BRIGHT LIGHT SOURCES (PART II.)

THE ELECTRIC DISCHARGE LAMP

By J. N. ALDINGTON, B.Sc., Ph.D., F.R.I.C., F.Inst.P., F.I.E.S.

(Of Siemens Electric Lamps and Supplies, Limited, Preston, Lancs.)

(Read before the Illuminating Engineering Society, on December 11th, 1945.)

In Part I. of a paper entitled "Bright Light Sources," read before this Society on November 14, 1944, attention was devoted almost entirely to considerations of incandescent tungsten filament lamps. The various factors which influence the brightness of these sources were discussed and illustrated by examples of a wide range of projector lamps. In the design of such lamps it was shown that, compatible with other essential features, the object was to concentrate the maximum possible energy in the smallest possible space. To achieve the optimum result it was necessary to take account of the optical system in association with which it was desired to use the light source.

In the present paper attention will be directed to considerations of the factors which influence the brightness of the electric discharge, and reference will be made to certain definite types of lamp which have emerged in the last few years as well as to certain lamps of an experimental nature, the properties of which justify their being classed as bright light sources.

GENERAL PRINCIPLES

To enable the discharge of an electric current through a gas or metallic vapour to produce a light source of high brightness some or all of the following factors must obtain:—

(a) High luminous efficiency.

(b) High-voltage gradients between the electrodes.

(c) High-current density in the discharge.

The inter-relation of these three factors will be understood by reference to a simple example. If the efficiency of light production in an electric discharge lamp is 1 L/W, then for a given size and shape the source of brightness will be only one-fiftieth of that of an identical lamp dissipating the same wattage at 50 L/W. The same energy dissipation between the electrodes might be obtained, however, either by a comparatively high voltage drop and a low current or by a comparatively low voltage drop and high current. These alternative methods for producing lamps of the same loading may have a marked effect on the efficiency of light production. For example, in the case of mercury vapour lamps the efficiency increases progressively up to about 55 L/W, with increases in the voltage gradient in the arc resulting from increases in mercury vapour pressure, the effect on efficiency of an increase in current at a constant pressure being much less marked.

The reverse result is produced with certain other gases and metallic vapours where the effect of increasing the pressure is to produce a decrease in the efficiency of light production.

It must be understood that these examples are not generalisations, but are true over specific regions in the wide range of operating conditions which may obtain in the design of electric discharge lamps.

An object of the present paper is to examine a number of different types of lamps which have emerged in more or less standardised forms as a result of studying the effects of some of the variables already mentioned. Consideration will be given to two main classes of electric discharge lamps, namely, metallic vapour lamps and gas discharge lamps. Only those types which are suitable for projection work will be discussed, and no attempt will be made to produce a complete catalogue. On the other hand, it is hoped that this brief review will illustrate the trend of developments during the last few years with perhaps some indication of possible lines for future development.

Attention will be devoted almost entirely to considerations of the lamps themselves and their applications. For information regarding circuit arrangements the excellent review by Messrs. Maxted and Hull should be consulted.[1]

METALLIC VAPOUR LAMPS

Among the metallic vapours which have been used in high brightness electric discharge lamps, mercury, cadmium, and zinc may be cited by way of example. By far the most important of these at the present time is the element mercury. A great deal has now been written regarding the possibilities of electrically excited mercury vapour as a source of light.[2-12] Of the numerous types of successful mercury lamps on the market or known in the art it is proposed to draw attention only to those falling in the classes designated below:—

(1) MB—High - pressure mercury vapour lamps operated in tubu-

lar quartz envelopes, loading below 100 W/cm.

(2) MD—Water-cooled quartz capillary tube lamps.

(3) ME—Air-cooled quartz bulb mercury lamps, loading above 100 W/cm.

Mercury Lamps, Type MB

This type of lamp, in both 80 and 125-watt ratings and in pearl or fluorescent bulbs, has found extended use for general illumination and street lighting purposes. There is, in addition, a quartz lamp in this category which has been designed specifically as a bright light source projection lamp. It consists of a tubular quartz bulb of 125 watts rating mounted in a

Fig. 1. 125-watt mercury projector lamp (type MB/D).

tubular clear glass envelope and finished with a prefocus cap, see Fig. 1. In the production of this lamp for projection purposes it was necessary to ensure by careful electrode design that the arc would burn steadily and without lateral movement. The problem of producing a lamp which would burn with a perfectly steady arc was solved in the laboratories of members of the Electric Lamp Manufacturers Association, and as a result MB/D (vertical burning lamps) have been made available for precision optical work. They may be operated either on A.C. mains with a suitable series choke or on D.C. mains with a series resistance. Suitable values for this resistance are given in Table 1.

TABLE 1.

RESISTANCE VALUES FOR D.C. OPERATION OF 125-WATT MB/D LAMPS.

Mains voltage.	Resistance (ohms).
200	76
210	86
220	92
230	102
240	110
250	121

The physical dimensions and general characteristics of this simple form of mercury vapour projection lamp are given in Table 2 below:—

TABLE 2.

DETAILS OF MB/D PROJECTION LAMPS.

	Type 1.	Type 2.
Lamp wattage	125	125
Supply voltage	200-250	200-250
Centre brightness of arc...	800-1000 stilb	800-1000 stilb
Overall length	185±5 mm.	145±10 mm.
Light centre length ...	115±2 mm.	95±5 mm.
Diameter ...	48±3 mm.	32±2 mm.
Outer envelope	Clear tubular	Clear tubular
Cap	P28/25	E27/25 B22/25–3-pin

An important feature is the linear nature of the source, the dimensions of which are approximately 3 mm. x 25 mm. As with other types of high-pressure mercury vapour lamp, a period of time up to 10 minutes must elapse before full brightness is attained, but once the lamp is in full operation the arc burns almost as steadily as the filament of an incandescent tungsten filament projector lamp. Other designs of air-cooled MB mercury vapour lamps were described by Francis and Wilson in a paper delivered before this Society in 1939.[9]

Mercury Lamps, Type MD.

The type of mercury vapour lamp in which a high-pressure mercury discharge is produced within a capillary bore thick-walled quartz tube cooled in a stream of running water, is now well known. It is available in 500 and 1,000-watt ratings. The principal characteristics of these two sizes of lamp are given in Table 3 above, from which it will be seen that the 1,000-watt lamp differs from the 500-watt lamp principally in respect of the arc length. The effect of this is to produce approximately twice the arc voltage drop at the same current. It is for this reason that the efficiency and brightness values of the two lamps are almost identical.

It will be realised from a study of this data that a 2,000-watt MD/H lamp will be produced by using an arc length of 50 mm. instead of the 25 mm. of the 1,000-watt type.

Figure (2) shows a typical example of a water-cooled mercury vapour lamp. Details of the water-jacket and water union are shown, from which it will be seen that the cooling water flows in the annular space between the quartz burner and an inner guiding tube, and returns in the outer space between this guiding tube and the

TABLE 3.

DATA ON 500 AND 1,000-WATT MD/H LAMPS.

Wattage	500 w.	1,000 w.
Open circuit voltage...	600	1,200
Arc length	13±2 mm.	25±2mm.
Lamp operating current...	1.35 amps.	1.40 amps.
Initial peak brightness	30,000 stilb	30,000stilb
Average life for 100 switchings	100 hrs.	100 hrs.
Efficiency	60 L/W.	62½ L/W.
Circuit	Operated on stray-field transformer	

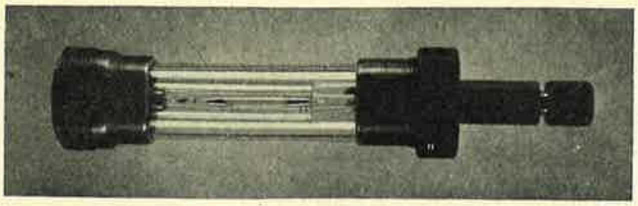
tubular wall of the outer jacket of the lamp. For convenience it has been arranged that one terminal of the lamp is earthed and the other terminal is brought out to a suitably insulated high-voltage connector. The chief value of this type of lamp lies in the fact that the high centre brightness of the discharge column is attained within two or three seconds after switching on. Its linear form renders it very suitable for projection work in which comparatively large areas require to be illuminated, or for the illumination of slits in certain optical equipment.

