in fact, so close together that the sodium lamp is often loosely stated to be a source of monochromatic yellow light with a mean wavelength of 5893 Å. This wavelength, corresponding to chrome-yellow light, is not far removed from the wavelength of maximum eye sensitivity (see Fig. 2) and this largely accounts for the high luminous efficiency obtained.

The efficiency of a sodium lamp is reduced rapidly as the current density is raised above a certain optimum value, and the lamp must therefore be operated at a low current density. The surface area of the tube in which the discharge takes place is thus necessarily large in relation to the wattage dissipated, and unless the tube is thermally insulated it would lose heat too rapidly to allow the metallic sodium within to be vaporised. A double-walled vacuum jacket, similar to that used in ordinary domestic vacuum flasks, is therefore used to enclose the discharge tube. The jacket, in most instances, is detachable and may be used for a second or third lamp after the first one fails.

As noted on page 75, the luminous efficiency of the lamp increases with the length of the discharge arc, other things being equal. Sodium lamps are therefore made with rather long discharge tubes which, for convenience, are bent into the form of a U. In using the lamp, it should be borne in mind that "excited" sodium vapour is opaque to its own radiation, i.e. the light from one limb of the U will not pass through the other; when the lamp is fitted horizontally into a reflector or refractor, as is normally the case, the limbs should be arranged one vertically above the other, as this position is found to give the greatest output from the fitting.

Hot sodium vapour is very active chemically and would attack ordinary glass. The U tube is therefore made of ply glass, the inner layer being of low silica content and high purity, and the outer ordinary soda glass. Even so, the lamp should never be moved while hot, otherwise the sodium might collect at one end of the tube, where it might attack the glass in the neighbourhood of the seal wires.

OPERATION AND CHARACTERISTICS

SO/H lamps are suitable for operation on A.C. supplies only. They contain droplets of metallic sodium evenly distributed along the length of the U tube, which is also filled with neon at a low pressure in order to

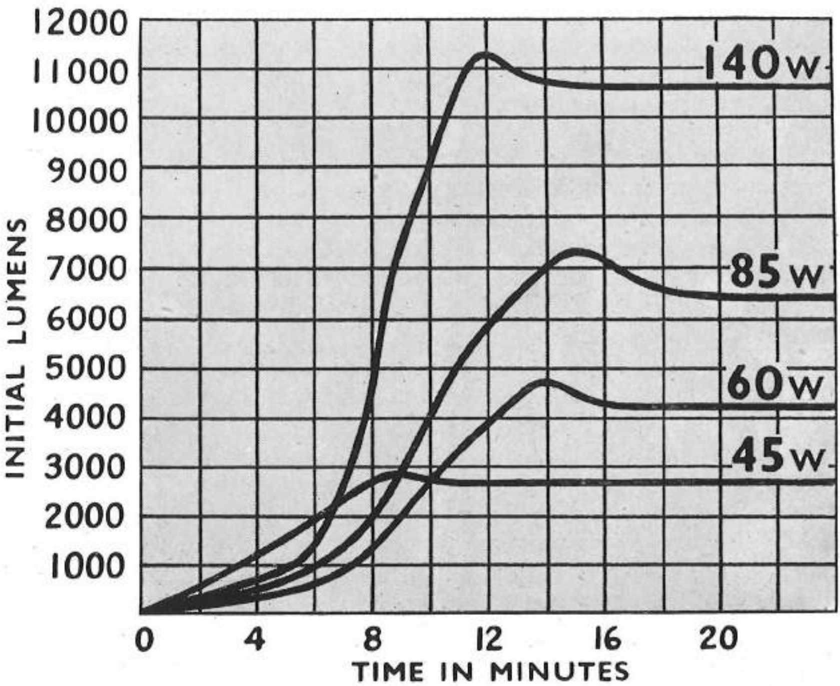


Fig. 34. Relation between the luminous output of sodium lamps and the time after switching on

assist starting. Each lamp must be connected to the mains *via* a step-up stray-field transformer with an open-circuit secondary voltage of about 480 v. which provides sufficient voltage for starting, with progressively lower voltage as the neon discharge vaporises the metallic sodium and the lamp current increases. The pitchfork support between the limbs of the U tube acts as an external auxiliary electrode and facilitates starting. Stable running conditions are reached after an interval varying from about 10 minutes with the 45 w. lamp to 20 minutes for the 85 w. lamp (Fig. 34). No auxiliary circuit is required to warm the oxide-coated electrodes, the heat of the discharge being sufficient to maintain them at a suitable temperature. The 45 w. lamp may, if desired, be burned in any position between horizontal and vertical, cap up, but the other three sizes must be used in the horizontal position, *never* cap down.

As the lamp operates at low vapour pressure, there is no delay in striking the arc if the lamp is switched on while still warm from previous burning. The brightness of the lamp at starting will of course depend on the amount the lamp has cooled since being switched off.

Should a relatively new lamp strike normally but take an exceptionally long time to reach full brightness, or even fail to reach full brightness at all, a faulty vacuum jacket is a likely cause. Poor vacuum would permit too much heat to be convected away from the lamp, so that it never reached proper operating temperature.

The SO/H lamp operates at a vapour pressure and temperature which give maximum luminous efficiency combined with high light output. Should excess voltage be applied to the lamp, lamp wattage will rise, but at the same time the luminous efficiency will be decreased owing to the fact that a lower proportion of the energy radiated will be in the visible waveband, and a greater proportion in the infra-red. The light output may in fact rise by some 2 per cent. at slight excess voltage (Fig. 35), but at greater voltages starts to fall. If the mains voltage is too low, light output again decreases. Either too high or too low mains voltage will result in a shortening of useful lamp life, the former by overheating the electrodes and thus evaporating the active coating, the latter by under-heating the electrodes, leading to loss of active material by sputtering. The end of life may be indicated either by failure to start, due to the transformer being unable to supply sufficient voltage to overcome the loss of electrode material, or by the light output falling to an uneconomic figure due to the migration of sodium to one end of the U tube.

One size of transformer is suitable for any of the three smaller sizes of sodium lamps, since they all operate at the same current.

Lamp details will be found on page 144.

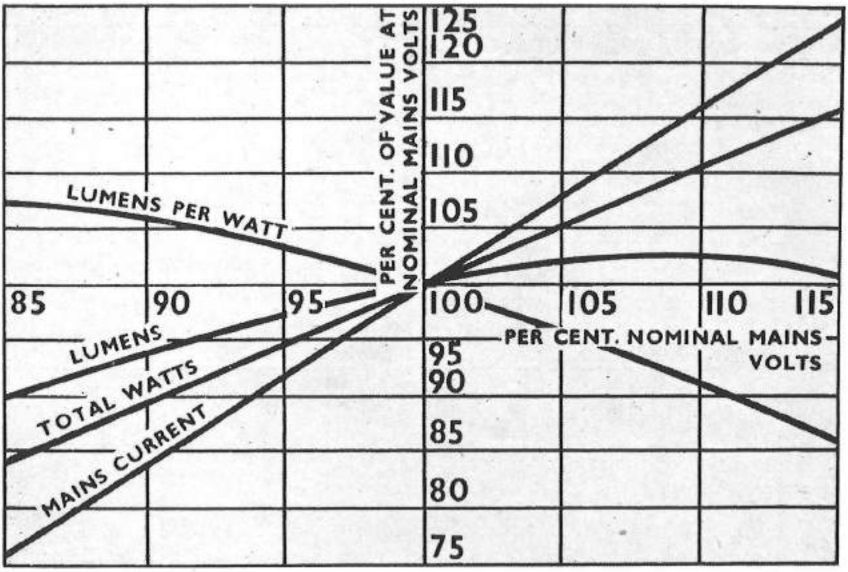


Fig. 35. Effect of variation of mains voltage on the lamp characteristics of sodium lamps

The power factor of the lamp and transformer alone is about 0·3. Power factor correction is obtained by connecting across the mains a capacitor of the value shown below.

Capacity in mfd. to give the following power factor

Lamp Watts	Mains Voltage	0·7	0·75	0·8	0·85	0·9
45	190–210	18·0	19·0	19·5	—	—
45	210–230	16·0	17·0	18·0	—	—
45	230–250	13·5	14·0	15·0	—	—
60	190–210	17·0	18·0	19·0	20·0	22·0
60	200–220	15·0	16·0	17·0	18·0	19·0
60	220–240	13·5	14·5	15·5	16·0	17·0
60	240–260	11·0	12·5	13·5	14·0	16·0
85	190–210	16·0	17·0	19·0	21·0	23·0
85	200–220	14·0	16·0	17·0	18·0	20·0
85	220–240	11·5	12·0	13·0	14·0	16·0
85	240–260	9·0	10·0	11·0	12·0	13·0

Capacity in mfd. to give the following power factor—*continued*

Lamp Watts	Mains Voltage	0·7	0·75	0·8	0·85	0·9
140	190–210	27·0	29·0	32·0	35·0	38·0
140	200–220	24·0	26·0	29·0	32·0	34·0
140	220–240	18·0	20·0	21·5	23·0	25·0
140	240–260	15·0	16·0	18·0	19·0	22·0

Since metallic sodium may burn if brought into contact with moisture, care should be exercised when breaking up old lamps for disposal. The best plan is to break them up into small pieces in a bucket or other suitable container which is then stood in an open place and filled with water. After a few minutes the residue may be removed safely.

TUBULAR FLUORESCENT LAMPS (TYPE MCF/U)

CONSTRUCTION

The lamp consists essentially of a clear glass tube coated internally with fluorescent powder, and with an electrode sealed into each end. Since the electrodes require to be heated before the lamp strikes, both ends of each electrode are brought out of the ends of the lamp and connected to suitable caps. The tube is filled with a very low pressure of mercury vapour, with a little argon to assist starting, and operates at a temperature low enough to permit the fluorescent powder to be used on the internal surface of the tube.

The electrodes are fitted with metal extensions which act as anodes, while the hot electrodes act as cathodes during the other half of the A.C. cycle. No auxiliary internal electrode is required for starting, which is effected by means of the special circuit employed.

TECHNICAL

When an electric discharge passes through mercury at very low vapour pressure the amount of light generated is very small, but some 60 per cent. of the input wattage may appear in the form of ultra-violet radiation,

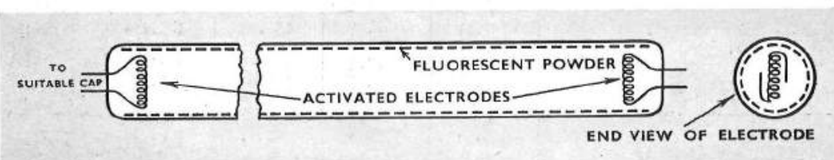
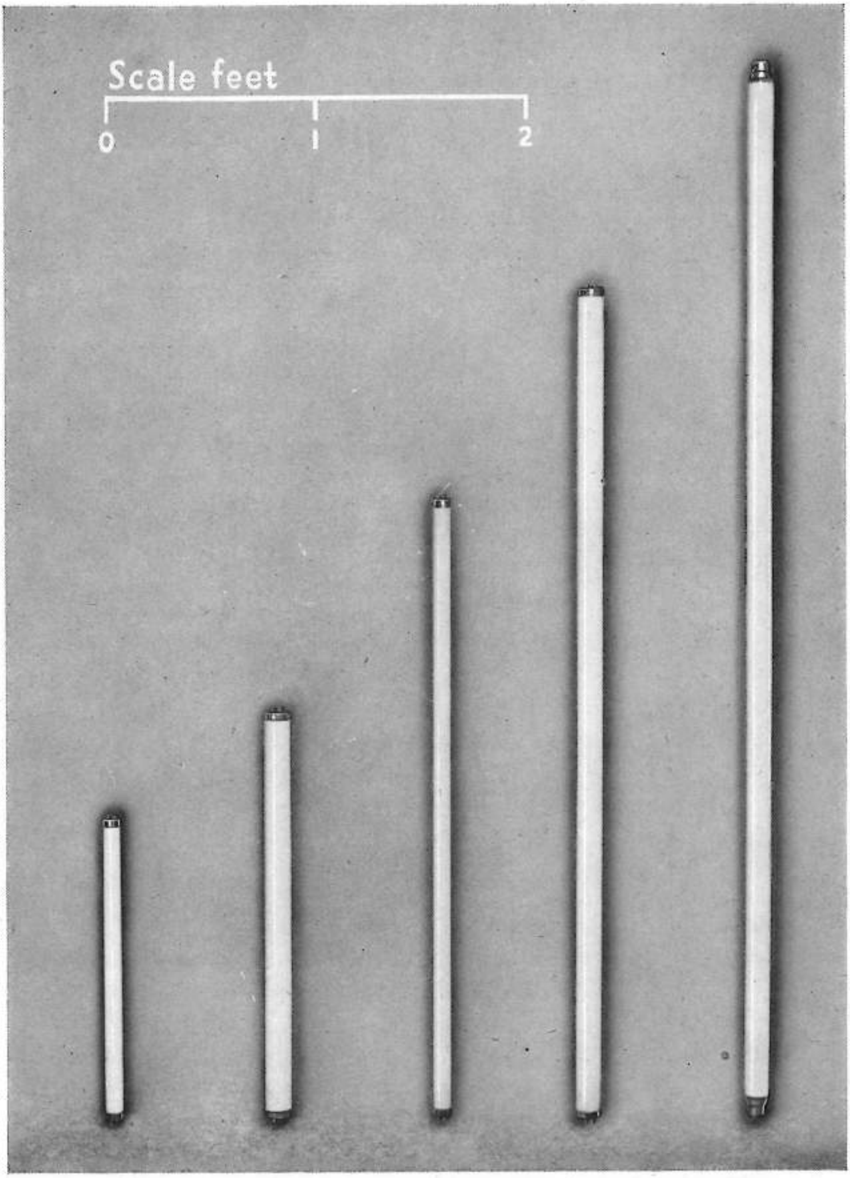


Fig. 36. Simplified diagram of a hot-cathode fluorescent lamp. In the case of an instant-start lamp a conductor connecting the shells of the caps is fixed along the outside of the lamp



The standard range of fluorescent lamps up to 5 ft. in length (left to right) 15 w. 1½ ft. × 1 in.; 20 or 40 w., 2 ft. × 1½ in.; 30 w., 3 ft. × 1 in.; 40 w., 4 ft. × 1½ in.; 80 w., 5 ft. × 1½ in.

