Electric Lamps: Discharge

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Electric Lamps

Section D

Discharge Lamps

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Foreword

This is the last of a series of four publications which together form a new book on Electric Lamps. The sections are all to the same format, and a suitable binder is available to hold them all.
The individual section titles are —

Section A — Fundamentals of Light and its Production.
Section B — Fluorescent Lamps.
Section C — Incandescent Lamps.
Section D — Discharge Lamps.

The books have been written primarily to assist those who use lamps, specify them or buy them, and to give information on the characteristics of various types and the reasons why they are made in certain ways. The books are not intended for the lamp physicist, but present the salient facts so that they may be readily understood. International system (SI) units are used where they are applicable (BS 3763 refers).

Historically, electric discharge tubes are older than filament lamps, and in spite of working with inadequate vacuum pumps, scientists from about 1800 onwards began to take an interest in the production of light by this means. It was not until the last few years of the century, however, that discharge tubes began to be seriously considered as illuminants.

One of the first installations on a commercial scale was in America in 1904—a cold cathode carbon dioxide tube powered by a high voltage transformer, followed shortly afterwards in this country by an installation in the courtyard of the Savoy Hotel, London.

Progress since then has been spectacular. Commercial production of high efficiency mercury and sodium lamps started in 1933, followed by colour improved mercury in 1937. Development is continuous and sometimes rapid. Techniques improve, giving higher efficacies and longer lives with greater reliability, whilst new ideas and processes produce new light sources such as the mercury halide and high pressure sodium types recently introduced. As with any new development, changes are inevitable as time goes on, and although the information on these two types is correct at the time of going to press, if precise data is required it should be checked with the lamp manufacturer.

It should also be noted that certain data ordinarily found in catalogues, such as lamp dimensions, have been omitted from this book. Many types of lamp are covered by British Standards, and where they are not it is obviously wiser to rely on the information provided by the manufacturer. Both BS 3677, Mercury Vapour Discharge Lamps, and BS 3767, Sodium Lamps (Integral type), are currently under revision.

A short index is included for the convenience of anyone wishing to refer to a particular point. The references used throughout are to paragraph numbers, thus (3.6), (21.4), etc. References having a prefix A, B or C are to those sections in the series.

Contents

Part 1 Mercury Vapour Discharge Lamps

1. Classification

1.1 A high pressure mercury vapour (HPMV) lamp consists essentially of a relatively small, very strong arc tube, containing a drop of mercury and certain gases at pressures from 1 to 10 atmospheres, suitably protected by an outer envelope. The nature of the filling, the pressure developed and the current density determine the characteristic radiation of the contents of the arc tube.

1.2 For some applications, particularly industrial, the light emitted from the plain mercury lamp may be tolerable; it can, however, be colour modified in various ways:

(a) By using a tungsten filament within the lamp which serves both as a current limiting device for the discharge and emits useful light.

(b) By applying a phosphor coating to the inside of the outer envelope.

(c) By introducing one or more metal halides into the discharge tube in addition to the normal mercury.

1.3 The various types of lamps are identified by a letter classification common to all British lamp manufacturers. The designation is made up of four or five letters, with the following meaning—

1st letter:

This is always M, denoting a mercury lamp.

2nd letter:

A indicates a glass arc tube loaded above 10 watts/cm of arc length.
B indicates a quartz arc tube loaded below 100 watts/cm of arc length.
D indicates a quartz arc tube with forced liquid cooling. (Rare).
E indicates a quartz arc tube loaded above 100 watts/cm of arc length.

3rd and 4th letters:

These denote the characteristic feature as follows —
F — a fluorescent coating on the outer envelope.
I — a halide additive to the arc.
L — luminescent.
R — an internal reflector.
T — an internal incandescent filament.
W— a Wood's Black Glass outer envelope.

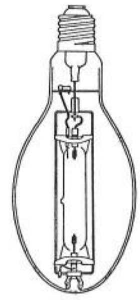
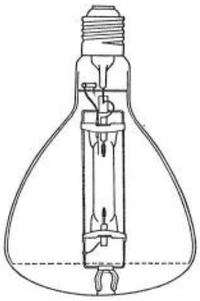
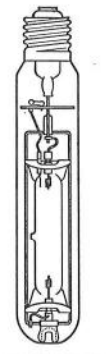
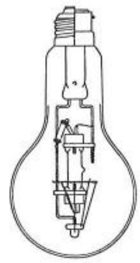
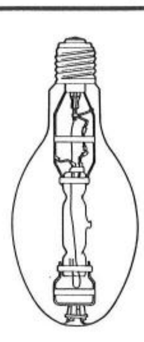
Last letter:

Always follows an oblique stroke, and indicates the permissible burning positions.
U — Universal burning.
V — Restricted to vertical, cap up.
D — Restricted to vertical, cap down.
H — Restricted to horizontal burning.

1.4 The main types of lamps in current use, with the ratings available and their characteristic shapes, are shown in the table opposite.

1.5 MA types, which do not have a quartz arc tube, may be considered obsolescent and are being superseded by the MB types.

1.6 Some MA/V lamps may be burned horizontally under certain conditions if a magnetic deflector is incorporated in the fitting to correct the upward bowing of the arc due to convection. Otherwise the arc would melt the glass of the arc tube at the point of contact.

Type	Ratings	Cap †	Typical shape
MBF/U Has an internal fluorescent coating on the bulb, which is hard glass for 250W and above.	50W 80W 125W 250W 400W 700W 1000W (LV) 1000W (HV) 2000W	E27 E27 or B22d — 3 E27 or B22d — 3 or E40 E40 (250W, 400W, 700W, 1000W (LV), 1000W (HV), 2000W)	
MBFR/U Has a 'built-in' internal reflector and the outer bulb is shaped accordingly.	250W 400W 700W* 1000W*	E40	
MB/U The 80W and 125W sizes use either ellipsoidal or pear shaped soft glass outer bulbs with a pearl finish; the others use hard glass, and are tubular as shown. The outer bulb of the 1000W (HV) lamp may be soft glass and is larger and of different shape, similar to the MBF/U type.	80W 125W 250W 400W 1000W (LV) 1000W (HV)	E27 or B22d — 3 E27 or B22d — 3 E40 (250W, 400W, 1000W (LV), 1000W (HV))	
MBFT/Uand MBTL/U* Additional to the tungsten filament which is inside the soft glass outer bulb, the latter is internally coated with a fluorescent powder. This makes possible a 'red ratio' of 12% (2.5).	100W 160W 250W 500W	E27 or B22d — 3 (100W, 160W) E40 (250W, 500W) *The MBTL/U may have a pearl envelope and no fluorescent coating.	
MBI Arc colour-modified by the addition of one or more metal halides. These lamps may be in a tubular bulb.	400W 2000W	E40	

†B22d — 3 cap = 3 pin BC   E27 = E.S.   E40 = G.E.S.

2. Considerations affecting the spectral power distribution

2.1 The theory of the electric discharge has been described in Section A (A2.8—2.11); the characteristics of low pressure mercury arcs in Section B (B2). The latter rely on the resonance radiation in the ultra-violet at 253.7 nm as the main source of energy.

2.2 At pressures of one atmosphere—or a little above—re-absorption of the 253.7 nm radiation is almost complete, and much of the radiation is then in the visible part of the spectrum at 404.7 nm, 435.8 nm, 546 nm, and 577 nm to 579.1 nm; a certain amount of long wave ultra-violet at 365 nm is also produced (Figure 1).

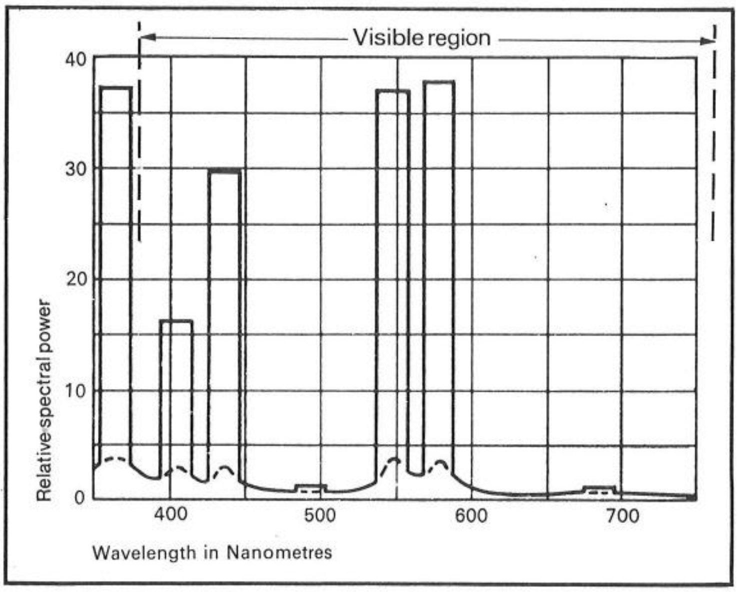


Figure 1
Spectral power distribution typical of most clear mercury lamps.

In general, as the pressure increases, it tends to shift a larger proportion of emitted radiation into longer wavelengths, and at extremely high pressures there is also the tendency to spread the lines into wider spectral bands, but these will be less continuous in form than the radiation from an incandescent body. HPMV lamps operate at internal gas pressures of 2 to 10 atmospheres, and the extra-high pressure compact source lamp about 20 + atmospheres.

2.3 A fluorescent coating on the outer envelope can do two things—

(a) By using an appropriate phosphor (A2.23—28), ultra-violet energy can be converted into visible light, thus making possible a higher overall efficacy, although the increase is limited because the coating itself absorbs some of the visible light emitted directly from the discharge (Figure 2).

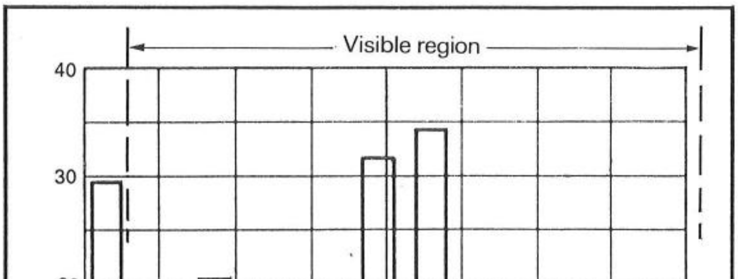


Figure 2
Typical spectral power distribution using a phosphor biased to increase efficacy.

(b) By using a phosphor which emits most of its energy in the red region, greatly improved colour rendering may be obtained (Figure 3).

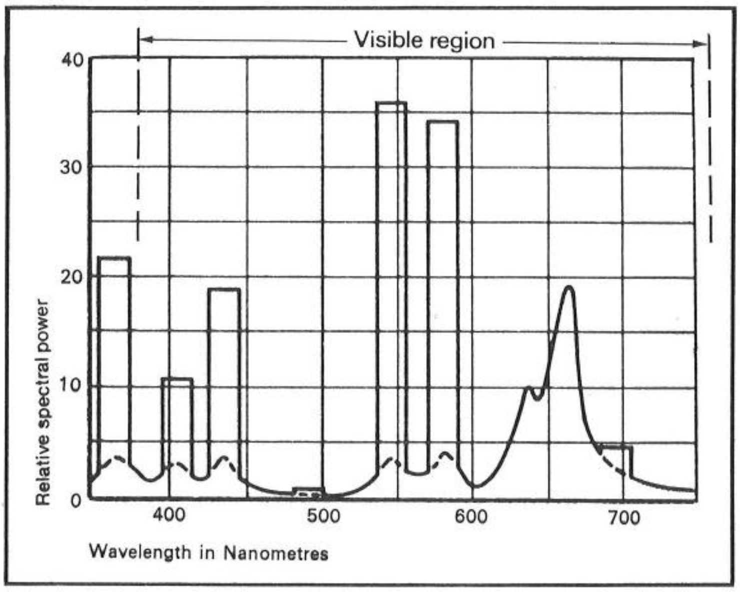


Figure 3
Typical spectral power distribution using a phosphor primarily to improve colour rendering.

2.4 In practice, the phosphors used may represent a compromise. Magnesium fluoro-germanate is used in most British lamps; this converts the ultraviolet at 365 nm into visible red between 625 nm and 675 nm, giving a near white colour appearance and fairly good colour rendering. The recent introduction of rare earth activated phosphors represents a departure from the above practice.
An alternative phosphor, strontium ortho-phosphate gives higher efficiency but a lower red ratio (2.5).
The phosphor efficiency falls off above a temperature of 350/400°C, and it is therefore desirable to use fairly large egg-shaped outer bulbs.

2.5 Natural daylight contains approximately 15% red; a pearl or clear HPMV lamp has only 1%.
The amount of red content can be defined by the percentage of the total light output which will pass through a Wratten 25 red filter, and the resulting figure is known as the 'red ratio'.
MBF lamps can achieve a 'red ratio' of up to 9%, which gives a reasonably good colour appearance and colour rendering. At the same time, some ratings have a higher lumen output than the corresponding clear or pearl MB lamps.

2.6 Another method of increasing the efficacy and improving colour is to add selected metal iodides to the discharge.
Suppose an element could be found which could be excited in the arc tube without interfering too much with the basic mercury discharge (i.e. by using the space surrounding the core of the arc — see 3.3) two things would be possible —

(a) The characteristic spectrum of the element would be added to that of the mercury.
(b) The total light output of the lamp would be increased accordingly.

Certain alkali metals are suitable, but in practice these would attack and soon destroy the quartz tube.
However, by introducing them in the form of the iodide, in the region close to the core of the arc the temperature causes the atoms of the metal and the iodine to separate, and they diffuse through the volume of the arc tube. But when they meet in the region of the comparatively cool walls they re-combine into the iodide, thus protecting the quartz from direct contact with the pure metal.
The iodides are also more volatile than the metal alone.

2.7 Certain metal iodides produce characteristic colours in emitted light viz —
Thallium iodide — green
Sodium iodide — peach
Indium iodide — blue

2.8 By combining these in the right proportions, a brilliant white light can be obtained, and such a lamp has an efficacy about 20% higher than a conventional type. As little as 10% of the total visible light may come from the mercury lines.
At present there is no standardization between lamp makers as to the type and/or proportions of iodides used, and so the resulting colour properties may vary slightly between various makes.
A typical objective is —

400W MBI lamp.

Nominal Chromaticity Co-ordinates x = 0·345 y = 0·38

Band	1 Far violet	2 Violet	3 Blue	4 Blue-green	5 Green	6 Yellow	7 Light Red	8 Dark Red
Wavelength (nm) limits	380–420	420–440	440–460	460–510	510–560	560–610	610–660	660–760
Percentage luminance in spectral bands	0·03	0·079	1·38	2·34	49·9	41·7	4·2	0·35

Nominal chromaticity co-ordinates for coloured versions of this rating are —
Blue x 0·22 y 0·18
Green x 0·28 y 0·60

2.9 Chlorine, bromine, fluorine and iodine constitute a group known as the halogens, so a mercury lamp to which any of the metal salts of these have been added may be referred to as a mercury halide lamp.
As the colour is generated direct by the arc, no further modification by a phosphor is required, and a clear glass outer envelope is used. The light source is therefore as compact as the MB types, allowing much more precise optical control than can be obtained with MBF lamps.
Colour stability is reached after the first 100 hours burning.
There may be a small spread in colour appearance between individual lamps even from the same manufacturer (B2.35).

3. Construction

3.1 An HPMV lamp consists essentially of an arc tube, enclosed within an outer envelope, suitably capped for support and with electrical connections. Many of the parts are subject to severe electrical and thermal stresses, pressure gradients, intense radiation and chemical attack by substances in an ionized state. The lamp must be capable of being handled and transported, and may be required to give many years of satisfactory service in situations subject to vibration, humidity or chemical corrosion.