Various modifications of the original MD/H lamps have been worked out to produce a light source of larger projected area. For example, two or more burners may be mounted side by side within a single water jacket. In another design a mirror has been introduced into the water jacket so arranged that two images of the source appear one on each side of it and in the same optical plane.[15] Experimental lamps have been made in which the quartz burner is bent into the form of a bight or a spiral,[16] but these designs have not been found capable of the same high loading per unit length as the straight tube, and it has been found more difficult to provide adequate cooling. It will have been realised that the function of the water is to prevent the quartz capillary tube from reaching an excessively high temperature. A similar cooling effect may be produced by means of an air blast, and this method has been applied in certain special circumstances although the loading of the lamp per unit length cannot be made as high as in those cases where a liquid cooling medium is employed. While in many cases it is possible to operate the water jacket directly from the water supply mains, the cooling water then flowing to waste.

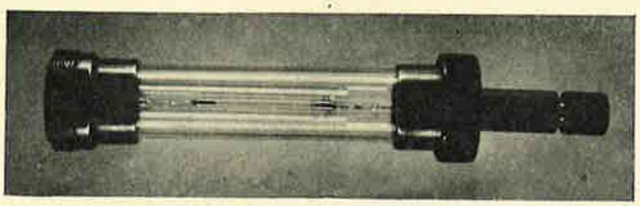
for some purposes it has been found essential to use a water circulating system. Equipment has been designed in which the cooling liquid after leaving the lamp is reduced in temperature by means of a radiator before being returned once more to the lamp, and in another design a small reservoir of water acts both as of the light from the MD/H mercury lamp which has been found most suitable for obtaining rapid exposures.

Mercury Lamps, Type ME

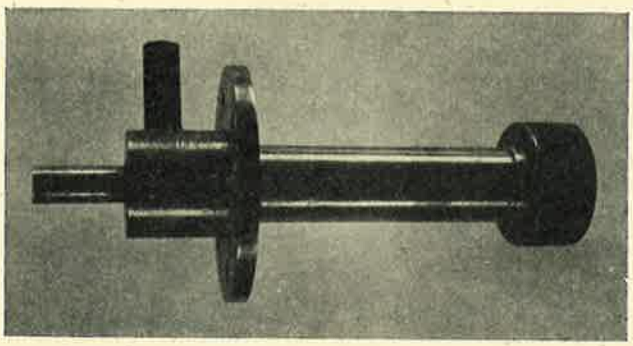
As distinct from the linear arc of the types of lamp just described, the arc of the ME lamp is practically spherical in form. The smaller lamps



500-watt.



1,000-watt.

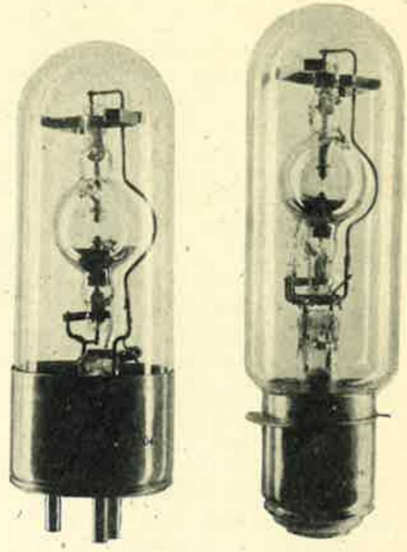


Water union.

Fig. 2. 500 and 1,000-watt water cooled lamps (type MD/H) with holder and water union.

a storage tank and cooling vessel in the water circulating system. To cater for the eventuality that failure to switch off the lamp before the flow of water ceases might result in damage to the lamp due to overheating, an electrical cut-out operated by a reduction in the flow of water may be fitted in the cooling system. Some very compact arrangements of this nature have been applied in practice, and experience has shown that both the 500 and 1,000-watt MD/H lamps can be made to give reliable service under a wide variety of conditions of use. For example, 500-watt MD/H lamps have been used by Messrs. Ross, Ltd., for the printing of high definition graticules and hundreds of thousands of these graticules have been produced with the aid

of 250 and 500-watt rating have already been described.[9, 10, 11] They have entered the optical instrument and illumination fields in competition with small carbon arcs, and with high brightness tungsten filament projector lamps, and where a high and uniform brightness is required, they represent the most convenient and most efficient bright light source yet available. For example, the Hilger universal projector and the Hilger tool makers projectors utilise 250-watt ME lamps of the type shown in Fig. 3(a). The excellent definition of these profile and inspection projectors is assisted by the high brightness and stable arc of the latest forms of ME lamp. Beside the three-pin base mounting this lamp is also available in a standardised form with a



(a) (b)

Fig. 3. 250-watt mercury projection lamps (type ME).

large prefocus cap, and this latter design is recommended for general purpose use. Fig. 3(b).

For certain experimental optical projection jobs the properties of the high-pressure mercury vapour arc have been utilised to provide a light source of approximately 1mm. x 1 mm. An experimental form of this lamp will be demonstrated. It is a small edition of the types of ME lamp which are now well known. In its design it was necessary to pay special attention to means for ensuring that the arc remained stationary between the electrodes, as with such a small source any movement of the arc would severely affect the usefulness of the device. Such lamps are not generally available at the present time, but they indicate a limiting form of this type of mercury vapour lamp. With a dissipation of 100 watts a point source lamp may have a brightness at the centre of the arc of about 50,000 stilbs. The author is not aware of any other light source of comparable small-size and brightness. Like all high-pressure mercury vapour lamps a period of time must elapse before full brightness is attained, but for many purposes this is not regarded as detracting from the usefulness of this interesting development.

Since the paper of Francis and Wilson read before this Society in 1939[9] a 1,000-watt ME lamp has become available, and a very considerable amount of development work has been carried out on larger sizes of naturally cooled lamps up to 15 kws rating.[18] Still higher wattage dissipations have been obtained by forced cooling of the bulb. It is proposed to briefly describe the 1,000-watt ME lamp and then to illustrate some of the principal considerations which influenced the development of lamps of much higher brightness. As will be seen from Fig. 4, the 1,000-watt ME lamp is designed for operation in free air, that is to say the quartz bulb is not enclosed within an outer jacket, as is standard practice with the 250 and 500-watt types, and therefore a double-ended design has been found convenient. Similarly, all lamps designed for loadings greater than 1 kw rating are of the jacketless type. In the case of the 1,000 watt lamp the terminals are situated at a sufficient distance from the spherical bulb in which the discharge takes place to enable them to operate at a reasonable temperature in free air. The bottom terminal of the lamp is fitted with a prefocusing disc, which is not only used for establishing contact but which locates the exact position of the source in respect to the lamp holder and enables replacements to be effected without the need for adjusting the lamp in relation to the associated optical system. Other designs have been developed which allow both electrode connections to terminate at one side of the bulb instead of at diametrically opposite sides, as in the type illustrated. The centre brightness of the 1,000-watt ME lamp, see Table 4, is higher than that of any generally available light source except the larger sizes of high-intensity carbon arcs.

Table 4.

Characteristics of 1,000-watt Type ME/D Lamp.

Overall length	245±2.5 mm.
L.C.L. from back of supporting ring to face of remote electrode ...	120±1 mm.
Starting current ...	c. 20 amperes
Running current ...	c. 16 amperes
Bulb diameter	55 mm. max.
Cap	Special ring type
Initial efficiency ...	50-55 L/W. approx.
Peak initial brightness...	40,000 stilb
Electrical circuit ...	Series choke

A limiting feature for some applications is the fact that six or eight minutes must elapse before full brightness is obtained, but for many purposes this fact does not affect the usefulness of the source. A study of the table of characteristics of the 1,000-watt ME lamp reveals that the starting current is of the order of 20 amperes, and therefore the quartz to metal seals must be designed for this current. This follows from the fact that the arc voltage drop when the lamp is in full operation lies between 60 and 75 volts. Assuming a linear relationship, therefore, a 5-kw ME lamp would require seals capable of carrying about 100 amperes and a 10-kw lamp seals carrying about 200 amperes.