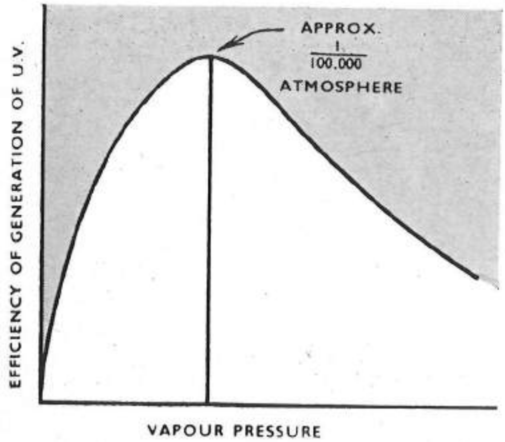


Fig. 37. As mercury vapour pressure is increased the efficiency of generation of ultra-violet increases to a maximum, then falls owing to re-absorption of the radiation by the vapour

particularly at a wavelength of 2537 Å. Fluorescent powder or powders can be manufactured which will convert this radiation very efficiently into light with a continuous spectrum, and by a suitable choice of powder(s) it may be possible to obtain from a discharge source a light which closely approximates natural daylight or any other colour of light.

The dimensions of a tubular fluorescent lamp are determined by considerations of wattage dissipation, vapour pressure and current density.

1. The amount of ultra-violet generated depends, other things being equal, on the wattage dissipated in the discharge column. In order that this wattage shall be a large proportion of the total lamp wattage, the discharge column must be long (page 75).
2. If other conditions are kept constant but vapour pressure is raised from zero, the efficiency of generation of ultra-violet at 2537 Å will at first rise (Fig. 37) but reaches a peak value and thereafter falls because an increasing amount of radiation becomes re-absorbed by the vapour. It is found that a vapour pressure of about $\frac{1}{100000}$ atmosphere is the optimum value, and tube temperature must therefore be controlled so as to give approximately this pressure.
3. Other things being equal, maximum efficiency of generation of 2537 Å ultra-violet requires very low current density (amps. per sq. cm.) in the tube (Fig. 38). On the other hand, very low current density in a tube of reasonable diameter means that total tube current is low, therefore tube watts are low; therefore, however efficient, not very much ultra-violet will be generated. Thus a compromise between the requirements of maximum efficiency and total useful radiation must be reached.

The final choice of dimensions for commercially-produced lamps is, of course, the result of a compromise between practical considerations and the factors outlined above.

ENERGY CONVERSION

The manner in which the input energy of a fluorescent lamp is dissipated is approximately as follows (based on the 80 w. lamp):—

	Generation of conducted and convected heat by:—		Generation of short-wave ultra-violet			Generation of light from the discharge
	Cathode Fall	Discharge Column				
In plain 80 w. tube, with no fluorescent coating, wattage is dissipated thus:—	12	18	48			2
When fluorescent coating is added, the 48 w. ultra-violet is converted thus:—			To conducted and convected heat 13	To radiant heat 24	To fluorescent light 11	

	Conducted and convected heat	Radiant heat	Light
The complete lamp dissipates wattage thus:—	43	24	13
Wattage dissipation of a number of theoretical 80 w. gasfilled lamps totalling equal light output	80	153	22*

* The discrepancy between this figure and the one immediately above is due to the gasfilled lamp generating most of its light at the red end of the spectrum, to which the eye is comparatively insensitive.

It will be seen that fluorescent lamps give about half as much conducted and convected heat as gasfilled lamps of equal light output, and this may be important in, for instance, air-conditioned interiors where heat removal may be a problem. The heat radiated by a fluorescent lamp, however, is only a small fraction of that from equivalent gasfilled lamps, and herein lies a great advantage, for radiant heat travels with the light and warms

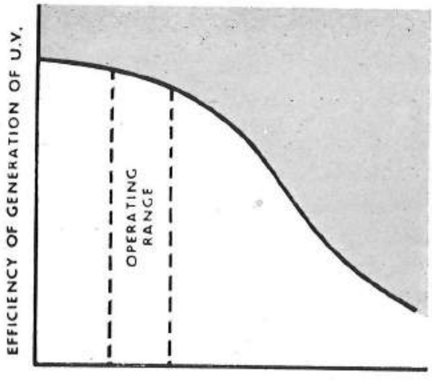


Fig. 38. Considerations of efficiency require the current density in a fluorescent lamp to be low, yet high enough to give a useful lamp wattage

everything the light reaches directly. Thus fluorescent lamps may, if desired, be mounted low to give high illumination values without the heat discomfort formerly associated with low mounting.

COLOUR

In early examples of the tubular fluorescent lamp, from 1940 to 1947, the powder used was a mixture of three other powders, with proportions adjusted to give either the "daylight" or "warm white" colour desired. The three primary powders were commonly:—

Zinc beryllium silicate, fluorescing yellow
Magnesium tungstate, ,, blue
Cadmium borate, ,, red

Each of these had to be mixed in manufacture with a minute trace of an "activator" which controlled the effectiveness of the powder, then all three were mixed together. By 1947, however, prolonged research had enabled a single powder—an activated calcium halophosphate—to be produced and used in lamps to give white and near-white colours of light, according to the activator employed. Standardisation of colour was thus simplified, and the new powder gave, in addition, a considerably greater light output coupled with better maintenance of light throughout life.

There is no difficulty in producing a near-white fluorescent lamp of any particular shade. However, a lamp having the same overall colour as for example daylight will not necessarily render colours exactly as daylight does for its spectrum may be slightly different. Of importance to the user of fluorescent lamps is the fact that out of the almost infinite number of possible shades standardisation of a range of colours has been achieved, the colours selected combining good colour quality with high luminous efficiency and maintenance through life.

The "natural" colour lamp, introduced in 1948, gives fairly true colour rendering, and is likely in due course to become more widely used than the "daylight" which, though appearing to be of very similar colour, is deficient in deep red light. The "warm white" lamp gives a pinker light which may be more acceptable for some purposes.

Where the radiating properties of a light source are similar to those of a "black body" the colour of the light may conveniently be described by assigning to it an appropriate "colour temperature," e.g. a source with a colour temperature of 4000° K. would give a colour of light similar to that of a "black body" at 4000° absolute (= 4000° K.).

The spectra of three of the four present standard colours of fluorescent lamp are not in close agreement with that of a black body, and British lamp manufacturers in general consider that to quote figures of colour temperature for them would be more misleading than informative.

There is no particular problem associated with the production of coloured light by means of fluorescence, and colours additional to the present standards will probably be made in the future.

Colour matching lamps are referred to on page 145.

THE CIRCUIT

Normal mains voltage is generally insufficient to initiate a discharge in an MCF/U lamp when the electrodes are cold and the gas and vapour contents of the tube in an un-ionised state. Means must therefore be found to heat the electrodes before starting, and to arrange for a degree of pre-ionisation of the vapour, or to provide a high voltage, or perhaps to do all these if a simple and reliable method can be found. The method usually adopted is as follows:—

Each electrode is constructed of tungsten wire in the form of a coiled coil through which a current is passed for a few moments before the discharge strikes. This has the effect of heating the electrodes and their coating of rare earth oxides, making them more capable of emitting electrons and thus reducing the voltage required for starting. At the same time, the passage of current through the coils sets up a small potential sufficient to initiate a glow discharge between opposite ends of each electrode, thus ionising the gas and vapour in the vicinity of the electrodes and further aiding the striking of the main discharge. When the electrodes have become sufficiently warm, the heating circuit is broken automatically (Fig. 39) and the choke, in resisting the sudden interruption of current, generates a momentary high voltage by self-induction. This high voltage is impressed on opposite ends of the lamp, and is sufficient to initiate the main discharge; ordinary mains voltage is subsequently more than sufficient to maintain it.

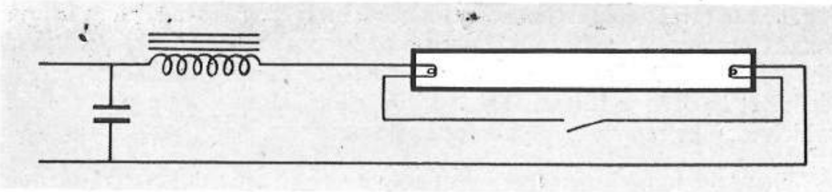


Fig. 39. Schematic diagram of a simple hot-cathode fluorescent lamp circuit

In adopting this device, the manufacturers have deliberately balanced the advantages against the disadvantages. On the debit side there is the fact that an auxiliary circuit is necessary, and a delay of, say, 1 to 2 seconds occurs after switching on before the lamp strikes. On the credit side, non-productive electric power consumed is reduced to a minimum, and the electrodes receive the gradual pre-heating which ensures a long and efficient life.

An alternative method, applicable at the time of writing only to the 80 w. lamp, is to connect a high-reactance auto-transformer across the lamp (Fig. 40). When first switched on, almost full mains voltage is applied across the lamp and transformer, and the electrodes are heated to operating temperature. When they become hot the applied voltage is sufficient to initiate the main discharge. Lamp voltage then falls to its normal operating value, and this reduced voltage is applied also to the transformer, which then supplies less electrode heating current. The electrodes are maintained at proper operating temperature partly by this current and partly by the action of the discharge. This method, which requires the presence of an earthed metallic strip connecting opposite ends of the lamp, gives a quicker start than the switch-operated circuit.

Various other methods of starting are, or from time to time have been, adopted. The least desirable from the point of view of lamp performance takes the form of a leakage reactance transformer or similar device to provide an extra-high open-circuit voltage which starts the lamp instantaneously without any pre-heating of the electrodes. It is possible that in due course electrodes will be perfected which will enable pre-heating to be dispensed with, but up to the time of writing it has not been found possible to avoid the disintegration and dispersal of active electrode coating when a discharge is forced between cold electrodes, thus very seriously reducing the useful life of the lamp.

STARTER SWITCHES

The automatic starter switches used to break the circuit when the electrodes are hot are of two types, Glow (voltage operated) and Thermal (current operated).

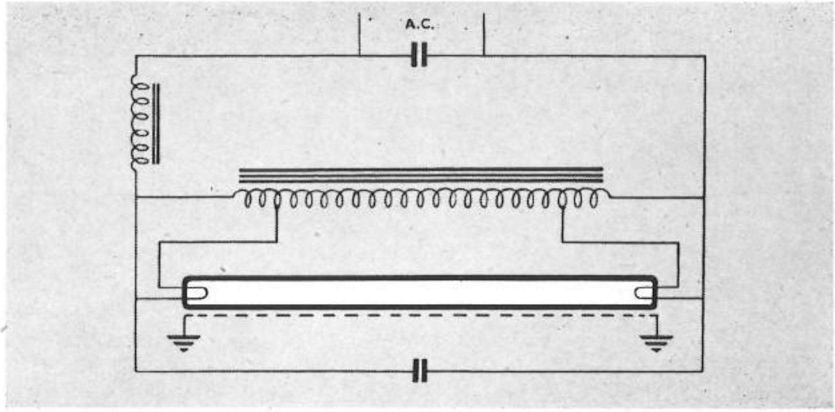


Fig. 40. Instant-start circuit diagram for a 5 ft. lamp. In practice the auto-transformer is smaller than the choke, and may be combined with it in one unit

1. *Glow Type* (Fig. 41)

A bulb filled with helium or other gas contains two contacts, one of which is mounted on a bi-metal strip. The contacts are normally open.

When the circuit switch is closed, almost full mains voltage appears across the switch contacts, and this is sufficient to strike a glow discharge between them in helium. The design of the starter is such that only a small current, up to 0·1 amp., flows at this stage, but the heat of the discharge warms the bi-metal strip and closes the contacts. This allows full heating current to pass through the lamp electrodes.

The closing of the starter contacts extinguishes the discharge between them, and after a few moments the bi-metal strip cools sufficiently to open the circuit, thus starting the lamp. The voltage across the starter contacts is then equal to lamp voltage, and being well below mains voltage is insufficient to re-strike the glow discharge. The starter contacts therefore remain open until the next starting operation.

2. *Thermal Type* (Fig. 42)

Within a hydrogen-filled bulb, two contacts, touching each other at normal temperatures, are mounted on bi-metallic strips one of which is bent into U shape. Within this U, but not touching it, is a small coil of tungsten wire (the heater) connected in the main lamp circuit.

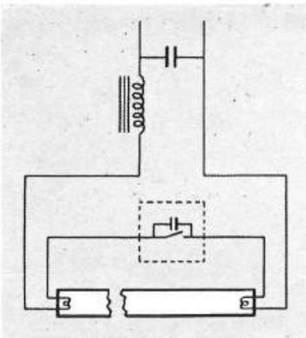


Fig. 41. Diagram of the glow starter circuit

When the circuit switch is closed, current flows through the heater and both lamp electrodes, raising the latter to operating temperature; it also warms the heater, which in turn warms the U strip and causes it to bend away from the other, thus breaking the circuit. The voltage then induced in the choke starts the lamp as explained previously.

It will be seen that when the lamp is alight, current continues to flow through the starter heater, thus keeping the contacts apart until the lamp is switched off, when the bi-metal U strip cools and the contacts close, ready for the next start.