3.2 The general construction arrangement in a typical 400W MBF lamp is shown in Figure 4.

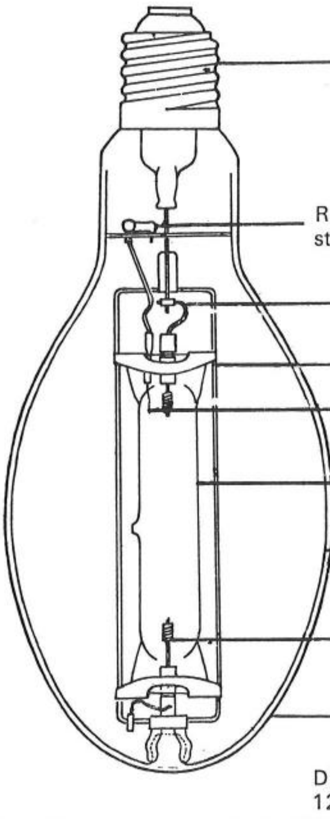


Figure 4

3.3 The Arc Tube

The arc tubes of the original HPMV lamps — the MA types — are made from alumino-silicate glass, which has a softening point around 950°C, and the arc operated at a pressure of about 1 atmosphere and a temperature of approximately 500°C. In fact, in the light of later developments, the pressure should be described as medium, and the MA lamps are now often referred to as such.

In modern lamps — the MB types — the arc tube is made of transparent silica (quartz), which due to its higher melting point — about 1000°C — enables a discharge to operate at much higher temperatures and pressures, 8 to 10 atmospheres with a temperature at the centre of the arc about 6000°K. The latter temperature falls rapidly to about 4000°K at the edge of the visible discharge, which is confined to a column in the centre of the arc tube, and from then on less rapidly through the surrounding space until very near the quartz wall which is about 800°C at its hottest point.

This results in some 25% increase in lumen output, and the lamp may be burned in any position. The quartz also transmits ultraviolet radiation at 365 nm from the discharge which can then be used to activate a phosphor coating on the inside of the outer envelope.

The tube contains an accurately measured quantity of mercury, which in a clear lamp at room temperature can be seen as small droplets on the wall of the arc tube, plus a few centimetres pressure of argon to assist starting. The quantity of mercury is critical, as to a large extent it controls the arc voltage and the operating pressure within the arc tube.

The most recent development is to introduce metal halides into the discharge tube in addition to the normal filling (2.6). Under this condition the temperature of the coldest region of the arc tube has to be carefully controlled, and precautions to reduce heat loss may have to be taken, which are unnecessary with the plain mercury discharge.

3.4 The Electrodes

There is a main electrode at each end of the arc tube, which serves the dual purpose of cathode and anode. These electrodes are constructed from coiled tungsten wire—or a combination of rod and helical wire overwind—containing in the interstices a compound of barium, calcium, thorium and tungsten oxides which form the emissive material. They are robustly constructed to withstand cold starting, since no arrangements are made for preheating as in the fluorescent tube. There is also a plain metallic auxiliary starting electrode close to one main electrode and connected to the other through a high resistance. In some cases auxiliary electrodes may be fitted adjacent to both main electrodes.

3.5 Support Frame and Lead-in Wires

The arc tube is supported in position by a strong nickel-plated frame, with metal braid connections acting as electrical conductors from the frame and lead-in wires. The quartz discharge tube presents a special problem in glass-to-metal seals, for no metal combines a very high melting point with a very low thermal expansion to match the characteristics of quartz. In practice the problem is solved by using thin elliptical strips of molybdenum foil passing through the quartz; strain exists in these seals but if the foil is thin enough no leaks will develop.

3.6 The Outer Envelope

The outer envelope is manufactured from high quality heat-resisting glass, the material and shape being governed by the lamp type. This outer envelope does four things—

1. Filters out any dangerous 253.7 nm ultra-violet radiation (B2.38) which is transmitted by quartz. Thus no attempt should be made to use any MB lamp if the outer envelope is broken.
2. Protects the arc tube and supports from damage, oxidation, corrosion and draughts.
3. Conserves the heat from the arc tube, increasing the lumen output and shortening the run-up time.
4. Carries the phosphor coating on its inner surface in the case of MBF lamps (2.4).

The envelope is normally filled with nitrogen (sometimes with some argon in addition) which also assists thermal stability and protects the frame and seals from oxidation.

Reflector type lamps have a specially shaped outer envelope (1.4). The crown of the bulb has a light-diffusing finish, while the remainder has a double coating, first with a reflective material such as titanium dioxide and then with a phosphor such as magnesium fluoro-germanate (2.4). When the outside of the lamp is clean, up to about 20% of the total light output passes through this coating, an average figure being about 15%. Thus, such lamps are useful in situations where cleaning is difficult, as any dirt which collects on the reflective portion does not impair the forward light through the crown.

3.7 Cap

Due to the high temperatures involved, great care is required in capping these lamps. Nickel plated caps are sometimes employed to reduce the risk of corrosion, and a cement which will withstand high temperatures during service over many years is necessary.

In some cases mechanical capping is used.

4. Operation

4.1 When a HPMV lamp is first switched on the normal mains voltage is not sufficient to cause a discharge between the two main electrodes, but it is enough to initiate a glow discharge in the argon carrier gas across the small gap between the starting electrode and the main electrode, producing enough ions and electrons to start the discharge between the main electrodes, which although they are cold, rapidly heat up to thermionic emission temperature. The rise in temperature also vaporizes the mercury, which first operates as a low pressure mercury vapour discharge and appears dull and inefficient. As the temperature continues to rise, the mercury vapour pressure increases, and likewise the efficacy, until all the mercury has vaporized, and the pressure reaches an optimum value. In this fully run-up condition the effect of the argon is insignificant, and the starting electrode has no material effect on the performance of the lamp, since the current through it is limited to a few milliamperes by a high value series resistor.

4.2 The operating mercury pressure, and hence the efficacy, does not depend on the temperature of the surroundings, in contrast to the behaviour of the tubular fluorescent lamp which is greatly affected by ambient temperatures.

4.3 The length and diameter of the arc tube, which determine the electrical characteristics, are chosen so that the voltage across the lamp when warmed up is about 60% of the supply voltage; this ensures there is sufficient voltage available to re-ignite the arc after it is extinguished at the point of zero current which occurs at each half-cycle on a.c. supplies.

4.4 To achieve the fully run-up condition may take from 3 to 12 minutes, according to the type of lamp and operating conditions. The MBI lamps run-up in half the time, and can reach 80% of maximum light output in about 1½ minutes. During this time the

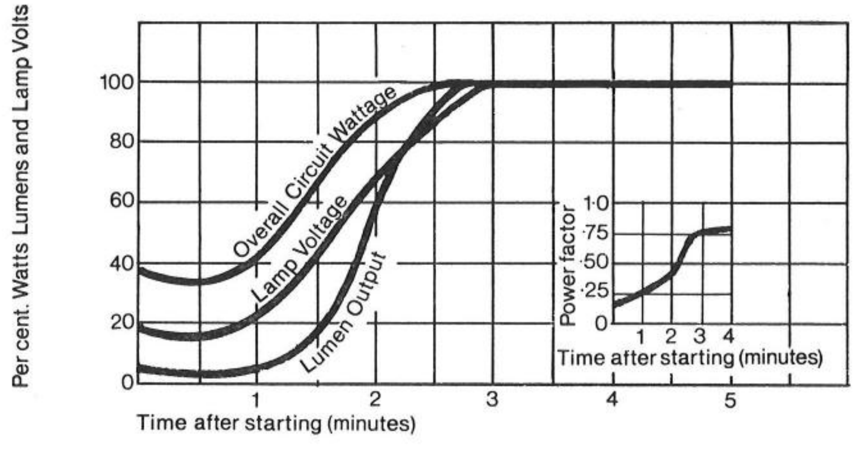


Figure 5

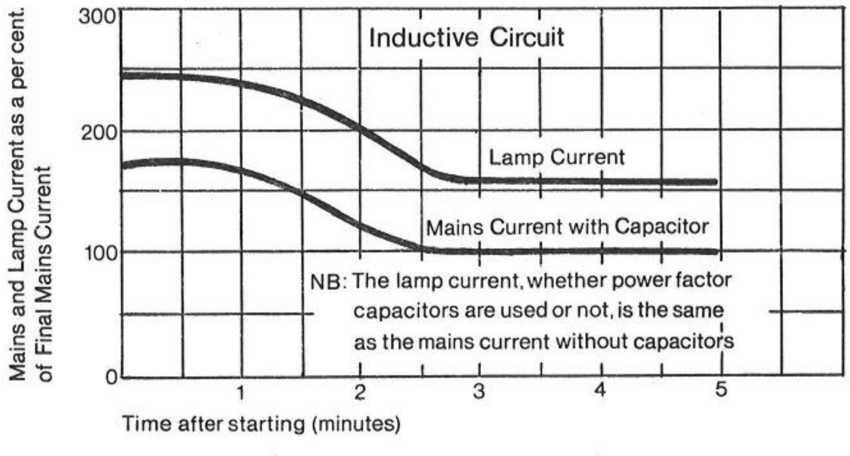


Figure 6

lamp voltage is rising and the current diminishing. (Lamp starting current may be double that of the running current.) Figures 5 and 6 indicate what happens to voltage, current, power and light output during the run-up time in a typical MB type lamp.

4.5 On normal a.c. supplies the discharge current passes through zero, each half-cycle. However, on inductive circuits, the periods of zero current are so short that ionization is maintained, so that the discharge readily re-starts in the next half-cycle.

4.6 The current through an HPMV lamp is substantially in phase with the voltage across it, but as voltage and current wave forms are distorted the power factor of the lamp alone is about 0.9. The reason for this distortion is that the discharge current during each half-cycle does not commence until the voltage has risen to a certain value (the striking voltage) and it ceases to flow before the voltage falls to zero (the extinction voltage).

4.7 When a lamp is switched off, it will not re-start until most of the mercury vapour has re-condensed. It may take several minutes to cool down sufficiently, reducing the pressure and congestion of the atoms, until the mean free path is again enough to enable the free electrons to attain the necessary velocity to start the ionizing process. No harm will be done to the lamp if the mains switch is left in the on position during the cooling process, and the lamp will re-strike immediately the required condition is reached.

4.8 Current Limitation

The optimum performance of the lamp is therefore dependent on a number of factors associated with starting and running conditions. In common with all discharge lamps, this one has a negative resistance characteristic—once the arc has struck, the current increases rapidly to a value which would destroy the lamp if it were not limited by a series impedance, which may be a tungsten filament, choke or leakage-reactance transformer.

4.9 In MBT lamps, the limiting device is a tungsten filament in series with the discharge tube and within the outer envelope. This contributes to the total light output, and enables the 'red ratio' to reach about 12%, although the lumens per watt efficacy is only about 40% of the figure obtainable with an MB lamp and conventional circuit. At starting, the filament carries the major part of the load. When fully run-up it contributes about 20% of the total light output. The great advantage of this type of lamp is that being independent of external control gear, it may be used as a direct replacement for incandescent lamps, and due to its long life is useful in installations where maintenance costs are high or access difficult. The luminous efficacy is about twice that of an incandescent lamp of corresponding wattage.

4.10 The conventional means of limiting the current with an a.c. supply is by means of a choke (A2.14—2.22). It is important that the choke be suitable for the lamp and the actual voltage of the supply. Chokes are usually tapped so that the latter can be matched within close limits. Incorrect matching of lamp, choke and supply voltage can result in loss of light output and the lamp may even go out when hot if the voltage at the terminals is substantially less than that for which it was designed. Severe under-running of a lamp can cause rapid loss of emitter from the cathodes, whilst severe overloading will raise the arc-tube temperature which can cause the quartz arc tube to swell, or break down. Either condition will adversely affect the life of the lamp (4.15).

4.11 The Choke

The choke used is normally of the solid filled type, using a thermosetting polyester resin, which cannot melt, is free from voids and makes good thermal contact with the steel case. The case is not only a convenient means of carrying the terminals and fixing lugs, but it screens any stray magnetic field from the choke and prevents vibration and noise from being induced into adjacent parts of a lighting fitting.

Some hum is inevitable from a choke, but in the type of situations for which mercury lamps are eminently suitable the low noise level of a well made choke can be disregarded.

A choke—with capacitor if required—is available housed in a cylindrical case which has a tapped entry top and bottom. It is thus an easy method for introducing the control gear between the fitting and its suspension, which in some cases will be more convenient than mounting it separately some distance from the fitting.

The average life of a well made choke should be between 10 to 20 years, always provided it is initially correctly chosen and installed.

4.12 Power Factor

Although the apparent power factor of the lamp itself is nearly unity, in a choke or transformer controlled circuit the power factor of the complete circuit is about 0.5 to 0.6 lagging.

A low power factor is undesirable because—

1. It unnecessarily increases the current and kVA demand from the supply.
2. The useful load that can be carried by cables and accessories is reduced.
3. The Electricity Board may impose special tariffs for a low power factor load.

Correction to 0.8 to 0.9 is usually acceptable, and can be obtained by connecting a suitable capacitor across the mains (see Appendix I). The capacitor takes a current which is leading in phase and this partly cancels the lagging current taken by the choke.

4.13 The Capacitor

The capacitor usually consists of a paper and aluminium foil core impregnated with a liquid or solid dielectric medium. Typical impregnants are shown in the table below. Capacitors may suffer damage if subjected to excessive temperature, so the metal container (normally aluminium) is usually marked with the maximum operating temperature, the maximum working voltage and the capacity in microfarads. A small discharge resistor is incorporated to allow the charge to leak away after switching off the supply.

Capacitor Impregnant	Permitted Temperature Limits
Chlorinated Naphthalene	— 25°C to + 50°C max.
Mineral oil	— 40°C to + 60°C max.
Pentachlorodiphenyl	— 5°C to + 70°C max.
Trichlorodiphenyl	— 40°C to + 70°C max.

These maximum temperatures should not normally be exceeded in ordinary service in the UK, but precautions may have to be taken in abnormally hot situations.

4.14 Lumen Maintenance

The lumen output of an HPMV lamp decreases throughout its life, the rate being more rapid during the first few burning hours. Different types of lamp differ slightly in lumen maintenance, but Figure 7 can be considered typical.

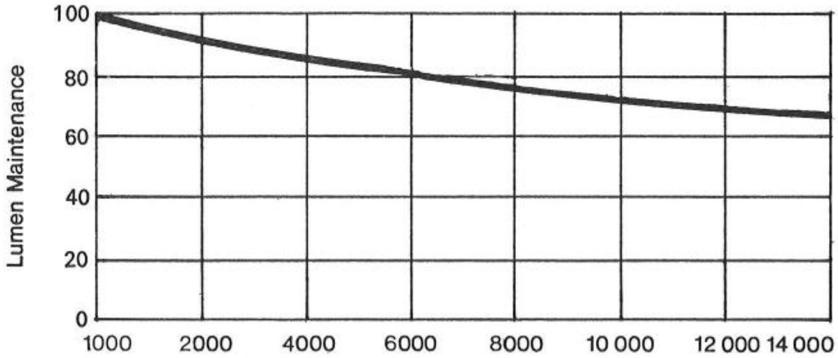


Figure 7

4.15 Life

1. Ultimate failure of an HPMV lamp is caused by the cumulative effect of the loss of minute quantities of the emissive material from the electrodes; some of this material is deposited on the inner surface of the discharge tube every time the lamp is switched on, and leads to higher striking voltages being required. The loss of the emitter is thus accelerated by frequent switching, as the electrodes have most work to do at switch-on and run-up.
   The life obtained depends on many variable factors, and users should refer to the lamp maker concerned for a nominal life value applicable to the lamp involved.
2. The useful life may not correspond to the nominal life, and certainly does not usually correspond with the physical life up to the point of failure, which can be very long indeed. A very old lamp may still be working, but it is worth replacing because a new lamp will give substantially more light for the same cost in electricity.
3. With an installation of lamps all switched together, the best time to replace lamps is at some convenient time before they fail or show signs of imminent failure. Group replacement, that is the replacement of all the lamps at once, if carried out at intervals of a year or two years or whatever other interval is appropriate for the circumstances, avoids nearly all the labour cost and disturbance caused by replacing lamps individually as they fail, and can therefore result in considerable economies even though there may be some potential life remaining in the discarded lamps. The most economic interval between group replacements will depend on the circumstances of use and the comparative labour costs per lamp of individual and group replacement.