HIGH WATTAGE TYPE ME LAMPS

The design of heavy current direct refractory metal to quartz seals has been one of the many achievements of the laboratories of members of the Electric Lamp Manufacturers Association. This will be appreciated when I state that current densities of the order of 10,000 amps. per sq. cm. can be passed through hermetic seals which consist of thin foliations of molybdenum sealed either directly into quartz tubing or into the annular space between two concentric quartz tubes.[19] 250-ampere seals of this type are shown in Fig. 5, which illustrates two ratings of high-power ME lamps. Not only is it necessary in the production of higher power ME lamps to use seals which, while carrying currents of 100 amperes or more, are capable of operating at temperatures considerably in excess of normal, it is also necessary to use quartz bulbs of adequate size to enable the heat generated by the discharge to be dissipated and of an adequate strength to withstand the internal pressure. In this connection and by way of example a bulb of about 100 mm. in diameter is required for an ME type lamp of 10-kw rating. Even so, during the operation of the lamp this bulb in free air will reach a temperature of the order of 750° C. For many purposes, particularly those connected with the nature of the available current supplies, it has been found necessary to design high-power ME lamps for use on direct current as well as alternating current supplies. Whereas the lower wattage lamps are chiefly made for A.C. supplies, but may also be designed for D.C. circuits in the case of the larger lamps, it has been found that the direct current lamp has been the most generally

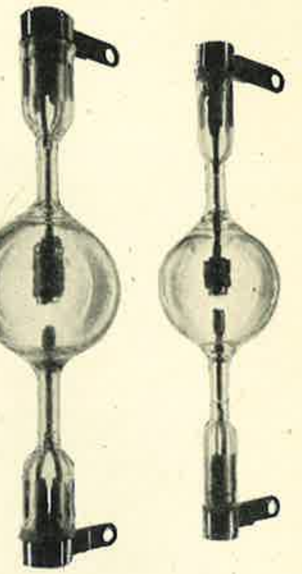


Fig. 5. 15 kw and 10 kw mercury vapour projection lamps (type ME).

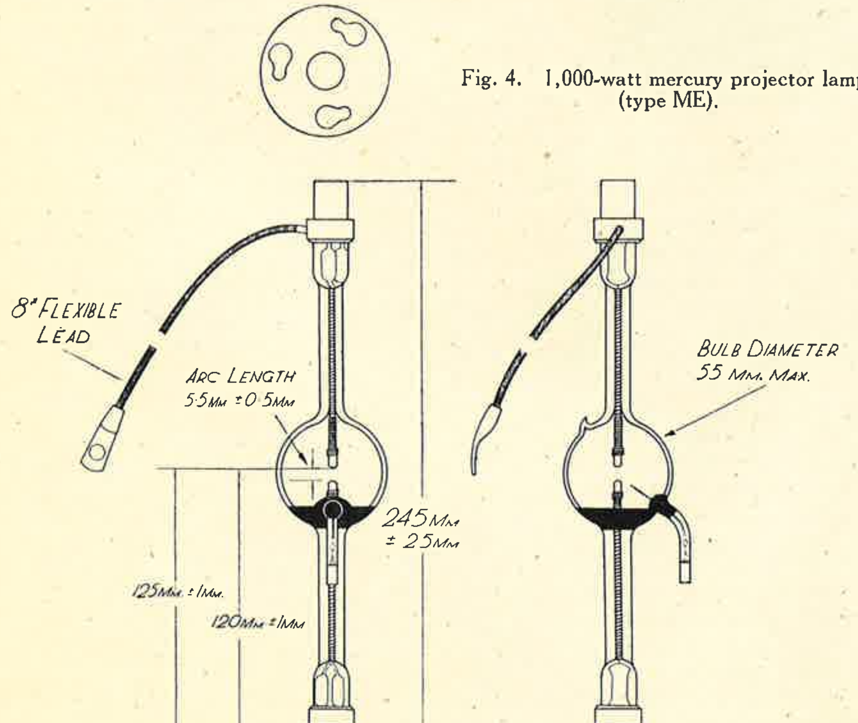


Fig. 4. 1,000-watt mercury projector lamp (type ME).

useful. The relative sizes of anode and cathode which have been found satisfactory in the production of these very large lamps is shown in Fig. 5, from which it will be seen that the mass of the anode is many times that of the cathode. It is also interesting to note that in order to develop the designed voltage drop of about 75 volts a bulb of 100 mm. diameter requires about 15 grammes of mercury. Initiation of the discharge is assisted by the presence of a low pressure of inert gas within the bulb just as in the case of the smaller lamps, and may be facilitated by the use of either a high voltage or high frequency discharge applied in one of the usual ways. Some of the more interesting features and characteristics of these high-power ME type lamps will now be discussed.

In order that the maximum amount of light can be collected from the arc it appeared essential at an early stage in the development of these lamps that the electrodes should be so designed as to intercept from the arc a minimum amount of the emitted flux. This was particularly necessary where the lamp was to be used for the illumination of large aperture mirrors. It has therefore become general practice to cut away facets from both the anode and the cathode faces so as to reduce to a minimum obscuration of the collecting surface of the optical system.[17] The effect of this design feature is shown in the polar curve, Fig. 6, which gives the candle power of a 10-kw mercury arc along the main axis of the arc. It will be seen that the cathode produces little obscuration down to about 50° below the horizontal, while there is an increasing amount of obscuration by the anode above an angle of about 40°. The polar curve was taken on a lamp with the electrodes arranged in the form shown in the inset piece of Fig. 6. The arc brightness distribution of a typical lamp of 10 kw rating is shown in Fig. 7, from which it will be seen that with an arc length of 8.8 mm. a peak arc brightness greater than 80,000 stilbs. was obtained. The illustration shows both the brightness distribution along a line joining the centres of the anode and cathode as well as in a plane bisecting the electrode axis. From a study of the properties of the mercury vapour arc over a wide range of operating conditions, the author has reduced two equations which enable the properties of the high current density mercury vapour arc to be predicted in terms of three variables only, namely:—

L=arc length in cm.
V=arc voltage
A=arc current

These approximate relationships are:—

$$B_c \text{ (stilbs)} = 3.0 \times \left(\frac{V}{L}\right)^{1.5} \times A^{0.7}$$

and

$$w \text{ (cm.)} = \frac{1.4 \times A^{0.3}}{\left(\frac{V}{L}\right)^{0.5}}$$

*

* Where Bc = peak brightness at centre of arc
w = width of arc at half Bc.

It can be shown that these expressions are valid over a range in brightness from 100 to 100,000 stilbs. It therefore appears legitimate to assume that they can be used to predict the behaviour of high wattage arcs designed to produce still higher peak brightness values. Applying them to the case of lamps of 30 kw loading designed for an arc voltage of 80 and with different values of arc length the following values are obtained:—

Loading 30 kw.

Arc length mm.	Calculated values of centre brightness Bc (stilbs).
5	4.14×10^5
6	3.14×10^5
7	2.45×10^5
8	2.05×10^5
9	1.72×10^5
10	1.46×10^5

These values should be compared with average data for the brightness of the sun's disc of 1.6×10^5 stilbs. Whether these extremely high values are capable of practical realisation is still a matter for investigation. Considerations of the problems involved in the production of high power ME lamps led to the conclusion that increased brightness would have to be obtained by increasing the current rather than by increasing the voltage gradient. The reasons which led to this conclusion are set out below:—

(1) The increase of bulb diameter consequent on the necessity for a greater wattage dissipation would reduce the bursting strength of the quartz bulb. The expression:—

$$P = \frac{4\,TF}{D}$$ where P = bursting stress in lb. per sq. inch.
F = tensile strength in lb. per sq. inch.
T = wall thickness in inches.
D = diameter in inches.

indicates that for spherical shells the bursting stress is inversely proportional to the diameter. While the reduction in strength, consequent on increased diameter, could theoretically be compensated by increased wall thickness, this compensation could in practice only be applied to a small extent, as with too great a wall thickness for the quartz bulb thermal stresses set up during fabrication or operation of the lamp would probably lead to rupture due to cracking.