The bi-metal strips are twisted to compensate for normal variations of atmospheric temperature. The heater consumes up to 1 watt of electrical power.

Except for replacements to existing installations, all starters are now enclosed in a metal canister having a four-pin base fitting into a standard size of socket. The pins are of different sizes, the two larger ones being connected to the switch contacts and the two smaller to the ends of the

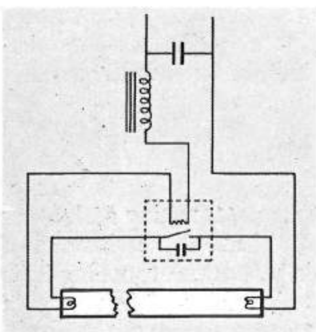
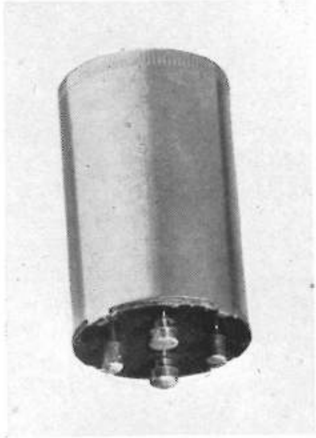


Fig. 42. Diagram of the thermal starter circuit

The metal canister containing either a glow or thermal starter



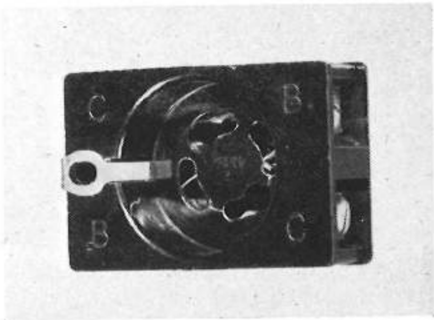
heater if the canister contains a thermal starter; if not, the two smaller pins are short circuited within the canister.

STARTER SOCKET

The standard socket is arranged with a slotted base so that the starter cannot be inserted incorrectly. Connections to the switch contacts of the starter are taken out to copper terminals at opposite corners of the socket, and those to the heater (if thermal starter) to the other two corners.

When the starter is removed, the socket blades making contact with the two smaller canister pins fall back on to a solid bar which short-circuits them. This device ensures that if necessary a starter may be removed without extinguishing the lamp.

In general, complete lighting fittings are wired up on the assumption that a thermal type starter will be used, as if this is done either type may be used at will.



Starter socket. The holes receiving the starter pins are of different sizes so that the starter cannot be inserted wrongly

RADIO INTERFERENCE SUPPRESSOR

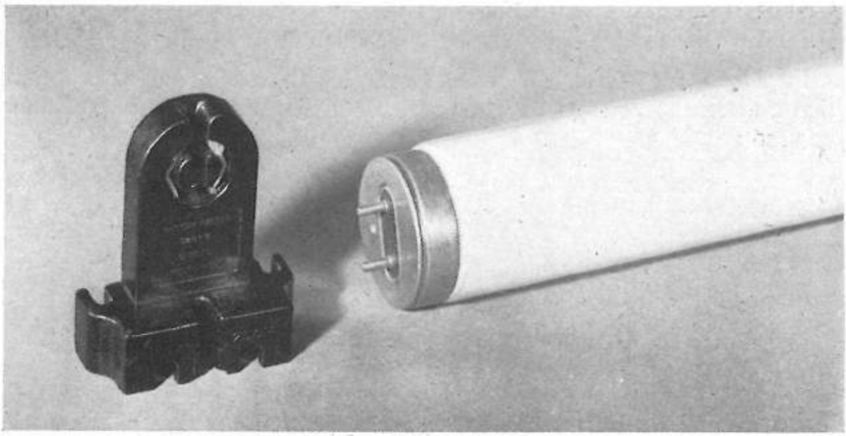
A small capacitor is connected across the starter contacts (and, in effect, across the lamp) in order to prevent radiation of any radio frequencies that may be generated within the lamp, and is generally effective in doing so except where the receiver is very close to the lamp. In such cases, if neither can be moved, removal of the lamp from its holders and rotation through 180° about its major axis, should effect a cure.

The radio suppressor assists the starter to break the circuit cleanly and gives a more certain start. It is normally enclosed with the starter in the canister. In early types of glow starter a 100 ohm resistor was connected in series, but this is now found to be unnecessary. Radio interference may also be caused by mains-borne disturbance originating in the lamp. The radio suppression capacitor is generally sufficient to damp this interference, and only in exceptional cases will a special filter circuit in the mains be necessary.

LAMPHOLDERS

The 80 w. lamp requires a B.C. lampholder at each end. 40 w. lamps and smaller sizes are fitted with bi-pin caps which require special holders into which the lamp is inserted and then turned 90° to lock into position. If the lamp is not properly inserted, it will not turn and the pins may suffer damage.

Due to the shortness of the lamp pins ($\frac{9}{32}$ in.) it is essential that holders be spaced accurately in order to prevent lamps from falling out or being



Bi-pin lamp cap and holder. The nominal length of lamps with bi-pin caps includes a lampholder at each end

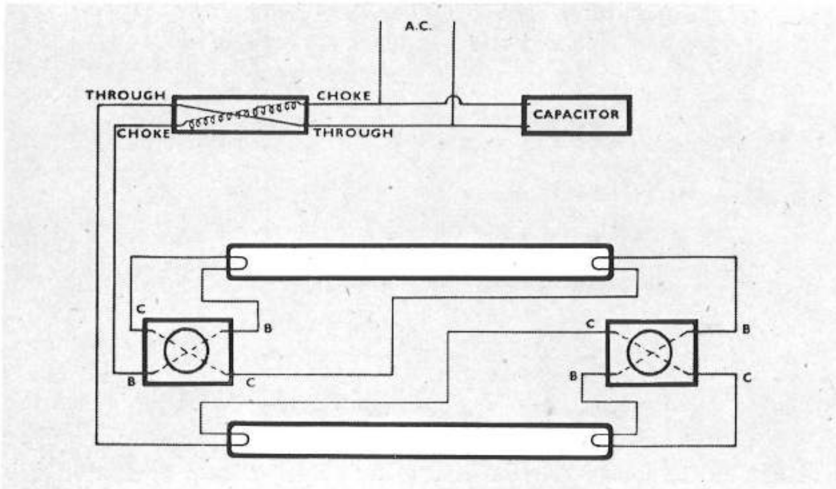


Fig. 43. Series circuit diagram for two 2 ft. or $1\frac{1}{2}$ ft. lamps. Starter socket terminals CC connect to the switch blades of the starter

too tight a fit. A small projection (which can be snapped off if not required) is moulded on to the rear cover-plate of each holder to assist correct location when mounted on wood or other soft material. Another type of holder, giving spring-loaded end-on pressure on the pins, has also been developed but has not yet been generally adopted.

Home Office regulations require the brass shell of bi-pin caps to be earthed. A spring clip mounted immediately in front of each holder does this conveniently, and also retains the lamp securely in position.

SERIES OPERATION

Lamps of the following sizes operate *singly* on 100/130 v. mains, or *two in series* on 200/250 v. mains:—

40 watts (2 ft. $\times$ $1\frac{1}{2}$ ins.) 20 watts (2 ft. $\times$ $1\frac{1}{2}$ ins.) 15 watts ($1\frac{1}{2}$ ft. $\times$ 1 in.)

For series operation of a pair of lamps, only one suitable choke is required, but each lamp of the pair must be of the same wattage rating. Single-lamp operation of the last two of the above-mentioned lamps on 200/250 volt mains is satisfactory provided that the circuit is designed to prevent cold starting of the lamp.

Starting arrangements must be provided for each lamp, either by two separate starter switches or by a composite 2-circuit switch. For the separate switches on account of the relatively low lamp voltage with these short lamps, the current-operated thermal type of starter is generally

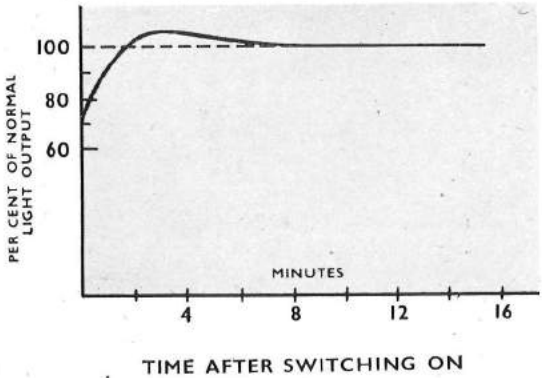


Fig. 44. Variation of light output of a fluorescent lamp for the first few minutes after switching on

employed, and is connected as shown in Fig. 43. With the composite 2-circuit switch the glow principle is used.

It should be borne in mind that a fault in one lamp or starter may strongly affect the other parts of the circuit (e.g. if the contacts of one starter fail to open, the other lamp will start normally but be seriously over-run; also the choke windings and the electrodes of the lamp to which the faulty starter is connected may eventually be damaged). It is therefore very advisible to investigate and rectify any such faults as soon as possible.

OPERATING VALUES

Light Output

At the instant of switching on, lamp temperature is equal to that of its surroundings, and as a result the vapour pressure within the tube is lower than its designed value. This is turn will affect both the wattage consumed and the efficiency of light production, so that the light output is slightly less than normal (Fig. 44).

During the first few minutes that the lamp is alight, the vapour pressure rises owing to the heat of the discharge, and light output increases to its normal value, or in some instances (as when installed in a closed-top trough fitting) to a value fractionally higher than normal; if this occurs, it gradually falls again to normal during the next fifteen to twenty minutes. It is therefore apparent that photometric readings should not be taken until the lamp has been burning for more than a quarter of an hour.

During its life, the light output varies approximately according to the curves shown in Fig. 45. There is a comparatively rapid drop, thought to be largely due to poisoning of the fluorescent powder by the mercury vapour, during the initial stages, and then follows a very slow and steady decline until the end of life.

Three figures of light output are quoted on page 145 for different stages of lamp life.

Brightness

The brightness of a tubular fluorescent lamp varies according to the light output at various stages of life. At the ends, near the electrodes, the brightness decreases.

The figures below refer to the maximum brightness as seen with the lamp at right angles to the line of view, but at more end-on viewing positions, particularly where the line of sight makes an angle of less than 25° with the major lamp axis, brightness is considerably reduced.

Watts	Brightness (Candles per sq. in.)		
	At 100 hours	Average thro' life	Final
80	$4\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{1}{4}$
40 (4 ft.)	$3\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{1}{4}$
40 (2 ft.)	$4\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{1}{4}$
30	$4\frac{1}{4}$	$3\frac{3}{4}$	$3\frac{1}{4}$
20	$2\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{1}{2}$
15	$3\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{1}{2}$

Power Factor Correction

Power factor correction of single-lamp or series circuits is normally effected by means of capacitors of the following values, connected across the mains:—

1–80 w. or 2–40 w. (2 ft.) in series . . . . . . 7·5 mfd.
1–40 w. (4 ft.), or 1–30 w., or 2 × 20 w. or 2 × 15 w. in series . 3·25 mfd.

These give a corrected power factor of 0·85–0·9 lagging in each instance. The uncorrected power factor is about 0·5 lagging.

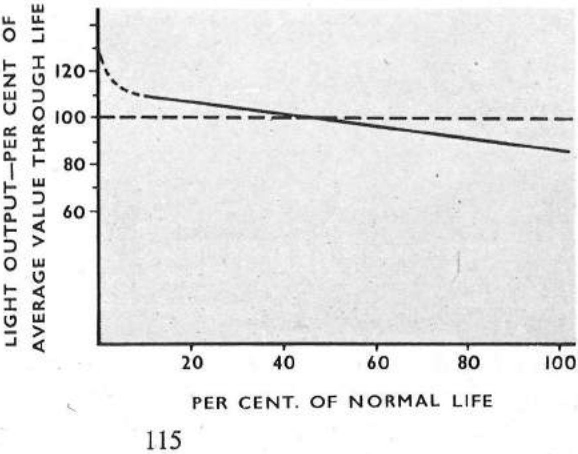


Fig. 45. Typical curve of light output of a fluorescent lamp throughout life. (Average throughout life taken as 100 per cent.)

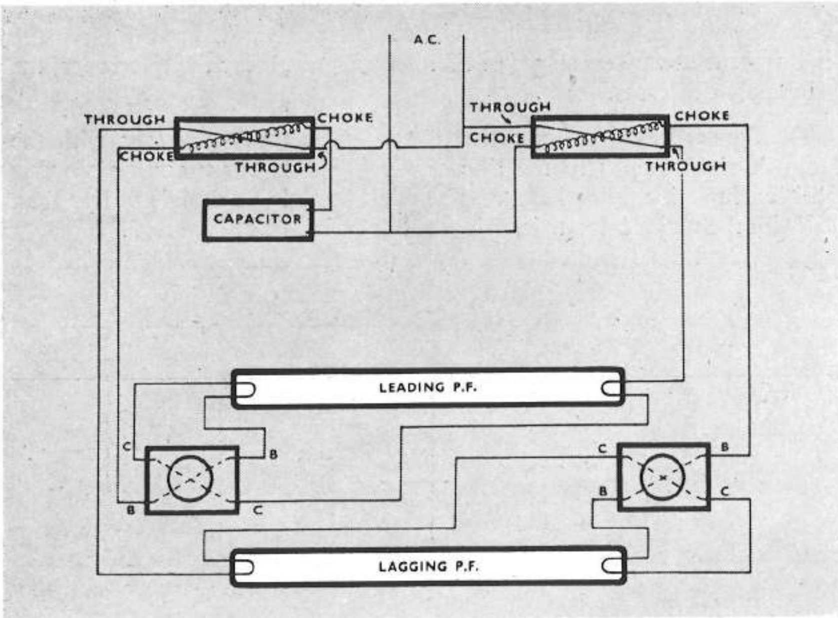


Fig. 46. Diagram of twin-lamp circuit for 3 ft., 4 ft., and 5 ft. lamps. On some mains voltages, choke ratings may be dissimilar

Cyclic Variation of Light Output

Though the discharge arc is extinguished 100 times a second on 50 cycle A.C. supplies, the light output does not fall to zero at these instants since the fluorescent powder is slightly phosphorescent and continues to glow throughout the extinction period. The cyclic flicker of the light is thus much less marked than would otherwise be the case and is generally unnoticeable on stationary or slow-moving objects.