4.16 Stroboscopic Effect

Stroboscopic flicker of a moving object can occur if the motion repeats or appears to repeat itself synchronously with the pulses of light from the lamp. For example, with a 4-spoked wheel revolving at 1500 r.p.m. one or other of the spokes will be pointing to 12 o'clock 100 times a second. If a light flashed instantaneously at these moments, the wheel would appear to be stationary, and such an effect is in fact obtainable with 'flash tubes' used for photography; but with MBF lamps a moving object can seldom if ever be mistaken for a stationary one.
The afterglow from the fluorescent powder in the MBF types helps to reduce this effect, and where it is considered really necessary it can be further reduced by operating lamps on different phases of the supply, providing it is possible to ensure that at least one source on each phase contributes materially to the illumination at the point in question.

4.17 D.C. Operation

It is not really practicable to operate these lamps on d.c. A resistance has to be used to limit the arc current; this results in considerable power being wasted in generating heat. The arc tube blackens rapidly, so the lumen maintenance is poor. This is because the cathode, being designed primarily for a.c. operation, runs too hot on d.c., resulting in the emissive material being driven off too rapidly from the cathode on to the wall of the arc tube. The lack of a.c. voltage peak in the circuit may make starting difficult.
Should only a d.c. supply be available, the best way is to use thyristor invertors to convert the d.c. supply to a.c. This is reliable and comparatively economical.

5. Effect of operating conditions

5.1 Effect of High or Low Mains Voltage

Figure 8 shows how the characteristics of a typical 400W lamp change with variation in the supply voltage. Curves for other ratings are similar. Small percentage variations in the supply voltage, either up or down, affect the light output some 3 to 4 times as much.

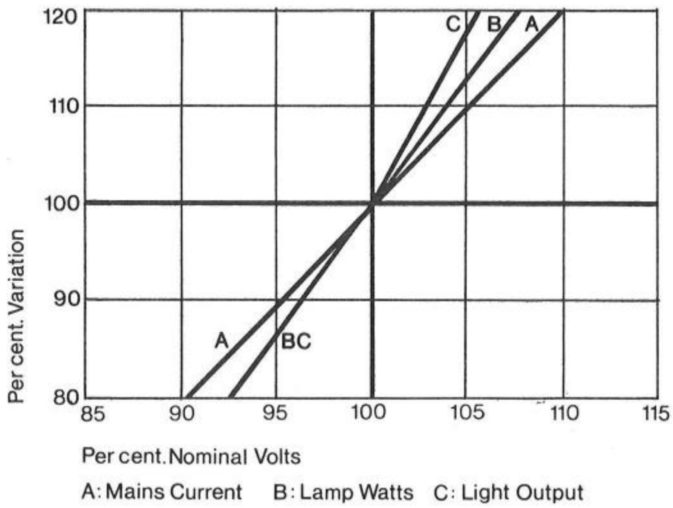


Figure 8
Effects of mains voltage fluctuations.

Consideration is given when designing a lamp to the effect of a sudden drop in the supply voltage of the magnitude likely to be experienced in practice. An average lamp on 240V nominal can tolerate up to a 30V drop over about 1/25th second without going out; on 400/450V this becomes 50V.

If the voltage drops more slowly, the tolerable maximum voltage drop increases.

Equipment should be matched to the average actual supply voltage at the point, rather than accepting that this always corresponds to the nominal declared voltage.

5.2 Low Temperature Operation

All mercury lamps normally will operate satisfactorily in ambient temperatures down to —5°C. At lower temperatures the main problem involved is the striking of the lamp.

One method to assist striking under these conditions is to make sure that the silica arc tube is free from residual impurities, as these can be the cause of unreliable starting. The voltage required for starting can be substantially reduced by using a 'clean' tube (Figure 9); current lamps should be satisfactory down to —30°C at 240V.

In contrast to fluorescent tubes, wide variations in ambient temperatures have little effect on the light output of mercury lamps, making them particularly suitable for applications where low operating temperatures are involved. The time taken to reach stable conditions may vary slightly with ambient temperature.

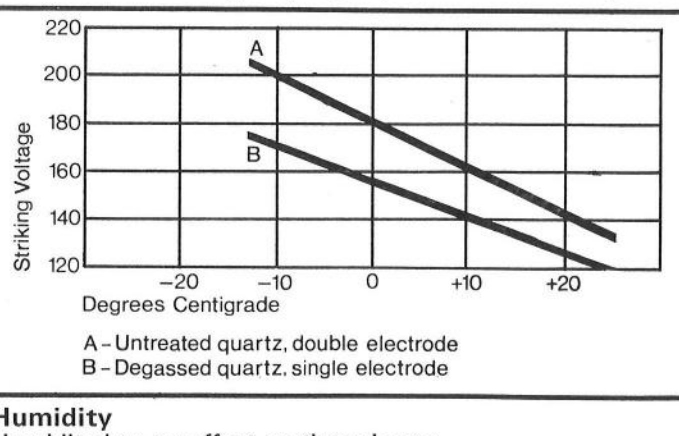


Figure 9

5.3 Humidity

Humidity has no effect on these lamps.

6. Circuits

6.1 Single Phase Circuits

Typical circuits are shown in Figures 10 and 11.

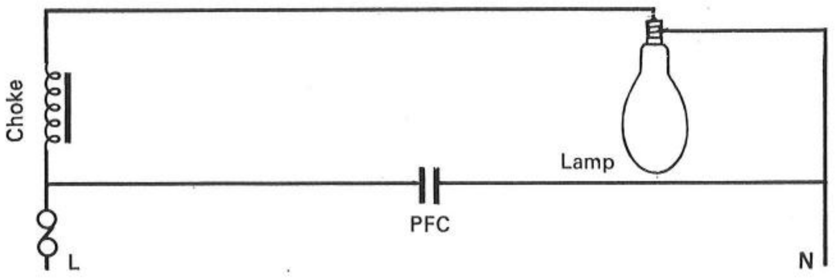


Figure 10
The standard circuit for an MB type mercury lamp on mains volts 50 Hz supply.

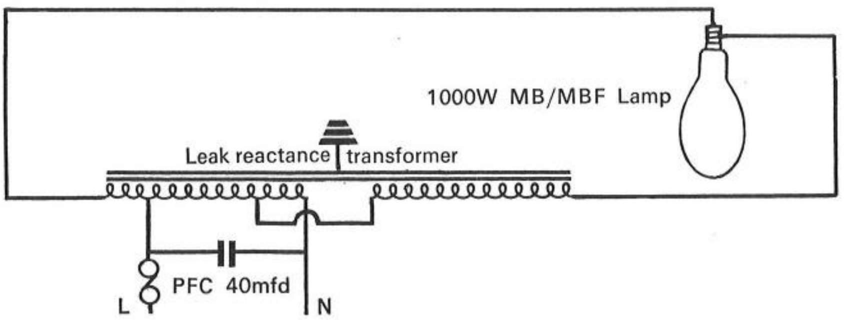


Figure 11
The circuit for a 1000W (high voltage) MB type lamp on a single phase supply using a leak reactance transformer.

6.2 The 400W mercury halide lamps need special control gear, and due to differences between various makes of lamp, the gear must be matched in accordance with the manufacturer's instructions. Some are not suitable for use on a supply below 230V. The permitted burning positions also vary between makes.
Whilst the long term objective is that control gear should be interchangeable, this is not so at present and the three circuits used are shown in Figure 12.

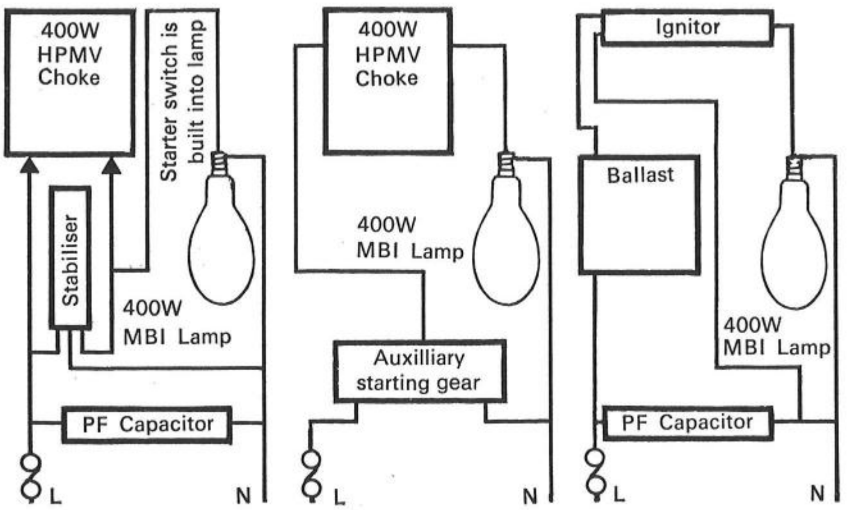


Figure 12
Circuits at present used for 400W MBI lamps. Each is appropriate to an individual make of lamp.

6.3 Three-phase Circuits

When HPMV lamps other than the 1000W (high voltage) type are operated on a three-phase four wire supply — i.e. connected phase to neutral — a current will flow in the neutral conductor of a balanced three-phase system due to the harmonics inherent in the current waveform of the lamps. This is aggravated during the running-up period due to the changing power factor of the lamps. It is advisable therefore that the current carrying capacity of the neutral conductor should be similar to that of the phase conductors.

6.4 The 1000W high voltage type lamp is used across two phases of a 350/450V supply — Figures 13 and 14. There is lower current in the circuit cables, and the voltage from the fitting to earth is no more than for a single phase supply.

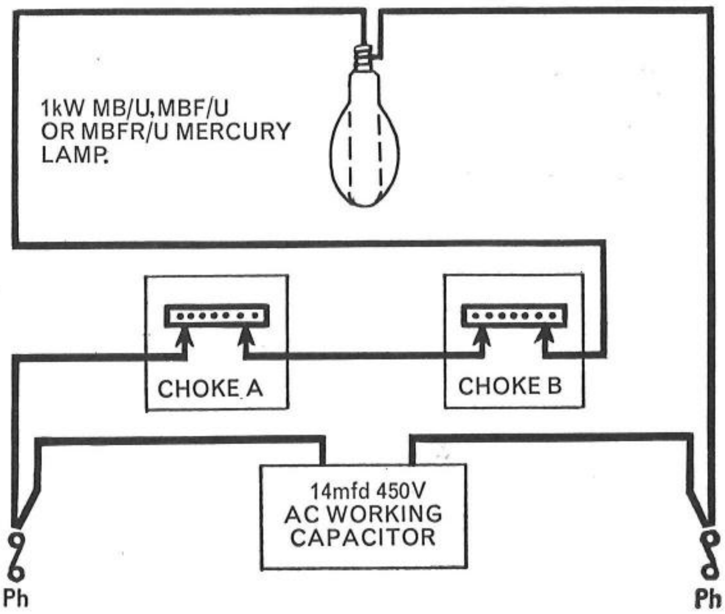


Figure 13
Diagram showing how the components are connected for a 1kW high voltage MB lamp on a 3-phase 350/450V supply, using 2 tapped chokes in series, rather than a single choke which becomes bulky and heavy to handle.

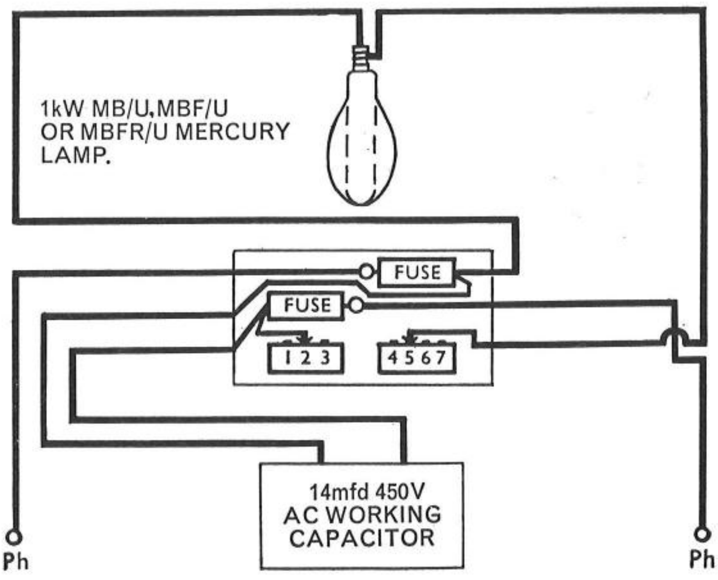


Figure 14
Diagram showing how the components are connected for a 1kW high voltage MB lamp on a 3-phase 350/450V supply, using a single choke having fuses and capacitor connection terminals incorporated.

7. Applications

7.1 All HPMV lamps have the advantages of a relatively compact source operating reliably at high efficacy over a long life.
The colour appearance and colour rendering of the MBF types have provided an acceptable and economical source, but the introduction of the halide lamps, both white and coloured, has opened up a much wider field of application, and the user has a wide choice from which to assess the most suitable type to meet particular circumstances.
MBFR lamps are particularly useful in dirty situations or where fittings are difficult to clean. They may be used without fittings, but often employ special skirt type fittings which provide cut-off, redirect some of the back-light forwards, and give mechanical protection to the lamp.
MBT type lamps may be fitted as replacements for tungsten lamps, being particularly useful in installations where maintenance costs are high. These lamps are physically interchangeable with certain GLS lamps, e.g. 250W MBFT/MBTL with 300W GLS; 500W MBFT/MBTL with 500W GLS.

7.2 The following is a list of typical applications, but is by no means comprehensive.

Exterior

Street lighting.
Football field lighting.
Sports lighting.
Building sites.
Large area lighting — railway yards, stockyards, docks, quays.
Garages, car parks.
Colour floodlighting.

Interior

Industrial interiors. The MBI lamps will make it possible also to include exhibition halls, stadia, swimming pools, airport terminals, etc.
In flameproof or similar equipment where maintenance is expensive.
Shop window lighting — usually in conjunction with tungsten.

Specialized uses

Photo-chemical processes including photo-copying — MB lamps are normally used.

Horticulture. Both MB and MBF lamps are used, mainly in the 400W rating, but a special version is available specifically for this application. Various plants have specialized requirements which dictate which type of lamp is most suitable. Further detailed information may be obtained from The Electricity Council (EDA Division).

8. Special lamps

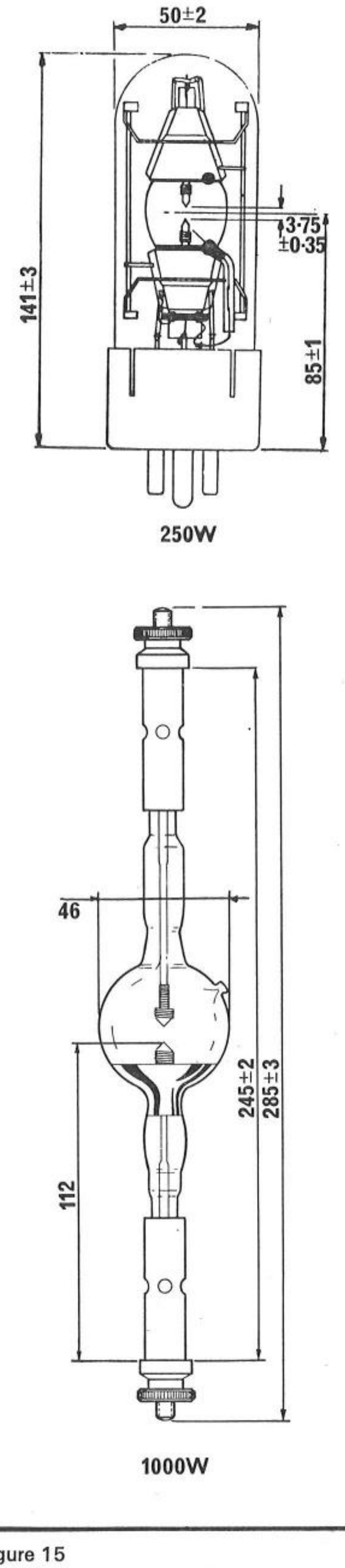


Figure 15
Typical compact source ME/D lamps,

8.1 Black Glass MBW/U Lamps

This is a conventional 125W MB mercury lamp in which practically all visible radiation is absorbed by the Wood's 'black glass' used for the outer envelope, which transmits ultra-violet of wavelength 365 nm. This radiation is not dangerous, but these lamps are uncomfortable to look at, and should not be viewed directly for extended periods. The light can be used to excite fluorescence in certain powders and paints, such effects are often used on the stage, and for decoration or display.