Practical experience with the smaller high brightness lamps, in

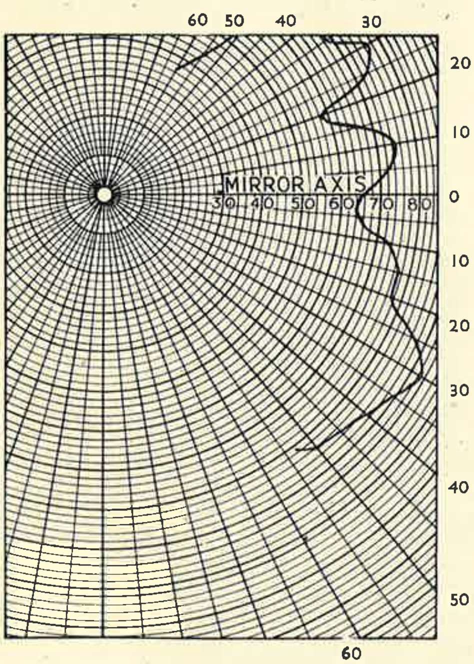


Fig. 6. Polar distribution about mirror axis of light flux from 10 kw ME lamp (wattage 10 kw, voltage 83 v., current 120 amps.).

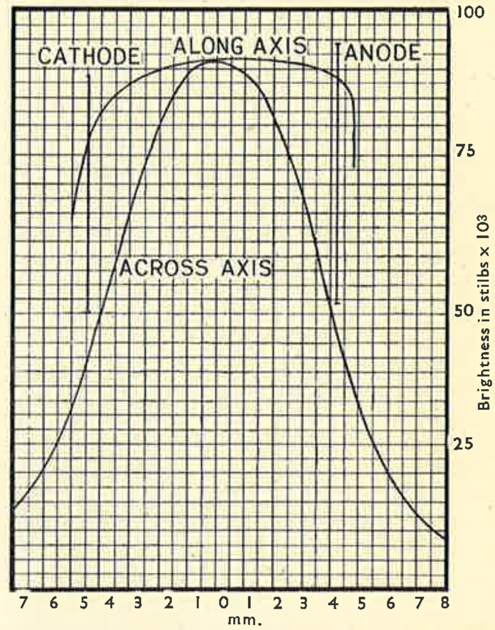


Fig. 7. Typical distribution curve for 10 kw lamp.

which voltage gradients of the order of 200 volts per cm. were employed, had shown that explosive rupture sometimes occurred. It thus appeared expedient to employ a reduced mercury vapour pressure, and therefore a reduced voltage gradient for lamps of higher wattage and greater bulb diameter.

Some work by Dawihl and Rix [13, 14] on the mechanical strength of quartz glass showed that spherical bulbs of about 40 mm. in diameter with a mean wall thickness of about 2.5 mm. burst at 73 to 110 atmospheres at room temperature and at 117 to 133 atmosphere at 800° C. They attributed the increased strength at the higher temperature to changes in the structure of the quartz.

As mentioned above, in the early work with these lamps, explosive rupture occasionally occurred during operation at about 25 atmospheres pressure, probably due to a combination of mechanical and thermal stresses. This was an important point as the quartz bulbs used for preparing the lamps were similar in dimensions to those used by Dawihl and Rix to obtain their mechanical strength data summarised above. The temperature of operation was also similar, namely, about 800° C. It appeared, therefore, that a factor of safety of at least 5 : 1 was not excessive, especially in view of the temperature gradients which were bound to occur during the operation of these high-pressure mercury lamps.

Employing the Dawihl and Rix data, which gives minimum tensile strength values for quartz of 5,300 lb. per sq. inch, we have the following values for the bursting pressure of quartz bulbs calculated from the expression $P=\frac{4\ FT}{D}$ given above:—

Bulb diam. in inches	Wall thickness inches	Bursting pressure Atmospheres	Maximum safe internal pressure allowing 5 : 1 factor of safety
2	0.2	140	28
3	0.2	95	19
4	0.2	70	14
5	0.2	56	11

From column 4 it appeared that for quartz bulbs of 2 in. to 5 in. diameter, with a wall thickness of 0.2 in., which was considered a workable value, it would be necessary not to materially exceed 25 atmospheres working pressure on 2-in. diameter bulbs and to use lower pressures where larger bulbs were employed.

(2) The effect of reducing the value of $\frac{V}{L}$ in the design of larger lamps would be to decrease the peak brightness for a given current as Bc is proportional to $\frac{V^{1.5}}{L}$.

(3) To give an overall increase in brightness it would be necessary to use much increased currents, as Bc varies as $A^{0.7}$.

(4) The reduced voltage gradients contemplated for the larger lamps would lead to lower arc voltages if the arc gap was kept constant. It therefore seemed logical to consider an increase of arc length for the larger lamps to compensate for the reduced gradients and to maintain the arc voltage at about 75 volts, which was the designed value in the small high brightness lamps so far described which had an arc length of 4 to 5 mm. For these reasons, a lamp of 15 kw would be designed in general with an arc length of 10 to 12 mm., and correspondingly larger values might be employed for lamps of still higher rating. Enough has been said to indicate that the high current density mercury vapour arc is not only a potential rival of the carbon arc but is capable of being made already in sizes of higher brightness than that of the carbon arc.

Electrode Configuration

The use of a single anode and a single cathode to carry the current to and from the high current density mercury vapour arc has certain obvious disadvantages when the design of very large lamps is under consideration, and also for certain optical reasons. For example, the current in the arc is limited to the current which a single electrode will carry and which a single seal will carry. Considerations such as these led to the development of multi-electrode lamps. Designs have been tested in which two or more pairs of co-operating electrodes have been used to carry the current into the arc.[20] The physical arrangements of these electrodes may be such that the various component parts of the arc coalesce together to form a homogeneous source. In an alternative design, a single cathode has been used to serve two or more anodes. In such ways it has not only been found possible to produce higher power lamps, but it has also been possible to design lamps in which the shape of the arc and the distribution of brightness across the arc can be modified to a desirable extent. While such developments are still in their infancy, it was felt that in a review

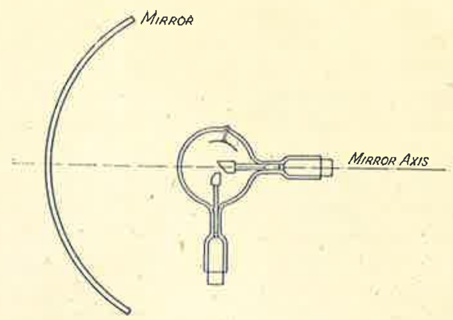


Fig. 8. Diagram of ME type lamp showing right-angle arrangement of electrodes and collector shield to intercept arc flame.

of this sort it was worth while to indicate something of the trend of research in this interesting and important field. An example of a lamp with the electrodes arranged at right angles to one another and fitted with a collector shield to intercept the arc flame and prevent its impingement on the quartz bulb is shown in Fig. 8.

A preferred arrangement is one in which two co-operating anodes are used and the cathode is located in line with the axis of one anode and at right angles to the axis of another.[21] This arrangement has the added advantage that for some cases where it is desirable to tilt the lamp at all angles from the horizontal to the vertical the arc flame is always intercepted by one or other of the anodes.

Magnetic Control of the Arc Flame

With certain designs of very high power ME lamps it is found that the arc flame becomes of pencil shape and impinges on the surface of the containing vessel leading to localised devitrification of the quartz. Arrangements have been worked out for the dispersal of this arc flame, which consist of a magnetic field produced transversely to the arc to cause the high temperature particles of the convection stream to move out of the vertical path and normal to the lines of force of the magnetic field. In one such system the magnetic field comprises that between the poles of a horseshoe magnet, the poles being situated one on each side of and transverse to the arc. Alternatively, the field may be a free field emanating from one pole of a bar magnet at right angles to the arc. The magnetic field can be produced by an electro-magnet, the windings of which are so arranged that the intensity of the field can be increased as the angle of the lamp from the vertical increases.[22]

A suitable circuit arrangement for magnet and lamp is shown in figure 9.

Some Experimental Data

As a result of the work outlined in the preceding sections a range of experimental high power ME lamps has been developed suitable for

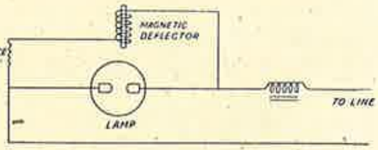


Fig. 9. Simple circuit arrangement for magnetic dispersal of arc flame.

operation without forced cooling and typical brightness data for such a range is given in the table below:—

DATA FOR EXPERIMENTAL ME LAMPS.