Where it is desired to reduce this effect still further, two methods may be adopted:—

1. Where applicable, to connect adjacent lamps to different phases of supply.

2. To connect pairs of similar lamps on the twin-lamp circuit described below.

Twin Lamp Circuit

In this arrangement (Fig. 46) the normal power-factor capacitor(s) are omitted, but a capacitor is inserted in series with one of the chokes, and

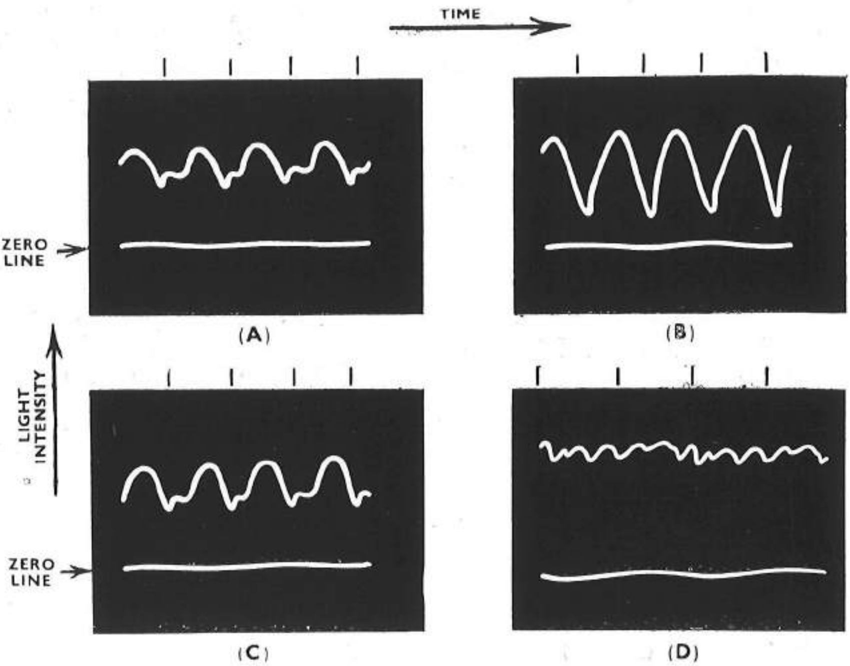


Fig. 47. Variation of light output of 80 w. fluorescent lamps on a 50-cycle supply. (A) Two lamps on twin-lamp circuit. (B) Two lamps both operated inductively. (C) Two lamps on different phases of 3-phase supply. (D) Three lamps, each on one phase of a 3-phase supply

results in a leading power-factor for that lamp circuit. Electrical constants are chosen so that this leading power-factor balances the lagging power-factor of the other lamp circuit, resulting in an overall power factor of very nearly unity (about 0·95).

The current in one of the lamps is displaced relative to the other by about 120°, and the light output cycles are similarly displaced. Peak output from one lamp therefore occurs at the instant that output from the other is nearing a minimum, and if the two lamps are in a single fitting, or are near together, the total light flux received at the working plane does not vary appreciably from instant to instant (Fig. 47).

In the lamp circuit with series capacitor a degree of resonance has to be provided in order to exert the required control over lamp voltage and current, and some 375 v. is impressed across the capacitor, which must be of appropriate voltage rating. Capacity values usually employed are 7 mfd. (80 w. or 2 × 40 w. 2 ft.); 3·5 mfd. (40 w. 4 ft. or 2 × 20 w.); 2·7 mfd. (30 w.); 2·7 mfd. (2 × 15 w.).

The two chokes also require to be of different voltage rating, as follows:—

Mains Voltage	Choke Rating	
	Lagging Circuit	Leading Circuit
200/210 220/230 240/250	200/210 220/230 240/250	240/250 220/230 200/210

In the U.S.A. a "compensator" (a small inductance) is generally inserted in the switch circuit of the "leading" lamp(s). The aim is to improve the starting characteristics of the lamp(s), but at the time of writing this device has not been generally adopted by British manufacturers.

On 200/250 v. A.C. supplies each "leg" of the twin-lamp circuit may, if desired, consist of two similar 2 ft. lamps connected in series (Fig. 48).

Mains Current

When MCF/U lamps are operating with appropriate control gear on 200/250 volt A.C. mains, the current in the mains is approximately as shown below:—

CURRENT IN MAINS.

With Inductive Control (Lagging Power-Factor)

1–80 w. or 2–40 w. (2 ft.) in series. 7·5 mfd. P.F. capacitor	1–40 w. (4 ft.) or 2–20 w. in series. 3·25 mfd. P.F. capacitor	1–30 w. or 2–15 w. in series 3·25 mfd. P.F. capacitor
0·5 amps.	0·25 amps.	0·17 amps.

With Lamps on Twin-Lamp Circuit

2–80 w. or 4–40 w. (2 ft.) 7 mfd. capacitor	2–40 w. (4 ft.) or 4–20 w. 3·5 mfd. capacitor	2–30 w. or 4–15 w. 2·7 mfd. capacitor
0·8 amps.	0·4 amps.	0·34 amps.

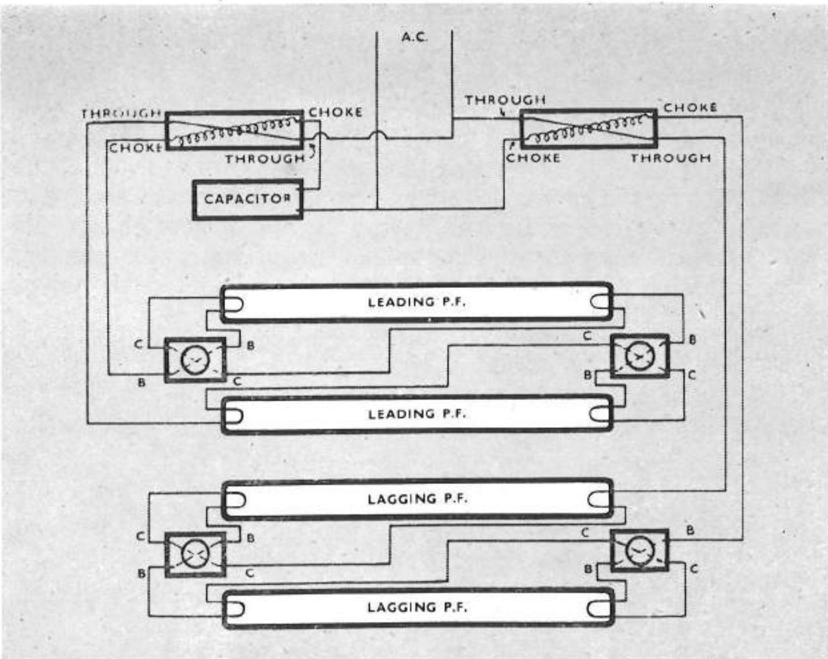


Fig. 48. Diagram of four-lamp series-parallel circuit. The upper pair are controlled capacitatively, the lower pair inductively

Emission of Ultra-Violet

The ultra-violet waveband may conveniently be divided as follows:—

(i) *Wavelengths between* 4000 Å *and* 3250 Å. These have no known medical or therapeutic effects. Under 50 L/ft.^{2} of fluorescent lighting, these wavelengths are present about one quarter of one per cent. as strongly as in natural sunlight.

(ii) *Wavelengths between* 3250 Å *and* 2900 Å. These are responsible for the tanning effect of sunlight. Under 50 L/ft.^{2} of fluorescent lighting, these wavelengths are present about two-thirds of one per cent. as strongly as in sunlight.

(iii) *Wavelengths less than* 2900 Å. These are potentially dangerous, blistering radiations sometimes used for sterilising and germicidal purposes.

Laboratory tests with equipment capable of accurate measurement of the intensity of these radiations at a strength as low as one-tenth of that known to be safe for a child under continuous exposure are *unable to detect the presence of such radiations* from fluorescent lamps. It is therefore correct to state that no dangerous radiation is emitted.

Some of the harmless long-wave ultra-violet, which is present in approximately equal quantities in fluorescent lamp light and tungsten filament lamp light of equal intensity, may however give rise to weak fluorescent effects which may be noticeable with some coloured objects. Certain dyes, particularly some blue and purple hues, are particularly sensitive to this ultra-violet and may undergo appreciable changes of apparent colour under natural daylight at different times of day, and under the various types of artificial illuminant in common use to-day.

Effect of Voltage Variation

The effect of mains voltage variation on the 80 w. lamp in a "lagging" circuit is shown in Fig. 49, the percentage variation with the 40 w. lamp

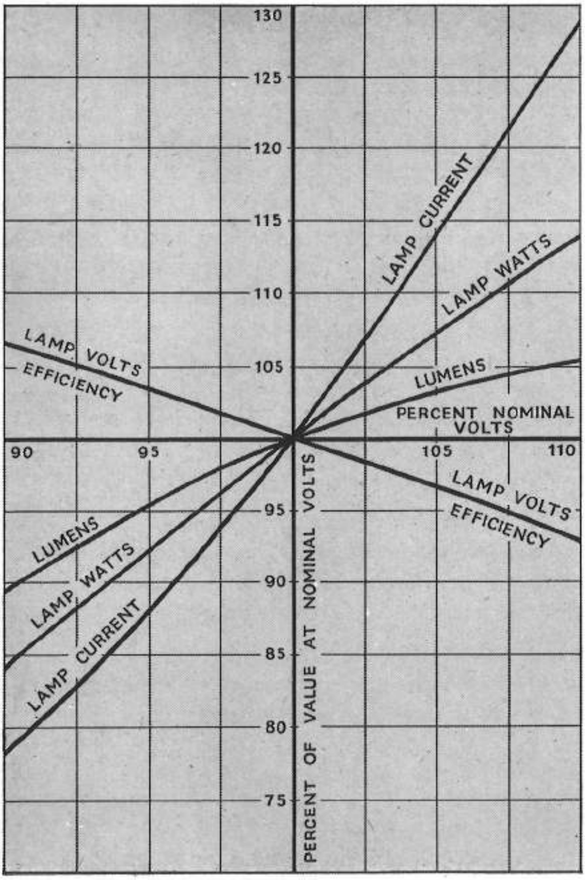


Fig. 49. Effect of variation of mains voltage on the characteristics of an 80 w. lamp. Curves for 4ft. lamps are similar

being substantially the same. It will be seen that a 1 per cent. variation of mains voltage changes the light output by less than 1 per cent., whereas the change with filament type lamps is about 4 per cent.

Apart from causing a change in light output, normal variations in mains voltage have no serious effect on lamp performance. At exceptionally low voltage, however (e.g. below 185 v. with normal room temperature on a nominal 200 v. supply, with a rather wider margin of safety at higher nominal mains voltages), lamp operation may become erratic, either because the lamp voltage available is not sufficient to maintain the arc, or because the starter contacts continually tend to close and re-open.

Effect of Temperature

MCF/U lamps give their rated light output in still air at an ambient temperature of 20° C., corresponding to a tube wall temperature of about 48° C., and this condition is likely to be realised with a single-lamp trough fitting in an ordinary interior, but a change in lamp temperature will vary the internal vapour pressure. This in turn affects both the wattage consumed by the lamp and the efficiency with which 2537 Å ultra-violet is generated, thus causing a change in light output as shown in Fig. 50.

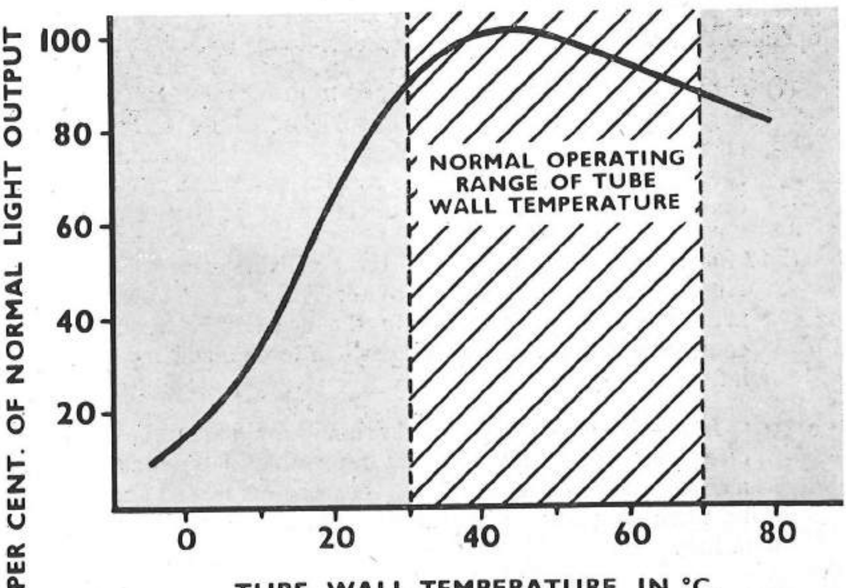


Fig. 50. Effect of tube wall temperature on the light output of a fluorescent lamp. In open fittings lamps usually operate at about 50°–55° C.