MBW lamps have some applications in commerce and industry, e.g. articles can be marked so that the marking is invisible under normal light but apparent when viewed by the light from this lamp. Some laundries use this method of identification.

The light can also be used to detect the presence of certain kinds of oil and grease, alterations to documents, and has certain applications in the food processing industry.

8.2 Compact Source ME/D or C/S Lamps

The purpose of this type of mercury lamp is to provide a very high brightness source of small physical size, and they are made in several ratings, the lowest being 50W.

The discharge takes place within a quartz arc tube, spherical or isothermal in shape, and although the arc may be only a few millimetres long, the walls of the tube have to be several millimetres thick to withstand the extra high pressures, generally above 20 atmospheres, at which these arcs operate.

Three types of construction are used—

(a) Bare quartz lamps with no outer envelope.
(b) Having a glass outer envelope.
(c) Contained within a metal box having a circular window of glass or quartz.

Due to the very high pressures involved, types (a) and (b) should only be used within a suitable protective housing.

This lamp is used mainly in projection apparatus, including projection microscopy, photomicrography and fluorescent microscopy. In conjunction with suitable filters it can be used as a high brightness source of monochromatic radiation.

Methods of operation vary; some lamps have an auxiliary electrode and start on mains voltage in a similar manner to high pressure lamps, and others require starting aids such as a high voltage pulse or a high frequency probe.

The electrodes are made of 3 to 5% thoriated tungsten, and may not have any emitter coating. Where currents above 15A are involved, they are usually blocks of tungsten shaped to provide sufficient surface area to radiate energy arising from a positive ion bombardment. The tips are made conical or wedge shaped to give controlled convection flow of the gas and to permit a greater angle of light to be collected from the concentrated arc.

To assist starting and run-up time both neon and argon are added to the mercury in the arc tube, and when a glass outer envelope is used, this is filled with nitrogen.

The 250W lamp shown in Figure 15 provides a high-brightness source of 200 Mcd/m^2 and a horizontal candle-power of about 1400 cd. The 1000W version has a brightness of 400 Mcd/m^2 with horizontal candle-power of some 6000 cd.

The lamps require some 10 to 15 minutes to run up to full brightness, whether the lamp is cold or hot.

Such a delay would be inconvenient for cinema projection—a major application of these lamps—and may be avoided by keeping the lamp 'simmering' (i.e. running at much reduced power) while it is not required for actual use.

When a.c. supplies are used, special chokes are necessary which suit the characteristics of these lamps, which differ from those of MB lamps although the wattage rating may be similar.

The principle of including metal iodides in the arc tube (2.6—2.9), is applicable to these lamps.

Part 2 Low Pressure Sodium Vapour Lamps

9. Classification

9.1 In low pressure sodium vapour discharge lamps, the emission is an almost monochromatic light of characteristic yellow colour coming from a double line in the spectrum at 589 nm and 589.6 nm. All objects appear as yellow, shades of yellow, brown or grey, but because the emitted energy is so near the maximum of the spectral luminous efficacy curve (A1.9), very high efficacies are possible, nearly 160 lm/W being claimed for some modern lamps.

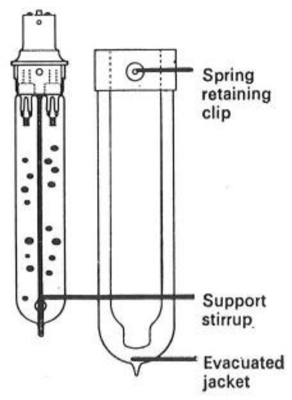
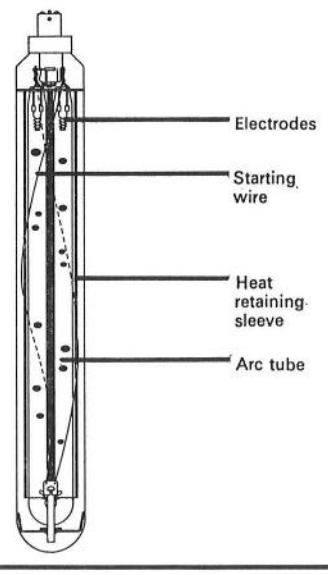
9.2 Lamp types are designated by a series of letters with the following meaning—

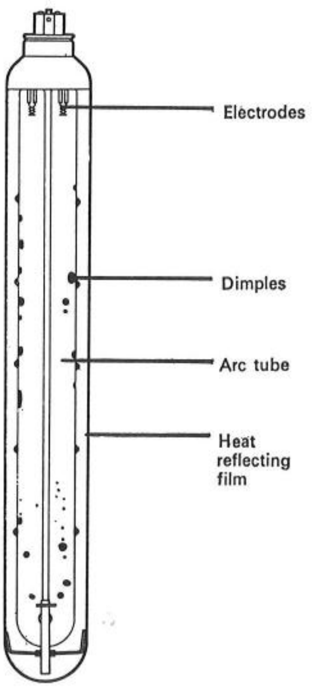
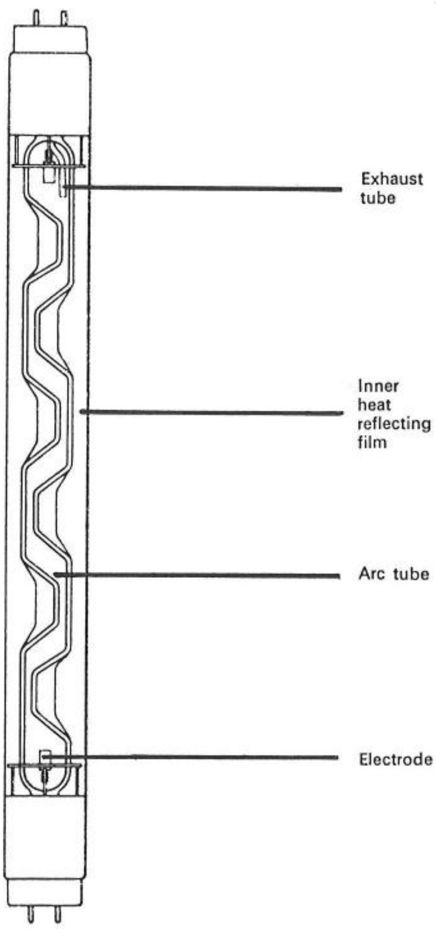
1st letter:
This is always S, denoting a sodium lamp.

2nd letter:
O indicates a U-shaped arc tube.
L indicates a linear arc tube.

3rd letter:
I indicates an integral construction, in which the arc tube and outer envelope are sealed together.
X indicates a high efficiency version using integral construction.
The letter after the oblique stroke indicates burning position (1.3 and 10.9).

9.3 There are four basic types in general use. These with their customary ratings and their characteristic shapes are shown below. For new installations, the high efficiency SOX lamps and SLI lamps are the obvious choice.

Type	Ratings	Typical Shape
SO/H An early design 'U' tube lamp. The outer jacket is removable. BC cap—B 22d.	45W 60W 85W 140W	
SOI/H The first version of the integral 'U' tube lamp. BC cap—B 22d.	45W 60W 85W 140W 200W	

Type	Ratings	Typical Shape
SOX The modern 'U' tube lamp. BC cap—B 22d.	35W 55W 90W 135W 180W	
SLI/H Linear lamp. Bi-pin cap—G 13.	60W 140W 175W 200W	

10. Considerations affecting lamp design

10.1 In contrast to mercury, sodium has a very low vapour pressure even at a temperature of several hundred degrees centigrade. The most efficient production of light requires the maintenance of an arc tube temperature of about 270°C — corresponding with a pressure of about 1/200 000th of an atmosphere — but with the current density as low as possible.

10.2 Increasing the current merely decreases the light, as the resonance absorption increases and energy is wasted at higher excitation levels, producing weak radiation at other wavelengths which contribute either little or nothing to the light output (Figure 16).

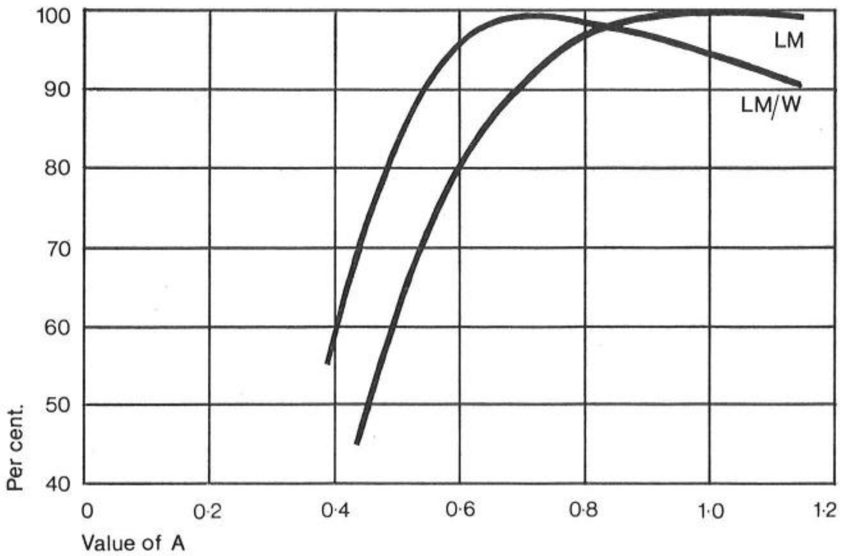


Figure 16
Variation in light output (lm) and luminous efficacy (lm/W) with current in a 90W SOX lamp.

10.3 Three factors have to be considered when designing an arc tube —

(a) Vapour absorbs its own radiation, therefore the best efficacy in terms of emitted light will be obtained if the discharge column is relatively small in diameter.

(b) But for sodium the best vapour pressure is at 270°C and produced by low current density. This requires the arc tube to be of relatively large diameter, and to maintain the temperature with such an arc tube at low power needs some method of heat conservation (10.8 and 11.3).

(c) Also sodium atoms tend to be attracted to the wall of the arc tube, so the greater the surface area with any given volume, the more uniform will be the discharge (11.1).

The optimum compromise has to be found.

10.4 In modern sodium lamps neon is used as a filler gas, at a pressure of about 6 mm of mercury, as this is about the pressure at which least energy is used in generating light. When a lamp is switched on, initially it is the neon which carries the current and generates the heat to vaporize the sodium, but once this has happened the sodium atoms, having a lower ionization voltage than neon, ionize much more easily and virtually carry the whole of the discharge. Within the arc tube the neon atoms out-number the sodium atoms by about 5000 : 1, and they also act as a buffer (B2.10).

10.5 A small quantity of argon, usually about 0·8% to 1·4%, is also added to assist starting (12.1); allowance is made for the fact that during life some of this will be absorbed by the glass walls. An additional starting electrode is not necessary, although some of the older patterns of lamp may still use an external probe (connected to one of the electrodes via the lead-in wire) as a starting aid.

10.6 When any arc tube is operating, there will be small differences in temperature along its length and in a sodium lamp the sodium will tend to collect at the coolest spots. If this is indiscriminate, the effect can be cumulative, for as a region loses its sodium atoms, part of the current will be carried by the neon, which will raise the local temperature and thus accelerate the migration of the remaining sodium to the cooler places.

Eventually this results in all the sodium emission being restricted to the few cool spots, and the remainder of the tube will emit only red neon radiation, and the lamp will become what is known as a 'red burner'.

Specific precautions are therefore taken to control this migration and ensure an even distribution of sodium throughout the discharge.

10.7 A further difficulty facing the lamp designer is that at the temperatures involved, sodium is chemically very active, and attacks any glass containing more than a very small proportion of silica; this includes both ordinary glass and quartz. Special sodium resistant glasses have been developed, and two basic types are in current use. Both are subject to damage by atmospheric moisture, and are expensive and difficult to work. To minimize these limitations, a two-ply drawn tube is employed, having a thin layer of resistant glass as a lining on the inside of a tube of standard soda-lime glass (11.1 and Figure 19).

10.8 As the low current density limits the heat generated in the arc, to maintain it as near as possible to the optimum of 270°C, it is essential to avoid loss of heat from the arc tube, and the method of achieving this heat retention is one of the ways in which lamp designs differ. The arc tube must be enclosed either in a vacuum flask — sometimes called a 'Dewar' flask — or in an outer envelope at high vacuum. In all integral lamps this is supplemented either by fitting a further sleeve of heat-absorbing glass closely round the arc tube, or by providing a very thin heat-reflecting light-transmitting film on the inner surface of the outer envelope (11.5).

10.9 In general, all sodium lamps must be burned in a substantially horizontal position. Sodium must not be allowed to collect by distillation and gravity either behind the electrodes which can cause short circuits to the wall, or in the bend of a U tube which can produce a 'red burner'.

The burning positions of the various types of current lamps are shown in Figure 17; the shaded portions indicate the permitted limits of the axis of the cap.

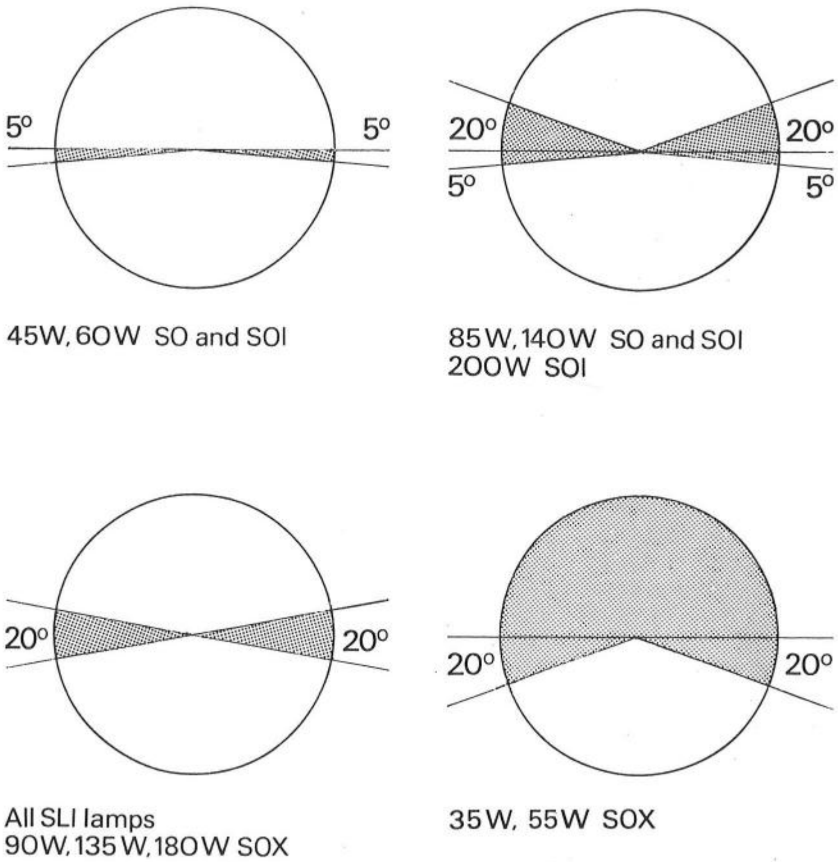


Figure 17
Position of operation of sodium lamps.

11. Construction

11.1 The Arc Tube

There are two basic shapes of tube—

1. A 'U' bend which makes a long tube into a relatively short, compact shape, providing mutual heating between the two limbs and allowing the electrical connections to be brought out conveniently into a single cap. It should be remembered that sodium vapour absorbs its own radiation (10.3) and consequently the light from one limb will not pass through the other, nevertheless due to the mutual heating effect of the two limbs, luminous efficacies up to 160 lm/W are attained.
2. A straight tube indented at regular intervals so that the cross section is approximately kidney shaped, thus increasing the surface area without increasing the volume, and at the same time functioning as reservoirs for the sodium, which maintains an even distribution of vapour during the life of the lamp. A typical tube is shown in Figure 18. A linear lamp is normally used with the indentations on the horizontal axis, not on the top and bottom. A more recent and efficient arc tube design has a clover leaf cross section capable of a luminous efficacy in excess of 150 lm/W.