Wattage	2,000	3,000	5,000	7,500	10,000
Arc length mm.	6–6.5	7	8–8.5	9	9.5–10
Lamp voltage	60–75	60–75	60–75	60–75	60–75
Lamp current, amps.	32	48	80	120	160
Centre brightness Bc (stilb)	40,000	45,000	55,000	65,000	75,000

It is an interesting fact that the efficiency of light production for each of these lamps is approximately constant at about 50 to 55 L/W. In the above table suitable values for arc length have been given for each of the wattages; although investigations have covered a range of arc lengths at each wattage. The effect of such changes on centre brightness and arc width may be predicted from the functions given in one of the preceding sections.

Colour Modulation of the Mercury Vapour Arc

There have been many proposals for modulating the radiation from the mercury vapour arc to enable more satisfactory colour rendering of objects viewed in its light. In the case of lamps of the type under discussion in this section, i.e., high brightness mercury vapour lamps, the use of fluorescence is not considered feasible and consideration must therefore be given to methods which directly modify the radiation from the arc itself. Of these the use of mixed metal vapours has received a considerable amount of study, and the most prominence has been given to the use of mixtures of mercury, cadmium and zinc. By such means it is feasible to modify the spectrum of the high-pressure mercury vapour arc in the manner shown in figure 10 (a and b). The introduction of cadmium giving as it does a prominent red line at 6438 A.U. is also useful in introducing blue and blue-green radiation at 4780 A.U. and 5086 A.U., the effect of these dominant spectral lines being to impart a blue appearance to the low current density arc while improving the colour rendering in both the red and blue regions of the spectrum. Where the lamp is used therefore for the projection of coloured slides or colour films the mercury cadmium ME lamp is to be preferred to the pure mercury lamp. Besides these notable effects, improvements in the colour rendering properties of the high pressure mercury vapour arc with increases in current density have already been the subject of comment and discussion. It is interesting, therefore, to study the effect of using higher current densities on the colour of the mercury cadmium lamp. The effects are useful as will be seen by reference to Figure 10 (c).

It will be seen that in the lamp of higher output with the same percentage of cadmium in the mercury, i.e., 10 per cent., there appears to be a preferential excitation of the cadmium radiation in the red region, thus causing an improvement in the colour rendering properties of the light. In this connection it is interesting to compare the colour of mercury radiation with that of the radiation from a 500-watt mercury cadmium lamp and the 9-kw mercury cadmium ME lamp in terms of the C.I.E. system.

COLOUR APPEARANCE OF ME. LAMPS.
C.I.E. CO-ORDINATES.

Lamp Type	x	y	z
500-w mercury	.311	.340	.349
500-w mercury cadmium	.293	.337	.370
9,000-w mercury cadmium	.361	.290	.349

Another method which offers interesting possibilities was discovered by accident when it was found that certain specimens of quartz tubing contained traces of lithium. It is well known that during the working of quartz some material volatilizes in the form of a white fume. This fume largely consists of SiO_2, but it was found that when the fume was deposited on the electrodes of certain types of ME lamp there occurred a powerful emission of red radiation which was found to be at 6708 A.U., coinciding with a dominant lithium line. As stated above, the source of this lithium was eventually traced to certain specimens of quartz. The question therefore arose as to whether this unwanted effect could be harnessed in a practical form of lamp, particularly as the amount of red which could be introduced in this way appeared to be greater than could be produced by the excitation of the mercury and cadmium spectra simultaneously. While it is not possible to predict what will eventually obtain, some interesting results have indicated that the arc spectrum of lithium can be excited simultaneously with the arc spectrum of mercury, and notwithstanding the volatility of lithium and its chemical reactivity the improved colour of the composite radiation is maintained for many hours.

A satisfactory solution to the problem of improving the colour rendering properties of the high-pressure mercury vapour arc is required before the arc can be used for the projection of standard colour films. If, however, a complete solution is not obtained, the possibility of modifying the processing of the film to make it suitable for the radiation from existing lamps should not be overlooked.

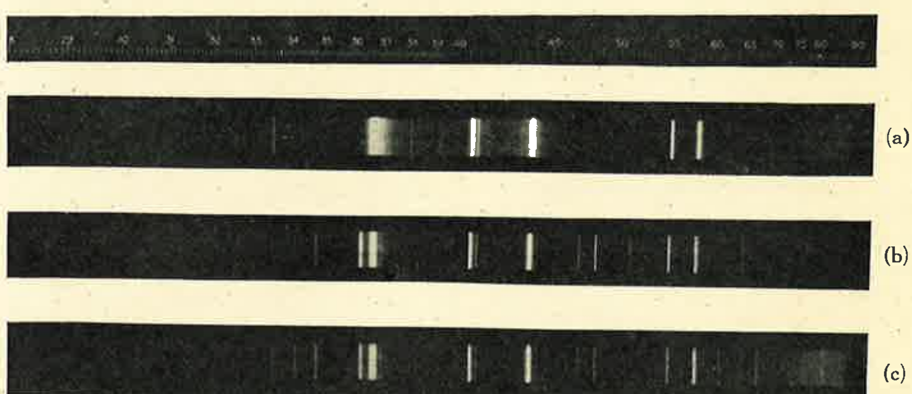


Fig. 10. Spectrograms showing radiation from mercury and mercury cadmium ME type lamps.
(a) 500-watt ME lamp, mercury only.
(b) 500-watt ME lamp, mercury cadmium.
(c) 9 kw mercury cadmium lamp.

Current Control and Starting of ME Lamps

As has been indicated in earlier sections, ME type lamps must be operated in series with a current limiting device which is conveniently a resistance for D.C. supplies and a choke for A.C. supplies. There are a number of different methods of ensuring reliable ignition of the arc, and some of these are now well known in connection with the more established types of high-pressure mercury vapour lamp. For example, the gas pressure and composition in the lamp may be so related to the electrode gap and the electrode activity that reliable ignition may occur on ordinary supply mains voltages without any additional starting means. In other cases, an ignitor electrode may be provided, or the lamp may be started by means of a high voltage pulse produced by an inductive surge from the choke or from a condenser charged to a high voltage. There are some interesting features regarding ignitor electrodes and some of these are set out in the succeeding section.

General Function of Ignitor Electrode

The use of auxiliary electrodes to facilitate the ignition of electric discharge lamps has been described by a number of workers.[23] In the simplest arrangement the ignitor electrode is situated very close to one of the main electrodes of the lamp and is connected through a high resistance, e.g., 50,000 ohms, to the opposite main electrode. When the lamp is switched into circuit the full potential difference between the main electrode is also established across the very small gap of about 1 mm. which separates the tips of the auxiliary electrode and the co-operating main electrode. A localised glow discharge therefore occurs, and the ionisation so produced allows of the almost instantaneous ignition of the main arc.

In an alternative arrangement a pair of auxiliary electrodes may be used, one very close to each main electrode and connected together through a high resistance. Simultaneous ionisation occurs in the vicinity of each main electrode when the circuit switch is closed, and ignition of the main arc follows immediately.

While these simple arrangements suffice for procuring the first ignition of the arc in discharge tubes up to 50 cm. in length from alternating current supply voltages of 250 volts, they will not function when a mercury lamp is in the high-pressure condition. In such cases it is necessary to allow the discharge tube to cool down to room temperature or thereabouts before the arc can be re-ignited from mains voltages. For A.C. lamps the incandescent auxiliary electrode offers a solution of this difficulty.

The Incandescent Auxiliary

This device consists of a tungsten helix mounted very close to one of the main electrodes of a high-pressure mercury vapour lamp and so connected that it can be raised to incandescence by the passage of an electric current. The transformer secondary feeding this auxiliary electrode, is connected through a suitable current-limiting device to the opposing main electrode. For the ignition of a 5-kw lamp from either the low or high pressure condition a suitable auxiliary can be made by winding a tungsten coil to the following specification:—

Number of turns	10
Wire diameter	0.6 mm.
Mandrel	1.0 mm.
Pitch of coil	0.8 mm.

The following factors have each an influence on the operation of the device:—

(a) Wattage dissipation of the filament.

(b) Temperature of the filament.

(c) Distance of the filament from the adjacent main electrode.

(d) The current flowing in the auxiliary gap.