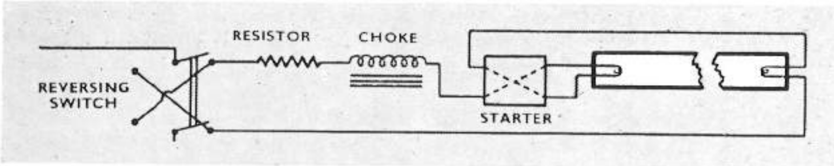


Fig. 51. Circuit diagram for D.C. supplies. The reversing switch should preferably be of the uni-directional rotary type

Enclosure to preserve lamp heat is obviously desirable when ambient temperature is low, and in well-designed street lighting fittings even the most severe weather does not cause a loss of light exceeding 10 per cent.

At temperatures below $-5°$ C. on 230 v. mains, or below 0° C. at mains voltages less than 200 v., some starting trouble may be experienced. Where such conditions are likely to occur, it is recommended that starters giving a relatively long pre-heating period be used, or alternatively that a hand-operated switch be substituted.

D.C. Operation

Though MCF/U lamps can be operated on direct current supplies, their advantage over filament type lamps is much less marked than when operated on A.C., for the following reasons:—

(1) Though the choke must be retained to provide the voltage impulse necessary for starting, it does not sufficiently limit the flow of direct current. A series resistor therefore has to be included in the circuit for this purpose (Fig. 51); this resistor consumes power, thus reducing the luminous efficiency of the circuit as a whole.

(2) After some hours of operation the positive end of the lamp goes dim compared with the negative end. This is due to electrophoresis, i.e. a migration of mercury to the negative end, and may be countered by fitting a reversing switch to change lamp polarity at intervals.

Note.—The reversing switch should preferably be of a uni-directional rotary type so that reversal of lamp polarity automatically takes place every time the switch is turned on. It should be fitted in place of the normal *circuit* switch, not the main switch.

(3) The lamp may not start easily on supply voltages below 220 v. D.C. It is recommended that thermal type or specially designed starters be used on D.C. supplies, whatever the voltage.

Approximate values recommended for the series resistor are as follows:—

Mains Voltage	Approximate Resistor Values (ohms)				
	1–80 w.	1–40 w. (4 ft.)	1–30 w.	2–40 w. (2 ft.)	2–15 w.
200	116	205	264	116	235
210	116	230	293	122	264
220	147	260	330	147	293
230	147	290	380	147	330
240	172	320	420	169	380
250	172	350	420	169	380

Fault Tracing

As fault tracing in fluorescent lamp circuits may be difficult until experience is gained, the following notes may prove a useful guide.

The end of useful lamp life may be indicated by the following symptoms:—

1. Lamp blinks on and off several times, probably with a shimmering effect along the tube.
2. Light output low, dark rings or patches along its length, with very dark rings near the cap.
3. A slow, pronounced flicker.

Faults may be recognised as follows:—

Symptom	*Probable Cause*
(*a*) Lamp appears quite dead when switched on.	1. Failure of supply or break in circuit (suspect broken electrode, lampholder plungers or heater of thermal starter). 2. Faulty starter.
(*b*) Lamp does not light when switched on, but one end glows.	1. Faulty thermal starter. 2. Earth in wiring of starter or radio suppressor unit. 3. Broken electrode.

Symptom	*Probable Cause*
(*c*) Lamp does not light when switched on, but both electrodes glow continuously.	1. Starter contacts have welded together or short-circuited. 2. Short circuit in radio suppressor unit.
(*d*) Lamp makes repeated efforts to start.	1. Lamp has run useful life. 2. Low voltage, cold draughts or low temperature. 3. Starter operation too rapid. 4. Incorrect control gear.
(*e*) Lamp continually starts and re-starts.	As (*d*) above. May also be due to glow starter continuing to glow while the lamp is alight.
(*f*) Column of light in the lamp appears to be moving, probably in a spiral.	Usually occurs only when lamp is new, and disappears after a short period of use.

Search for a fault can often be simplified by trying the starter from a suspected circuit in a good circuit. If the starter is found to be in order, the same procedure should be followed with the lamp from the suspected circuit. *A good lamp should never be inserted in a circuit that may be defective.*

8 FT. TUBULAR FLUORESCENT LAMPS (TYPE MCF)

Two 8 ft. long tubular fluorescent lamps became available in 1949.

(*a*) An 8 ft. (nominal) lamp of $1\frac{1}{2}$ in. diameter which, in all respects save length, is similar in construction to the 5 ft. 80 w. instant-start lamp.

This lamp is available in Natural colour only. A metal strip is cemented along the outside of the lamp to facilitate starting, but need not be earthed. The lamp may be operated at a loading of either 125 w. or 75 w., the loading being determined by the control gear, and may be associated with either of two circuits, both of which ensure adequate electrode preheating:—

Lagging power-factor circuit. A block-type leakage transformer is connected across the lamp (Fig. 52) where its purpose is to control lamp current, to step-up lamp voltage to the required value for starting (370 v. for the 125 w. and 450 v. for the 75 w. loading) and to supply heating current to the lamp electrodes. This heating current is automatically varied to suit both starting and running conditions as in the 80 w. instant-starting arrangements. With this circuit starting is practically instantaneous, and

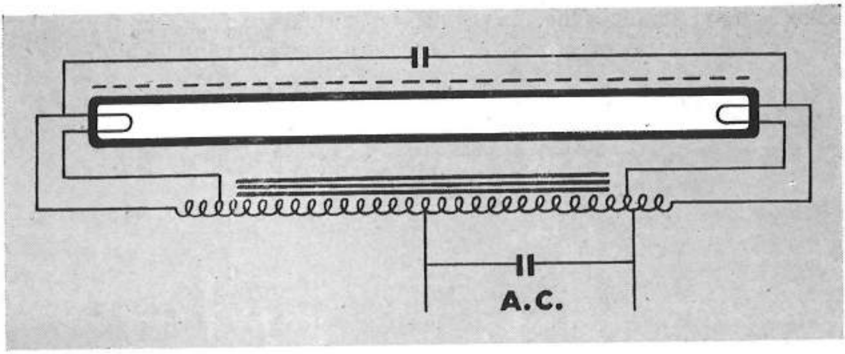


Fig. 52. Lagging power factor circuit for 8 ft. × 1½ in. lamps loaded to either 125 or 75 watts. Starting is instantaneous

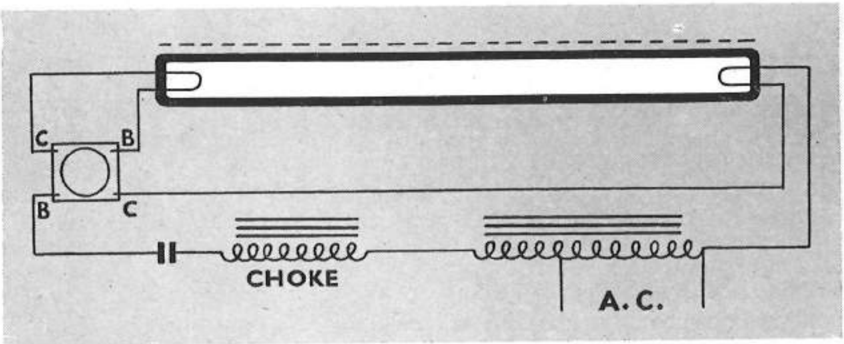


Fig. 53. Leading power-factor circuit for 8 ft. × 1½ in. lamp. The starting delay is similar to that for an 80 w. lamp with thermal starter. Suitable only for 125 w. loading of lamp

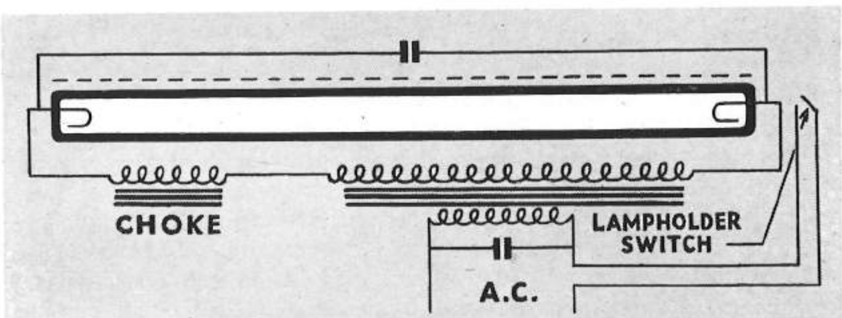


Fig. 54. Circuit for 8 ft. × 1 in. lamp, giving instant start with cold electrodes. A safety switch isolates the circuit from the mains when the lamp is withdrawn from its holders

transformers for either the 125 w. or 75 w. loading are available. The latter may sometimes be preferred on account of the lower brightness of the lamp.

The power-factor capacitor connected across the mains has the following value:—

Lamp Rating	Mains Voltage	Capacitor Value (mfd.)
75 watts	200/210	10
	220/250	7·5
125 watts	200/210	20
	220/250	15

A radio-suppression capacitor (0·02 mfd.) is connected across the lamp as usual.

Details of lamp performance, etc., are given on page 145.

Leading power-factor circuit. Standard (80 w. rating) elongated-type control gear is used with a thermal type of starter to give the normal delayed start associated with this type of circuit (Fig. 53). The power-factor capacitor of 7 mfd. is connected in series with the choke, and an elongated-type auto-transformer is required to raise the circuit voltage to about 250 v.

This circuit, which has a leading power-factor of about 0·85 may be preferred on account of the convenient shape of the control apparatus, but will generally be used for half the total number of lamps in conjunction with the lagging power-factor circuit for the other half, except where other inductive loads already exist.

This circuit is applicable to the 125 w. loading only.

(*b*) An 8 ft. (nominal) lamp of 1 in. diameter, similar to the American "slimline."

This lamp also is available in Natural colour only, and may be operated at a loading of either 50 or 70 w. according to the control gear used. This is a combined choke-transformer with an open-circuit voltage of some 750 v. which is sufficient to strike the discharge between the specially designed unheated electrodes. Once started, the action of the discharge heats the electrodes and maintains them at operating temperature. The lamp is fitted with a special cap at each end, fitting into special spring holders, one of which incorporates a switch which breaks the mains circuit when the lamp is withdrawn. A metal strip on the lamp aids starting.

Details of lamp performance, etc., are given on p. 145.

MISCELLANEOUS DISCHARGE LAMPS

COLD CATHODE TUBES

In order to strike and maintain a discharge in a long tube a much higher voltage will be required than for a short tube. Most of this voltage will be required for the discharge column and only a relatively small proportion may be wasted in the cathode fall; at tube lengths of the order of 9 ft., in fact, it may be an economic proposition to accept the high cathode fall occasioned by employing cold electrodes, since they have advantages in other directions which compensate for slight loss of efficiency compared with hot activated electrodes.

The electrodes used for cold cathode tubes are generally plain nickel or iron cylinders of considerable size in order to keep the current density at their surface low. They are housed in enlarged sections of the tube, one at each end, and are connected to a source of high tension, i.e. a transformer. Sometimes two leakage transformers working in tandem with the centre point of the secondary winding earthed are used with three standard 9 ft. 6 ins. (overall) mercury filled fluorescent tubes connected in series. These require a total of approximately 3600 v. at starting and 1900 v. in the running condition, the necessary voltage regulation being carried out automatically by the transformers. Each tube is rated at 70 w.

Since no pre-heating period is required, the tubes strike immediately the supply is switched on. Their life (nominally 10,000 hours) is relatively unaffected by the number or frequency of switchings, and they may be

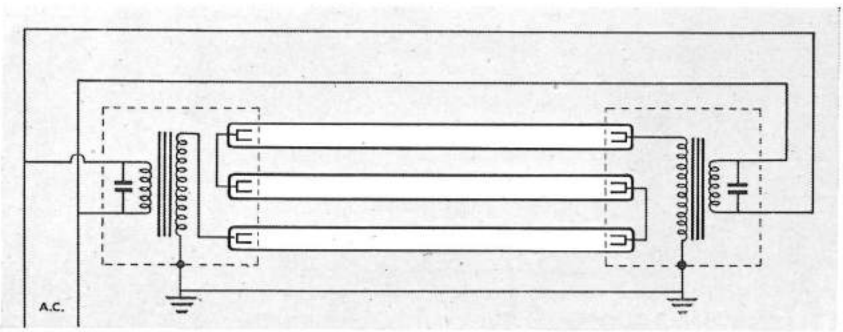


Fig. 55. Typical circuit diagram for three cold-cathode lamps in series. The high-voltage transformers have primaries in parallel and secondaries in series

dimmed (usually by means of a D.C. saturated choke or a reactor) down to almost zero light output. Other technical data are:—

> Length of luminous part of tube 8 ft. 6 ins.; diameter 20 mm.; normal current 120 m.a. in tubes, 1·3 amp. in mains; uncorrected power-factor 0·3, generally raised to approximately 0·85 by a 40 mfd. capacitor. The luminous efficiency depends on the fluorescent powders used, but is similar to that of 80 w. MCF/U lamps using the same powders.

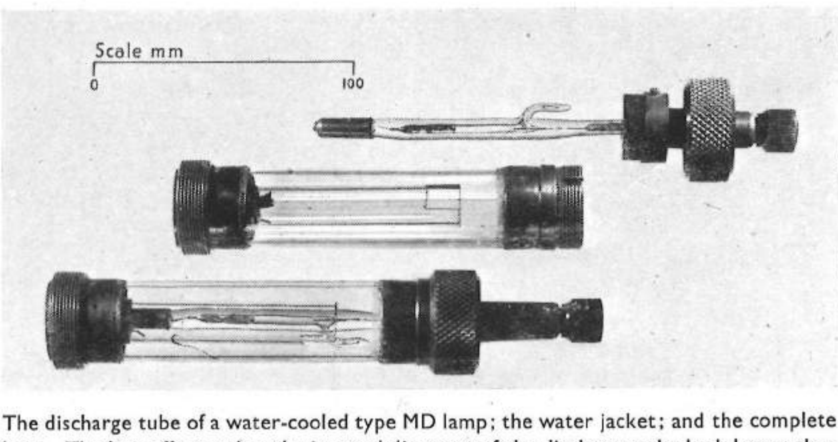
Various other cold cathode tubes are manufactured with neon, hydrogen, carbon dioxide and other fillings.