The inside of the arc tube is lined with a thin layer—1/50 mm thickness—of sodium resistant glass (10.7). Two types are commonly used. Alumino borate glass, used in SO and SOI lamps, absorbs some sodium during the life of the lamp, resulting in 'staining' and some loss of light. On the other hand, the sodium is well retained, and so the tendency of the sodium to 'migrate' towards the cooler parts of the tube is reduced.

Barium borate glass used in SOX and SLI lamps, is relatively non-staining, giving better lumen maintenance but there is a greater tendency for the sodium to 'migrate'. In SO lamps this must be counteracted by dimpling small hemispherical reservoirs into the walls, and this technique is adopted irrespective of which glass is used.

The tube contains a mixture of sodium, neon and argon; this has been described in 10.1, 10.4 and 10.5. A minute quantity of xenon may also be added in some lamps.

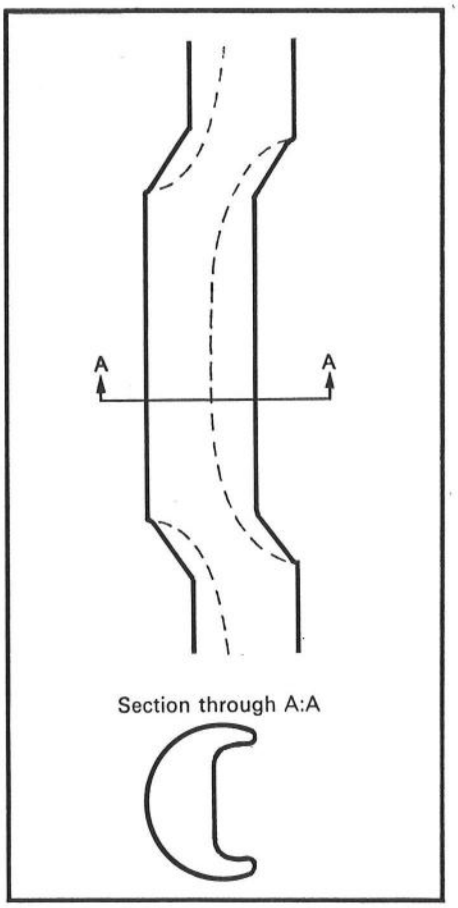


Figure 18
Formation of one type of arc tube for linear sodium lamps, providing large surface area and reservoirs.

11.2 The Electrodes and Seals

There is an electrode at each end of the arc tube, and these may be of coiled-coil or triple-coil design. They are made from tungsten wire coated with a compound of barium, calcium or other earth oxides which form the emissive material. They are clamped or welded to lead-in wires of copper clad nickel-iron, and these are often sheathed with a low conductivity glass to prevent electrolysis. In some lamps the sheath is further protected by a coating of sodium resistant glass. Further, the actual weld between the electrode and lead-in wires has to be shielded by covering it with a ceramic bead to avoid the tendency of the arc forming at this point during starting, as this might well crack the seal.

Efficient seals are vital to good lamp-life. A typical design is shown in Figure 19.

11.3 The need for heat conservation has already been discussed in 10.8. One solution is to surround the arc tube closely with a sleeve of heat-absorbing glass; in the case of a U-tube there may be one sleeve round each limb. These sleeves will reflect about 10% of the heat radiated from the discharge tube and absorb the remainder. They will thus get hot, and re-radiate both inwards and outwards in approximately equal proportions. More than one concentric sleeve may be employed, but each with diminishing effectiveness. A preferable solution to the use of sleeves is the film dealt with in 11.5.

11.4 The Outer Envelope

Outer envelopes are manufactured from high quality heat-resisting glass, and are cylindrical in shape.

In the SO lamp the envelope is an entirely separate Dewar flask, having a ceramic annular ring at its open end into which the 'U' shaped arc tube can be inserted, and retained in position by a

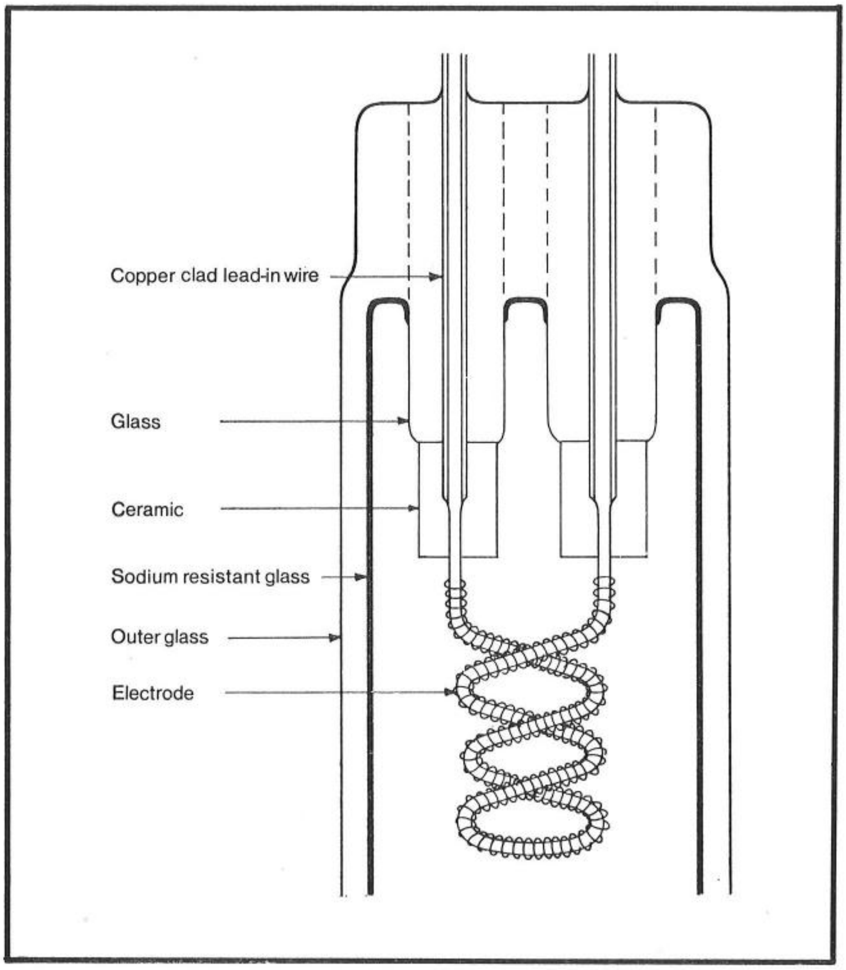


Figure 19
Seal for U-bend sodium lamp with detail of electrode construction.

spring loaded plunger which engages in a recess in the cap of the arc tube. This vacuum jacket may be expected to remain serviceable for about the life of three lamps. The illustration in 9.3 clearly shows the two components.

11.5 In all other types of sodium lamp the envelope is hermetically sealed to the arc tube, thus they are often described as 'integral' lamps. In lamps that do not have heat-resisting glass sleeves over the arc tube the inner surface of the outer envelope is coated with a heat-reflecting film which transmits light. Sometimes this film consists of layers of bismuth oxide and gold, sometimes of tin oxide. The choice is related to other characteristics of the design of a particular lamp. The tin oxide film does not reflect as much heat as the gold, but it transmits more light; figures of 75 to 80% heat reflectance with 85 to 90% transmission of sodium light are claimed. The most recent form of linear lamp also makes use of the electrical conducting properties of the heat-reflecting film coating as an aid to reduce starting volt levels.
The outer envelopes of integral lamps are evacuated to a very high degree, 'getters' being used to attain this.

11.6 In all types of lamp the arc tube, and heat-resisting glass sleeves if employed, are supported by a strong nickel-plated frame, by clips and one or more mica discs. Flexible connections are provided between the arc tube and cap.

11.7 The Cap

The standard cap for all 'U' type lamps is a special BC (BY 22d) made of ceramic to withstand the rather high voltage required to initiate the arc. There is a raised barrier across the cap between the contacts to increase the effective creepage distance and to avoid tracking.
Linear type lamps are of course double ended with a bi-pin cap (G 13) at each end similar to a tubular fluorescent lamp.

12. Operation

12.1 When a sodium lamp is first switched on, the normal mains voltage is insufficient to cause a discharge between the two electrodes, which requires an initial voltage of between 390V and 610V according to type, i.e. about twice the voltage across the stabilized arc. An arc is first struck in the argon gas, which in turn initiates a discharge in the neon, which emits its characteristic red light. The heat developed by the neon discharge gradually vaporizes the sodium, which may take some 15 minutes before the lamp reaches stability with an arc temperature of 260 to 300°C. The heat of the discharge is also sufficient to maintan the electrodes at a suitable working temperature. During this time the red of the neon discharge gradually gives way to the yellow of the sodium, and has no significance in the final emission (10.1, 10.4, 10.5).

12.2 Figure 20 shows typical starting characteristics.

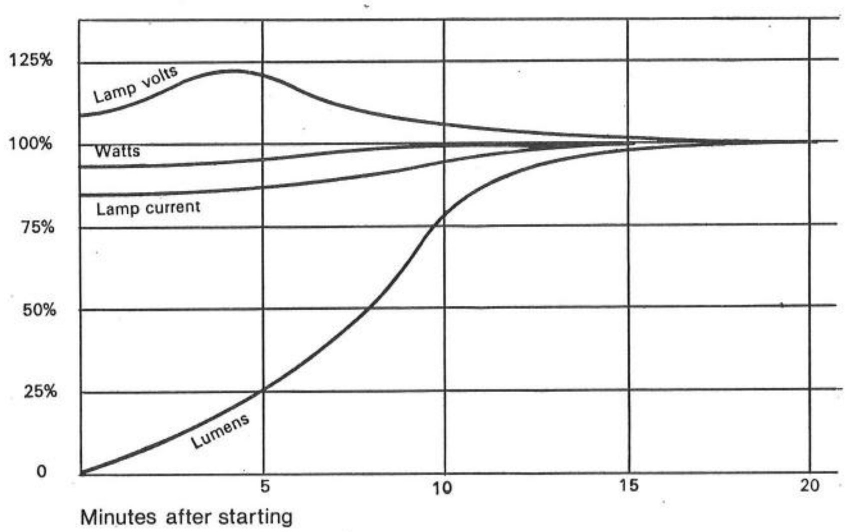


Figure 20
Starting characteristics typical of low pressure sodium lamps.

12.3 Current Limitation
In common with all discharge lamps, a sodium lamp needs a current limiting device, but additionally requires means of providing up to 610V for starting, this value varying with the type of lamp.
These conditions can be obtained by using a leakage reactance transformer. The same transformer is suitable for 35W to 85W 'U' tube lamps (Appendix 5) since they operate at the same current; for others a different transformer rating is required for each lamp size.
Note: When linear lamps were first introduced a starter switch circuit was used, in which case a choke or choke-transformer limited the current. Modern lamps may be operated in this way, but switchless circuits are normally preferred.

12.4 Power Factor
The waveform of the current is virtually sinusoidal, and is shown in Figure 21.
The waveform of the arc voltage, Figure 22, shows that during each half cycle the voltage is fairly constant with an extremely rapid reversal through the zero point at the end of each half cycle.
Thus, although the current and voltage are substantially in phase, the variation in waveform between them means that the wattage in the arc cannot be calculated by the product of voltage and current, and a power factor of 0.9 must be allowed for the lamp.
With the usual form of control gear the combined power factor including the lamp, will be about 0.4 to 0.5 lagging, therefore suitable capacitors have to be included in the circuit to correct the power factor (4.13 and Appendix 3).

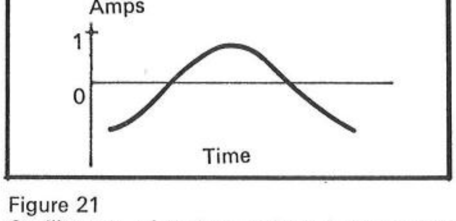


Figure 21
Oscillogram of typical sodium lamp current waveform.

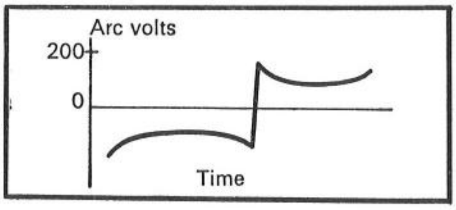


Figure 22
Oscillogram of typical sodium lamp arc-voltage waveform.

12.5 Lumen Maintenance

The light output of SO lamps decreases very gradually but steadily during life, mainly due to discoloration of the arc tube and deposition of emissive material from the electrodes on to the tube wall. It is assumed that the lamps will be operated only within the burning positions recommended by the manufacturers, to avoid premature failure.

However, as will be seen from Figure 17, lamps are designed to operate initially at a point between maximum efficiency and maximum light output, and a slight increase in mains voltage will raise the light output. Due to sodium distillation, the watts dissipated in a lamp rise somewhat during life, causing a shift towards the maximum light output position. In linear lamps it is possible therefore, by careful design, to achieve virtually 100% lumen maintenance.

12.6 Life

1. Ultimate failure generally results from exhaustion of the emissive materials, and to a secondary degree from absorption of the argon gas by the glass of the arc tube.
   The life obtained depends on many variable factors, and users should refer to the lamp maker concerned for a nominal life value applicable to a particular lamp.
2. The useful life may not correspond to the nominal life, and certainly does not usually correspond with the physical life up to the point of failure, which can be very long indeed. A very old lamp may still be working, but it is worth replacing because a new lamp will give substantially more light for the same cost in electricity.
3. With an installation of lamps all switched together, the best time to replace lamps is at some convenient time before they fail or show signs of imminent failure. Group replacement, that is the replacement of all the lamps at once, if carried out at intervals of a year or two years or whatever other interval is appropriate for the circumstances, avoids nearly all the labour cost and disturbance caused by replacing lamps individually as they fail, and can therefore result in considerable economies even though there may be some potential life remaining in the discarded lamps. The most economic interval between group replacements will depend on the circumstances of use and the comparative labour costs per lamp of individual and group replacement.

12.7 Disposal of Failed Lamps

The small quantity of metallic sodium will develop heat as soon as it comes into contact with moisture or water, so when discarding lamps it is worth taking precautions to avoid any risk of fire. One method is to break the lamps (not more than 20 at a time) into small pieces in a dry atmosphere, and put the pieces in a dry bucket of ample capacity. This should then be taken into the open, and the bucket half filled with water by means of a hose with the operator standing at a safe distance. After a few minutes any sodium will be rendered harmless and the broken pieces of lamp can be disposed of in the ordinary way.

12.8 Stroboscopic Effect

With the exception of the reference to phosphor, the considerations described in 4.16 apply, but in the applications for which sodium lamps are most suited and generally used, this effect is of negligible significance.

13. Effect of operating conditions

13.1 High or Low Mains Voltage

The effect of variations in the supply voltage on lamp watts, efficacy and lumen output of a typical 140W SOI sodium lamp is shown in Figure 23. Other ratings behave similarly.

The reason why substantially increasing the voltage barely increases the light output is that the greater power in the arc increases the sodium vapour pressure beyond the optimum value. Hence increasing the power results in less efficient production of visible radiation. This stresses the importance of the control gear being matched to the actual voltage at the point of operation rather than to the declared nominal voltage of the supply.