The general effect of these variables is discussed below. An increase in the wattage dissipated by the filament is advantageous in facilitating re-ignition of a lamp from the high vapour pressure condition. In the earlier experiments the glowing tip of a V-shaped filament was used, but it was subsequently found preferable to use the heavy tungsten helix mentioned above. The temperature of the filament, and thereby its thermionic emission, governs the voltage at which ignition of the auxiliary arc will occur. For example, if under a given set of conditions of high vapour pressure the auxiliary arc fails to strike then an increase in electrode temperature will generally cause arc formation. The incandescent auxiliary electrode must be mounted close to the adjacent main electrode in order to ensure that the auxiliary arc will form under the highest mercury vapour pressure which can arise. A gap of about 1 to 1.5 mm. between the filament and the adjacent main electrode will in most cases enable instant ignition of the main arc to take place at pressures equivalent to a voltage gradient of 90 volts per cm. Decrease in the auxiliary arc gap to less than 1 mm., however, reduces the voltage at which the auxiliary arc will strike, but also causes it to have a more localised character, and thereby limits the spread of ionisation. It is, therefore, preferable to have the maximum auxiliary electrode gap which will ensure reliable ignition of the auxiliary arc. This effect is to some extent also related to the magnitude of the current which is allowed to flow between the auxiliary electrode and the main electrode. If the auxiliary current is adjusted to a very low value then in all probability the main arc will refuse to ignite at the higher vapour pressures. With increase in the auxiliary arc current the resultant ionisation is increased and ignition of the main arc is ensured. The simplicity with which the incandescent ignitor electrode allows of the ready ignition of the arc at all pressures may still make it important in the further development of the high current density mercury vapour arc.

Utilisation of Mercury Vapour Lamps, Type ME

In its simplest form the standard type of ME lamp gives a substantially uniform radiation in the plane bisecting the arc at right angles to the electrode axis. It is difficult to utilise the whole of this radiation to the maximum advantage in many types of optical system. For example, in the film or slide projector the angle subtended at the centre of the arc by the first condensing lens of the optical system is probably of the order of not more than 90° to 120°. Some gain in the efficiency of utilisation can be obtained by the use of a mirror situated on the optical axis of the projector and on the side of the lamp remote from the condensing lens. If, however, the mirror is spherical and is arranged to project the light back on the arc itself the gain is quite small, due to the mercury vapour arc being impenetrable to its own radiation. The image of the arc may, however, be thrown to one side of the arc proper or, by means of a specially designed reflecting system, two images of the arc may be formed one on each side of the arc proper, the arc itself and the reflecting image each contributing to the flux falling on the condensing lens. While modifications to the flux distribution from the arc may be achieved by the methods described

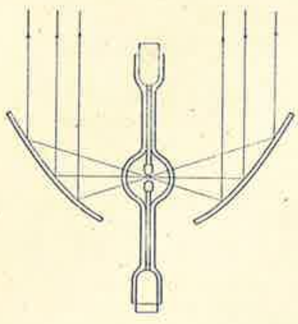


Fig. 11. Arrangement of ME lamp and deep parabolic mirror for maximum flux utilisation.

in an earlier section of this paper, there are certain cases when the reflecting system may be arranged to take advantage of the properties of the standard ME lamp in a very advantageous manner. One such arrangement is shown in Fig. 11, A deep parabolic mirror is fitted with an ME lamp of conventional type in which the electrode axis lies on the mirror axis. The mirror is therefore illuminated over its most effective area by the radiation from the lamp through an angle of 360° around the electrode axis. The centre of the mirror may be cut away, as no light falls thereon due to electrode obscuration. Such an arrangement is particularly useful where it is desired to throw a vertical pencil of light. The introduction of a mirror inclined at an angle of 45°, or of a right angle prism into the beam of light, may be used for horizontal projection. Such an arrangement illustrated diagrammatically in Fig. 12 might be used

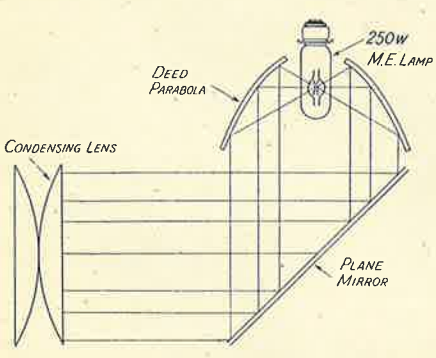


Fig. 12. Suggested arrangement of ME lamp, parabolic reflector, plane mirror and condensing lens of optical train.

in cinema or lantern slide projectors. In the case illustrated the initial light beam is projected downwards to facilitate ventilation around the lamp.

LOW-PRESSURE HIGH BRIGHTNESS GAS DISCHARGE LAMPS

As indicated in an earlier section, high current density in the discharge is one of the factors which leads to high brightness. It is an essential factor in the case of low-pressure discharge lamps as the voltage gradient in these lamps is very much less than in those of the high-pressure type. On the other hand, a low-pressure type of lamp is advantageous for some purposes in that it is already in a suitable condition for the passage of a discharge and does not require a preliminary burning period or pre-heating to reach the prepared condition. In the low-pressure discharge also, the arc in general fills the width of the discharge vessel, and therefore it is very suitable where a larger area of light source is required than is common with the standard type of high-pressure lamp. In order to obtain the required current density in the arc to give a source of high brightness it has become common practice to employ the discharge from a condenser charged to a relatively high voltage and to use the discharge tube to virtually short circuit the condenser. It will be understood that the effect of such a discharge is to produce a single flash of light, and the lamps described in this section of the paper are designed for the production of single flashes which may be isolated by relatively long periods of time or which may follow one another in rapid succession. Under these pulse conditions high order currents are produced, and the instantaneous wattage dissipation may reach very high values. For example a condenser of 50 mfds. charged to 4,000 volts has an energy content of 400 joules. If this energy is discharged through the tube in 100 microseconds the average power dissipated through the lamp is 4×10^6 watts. If we assume an average voltage over the discharge period of half the condenser voltage, i.e., 2,000 volts, then the average current during the discharge will be 2×10^3 amperes. These values and even higher ones may occur during the operation of flash tubes, and the amount of light which can be produced from single discharges can therefore reach very high orders. With a type of lamp which will be demonstrated during the reading of this paper a luminous output probably greater than 2×10^8 lumens is obtained with a brightness probably exceeding 5×10^4 stilbs. The practical utilisation of this phenomenon has resulted in the evolution of certain well defined lamp types and in several interesting applications, some of which will be mentioned.

The necessary components for producing high brightness flash discharges consist essentially of:—

(1) A bank of condensers together with suitable charging arrangements for giving between 2,000 and 10,000 volts.

(2) A lamp capable of withstanding the high thermal and electrical stresses to which it is subjected in the discharge cycle.

(3) Triggering arrangement for causing ignition of the discharge at a predetermined time.

With regard to (1), if a source of alternating current is available it is a relatively simple matter to transform to a suitably high voltage and then to rectify the high voltage supply and use the rectified output to charge the condenser. If only a low voltage D.C. supply is available then a vibrator inverter provides a simple means of converting to A.C. and this may be then used to feed a transformer to provide the necessary high voltage, which, after rectification, is used for condenser charging. In a third method, a low voltage battery supply may be used, and this may be converted to A.C. through a small rotary converter, which is then used for charging a condenser via a transformer and rectifier. In all cases, the object is to charge the main bank of condensers at a sufficiently rapid rate to allow of their periodic discharge through the lamp at whatever frequency is demanded by the purpose for which the light is intended.

(2) Flash Discharge Lamp

For most purposes the flash discharge lamp is designed with characteristics such that its striking voltage is substantially higher than the voltage to which the condenser is charged, and its extinguishing voltage should be as low as possible so that the maximum amount of energy from the condenser is dissipated in the discharge of the lamp. The lamp design must be such as will allow high order currents to be carried without damage either to the seals or to the glass or quartz tubing within which the discharge takes place.