Owing to their small diameter it is not difficult to bend the tubes, during manufacture, to any desired shape, and they can thus be "tailored" to suit a particular interior. Their adoption in much shorter lengths than the present standard, however, is unlikely to become general on account of the relatively low efficiency the use of cold electrodes then entails.

TYPE MD LAMPS

For some purposes, notably for high power projection, a light source of very small dimensions, high wattage and extreme brilliance is required. Since the discharge arc must be short the lamp must be designed for a very high vapour pressure so that arc voltage shall be sufficiently high to give a lamp wattage of the required magnitude.

One of the chief difficulties connected with very high pressure discharges



The discharge tube of a water-cooled type MD lamp; the water jacket; and the complete lamp. The lens effect makes the internal diameter of the discharge tube look larger than it is is that convection currents of vapour within the discharge envelope become very violent if given sufficient space in which to circulate, and may blow the arc against the walls of the envelope, causing the latter to overheat. A practical solution is found in making the discharge envelope of very small bore—about 2 mm.—in which the arc becomes surrounded by a sheath of non-luminous vapour which to some extent insulates it from the quartz walls of the tube. Natural cooling, however, is insufficient to maintain at a safe working temperature a very small quartz tube in which a high wattage is dissipated, and forced cooling by means of a water jacket has to be adopted.

At the high vapour pressure (about 80 atmospheres) and high electrical loading per cm. of arc employed in MD/H lamps the "line" radiations typical of discharge lamps operating at lower pressures broaden into narrow bands, and also the weak red radiations are strengthened. The continuous-spectrum radiation from the very hot parts of the lamp also add red light, with the result that the colour of light from the MD/H lamp is whiter and of a more natural character than from, say, MA lamps.

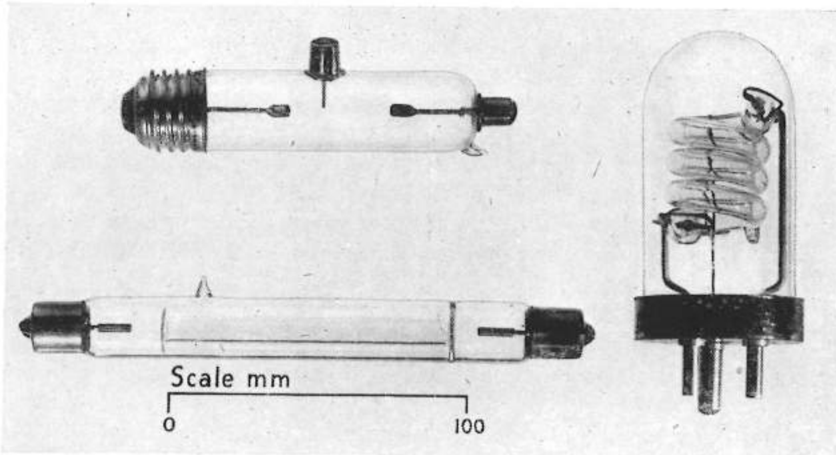
When the lamp strikes, the metallic mercury content of the discharge envelope is very rapidly vaporised by the heat of the discharge, this action continuing until in a very few seconds the cooling effect of the water jacket becomes equal to the heating effect of the discharge, at which point full light output has been reached and stable operation commences.

Maximum arc brightness (average throughout life) is 200,000 c./in.^{2}. Lamp life is dependent on number of switchings, but for 100 switchings nominal life is 200 hours (500 w.) and 150 hours (2000 w.).

FLASH TUBES

Both professional and amateur photographers have long felt the need of a light source giving an intense light for an infinitesimal period of time, in order to be able to take true "snaps" and to obtain clear and undistorted pictures of very rapidly moving objects.

Until recently photoflash lamps (containing magnesium or aluminium in the form of foil or wire ignited in an atmosphere of oxygen) were generally used, the camera shutter being synchronised with the period of maximum brightness of the lamp; in this case maximum shutter speed is the limiting factor which determines whether a clear picture of a moving object can be obtained.



Three typical flash tubes. The right-hand type is also available with a small pilot lamp mounted within the helix to assist focussing

Recently flash tubes have been developed commercially in various sizes. These give an enormous light output for a period varying from a few micro-seconds upwards, depending on type, and can be connected so that the flash is repeated (though perhaps at a reduced intensity) at absolutely regular intervals and at any frequency likely to be required. With these lamps the flash is far quicker than the most rapid shutter, and enables even bullets in flight to be completely "arrested" in a photograph.

The lamp consists of a straight or coiled vitreous tube filled with xenon or krypton connected to a bank of capacitors which are trickle-charged by means of a rectifier and transformer operating on A.C. or interrupted D.C. supply. In their most usual application, for single-flash operation, capacitors are generally charged to a high voltage which is not sufficient to flash the tube, a "trigger" circuit being used for this purpose. Triggering can be made extremely sensitive, and may be operated by light, heat, sound, or any other physical factor which can be changed into the form of an electrical impulse. Other things being equal, flash speed is a function of capacitor value, and light output a function of the voltage employed.

Due to the very high current density in the discharge, the spectrum of the emitted light consists of a great number of line radiations throughout the visible waveband, and the colour of the light is a good approximation to natural daylight. Flash tube life depends on the manner in which it is used, and normally extends over many thousands of flashes.

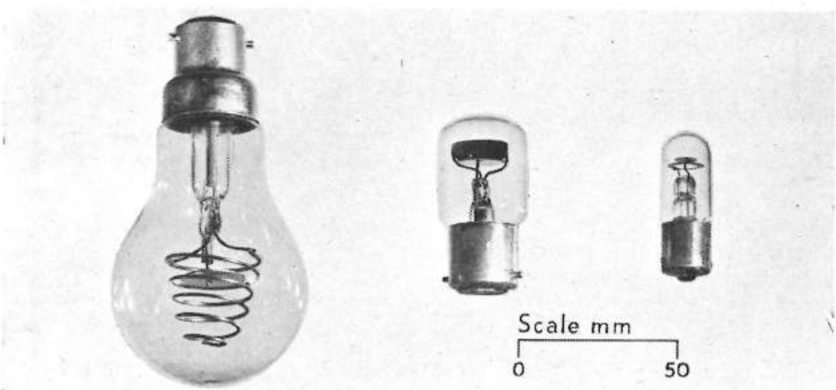
Data for some typical flash tubes are given below:—

Form	Arc Length (cm.)	Tube Bore (mm.)	Normal Operating Voltage	Single-flash Operation		Continuous Operation
				Max. Capacity (mfd.)	Max. Energy per flash (joules)	Loading (watts)
Helix	78	13	4000	2000	16000	500
Helix	46	11	2000	200	400	50
Helix	27	5	2000	50	100	30
Straight	30	5	2000	100	200	40
Straight	20	5	2000	60	120	26
Straight	10	6	2000	30	60	13
Straight	3	24	7500	2	56·3	—
Helix	21	5	2500	20	62·5	—

NEON GLOW LAMPS

The characteristic red glow from the negative electrode of a discharge in neon is suitable for use in many indicator-type lamps, where the amount of light generated is of secondary importance to the attention it demands by its bright colour.

A very low pressure of neon is always employed, and the current is limited to a few milliamps by means of a series resistor concealed in the lamp cap. The glow developed in these lamps as a result of a minute flow of current makes them particularly suitable for visual test of insulation resistance.



Three typical neon glow lamps. The Beehive lamp on the left is often used as a night light

Since the glow emanates from the surface of an electrode, one electrode is often enlarged and made in spiral or other suitable form to fill the bulb. On D.C. supplies, the enlarged electrode should be connected to the negative pole of the supply, otherwise very little glow will result.

POINTOLITE LAMPS

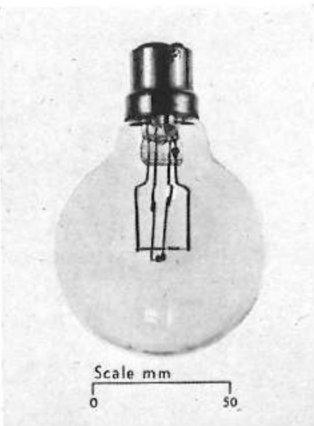
These lamps are intended primarily for optical work where a steady concentrated source of light is required.

A glass bulb is filled with an inert gas at low pressure, and contains two (or three) electrodes, one being a tungsten spiral part of which is covered by a tube (the ioniser) coated with electron emitting material. For D.C. operation the other electrode consists of a small globule of tungsten, and for A.C. there are two such globules separated by a short gap.

On D.C. the spiral is connected, *via* a suitable ballast resistance, to both poles of supply, and the globule also *via* a resistance to the positive pole. When switched on, the spiral heats the ioniser, which incandesces and ionises the gas in its vicinity. A push switch then disconnects the ioniser from the positive pole of supply, and an arc forms between the ioniser and globule, heating the latter to incandescence.

On A.C. the action is similar up to this stage, but the lead connected to the ioniser is then transferred to the second globule and the arc re-forms between globules.

Standard sizes for D.C. operation are 30, 100, 500 and 1000 C.P., each with a brightness of approx. 8500 candles/in.^{2} and for A.C. 150 C.P. with a brightness of approx. 8000 c./in.^{2}.



Pointolite lamp for A.C. The arc forms between the two tungsten globules at the centre of the bulb

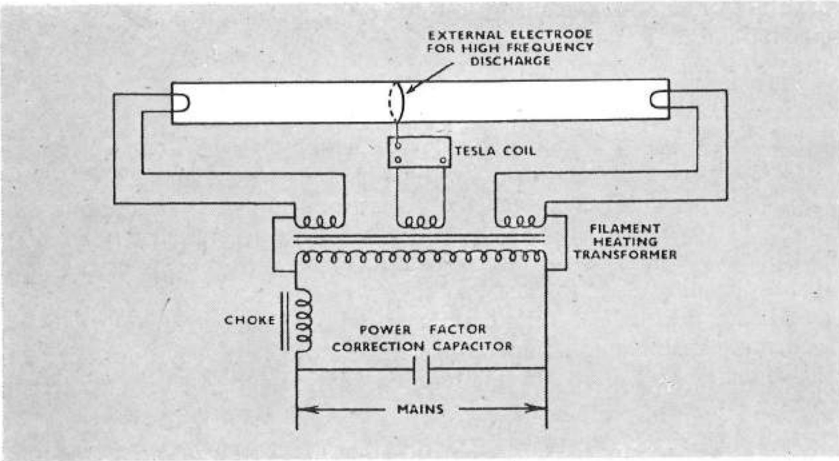
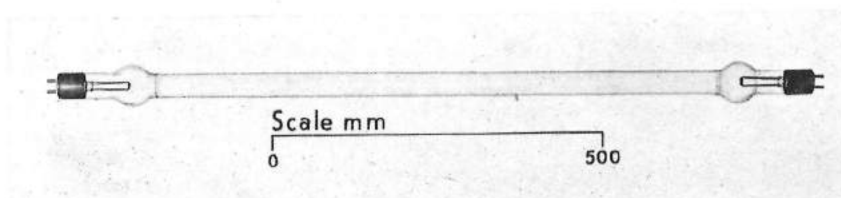


Fig. 56. Typical circuit diagram for a floodlighting discharge lamp. The Tesla coil only operates during the pre-heating period before the lamp strikes

COLOUR FLOODLIGHTING LAMPS (TYPES MC/H AND NE)

Before electric discharge lamps became generally available, the production of coloured light for floodlighting or other purposes necessarily entailed the use of colour filters to absorb the unwanted constituents of the white or near-white light source used. This process, though simple, is very wasteful and unlikely to be justifiable for long-term use.

The characteristic colour of light from various kinds of discharge lamps, however, enables certain colours to be obtained with little or no filtering and therefore at relatively high luminous efficiency. MA or MB lamps may be used to give bluish-white light at efficiencies ranging from 32 to 36 lumens per watt, and SO lamps to give yellow light at between 49 and 64 L/W; and a range of low-pressure mercury (type MC/H) lamps



A 400 w. neon floodlighting lamp (type NE) giving red light at an initial luminous efficiency of 11 lumens per watt have been made to give shades of blue or green, and neon (type NE) to give red light.

Each lamp requires a choke, an electrode heating transformer, and a Tesla coil. When supply is switched on, the electrodes heat up and the Tesla coil produces a high-frequency discharge by means of an external electrode, usually in the form of a piece of wire twisted round the middle of the lamp. This causes sufficient local ionisation to enable the main discharge to strike between electrodes, which are at almost full mains potential. As soon as the discharge strikes, the voltage across the transformer primary falls to lamp voltage, which is considerably less than mains voltage; thus the Tesla coil then becomes inoperative, and the electrodes are maintained at operating temperature partly by the action of the discharge and partly by the reduced heating current from the transformer.

All the above lamps are designed for the horizontal burning position, but may be used in other positions without appreciable loss of performance.

LAMP ECONOMICS

Which Lamp gives the Cheapest Light?

ANY GENERAL STATEMENT THAT, for instance, fluorescent lamps give cheaper lighting than filament lamps, or *vice versa*, is almost certain to be misleading in some instances, especially where the cost of electricity is abnormally high or low, or where the installation is in use for an exceptionally long or short total period per annum.