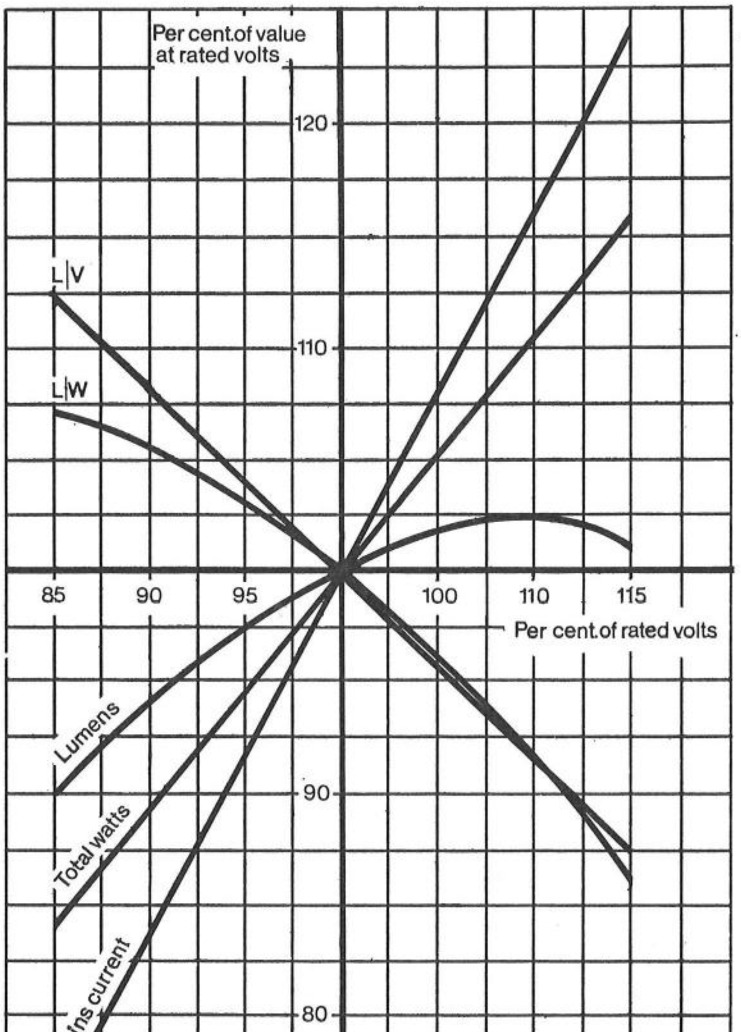


Figure 23
Effect of variations of mains voltage on the characteristics of a typical sodium lamp.

13.2 Low Temperature Operation

Due to the high degree of thermal insulation inherent in the design of sodium lamps, the light output is virtually unaffected by the range of ambient temperatures normally encountered, and starting should be quite satisfactory down to —20°C.

13.3 Humidity

The only type humidity may affect is the SO with detachable vacuum jacket. Under conditions of high humidity there may be some difficulty in starting unless the outside of the arc tube has been treated with a water-repelling substance, e.g. silicone wax which splits up a moisture film into separate droplets, making a high resistance path.

14. Circuits

14.1 The standard circuit for all lamps up to and including 180W uses a high voltage leak reactance transformer and a power factor correction capacitor (Figure 24).
Other variants of the switchless type circuits may be used with certain linear lamps (Figure 25).

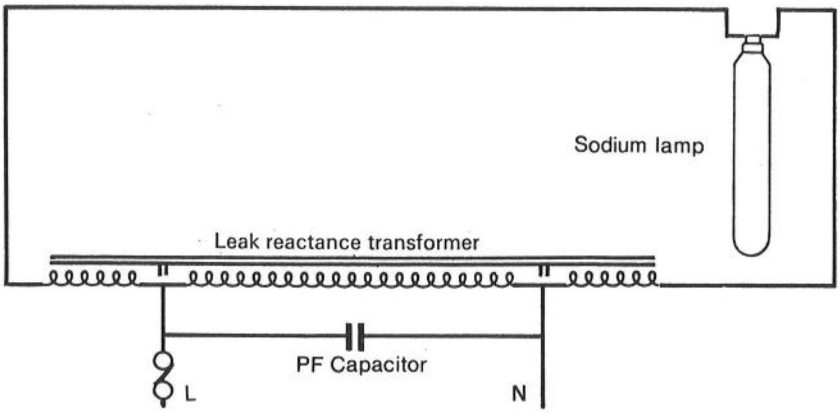
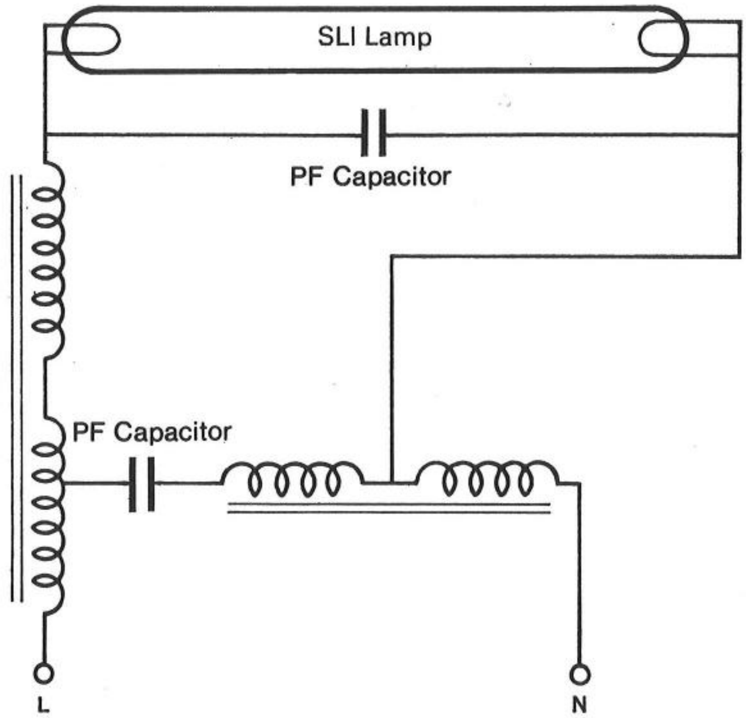


Figure 24
Standard leak reactance transformer circuit, 200/250V 50 Hz a.c.



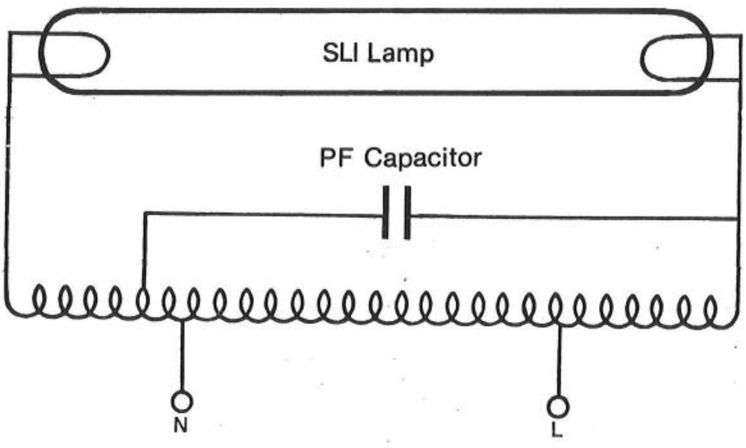


Figure 25
Typical switchless start circuits, 200/250V 50 Hz a.c

14.2 The cathodes of the linear SLI lamps, being basically similar to those used in fluorescent tubes, may be preheated by introducing a starter switch into the circuit. This method reduces the initial voltage required for starting, and thus enables smaller wound gear to be used. It may also marginally increase the useful life of the electrodes, but the introduction of another replaceable component may be a disadvantage. These circuits, Figure 26, however, show some economy in capital cost compared with switchless versions.

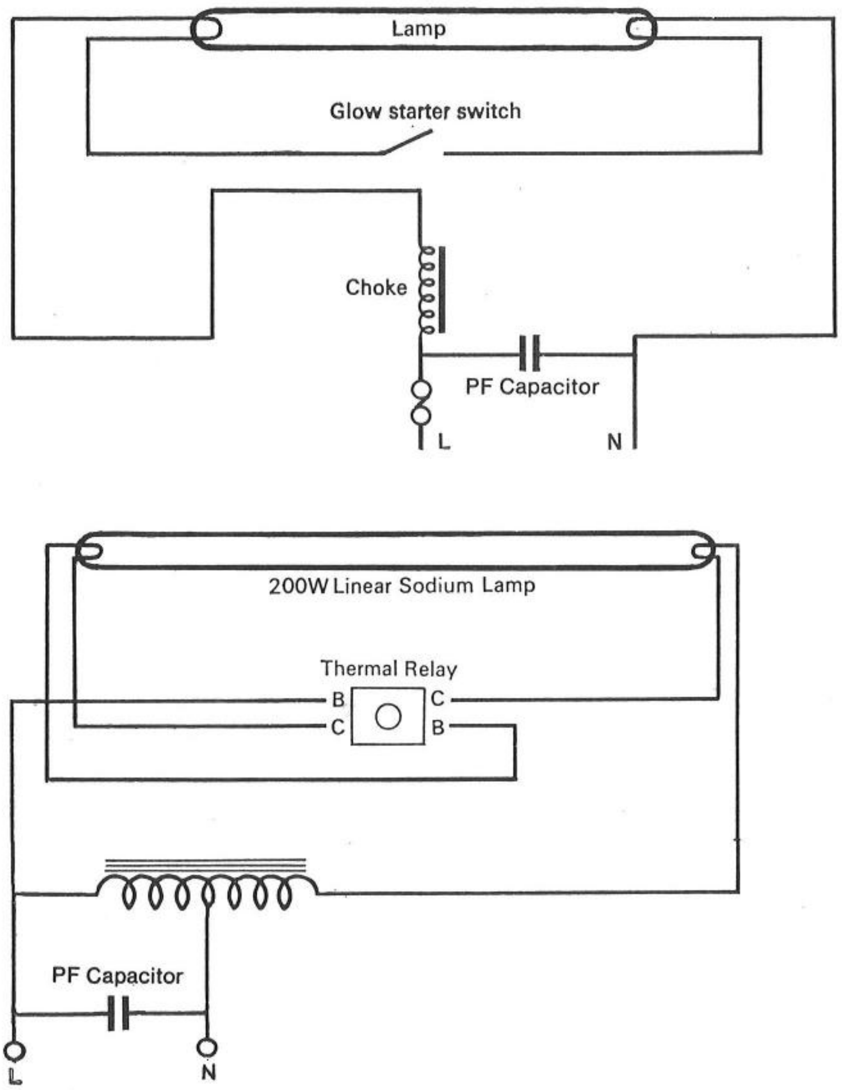


Figure 26
Typical linear switch start circuits, 200/250V 50 Hz a.c.

15. Applications

15.1 The obvious advantage of the low pressure sodium lamp is its high efficiency, but the monochromatic colour limits its applications to those where colour rendering is not of importance. It is widely used for street lighting.
It also has an application in situations which demand illumination of a strong yellow colour; where this applies it has been used successfully for colour floodlighting of buildings and even foliage where specialized effects are required.

Part 3 The high pressure sodium vapour lamp (HPSV)

16. Considerations affecting lamp design

16.1 The effects of increasing the pressure in a discharge have been referred to in 2.2. As the pressure of sodium vapour in a lamp is raised, this results in—

(a) The resonance emission becoming absorbed and being replaced by additional bands on either side; at the same time these bands are widened so that a substantially continuous spectrum is produced over the range of visible wavelengths, so colour improves as pressure increases (Figure 27).

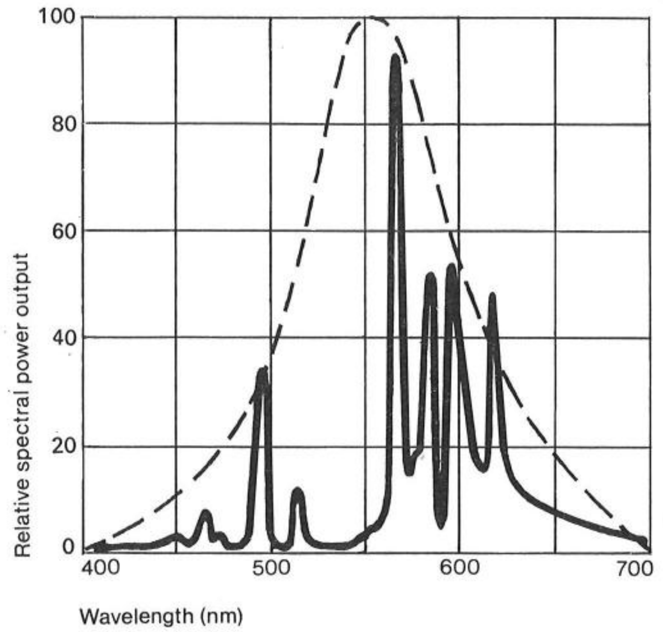


Figure 27
Spectral power distribution of a high pressure sodium vapour lamp (continuous line) with the eye-sensitivity curve superimposed (dotted).

(b) The efficacy falling first to a minimum, then rising until it reaches a maximum and then falling away again. At a pressure of about half an atmosphere efficacies of the order of 100 lm/W can be obtained.

The efficacy and colour of the discharge are therefore both dependant upon vapour pressure and are therefore inter-related.

16.2 Until recently, it has not been possible to make a lamp with such characteristics, as at the temperature involved the sodium is so chemically active that no known material for an arc tube could withstand it.

However, a new material has been developed—sintered high density poly-crystalline alumina—which, as its name implies, consists of pure alumina powder with certain additives, and which is finally sintered in hydrogen at a very high temperature for several hours.

16.3 Thus for the first time it is possible to make a lamp, based upon a sodium discharge, which is not monochromatic. The new lamp has a colour appearance identical to that of a black body at 2100°K, and balanced colour rendering properties sufficiently good to enable all colours to be recognized, although there is some emphasis on reds and yellows.

The position of this lamp on the C.I.E. chromaticity diagram relative to other lamps in general use is shown in Figure 28.

16.4 The lighting design lumens of the 400W lamp are 90 lm/W, higher than any lamp other than monochromatic sodium. The actual light source is fairly compact, and has a maximum luminance of approximately 9 Mcd/m^2, making accurate optical control in one plane easy to obtain.

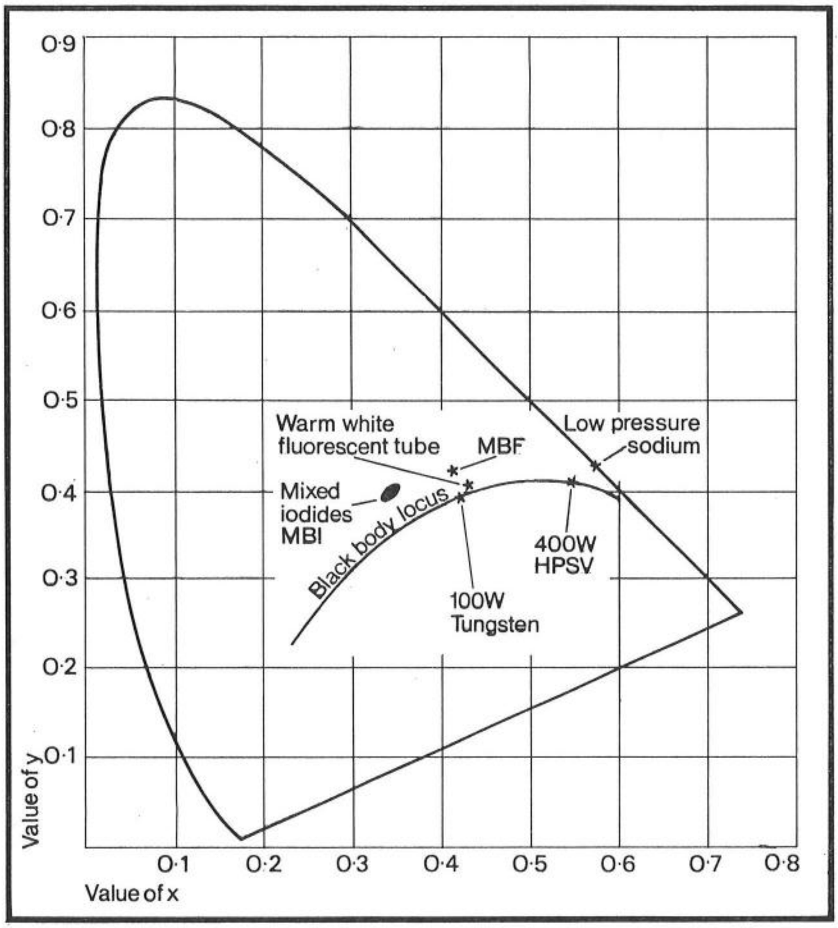


Figure 28
The C.I.E. chromaticity diagram shows the position of the HPSV lamp in relation to other lamps in general use. Its colour rendering properties make all colours recognizable.