Experiment has shown that there is an upper limit of loading which each type of vitreous material will safely withstand whether in single or multiple flashes. Quartz is capable of the highest loading of all. The so-called hard glasses come next on the list and the soft glasses can only safely withstand lower currents. Nevertheless, even with lime soda tubing, current densities of the order of 1,000 amperes per sq. cm. may be safely passed in single flashes, at higher loadings the inside wall of the glass becomes "crazed." If, as is necessary for some purposes, it is desirable to pass a sequence of discharges at higher frequencies, e.g., 10 to 500 per second, then the current density of each flash must be correspondingly lowered, otherwise the integrated load may cause over-heating of the tube wall. It is therefore necessary to take care of three main factors in regard to the tube design:—

(i) The current density in a single flash must not be so high as to cause volatilisation or melting of the inner surface of the tube.

(ii) The total power dissipated by the lamp must be such that an allowable temperature rise is not exceeded. The value of this temperature rise depends on the material of which the tube is constructed.

(iii) The tube itself may be either straight or it may be bent into spiral or other configuration according to the purpose for which the emitted light is required.

Various types of flash discharge lamp will be demonstrated during the course of the lecture. There is a maximum current which a given tube will pass and therefore when this peak current is reached the effect of discharging a greater quantity of electricity through the tube is to increase the duration of the flash.

The value of the peak current is determined both by the physical dimensions, i.e., length and diameter of the discharge tube and by the nature and pressure of the gas. With these requirements in mind a series of tubes have been developed which can be used to cover a wide variety of illumination purposes.

In Sieray tubes F.T.2 and F.T.3, in order to obtain a compact type of light source the discharge tube proper is bent into the form of a close helix. The F.T.2 tube can carry a single flash of 400 joules, while the F.T.3 tube can be loaded to 200 joules for a single flash. The F.T.4, 5, and 6 tubes are of straight form and have discharge path lengths of 30, 20, and 10 cm. respectively. The F.T.7, 8, and 9 tubes are similar, but the discharge path is confined within a quartz tube to enable higher loadings up to 300 joules to be used. Much larger tubes than these illustrated have been developed for special purposes. A typical range is illustrated in Fig. 13. In each case the gasfilling in the tube is either krypton or xenon, which have been found to give the

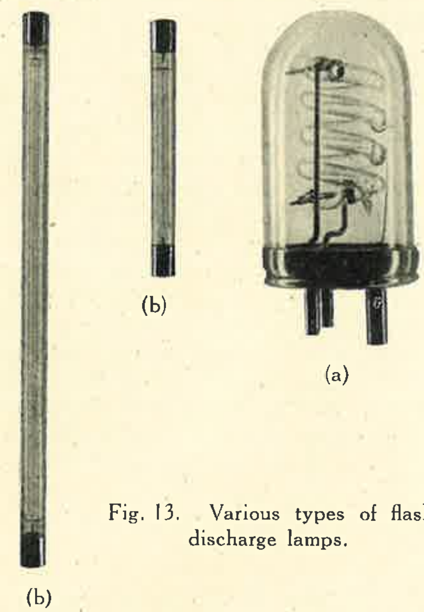


Fig. 13. Various types of flash discharge lamps.

highest visual and photographic efficiencies. A whole series of different fillings have, however, been investigated, and a common feature of them all is the fact that the high current density causes excitation of very complex spectra, and therefore of a light which in most cases approximates to white light. This will be demonstrated during the course of the lecture. The possibility of utilising the special properties of mercury and other metallic vapours under flash conditions has not been overlooked, and experimental devices have been worked out to utilise mercury vapour both at high and low pressures. With many gases and metallic vapours simultaneous excitation of the various components can occur, and the conditions may be so arranged that there is a high output in the U.V. region, see Fig. 14. This output may be used for the excitation of fluorescent coatings. By the use of powders of long afterglow, i.e., powders exhibiting phosphorescence, it is possible to partially bridge the gap between successive pulses of radiation from the tube, providing that the frequency of pulsing is 100 cycles per second or higher. While so far no practical use has been found for this application of fluorescence, it is not impossible that it may become of importance at some future date.

With regard to tube life, it is difficult if not impossible to give accurate figures. The conditions of operation to some extent determine the life, and in some cases it is necessary, for example, to have a different electrode arrangement for a tube designed for single high power flashes than when the tube is required for the same total energy dissipation but occurring in recurring series of flashes. Lives of hundreds of thousands of flashes are, however, normal.

(3) Triggering of the Discharge

As explained in (2) above, it is an essential feature in most types of circuit used for the operation of flash lamps that the striking voltage of the lamp is substantially greater than the voltage to which the condenser is charged. If this were not so, as the tube is connected directly across the condenser terminals, immediately its striking voltage is attained in the charging cycle the tube would break down and discharge the condenser, irrespective of any control unit which might be employed therewith. The resistance of the tube, therefore, at the condenser voltage must be of a very high order so that little or no leakage occurs. The discharge may then be initiated by the application of a suitably high voltage to either an ignitor electrode situated within the discharge path or by means of a third electrode taking the form of a thin wire wrapped round part of the outside of the discharge tube proper, or by the stimulus of an adjacent high frequency field. It will be realised that with any of these arrangements, provided that the condenser can be charged up at a sufficiently high rate, ignition of the tube can be controlled by means of an external circuit operating on the high voltage ignitor electrode.

Application of Condenser Flash Tubes

The flash discharge tube is suitable for use as a stroboscopic illuminator, as a high power source of single flashes, as an illuminant for high speed photography and for other purposes. To this end the discharge tube permanently connected across the terminals of the main condenser is arranged in suitable relationship to a lens or mirror optical system, so that the tube output illuminates the moving object under investigation. The condenser is connected to a charging circuit of the correct D.C. voltage and of sufficient output to load the condenser for each flash in an interval of time substantially less than the period which must elapse between consecutive flashes. The flashes themselves are brought about in synchrony with the repetition rate of the object to be illuminated either by means of a make and break contact mechanism actuated by the movement of the equipment under investigation or by some other periodic means which can be accurately controlled and timed in relation to the desired frequency of flashing. With a suitably designed combination the total duration of a flash may lie between 5 and 100 microseconds, according to the lamp and circuit in use. If, therefore, the source is required for the examination of, say, a shaft rotating at 3,000 r.p.m. the shaft will make one complete rotation in 20 milli-seconds. With a duration of flash therefore of, say, 20 microseconds the shaft will be illuminated in each revolution for

$$\frac{20 \times 10^{-3}}{20 \times 10^{-6}} \times 360^\circ \text{ of arc} = .036^\circ.$$

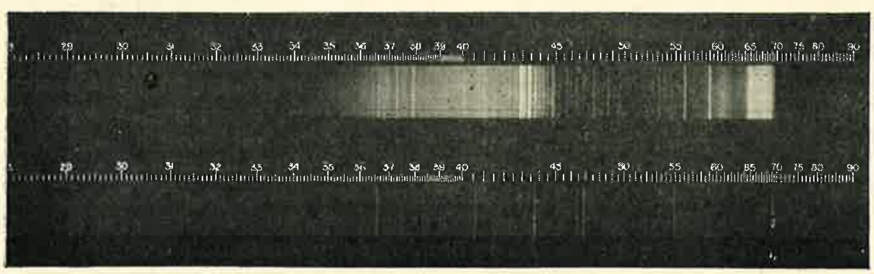
This gives of course very sharp definition and an apparently complete arrestment of the movement of the shaft as will be demonstrated during the lecture.

It is not proposed in a general review of this type to discuss in any detail the types of circuit which have been developed for the triggering and operation of condenser flash discharge tubes. Edgerton, of M.I.T. in America, has developed circuits employing the Strobotron, which is a cold cathode grid glow tube for controlling the triggering circuit. The hot cathode grid controlled rectifier known as the thyratron may be similarly employed, and use may be made of the simple condenser resistance relaxation oscillator for providing the self-actuating flashing system or the grid of the thyratron may be controlled by mechanical or electronic means to actuate the triggering impulse. Alternatively a hard valve time base may be used. Arrangements have been worked out which enable a beam of light falling on a photocell to act as the controlling mechanism, which, through a suitable circuit arrangement, can bring about the high power discharge from the condenser through the flash tube.