The total annual cost of lighting is made up of two parts:—

1. *Fixed annual charges*, which include:—
   - (*a*) Capital cost of fittings, excluding lamps
   - (*b*) Capital cost of control gear, if required
   - (*c*) Capital cost of installation work

   } All amortised over a convenient period, say 5 or 10 years.
   - (*d*) Annual kW, kVA or other fixed charges for current, if any.
2. *Annual running costs*, which include:—
   - (*e*) Annual cost of current used, *excluding* kW, kVA or other fixed charges.
   - (*f*) Annual cost of lamp replacements and other consumable articles such as starter switches, if any.

It is commonly found that an intending user may not realise that a relatively high total sum by way of fixed annual charges (under (1) above) do not necessarily indicate a relatively expensive installation when *total* cost per unit of light delivered is considered. It so happens that the most efficient lamps available to-day require certain auxiliary equipment which swells the capital cost; but their high efficiency reduces the running cost. Whether the reduced running cost counter-balances the increased capital cost can be worked out by very simple mathematics, and must, in fact, be worked out where any doubt exists.

One general statement can, however, be made. The longer the total burning hours per annum, and the higher the cost of current (including fixed charges) the more likely it is that high efficiency lamps, in spite of their greater capital cost, will give cheaper lighting in the long run.

For a true indication of comparative costs, installations should of course be compared on a basis of *average cost per lumen delivered* at the working plane throughout the life of the installation. Thus the wattage required for each installation should be calculated not only on the light output or luminous efficiency throughout life of the lamp itself, but must also take into account the loss of light and depreciation due to the particular type of fitting selected for each. In other words, the coefficient of utilisation* for each type of fitting and for the interior concerned must be included in the calculation.

Lamp Renewal Rate

In a large installation employing many lamps which are replaced as and when they fail, a very considerable time will pass before the lamp renewal rate settles down to a steady figure of so many per week or per month.

As shown in Fig. 17, page 51, very few lamps would burn out during the first few hundred hours, but the rate of failure and replacement rises to a peak after a period corresponding roughly to rated lamp life. Thereafter the rate of replacement falls, to rise again to a second but lower peak after a period of twice rated lamp life; a third but still lower peak occurs after a period of three times rated lamp life, and so on, until the rate settles down to a level line corresponding to the ultimate weekly (or monthly) figure shown as 100 per cent. in Fig. 57.

In practice, chance or circumstances will vary the actual replacement rate above or below the theoretical rate shown in the curve, but the larger the installation and the more uniform the performance of the lamps the more nearly will the theoretical and practical results agree.

* *Coefficient of Utilisation.* Numerically this is the total lumens reaching the working plane, divided by the total lumens generated by the lamps. It depends on the efficiency and distribution of the fitting, on the proportions of the room and on the colour of the decorations. See "Illumination Design for Interiors" or Handbook No. 2 "Interior Lighting Design."

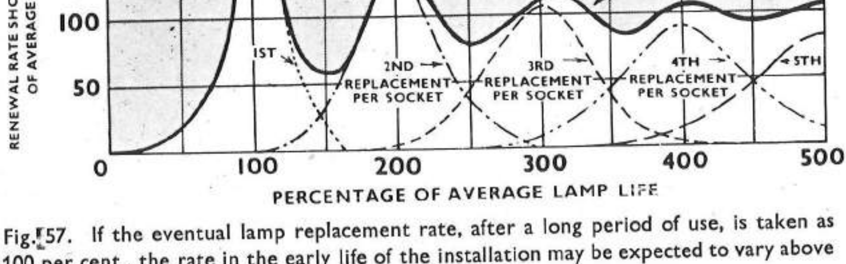


Fig. 57. If the eventual lamp replacement rate, after a long period of use, is taken as 100 per cent., the rate in the early life of the installation may be expected to vary above and below 100 per cent. according to the full-line curve

From the curve it will be apparent that a steeply rising or falling lamp renewal rate measured over a short period, even when the installation is several thousand lighting hours old, does not necessarily indicate a change in lamp performance. It may be a perfectly natural phenomenon, and early snap judgment of lamp quality based on renewal rate only should therefore be avoided.

Group Replacement

Though at first sight it would seem wasteful to discard a lamp which still works, it may nevertheless be more economical and convenient to do so than to wait until it burns out. This is particularly true in the following cases:—

1. Where it is expensive in time and labour to replace individual lamps as and when they fail, e.g. with very high mounting, and in street lighting.
2. Where a burned-out lamp may cause a loss of business on account both of the lack of light and the disorganisation caused while it is being replaced, e.g. in shops.
3. Where a burned-out lamp spoils the appearance of an interior.

It should be borne in mind that the annual cost of lamp renewal is generally a very small fraction of the total annual cost of the lighting, which includes a due proportion of the capital charges on the installation, and the cost of current and maintenance; and some of these charges continue whether the lamp works or not.

It is thus apparent that if the average useful lamp life is deliberately reduced by discarding all old lamps and replacing them after a period of, say, 80 per cent. of normal lamp life, the first result is a loss not of 20 per cent. of the total lighting cost, but of some figure very much less than this, say, for the sake of illustration, 5 per cent.

On the other hand, there may be advantages which more than compensate for this. In the first place, during the first 80 per cent. of normal life few lamps would fail, and these might be replaced immediately with marked lamps which, after the next complete change, could be used again for further casual replacement. Thus there would be very little interference due to lamps failing during business hours.

Secondly, lamp replacement of the whole group could be organised to occur at the week-end, in summer, or at some other slack period when interference with business would be at a minimum.

Thirdly, the labour cost of replacing all lamps at once would be considerably less than that of piecemeal replacement. And fourthly, the appearance of the installation would be improved.

It is not suggested that a system of group replacement would be suitable in every case, but in a highly organised business it is worth while investigating its possibilities, for a marked advantage may sometimes be obtained.

LAMP DATA

The tables on the following pages give the lamp data most generally required. The figures are correct at the time of going to press, but devellopments may, of course, make them out-of-date subsequently. This is especially likely to occur in the case of electric discharge lamps; for instance, the recent development of halophosphate fluorescent powders led to an immediate increase of some 50 per cent. in the light output and efficiency of tubular fluorescent lamps.

FILAMENT LAMPS

LAMPS FOR GENERAL LIGHTING SERVICE (G.L.S.)
(See B.S.S. 161)

Watts	Dimensions (m/m.)			Nominal Average Lumens through Life*			Average Life (hrs.)	Standard Cap	Remarks
	Overall Length	Dia.	Light Centre Length	110v.	230v.	230v. coiled coil			
15	92·5±3·5	55±1	65±3	133	113	—	1000	B.C.	For fuller details of light output, see page 48; for standard voltage range, page 53; for current and resistance values, page 55.
25	100±3·5	60±1	70±3	228	206	—	,,	,,	
40	110±3·5	60±1	80±3	449	330	389	,,	,,	
60	117·5±3·5	65±1	85±3	759	584	665	,,	,,	
75	125±3·5	70±1	90±3	1000	785	883	,,	,,	
100	137·5±3·5	75±1	100±3	1400	1160	1270	,,	,,	
150	160±4·5	80±1	120±4	2230	1970	—	,,	,,	
200	178±5·5	90±1	133±5	3090	2725	—	,,	E.S.	
300	233±7	110±1·5	178±6	4950	4430	—	,,	G.E.S.	
500	267±8	130±1·5	202±7	8950	7930	—	,,	,,	
750	300±9	150±1·5	225±8	14270	12740	—	,,	,,	
1000	300±9	150±1·5	225±8	19640	17800	—	,,	,,	
1500	335±9	170±1·5	250±8	30220	28380	—	,,	,,	

* These values are intended only to afford practical guidance for design purposes.

GASFILLED PROJECTOR LAMPS

Class and B.S.S. No.	Watts	Voltage	Overall Length (mm.)	Dia. (mm.)	Light Centre Length (mm.)	Standard Cap	Nominal Average Lumens through Life	Objective Average Life (hours)
A.1 (B.S.S. 1522)	25	50	57±3	16±1	29±2	B.15s/21	—	50
	50	115	76±3	25±1	34·5±2	B.15s	—	50
	100	30, 115, 200/250	133±7	25±1	55·5±0·5	P.28/25	—	50
	250	50, 115, 200/250	133±7	32±2	55·5±0·5	P.28/25	—	50
	300	115	133±7	32±2	55·5±0·5	P.28/25	—	25
	500	115	133±7	32±2	55·5±0·5	P.28/25	—	25
	500	115, 200/250	133±7	64±2	55·5±0·5	P.28/25	—	50
	750	115	133±7	38±2	55·5±0·5	P.28/25	—	25
	900	30	235±10	64±2	84±0·5	P.40/41	—	50
	1000	115, 200/250	235±10	64±2	84±0·5	P.40/41	—	50
B.1 (B.S.S. 1522)							(115v.) (200–250v.)	
	100	115, 200/250	115±10	80±2	75±5	E.S.	960 830	800
	250	115, 200/250	125±10	95±2	75±5	E.S.	3130 2700	800
	500	115, 200/250	180±10	130±5	115±5	G.E.S.	7180 6310	800
	1000	115, 200/250	180±10	130±5	115±5	G.E.S.	15660 13920	800
B.2 (B.S.S. 1522)	500	115, 200/250	267±8	130±5	202±7	G.E.S.	7170 6310	800
	1000	115, 200/250	300±9	150±5	225±8	G.E.S.	15660 13920	800
E. (B.S.S. 1522)	500	115, 200/250	135±10	100±2	60±0·5	P.28/25	—	100
F. (B.S.S. 1522)	9	18	36±3	18±1	25±2	M.E.S.	—	100
	24	12	60±5	38±2	44±5	S.B.C.	—	100
	30	6	57±5	35±2	47±5	S.E.S.	—	25
	48	6	60±5	35±2	40±3	S.B.C.	—	100
	48	12	70±5	50±2	40±3	S.E.S.	—	100
G. (B.S.S. 1015)	Amps. 0·75	4	48±3	25±1	28·5±0·25	P.15s	—	50
	4	8	75±3	25±1	37·3±0·25	P.15s	—	100
	5	10	75±3	25±1	37·3±0·25	P.15s	—	100
	7·5	10	75±3	25±1	37·3±0·25	P.15s	—	100
Studio (B.S.S. 1075)	2000	115, 240	232±6	152·5±2	127±2	Bipost	45000 38000	100
	5000	115, 240	335±6	203±2	165±2	Bipost	122000 115000	100

ARCHITECTURAL TUBULAR LAMPS

Type	Length		30 mm. Dia. Watts
	mm.	Approx. Inches	
Straight Lengths	305 500* 500* 610 915 1220	12 19$\frac{11}{16}$* 19$\frac{11}{16}$* 24 36 48	35 40* 60* 75 110 150
Curved $\frac{1}{8}$ Circle of 25 in.rad. $\frac{1}{4}$,, 12$\frac{1}{2}$,, ,, $\frac{1}{2}$,, 6$\frac{1}{4}$,, ,,	500*	19$\frac{11}{16}$*	40† and 60
Right-angle bend	500*†	19$\frac{11}{16}$*†	40† and 60†

* Measured along centre line of lamp.
† Not available at present.

PHOTOGRAPHIC AND ENLARGER LAMPS

Type	Volts	Watts	Cap	Bulb Dimensions (m/m.)	Nominal Life (hours)	Colour Temperature (° K.)
Photoflood	100 110 200 210 220	275	B.C. or E.S.	65× 117·5	2–3	3400°
	230 240 250	500	E.S.	80× 160	6–8	3300°
	110	1000	G.E.S.	110× 233	10 (Max.)	—
Enlarger	110 210	400	E.S.	110× 253	100	—
Photographic	230 250	500	E.S.	100× 175*	100	—

* Club or round bulb shape.

ELECTRIC DISCHARGE LAMPS

MERCURY LAMPS (TYPES MA AND MB)

Type	Watts	Voltage Range A.C.	Diam. (mm.)	Overall Length (mm.)	Light Centre Length* (mm.)	Cap contact to lower Electrode† (mm.)	Nominal Efficiency (Lumens/Watt) Initial	Nominal Efficiency (Lumens/Watt) Final	Nom. Aver. Lumens through Life**	Nominal Average Life (hours)	Cap	Approx. Power Consumption in Choke (watts)
MA/V	250	200/250	48±3	290±8	170±8	240 max.	35	30	8000	3000	G.E.S.	15
MA/V	400	200/250	48±3	330±8	190±8	280 max.	42	33	14400	3000	G.E.S.	20
MA/H	250	200/250	48±3	290±8	170±8	—	33	26·5	7125	1500	G.E.S.	15
MA/H	400	200/250	48±3	330±8	190±8	—	41	32	13600	1500	G.E.S.	20
MB/V	80	200/250	80±1	160±4·5	—	—	37	29	2500	2500	3-pin B.C.	10
MB/V	125	200/250	90±1	178±5·5	—	—	42	30	4100	2500	3-pin B.C.	12
MAF/V Isothermal	400	200/250	165±1·5	335±7·5	—	—	38	30	12800	2500	G.E.S.	20
MAF/V Tubular	400	200/250	115±2	325±15	—	—	37	27	11600	1500	G.E.S.	20
MBF/V	80	200/250	110±1·5	178±5·5	—	—	37	29	2500	2500	3-pin B.C.	10
MBF/V	125	200/250	130±1·5	233±7	—	—	42	30	4100	2500	G.E.S.	12
MBW/V	125	200/250	90±1	178±5·5	128±5	—	—	—	—	1500	3-pin B.C.	12

* *Light Centre Length*—the distance from the contact cap (excluding solder) to the mid-point between main electrodes.

† This dimension may be required when considering the "cut-off" of direct lamp light by industrial type fittings equipped with lamps with clear glass outer envelope.

Most of the above details are included in B.S. 1270. The nominal efficiency and life figures are estimates of the average values for the lamps at present available.