17. Construction

17.1 Generally, the construction is much more akin to an HPMV lamp than to the low pressure sodium types previously described in this section. A typical construction of a 400W high pressure sodium vapour lamp is shown in Figure 29.

17.2 The Arc Tube

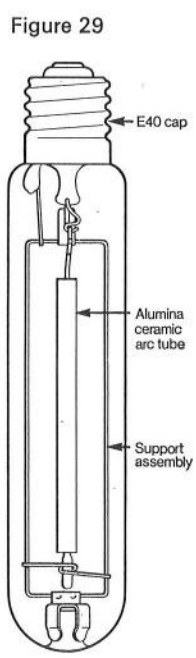
This is made from a non-porous ceramic tube (16.2) which will withstand sodium attack up to about 1600°C, and has a 90% transmission of visible light.

Unlike glass or quartz the alumina ceramic has no working range of temperature, therefore seals cannot be made in the conventional way. End caps of ceramic or sodium resistant metal, to which the electrodes have been fixed, therefore have to be cemented or welded to the ends of the tube. The type of electrode is basically similar to those used for HPMV lamps (3.4).

17.3 The arc tube contains sodium and a buffer gas, either argon or xenon, which also aids starting (10.5). A controlled amount of mercury may also be added, which has the effect of increasing the arc voltage but reduces the current, thus permitting smaller and cheaper wound control gear to be used.

The arc operates at a pressure approaching 1/3rd of an atmosphere, the temperature being about 1300°C.

Figure 29



17.4 The Outer Envelope

This is similar in both shape and construction to that of the MB/U lamp, and in common with all other sodium lamps, maximum heat conservation is necessary. The envelope is highly evacuated, metallic 'getters' being used, and a heat-reflecting film may be employed on the inner surface (11.5).

17.5 The support frame and capping follow the same principles as described in 3.5 and 3.7.

18. Operation

18.1 The arc strikes from cold electrodes as previously described, and the lamp will run up to 80% of maximum light output in an average time of about 1½ minutes. The typical time for a hot lamp to cool, re-start and run up again is about 2½ minutes.

18.2 The lamp will operate satisfactorily both in the vertical and horizontal burning positions without affecting its characteristics.

18.3 Current Limitation

A voltage slightly above that of the mains is necessary to start the discharge, so if a conventional series choke is employed to control the current, an additional device to assist starting is also required. A small capacitor may be fitted in parallel with the choke, to act as a stabilizer, and this helps the lamp to stand a sudden voltage drop in the mains without going out.

As the running current is higher than a 400W HPMV lamp, the chokes, although they may be similar in physical appearance, are not interchangeable. As this lamp is a recent development, circuitry has not yet become stabilized (20).

18.4 Initially the lamp wattage will be a little below 400W, but will gradually increase, reaching the nominal at a point about half-way through the rated life, and continuing this slow rise to the end of useful life.

18.5 Power Factor

This is lagging, and is corrected by a shunt capacitor across the mains (Appendix 3).

18.6 Lumen Maintenance

Whilst the efficacy in terms of lumens per watt may be expected to fall to some 83% over the objective life of 5000 hours burning, the rise in watts which accompanies it will compensate and, for practical purposes, the light output may be assumed to be constant throughout life, and the lighting design lumens may be taken as 36 000.

18.7 Paragraphs 12.7 to 12.9 apply to this lamp.

19. Effect of operating conditions

19.1 Effect of High or Low Mains Voltage

A 10% change in mains volts, either up or down, will make a corresponding 10% change in lamp voltage and lamp current, but a 20% change in lamp wattage and lumen output. The effect of intermediate changes in mains voltage may be taken as being pro rata.

19.2 Temperature Variation and Humidity

The starting voltage required is independent of ambient temperature, and as the lamp is unaffected by humidity it is suitable for operation anywhere.

20. Circuit

20.1 Whilst the long term objective is that control gear should be interchangeable between makes of lamp, this is not so at present. Two possible circuits are shown in Figure 30.

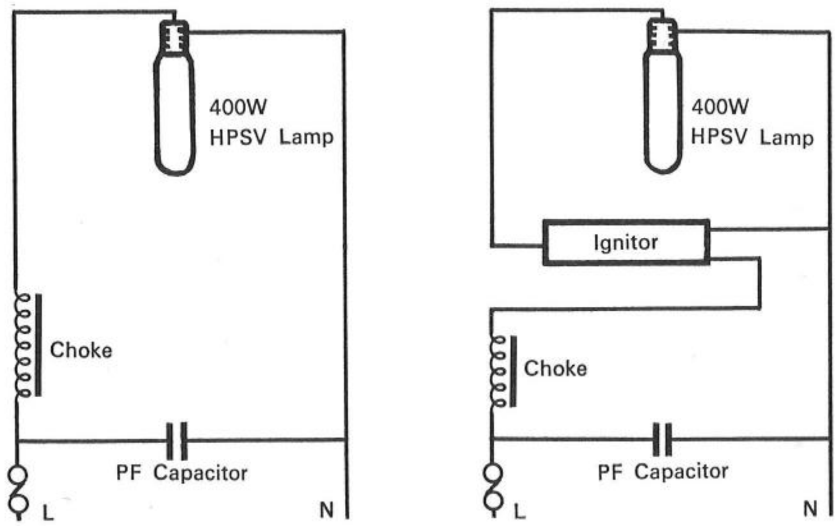


Figure 30
Two circuits at present in use. Each is appropriate to an individual make of lamp.

21. Applications

21.1 The small bright high efficacy source and acceptable colour of this lamp widens the field of application for sodium lamps, besides making possible more effective optical control.

21.2 For interiors of large area, with which discharge lamps are usually associated, the high efficacy may be a significant advantage. The new lamp may be used in exhibition halls, stadia, swimming pools, even churches and public buildings.

21.3 Outdoors, the lighting of streets and shopping centres is an obvious application; large areas such as car parks, where car identification will be made much easier, garage forecourts, marshalling yards, quarries, steel works and colliery surface works are typical of many others. The lamp is suitable for use with the high-mast lighting technique, and for the floodlighting of buildings, monuments or gardens. It will be particularly useful for floodlighting football pitches.

21.4 Future Trends
The HPSV lamp will become a valuable addition to established light sources. When lower wattage ratings become available, the potential applications will extend, especially in interiors, and will include offices, banks, schools and shops.
Efficacies may also tend to improve — 130 lm/W is considered to be practicable at a later stage.

Note : *Since the preparation of the text, a new rating of 310W has become available, and this operates on standard 400W HPMV control gear. It can thus be used as a direct replacement for a 400W MB or MBF lamp, only the choke tapping needing adjustment. The lighting design lumens are 27 000.*

Part 4 Special Purpose Lamps

22. Xenon lamps

22.1 The xenon lamp, using pure xenon for the discharge, has radiation characteristics which make it close to an ideal light source. The colour temperature is about 6000°K, and the spectral distribution curve (Figure 31) shows that in the visible region it is akin to sunlight. It is at the same time a powerful source of continuous ultra-violet and infra-red radiation, with a pronounced peak of the latter at about 900 nm.
The continuum extends up to 3000 nm. For a given light output, the xenon lamp radiates about twice as much infra-red as there is in sunlight.

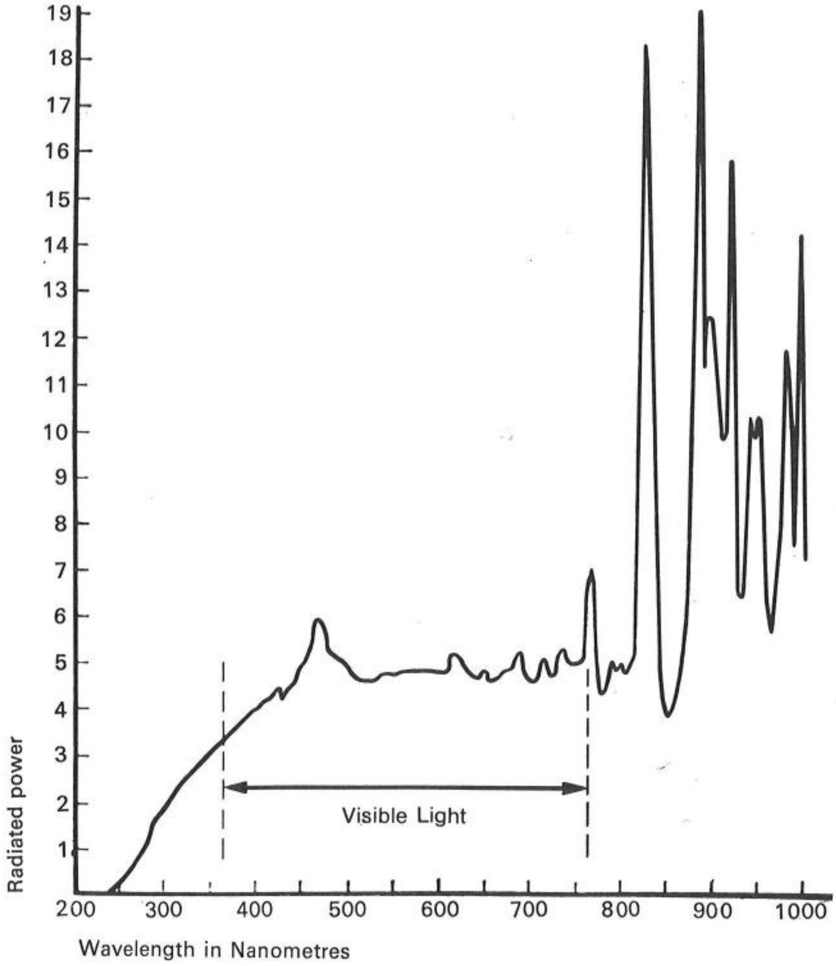


Figure 31
Spectral power distribution of xenon lamp radiation.

22.2 Xenon lamps operate over a range of pressures, and high loadings are possible. A prestige 300 kW lamp has been made, but lamps up to 20kW are in general use. The luminous efficacy is in the range 20 lm/W at 1kW to 50 lm/W at 20kW, varying according to the type of lamp.

22.3 As no starter gas is employed, full light output is obtained immediately the lamp is switched on.

22.4 There are two basic types of lamp (Figure 32) —

(a) The compact-source, using a high density short arc at extra high pressure — operating at up to 60 atmospheres — which can produce a point brightness at the cathode spot which is brighter than the sun, the useable areas of the arc being up to half the sun's brightness.

(b) The linear form, of simpler design and operating at considerably lower pressure and loading. The wattage rating is only limited by the length and voltage of the arc, as the tube must be both practical to make and convenient to use.

22.5 In spite of unique advantages, xenon lamps are not widely used because of the difficulty and cost of their operation. The lamps are expensive to make, and the control gear is bulky and heavy as it is necessary to provide for high current with low voltage for running and also a high-voltage high-frequency pulse to initiate the discharge. Due to the very high pressure which develops in the compact-source lamps, a burst could have serious consequences, so sensible precautions have to be taken. It must also be remembered that all the ultra-violet radiation above 200 nm is transmitted by the quartz, there being no outer envelope of ordinary glass.

22.6 The Compact-source Type

The arc is a few millimetres long, and operates in the centre of a spherical quartz envelope which has tubular extensions on one axis to accommodate the electrodes and their supports. The electrodes are solid tungsten, and as 'pip-growth' (which leads to electrode deformation) is more likely to occur with a fluctuating current, the lamps are usually designed to operate from a smoothed d.c. supply. The electrodes are therefore shaped specifically as an anode and a cathode.

Cold filling pressures of up to 12 atmospheres are commonly used, which represent operating pressures up to 60 atmospheres, and ratings range from 150W to 2kW. The smaller sizes up to 500W can be made for a.c. operation, but this results in reduced life. Above 500W, only operation from a d.c. supply having a ripple content less than 5% r.m.s. will enable the nominal life of 1000 hours to be achieved.

Compact-source lamps are used mainly for cinema projection, the 2kW size being the most popular for this purpose. This size also has a potential for light-houses, either flashing or continuous burning, and experiments are in progress to assess its practicability. The 250W rating is used in monochromators and projection microscopes; the 500W and 2kW in colour printers.

22.7 The Linear Type

The arc is wall-stabilized within a tubular quartz envelope. Comparatively low filling pressures are employed so that there is no explosion hazard with this type. The shape of the electrode does not materially affect arc stability and thus lamps can be made suitable for operation on a.c., and this is usual. Naturally the efficacies are lower than compact-source lamps of comparable rating, but in some cases the nominal life is 2000 hours.

Ratings of 1kW and 1.5kW are often used in fadeometers and colour matching units, whilst the 10kW and 20kW may be used for floodlighting large areas from only a few lighting points and where a sunlight quality of illumination is desired.

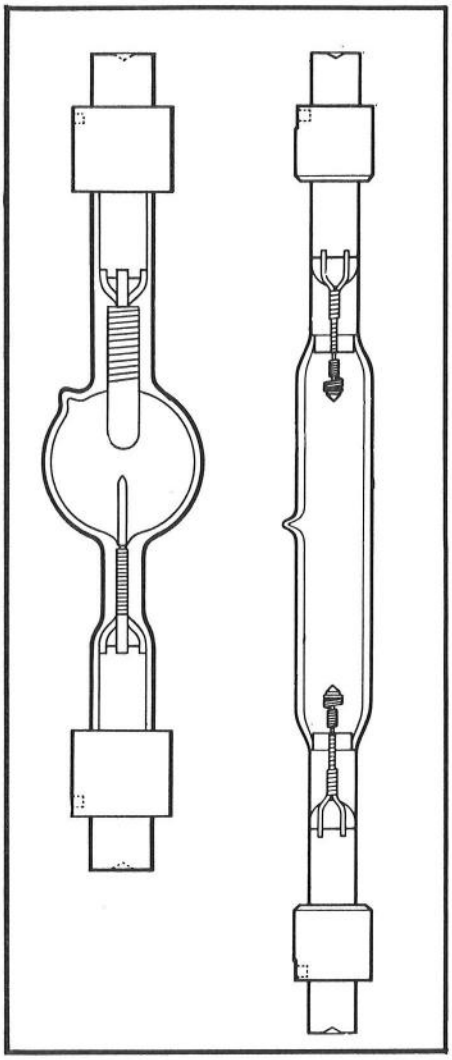
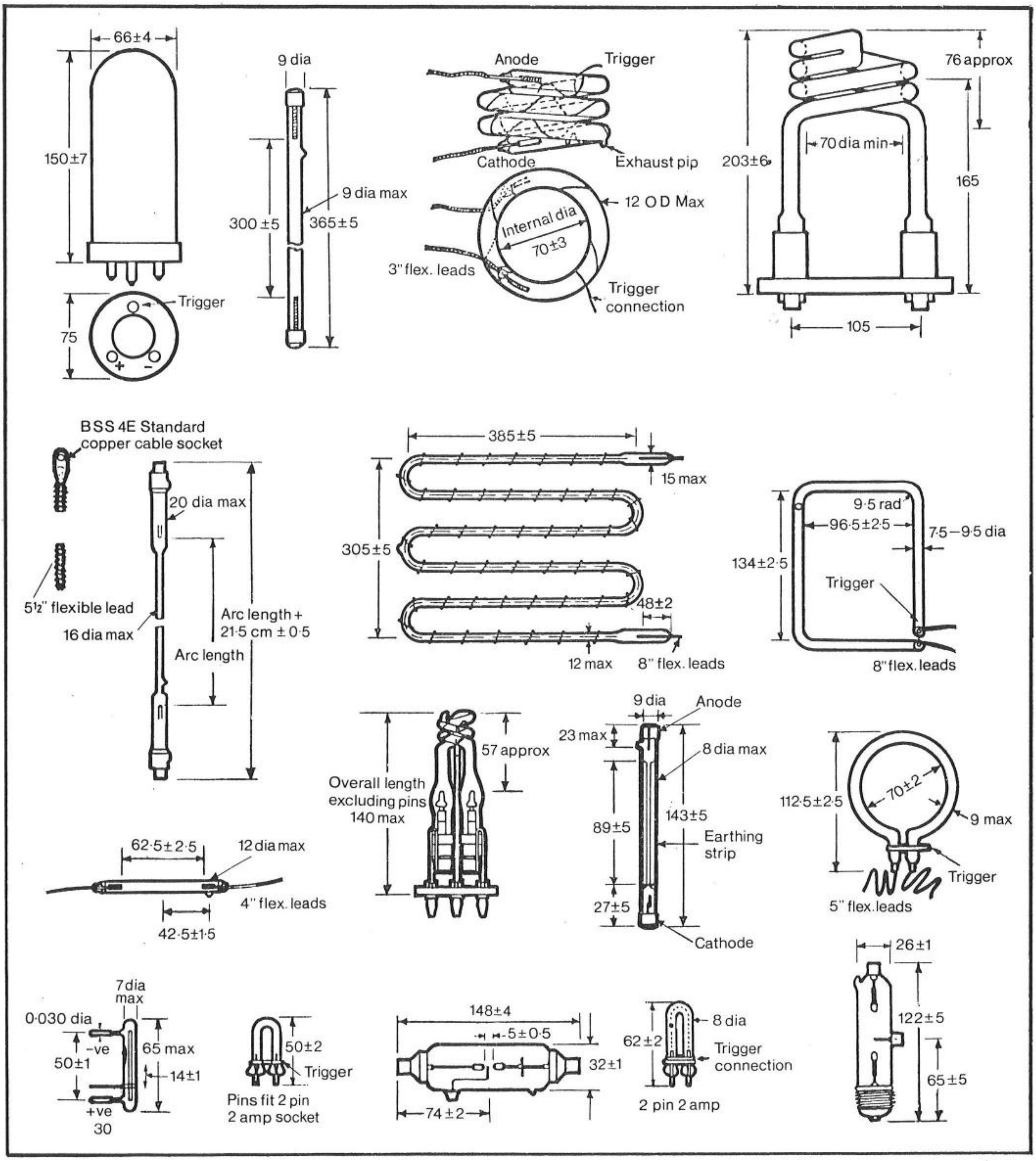


Figure 32
Typical constructions of xenon lamps. A 500W compact source for d.c. operation (left). A 1kW linear type for a.c. operation (right).