There is, however, a point of more general interest. While a single flash of high intensity may be used for photographic purposes, it is the product of intensity and time which governs the density of the resultant photographic image. In general terms, therefore, if we have a flash of one million lumens with a duration of 50 microseconds, the output can be described as a 50 lumen second output. Similarly, a flash of 10 million lumens enduring for 5 microseconds would have the same output of 50 lumen seconds, and the photographic result would be approximately the same as in the first instance. It is interesting to speculate on the effect on the visual mechanism of the eye of a 50 lumen second output produced in different ways. Perhaps the point can best be illustrated by means of a simple experiment. If we operate a 10-watt tungsten filament lamp at 5 L/W for one second, then the total output will be 50 lumen seconds. If now we operate a flash discharge tube with a duration of 50 microseconds and an average output over the period of 10^6 lumens, we will again obtain 50 lumen seconds, but the effect produced on the visual mechanism of the eye is immensely greater in the latter case than in the former. If, instead of single pulses, the output from the flash tube was arranged to form a sequence of pulses of, say, 200 per second, the retina would receive a series of images, presumably owing their density to the peak intensity attained in each pulse, and not to the integrated energy over the period of illumination. It is known that under high current density flash conditions the efficiency of the xenon-filled lamp is much greater than when the tube is operated continuously. The effect is due largely to the high order of excitation of the arc spectrum in the visible region and to the broad continuum of radiation. The question I want to ask is, Can this effect be utilised? Can a series of pulses of very short duration and high intensity following one another in such rapid succession that the visual impression is that of a continuum of light produce an apparent illumination when assessed visually much greater than can be produced by a similar dissipation of power operating through a continuously radiating source? If it can, then the merits of such a system should be investigated. Let us assume that the light from a cinema projector, for example, consisted of a series of pulses of radiation of very short duration but of a very high intensity. The cinema film could be driven continuously across the axis of the optical projection system, and there would be no cut-off of light by the chopping mechanism as no gate would be necessary. It would only be necessary to synchronise each pulse of light with each picture frame in order to obtain a stationary picture.

It is realised that in this simple example with the present picture frame repetition rate of 24 per second undesirable flicker will occur. The possibility, however, of utilising a sequence of several flashes during the stationary period of each frame with existing types of film movement mechanism could be considered. In this case the circuit would be arranged only to operate when the film was stationary.

There are, of course, numerous points which would require elucidation. For example, will the eye fatigue more rapidly to a source of light which is apparently continuous only because the retina is re-stimulated before the visual mechanism has



(a)

(b)

Fig. 14. Spectogram showing discharge through Krypton-Xenon mixture.

(a) Under high current flash conditions.

(b) Under continuous low current operation.

had time to recover from the previous stimulus. If such a system was adopted for special purposes or for general illumination, would the human eye ultimately be impaired due to the pulsing stimulus? We have to consider this surely in relation to the fact that the eye has evolved through aeons of time under the continuous radiation of the sun. In considering it account would have to be taken of the fact that the interval of time between each successive stimulation of the retina may be as high as 1,000 times the actual duration of the radiating stimulus. In other words, there would be long intervals of darkness punctuated by intense flashes of light, but the flashes would follow one another sufficiently quickly to give the appearance of continuous illumination. It would be necessary to assess whether under these new conditions the phenomenon of persistence of vision would follow the same general rules as have been established for light flashes of much longer average duration. Preliminary experiments have indicated that to produce a visual continuum with very short pulses the frequency of flashes must be several times that required with ordinary comparatively long duration periodic flashes, but this should not be taken as accurately established. The principle of a pulse lighting system has been illustrated in terms of its possible application to cinema projection, but it is no doubt capable of much wider application. Consideration is being given to its use for special cases of general illumination.

It would appear that the visual efficiency of such a lighting system can be made extremely high, as there is some evidence that the visual stimulus would be related to the peak illumination of a single pulse while the integrated power would be quite low as the duration of the dark period might be up to or more than 100 times the total duration of the light. At a frequency of 200 flashes per second, with each flash enduring for 50 microseconds, the time of illumination would be one per cent. of the total time but the illumination would appear continuous. For some purposes stroboscopic effects would render the use of such a system invalid, but it would appear that it has many features worthy of further investigation.

Among other uses for flash discharge tubes their application to high speed photography has received detailed study from Edgerton and his co-workers and in other laboratories both in America and in this country. Very high-power lamps have been used during the war by American Air Force photographic reconnaissance planes for low altitude night photography. The equipment was designed by Dr. Harold Edgerton of M.I.T. Small tubes of the F.T.3 type may be associated with suitable circuits to produce stroboscopic illuminators, and one such arrangement calibrated as a stroboscopic tachometer is already proving its value for many industrial and experimental investigations. While such arrangements have been known for many years, the light source has generally been of the neon lamp or cathode glow type. The introduction of the high-power condenser flash tube has enabled much greater light outputs to be obtained of a colour which is very acceptable both for visual or photographic examination. An interesting application is in connection with the photography of cloud chamber tracks in cosmic ray and similar investigations.

Conclusions

Metal vapour and gas discharge tubes of several new types have been described. Only those designs which may reasonably be described as bright light sources have been included in the present survey. It would seem that in both the case of the high-wattage mercury lamps and the high-power flash discharge lamps the development of the light sources has outstripped developments in their fields of application. The next phase will probably, therefore, be one of examining new ways in which they can be applied by the illuminating engineer to assist in the solution of both old and new problems. Meanwhile research on these comparatively new lamps is proceeding.

The author is indebted to the Directorates of Scientific Research, of the Ministries of Aircraft Production and Supply, for permission to include in the paper reference to work done at their request.

References.

1) Circuits for Discharge Lamps. Maxted and Hull. I.E.S., London, 1945.

(2) Electric Lamps. Solomon, M.A. Constable and Co., Ltd., London.

(3) Kuch and Retschinsky. Ann. d. Phys., 20, 1906.

(4) The Electrical Characteristics of Commercial Mercury Arcs. Buttolph, L. J. Rev. Sci. Inst., September, 1930-39, 487.

(5) Some Recent Developments in Gas Discharge Lamps. Aldington, J. N. Eng. Supp. Siemens Mag., No. 103, December, 1933.

(6) Electric Discharge Lamps. Ryde, J. W. Journal of the Royal Soc. of Arts, Vol. LXXXII, 1934.

(7) The High Pressure Mercury Cadmium Lamp. Spanner, H. J. Trans. I.E.S. (America), 1935, 2, 178.

(8) The Electric Discharge Lamp. A Survey of Development. Aldington, J. N. Assoc. of Public Lighting Engineers, 1936.

(9) Air-cooled High Brightness Mercury Vapour Lamps and their Application to Projection. Francis V. J., and Wilson, G. H. Trans I.E.S., Vol. LV, No. 4, 1939.

(10) Some Developments in the Production of Light by the Electric Discharge Through Mercury Vapour. Aldington, J. N. Siemens Eng. Supp., No. 178, 1940.

(11) Characteristics of Electric Discharge Lamps for Projection. Bourne, H. K. British Kinematograph Soc. Journ., 1941.

(12) Bol. (De Ingenieurs, E. 91, 1935).

(13) The Dependence on Temperature of the Mechanical Strength of Quartz Glass. Zeitschr. F. Tech. Physik, 1938, No. 10, pp. 294-296.

(14) Glass Tech. Ber., 1940, 18 (Oct.), 265. Dawihl and Rix.

(15) Water-cooled Lamps. E. G. Dorgello. Phil. Tech. Rev., June, 1937, p. 165.

(16) British Patent 489,051. Siemens.

(17) British Patent 559,315. Siemens.

(18) British Patents 559,393, 561,281, 570,324. Siemens.

(19) British Patents 512,974, 541,208, 551,136. Siemens.

(20) British Patents 476,818, 526,401, 559,318. Siemens.

(21) British Patent 570,324. Siemens.

(22) British Patent 570,583. Siemens.

(23) Electric Discharge Lamps. Ryde, J. W, Journ. of the Royal Soc. of Arts, Vol. LXXXII, 1934.

Electrical Discharges in Gases and Vapour. Aldington, J. N. Eng. Supp., Siemens Mag., No. 131, 1936. Also British Patents 448,891 and 410,558. Siemens.

Electric Discharge Lamps. Warren, H., and Davies, L. J. Inst. of Automobile Engineers, December, 1934.

British Patent 497,108. Pirani, M., Nelson, E.

Printed by THE ARGUS PRESS, LTD., Temple Avenue and Tudor Street, London, E.C.4, England.—7097.