** These values are intended only to afford practical guidance for design purposes.

MERCURY/TUNGSTEN LAMPS (TYPES MAT AND MBT)

Watts	Voltage Range	Max. Dia. (mm.)	Overall Length (mm.)	Light Centre Length (mm.)	Nominal Efficiency (Lumens/Watt)		Nominal Average Lumens through Life*	Nominal Average Life (hours)	Cap
					Initial	Final			
160	200/250	90±1	178±5·5	D.128±6 F.133±6	18·7	14·0	2400	2000	B.C. or E.S.
200	200/250	90±1	178±5·5	D.125±5 F.133±5	20·0	15·0	3400	2000	E.S.
250	200/250	110±1·5	233±7	D.173±6 F.178±6	20·4	15·0	4250	2000	G.E.S.
300	200/250	85±1	285±15	D.150±10 F.245±10	21·0	17·0	5400	2000	G.E.S.
500	200/250	100±1	355±20	D.182·5±20 F.305±20	25·0	20·0	10500	2000	G.E.S.

* These values are intended only to afford practical guidance for design purposes.

Most of the above details are included in B.S. 1270. The nominal efficiency and life figures are estimates of the average values for the lamps at present available.

MERCURY LAMPS (TYPE ME)

Type	Watts	Supply Voltage (A.C. or D.C.)	Lamp Operating Volts	Approx. Lamp Current (amps.)		Dimensions (mm.)			Max. Initial Brightness (c/in.^{2})	Cap(s)
				Starting	Operating	Overall Length	Dia.	Arc Length		
ME/D	250	200/250	60–75	4–5	3·7–4·6	130±3 excluding pins	Box 64×55	3·75±0·35	130,000	3-pin
ME/D	250	200/250	60–75	4–5	3·7–4·6	156±3 excluding pins	50±2	3·75±0·35	130,000	3-pin
ME/D	500	200/250	60–75	10	9	{240±10 {232±10	65±5 152±3	5^{+3}_{-1}	130,000	{P.40/41 or E.40/45 {Bi-post
ME/D	1000	200/250	60–75	20–22	{18 A.C.} {16 D.C.}	245±2·5	55 max.	5·5±0·5	260,000	Brass cylinders and prefocus flange
MEC/V	2500	100/250*	65–80	75 max.	33	315±5	65 max.	15±1	—	Flexible leads
MEC/H single ended	5000	110/250*	65–80	100	63–77	260 max.	90 max.	9·5±0·5	290,000	$\frac{5}{16}$ in. terminals
double ended	5000	110/250*	65–80	100	63–77	320±5	90 max.	9·5±0·5	290,000	Special ceramic
ME/V	7500	100/250	50–60	160 max.	136	430	110 max.	7	—	Flexible leads

* D.C. only.

LAMP DATA

SODIUM LAMPS (TYPE SO)

Lamp Watts	Voltage Range (A.C.)	Lamp Current (amps.)	Outer Bulb Dia. mm.	Overall Length mm.	Nominal Efficiency (Lumens/Watt)		Nom. Aver. Lumens through Life*	Nom. Aver. Life (hours)	Max. Brightness (c/in^2.)	Approx. Loss in Transformer (watts)	Cap
					Initial	Final					
45	100/250	0·6	50±2	238±10	60	44	2200	3000	60	20	B.C. Ceramic
60	100/250	0·6	50±2	300±10	70	51	3400	3000	60	20	,,
85	100/250	0·6	50±2	415±10	76	56	5400	3000	60	20	,,
140	100/250	0·9	65±2	518±10	76	57	9000	3000	60	25	,,

* These values are intended only to afford practical guidance for design purposes.

Most of the above details are included in B.S. 1270. The nominal efficiency and life figures are estimates of the average values for the lamps at present available.

TUBULAR FLUORESCENT LAMPS (TYPE MCF/U)

Watts	Nominal Lamp Voltage	Nominal Lamp Current (amps.)	Overall Length (inches)	Diam. (mm.)	Caps	Nominal Average Life (hrs.)††	Watts loss in choke (approx.)
15	56	0·3	18*	26 ± 1	Bi-pin	2500	7/12**
20	62	0·35	24*	38 ± 1·5	Bi-pin	2500	7/12**
30	103	0·34	36*	26 ± 1	Bi-pin	2500	12
40	50	0·88	24*	38 ± 1·5	Bi-pin	2500	10/20**
40	108	0·41	48*	38 ± 1·5	Bi-pin	2500	12
80	106	0·85	60 ± ¼	38 ± 1·5	B.C.	3000	20†
50 70	295 265	0·2 0·3	93⅞ ± ⅛	26 ± 1	S.C.C.	2000	—
75 125	170 210	0·4 0·85	96 ± ⅛	38 ± 1·5	B.C.	3000	—

* Total including standard bi-pin holders.

** First figure applies to single lamp on 100/130 v.; second figure to two lamps in series on 200/250 v.

† This figure refers to the elongated type of choke. The loss in the 80 w. cubic type is approximately 10 w.

†† Under specified test conditions. A specification is in preparation.

TUBULAR FLUORESCENT LAMPS (TYPE MCF/U)—*continued*

Watts	Daylight			Warm White			Natural		
	Nominal Efficiency (Lumens/Watt)		Nominal Average Lumens through Life*	Nominal Efficiency (Lumens/Watt)		Nominal Average Lumens through Life*	Nominal Efficiency (Lumens/Watt)		Nominal Average Lumens through Life*
	At 100 hours	Final		At 100 hours	Final		At 100 hours	Final	
15	—	—	—	34	25	420	31	23	380
20	—	—	—	38	27	620	34	24	560
30	—	—	—	46	35	1200	42	32	1080
40 (24″)	—	—	—	33	25	1160	30	23	1040
40 (48″)	50	36	1700	50	36	1700	45	32	1500
80	45	32	3000	45	32	3000	41	28	2700
50 / 70	—	—	—	—	—	—	51	38	2100 / 2900
75 / 125	—	—	—	—	—	—	46	36	2900 / 4900

Most of the above details of MCF/U lamps are included in B.S. 1270.
* These values are intended only to provide practical guidance for design purposes.

COLOUR-MATCHING LAMPS

In addition to the above, two types of colour-matching lamps are available, both giving light of a colour closely resembling that of a 6,500° K black body.

(1) Standard lamps with special fluorescent powder. At present the sizes available are 80 w. and 40 w. (4 ft.), all with luminous efficiency some 12 per cent. lower than that of the corresponding 'Natural' lamp.

(2) Two 40 w. (2 ft.) blue-fluorescing lamps designed to be contained in the same fitting as two 60 w. filament lamps, the two colours of light blending to give the required resultant colour at an average efficiency of approximately 14 lumens per watt (3,000 lumens).

CAP SHAPES AND DIMENSIONS

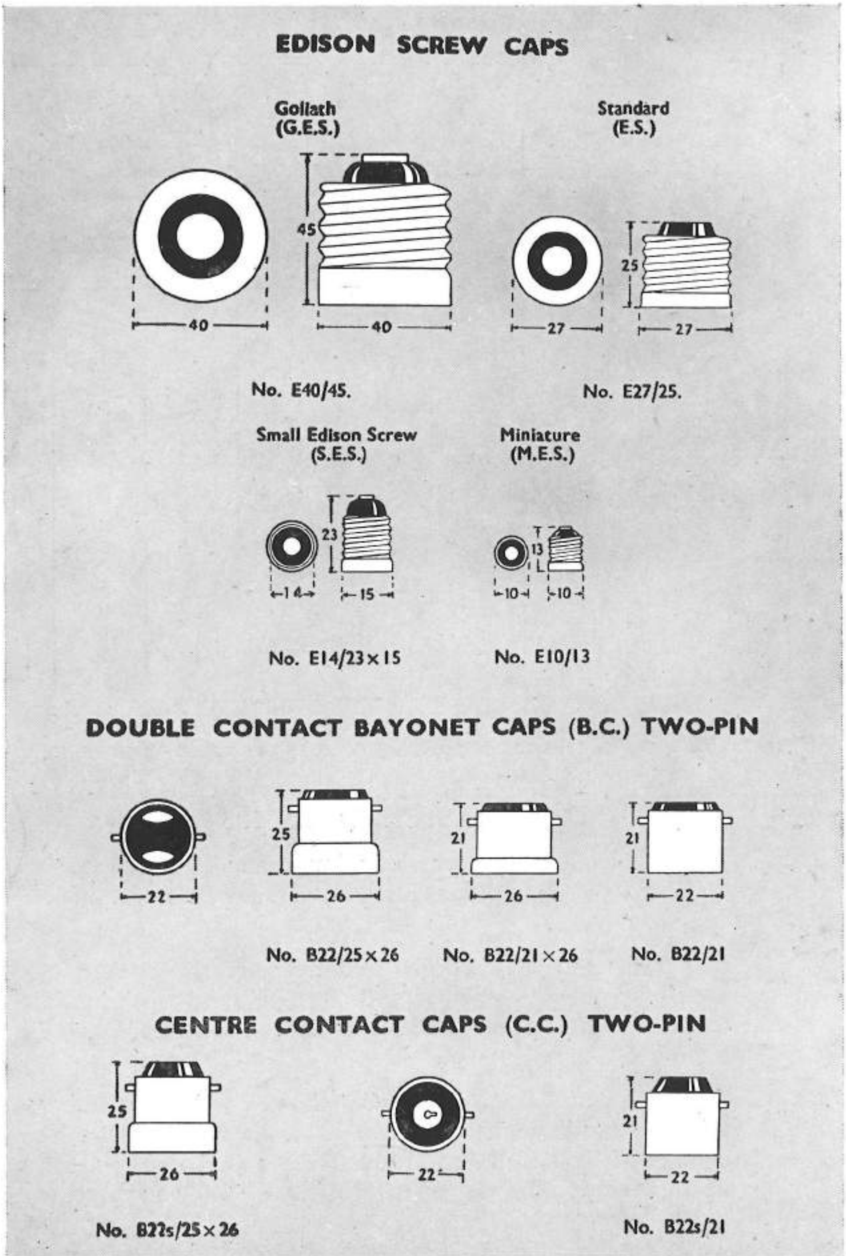


Fig. 58

CAP SHAPES AND DIMENSIONS

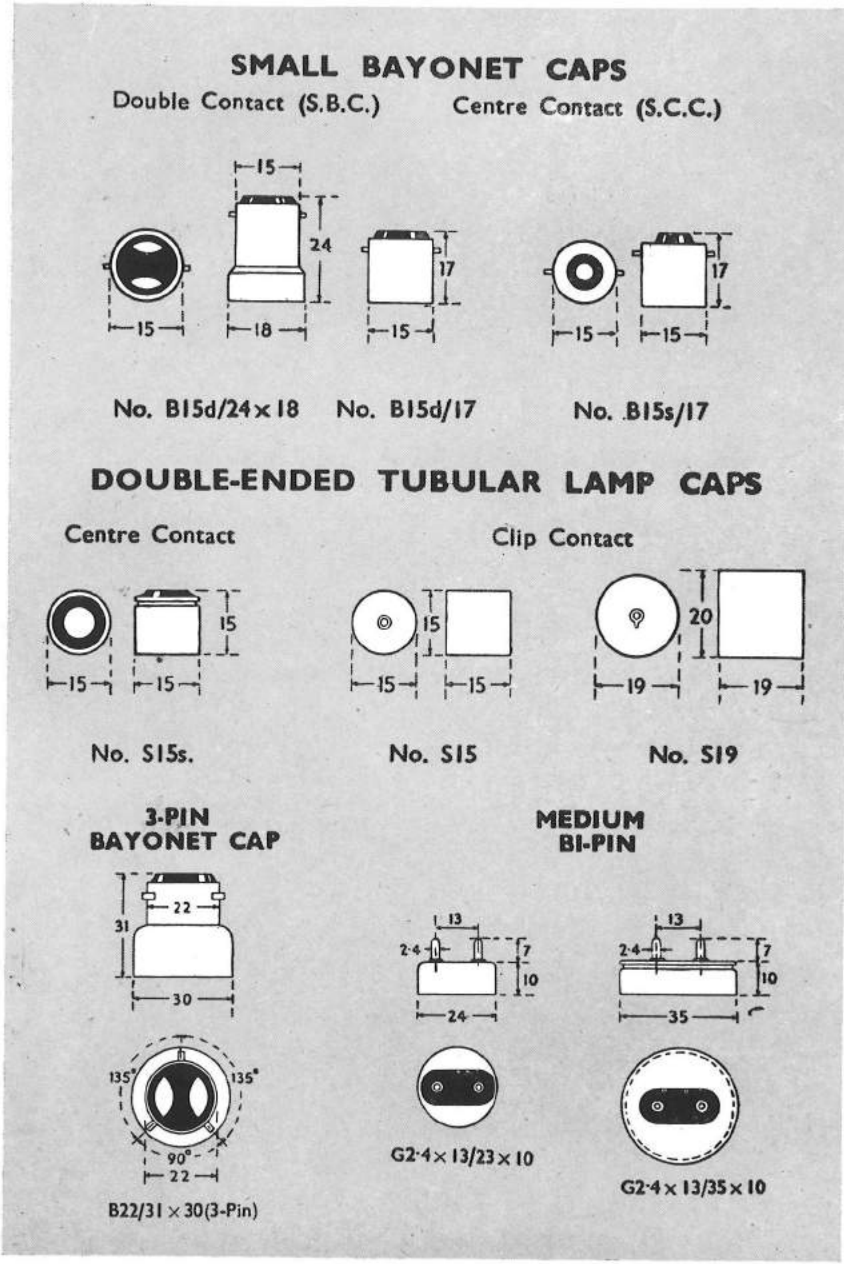


Fig. 59

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