23. Electronic flashtubes

23.1 The flashtube is a discharge lamp designed to convert stored electrical energy into an intense pulse of light of comparatively short flash duration. There is an enormous number of designs, which reflect their specialized but widespread use in commerce, industry and science, not forgetting the ubiquitous amateur photographer.
It is therefore only possible to deal broadly with the principles involved in the design of these lamps, as a detailed description of any one would be unrepresentative. An idea of the variety of types can be obtained from Figure 33.

Figure 33
Some of the numerous types of flashtubes available. Dimensions are mm unless otherwise stated.



23.2 Construction

The arc tube is made of glass or quartz, and the requirement for high efficacy means that generally the arc has to be comparatively long. For convenience the tube may be made more compact by forming it into a shape such as a spiral. The electrodes may be coils, rods or shaped, and with the exception of the very high power tubes, they have emissive coatings.

A trigger connection is necessary to initiate the discharge, and is usually an external wire wrapped round the tube, although sometimes a third electrode may be included instead, or a conductor coating of a metal oxide on the tube wall.

The loading, flash frequency, flash duration and flash interval between bursts all affect temperature and the problem of heat dissipation. The frequency of the flashes must be less than the time taken for the discharge gas to deionize.

The filling is therefore selected according to the requirement. Argon, hydrogen or krypton can be used, although xenon is most often employed due to the similarity of its colour of light to daylight (colour temperature is between 6000°K and 7500°K—see Figure 34). It also has the highest luminous efficacy, but the longest deionization time; this can be shortened by adding another gas at the expense of some efficacy. Alternatively for flash duration of the order of one microsecond a mixture of argon-nitrogen may be preferred.

Connections and caps vary, and some tubes have leads only. If a cap is used, a fourth pin may be included, arranged so that the very high voltage employed cannot appear at the holder until a lamp is inserted.

In some patterns a glass envelope surrounds the tube, and in the case of some extremely high loaded tubes forced air or liquid cooling may be necessary.

23.3 Operation

The prime source of energy is d.c., usually provided by a battery, which in the interval between flashes charges a capacitor via a resistor. The discharge has to be triggered and means of applying a high voltage pulse to the trigger wire or electrode have to be provided. A typical circuit is shown in Figure 34.

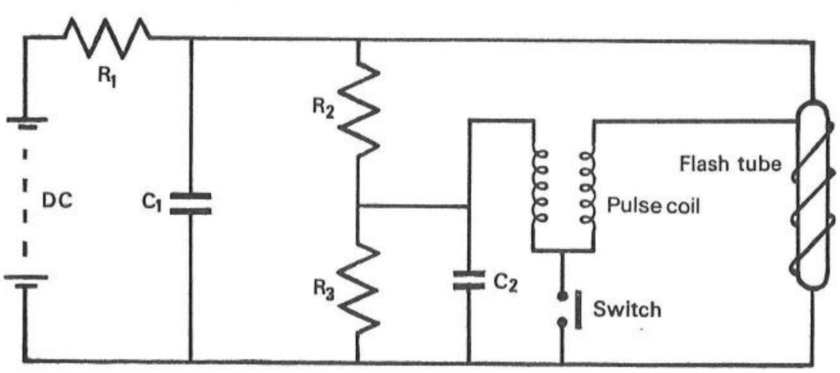


Figure 34
Typical circuit for flashtube.

When the switch is closed, capacitor C_2 discharges into the pulse coil, and the resulting high voltage pulse ionizes the discharge gas so that the capacitor C_1 is allowed to discharge by flashing the tube.

It is obvious that—

(a) Ionization must not occur below the maximum voltage across C_1, (when the battery may be 10% above nominal volts). The voltage of the tube necessary to prevent this is known as the hold-off voltage.

(b) The tube must ionize with the minimum voltage of the pulse (when the battery is 20% below nominal volts). The tube voltage necessary to ensure this is known as the minimum striking voltage.

For very high frequency flashing another method may be used, employing a thyratron and dispensing with the flashtube trigger.

A pulse higher than the self flashing voltage of the tube is produced, making the tube flash spontaneously each time the voltage is applied. This is called 'over-volting' and a typical circuit is shown in Figure 35.

Some circuits are much more complicated, but all have to be carefully designed to avoid unintentional or erratic firing, failure to fire, or to 'burn on' i.e. a failure to extinguish immediately after a pulse.

23.4 Life

The life of a flash tube depends upon a number of often related things. The nominal life is generally assessed upon single flash conditions at rated volts and energy, and is normally in the range of 5000 to 10 000 such flashes. In practice, however, the conditions are often intentionally varied to suit particular needs, e.g. if a tube having a nominal life of 5000 flashes is under-run at 20% of rated loading, the number of possible flashes may reach a million. Further a burst of high frequency flashes used for high speed photography may last only a few seconds. This would permit a degree of overloading as the burst would be over before the heat could build up sufficiently to damage the tube.

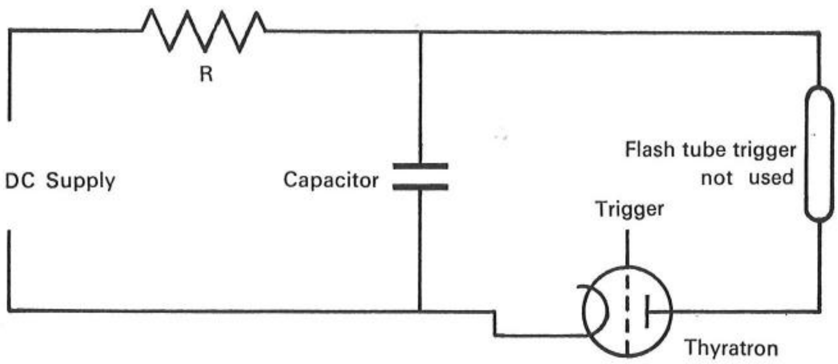


Figure 35
Basic 'over-volting' circuit, used much in stroboscopic work.

23.5 Applications

These are many and varied, but may be conveniently listed under five headings according to the mode of operation —

1. High energy dissipation. For aerial and studio photography and photochemical work.
2. Medium energy dissipation, with reasonably short flash duration. For amateur and studio photography, general industrial and scientific uses.
3. Short flash duration — in the microsecond region. For scientific applications.
4. Short arc, high loading. For laser stimulation.
5. Low energy, high frequency. For stroboscopic applications such as the inspection of moving parts.

24. Neon glow lamps

All the lamps so far described in this section use the positive column as the source of light, but in a discharge if the arc gap is sufficiently shortened, the luminous column will disappear entirely, and be replaced by light emanating as a glow surrounding the cathode, and thus visually identifying itself with the particular shape of the cathode whatever that may be.

Neon glow lamps make use of this effect, and the purpose for which they are required governs their size and shape. There are three easily recognizable groups —

(a) The largest, often in a GLS shaped bulb with a 'bee-hive' cathode, is normally loaded at 5W, and is used for very low level illumination such as required in a nursery at night. A ballast is necessary with all neon glow lamps, and in this case a suitable resistor is contained within the cap.
An extension of this group may be seen as a small sign, housed in a tubular bulb of clear glass, with the cathode made from sheet iron cut in the form of letters or numerals arranged as required.

(b) A medium size indicator lamp, normally loaded at 0.5W, having one electrode in the form of a disc and the other forming a shallow cylinder round the periphery and slightly off-set from the face. This presents a luminous button, and is normally used to indicate when a circuit is live. The bulb may be internally coated with a fluorescent powder, which makes possible a series of colours. These, of course, are only apparent when the lamp is on. The ballast resistor is in the cap.

(c) A miniature indicator lamp of low loading — 0.1W or 0.2W — sometimes with a cap and sometimes with lead wires only. A ballast resistor must be used externally, and on 200/250V a.c. the values required for the two loadings quoted above are 1 megohm and 0.33 megohm respectively.

The lamps may be operated on a.c. or d.c., and have a very long life expectancy — 10 000 hours for low brightness types and 5000 hours for high brightness types.

Appendix 1.
Mercury vapour discharge lamps

Electrical Characteristics
All values are nominal

Type	Rated wattage	Mains volts	Lamp current Amps. starting	running	Mains current Amps. starting	running	PF Capacitor rating* mfd.	Voltage	PF realized approx.	Control gear watts loss	Recommended fuse rating Amps. HRC	Wire
MBF	50	240	1	0·61	0·45	0·32	8	250	0·9	9	—	5
MB/MBF	80	240	1·3	0·8	0·8	0·5	8	250	0·9	15	5	5
MB/MBF	125	240	1·7	1·15	1	0·7	10	250	0·85	20	7	5
MB/MBF	250	240	3·75	2·15	2·5	1·4	15	250	0·85	25	10	5
MB/MBF	400	240	5·5	3·25	3·8	2·2	20	250	0·85	35	15	10
MBF	700	240	8	5·45	5	3·7	30	250	0·9	50	20	10
MB/MBF	1000 (LV)	240	12	7·75	9	5·3	60	250	0·9	40	20	10
	1000 (HV)	415	7	4	5	2·7	14	440	0·93	50	2	—
MBF	2000	240	14	8	9·8	5·75	40	440	0·95	80	—	—
MBI	400†	240										
MBI	2000 (HV)	415	14·8	8·35	7·3	8·75	40	440	0·85	80	—	—
MBT	100	240	—	—	0·6	0·45	—	—	—	—	—	—
MBFT/MBTL	160	240	—	—	0·9	0·65	—	—	0·96	—	—	—
MBFT/MBTL	250	240	—	—	1·25	1·05	—	—	0·97	—	—	—
MBFT/MBTL	500	240	—	—	2·5	2·1	—	—	0·96	—	—	—

†data under consideration.

*The values of capacitors shown are typical of those in common use; other values may be used to obtain specified degrees of correction.

Appendix 2.
Mercury vapour discharge lamps

Lighting Design Lumens

MBF	50W		1750
MB	80W		2700
MBF	80W		2720
MB	125W		4900
MBF	125W		5200
MB	250W		10 600
MBF	250W		11 000
MB	400W		18 800
MBF	400W		20 000
MBF	700W		33 600
MB/MBF	1000W	(LV)	49 000
MB/MBF	1000W	(HV)	52 000
MBF	2000W		118 000
MBFR	250W		10 250
	400W		17 200
	700W		30 800
	1000W	(LV)	40 000
	1000W	(HV)	45 000
MBT	100W		1250
MBFT/MBTL	160W		2560
	250W		4840
	500W		11 000
MBI	400W	white	25 000
		blue	6500
		green	23 000
	2000W		190 000

Note: MBFR lamps have a preferential distribution, therefore for illumination calculations it is often advisable to work from polar curves.

Appendix 3.
Sodium vapour discharge lamps

Electrical Characteristics
All values are nominal

Type	Rated wattage	Mains volts	Lamp current Amps.	Mains current Amps.	PF Capacitor rating mfd.	PF realized approx.	Control gear watts loss		Recommended fuse rating Amps.
Preferred types									
SOX	35	240	0·6	0·33	15	0·9	24		—
SOX	55	240	0·59	0·43	15	0·9	25		—
SOX	90	240	0·94	0·57	25	0·9	28		—
SOX	135	240	0·95	0·33	—	0·85	30		—
SOX	180	240	0·91	0·75	—	0·85	30		—
SLI	140	240	0·9	0·83	20	0·85	29		5
SLI	200**	240	1·6	1·2	30	0·85	40		5
	**25 000 lumens								
Non-Preferred types									
SOI	45	240	0·6	0·32	15	0·9	24		5
SOI	60	240	0·6	0·41	15	0·85	24		5
SOI	85	240	0·58	0·51	13	0·9	25		5
SOI	140	240	0·9	0·82	18	0·85	29		5
							A*	B†	
SLI	60	240	0·83	0·4	10	0·8	14	18	5
SLI	175	240	0·95	1·1	15	0·8	40	40	5
SLI	200**	240	1·6	1·3	20	0·8	30	45	5

**20 000 lumens

* Switch start circuit.
† Starterless circuit.

Appendix 4.
Sodium vapour discharge lamps

Lighting Design Lumens			
Preferred types	SOX	35W	4200
	SOX	55W	7050
	SOX	90W	11 900
	SOX	135W	20 000
	SOX	180W	28 500
	SLI	140W	20 000
	SLI	200W	25 000
Non-Preferred types	SOI	45W	2835
	SOI	60W	3900
	SOI	85W	6460
	SOI	140W	10 640
	SLI	60W	5700
	SLI	175W	20 000
	SLI	200W	20 000
High-Pressure type	HPSV	400W	36 000

Appendix 5
Interchangeability of sodium vapour discharge lamps

(a) A lamp in any of the groups below is interchangeable both *electrically* and *mechanically* with any other lamp in that group. Lamps in the first three groups are *electrically* interchangeable.

45W	SO/H
45W	SOI
35W	SOX
60W	SO/H
60W	SOI
55W	SOX
85W	SO/H
85W	SOI
90W	SOX
140W	SO/H
140W	SOI

(b) The following are interchangeable *electrically* but not mechanically.

135W	SOX
180W	SOX

(c) The following are interchangeable *mechanically* but not electrically.

140W	SLI
175W	SLI
200W	SLI

(d) The 60W SLI is not interchangeable with any other lamp.

Appendix 6
Typical power distribution in various types of discharge lamps

Lamp		Percentage power			
		Ultra-violet	Visible light	Radiated infra-red	Convected and conducted heat
400W	MBF	1·5	14	55	29·5
400W	MBI		Under consideration		
200W	SLI	0·5	22	36	41·5
400W	HPSV		Under consideration		
2000W	XENON	2	15	58	25

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Do you ever need to know—

What regulations or codes of practice or recommendations apply to the lighting of this or that location?

Who makes such-and-such a type of fitting?

What are the appropriate British Standards for lamps or chokes or other pieces of lighting equipment?

What are the latest and best examples of lighting for drawing offices, hospital wards, school classrooms, flyovers, etc. etc.?

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