Electric Lamps: Incandescent

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THE ELECTRICITY COUNCIL
MARKETING DEPARTMENT

With Compliments

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Electric Lamps Section C

Incandescent

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Foreword

Given the right materials and the necessary plant, anyone could make an incandescent lamp of sorts which would give some light for an indeterminate time. It might turn out to have a brilliant but short life, or a dull but long one, or something in between and the buyer of such a lamp would be taking pot luck. But nowadays a purchaser likes to know what he is buying even though the item may cost comparatively little; certainly anyone responsible for planning or running an extensive commercial or industrial lighting installation cannot afford to be in doubt as to what the lamps will do; he must know.

Where good lamps differ from not so good ones is in the extreme purity of the materials used, the microscopic accuracy of their construction and assembly, and the rigid quality control exercised in their manufacture. These things cost money, so also does the continual research devoted both to improving existing products and the development of new ones; for these things the lamp user must pay, though never was money better spent.

The voice of the industry in the United Kingdom is the Lighting Industry Federation of which all principal lamp and equipment manufacturers are members. It is responsible for both national and international standardization on such important matters as bulb sizes and caps so that users are assured of the mechanical and electrical interchangeability of lamps of similar types produced by different manufacturers. All the major lamp makers in the U.K. operate under licence from the British Standards Institution. This certifies conformity to British Standard Number 161 which involves the maintenance of a high and uniform quality in their products.

At the present time about 250 million incandescent lamps are sold in the United Kingdom each year and, in spite of the competition from other kinds of electric lamp, the number is still increasing. Most members of the public have little or no idea how a lamp works or why it is made in a particular way, and indeed it cannot be expected that they should. But this is a situation which often leads to lamps — which are precision products — being used in conditions for which they were not designed, and then being blamed for not behaving as the user expects.

It is the purpose of this publication to provide the reader with the information necessary to enable him to choose wisely and to appreciate what is involved in lamp design and manufacture in order to get the best service from a product which may appear simple but into which has gone so much in design, development and manufacture. It should also enable the lamp retailer to give reliable advice to his customers. It is hoped that it will also be of general interest to other sections of the public, and to those concerned with technical education. Some details normally found in manufacturers' catalogues have been omitted for two reasons. One is that catalogues are revised more frequently than this publication can hope to be; the other is that where two lamps of the same general type made by different manufacturers differ in detail it is obviously wise to rely on the information provided by the individual maker.

This is the third section of the series '*Electric Lamps*.' All sections are in the same format, 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

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 (4.6), (7.3), etc. References having a prefix A, B or D are to those sections in the series.

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1 A short history of the incandescent filament lamp

1.1 The story of artificial lighting, going back as it does to pre-historic times, ranges over a wide field and has been covered in numerous publications. Here it is appropriate only to give briefly the salient landmarks in a small and comparatively recent part of it — the development of the incandescent electric lamp. For those interested in a broader picture, there is an excellent *"Short History of Lighting"* published by HMSO, and this in turn gives a comprehensive bibliography of the subject.

1.2 The earliest experimental incandescent electric lamps to show promise of becoming practical light sources were devised independently by Edison in America and by Swan in the United Kingdom in 1878. Disagreement has long been expressed over which preceeded the other, and there is no wish to debate it here. Both claim to have been the first have supporting evidence. Swan's first lamp is illustrated in Figure 1. It comprised a carbon filament made from vegetable fibre sealed in a cigar shaped glass envelope with platinum wire leads. Though quite a high vacuum was obtainable by means of the pumps then available, oxygen was trapped in the filament and subsequently liberated in operation. This together with the non-uniform cross-section of the carbon filament and other deficiencies, resulted in unreliable performance and life.

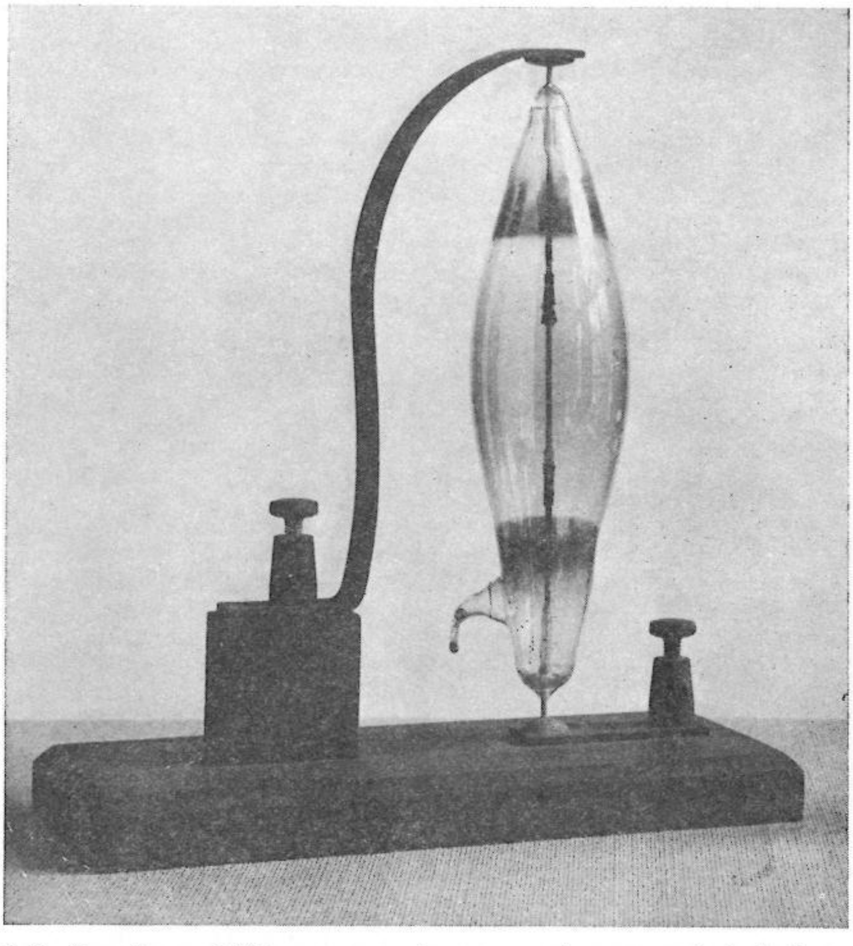


Figure 1
Swans first incandescent carbon filament lamp 1878

1.3 Over the next 27 years many improvements were made including the manufacture of filaments from a cellulose solution extruded through dies and subsequently carbonised. Developments in this process resulted in the production of commercially acceptable carbon filament lamps in forms not far removed from those still made for limited purposes. Early examples are illustrated in Figure 2.

1.4 The best efficacy obtainable with a carbon filament lamp having a satisfactory life was of the order of 2 to 3 lumens per watt and in endeavours to secure higher light outputs and efficacies, attention was turned to the use of metal filaments. In the early years of the present century lamps using filaments of Osmium and Tantalum were produced. Though improved efficacies were obtained, filaments of the former metal proved very fragile and only low voltage types with correspondingly thicker filaments were practical. Tantalum filaments, on the other hand, proved much more robust and had a satisfactory life on direct current supplies. But on a.c. they were unsatisfactory due to crystallization in the filament which led to premature failure.

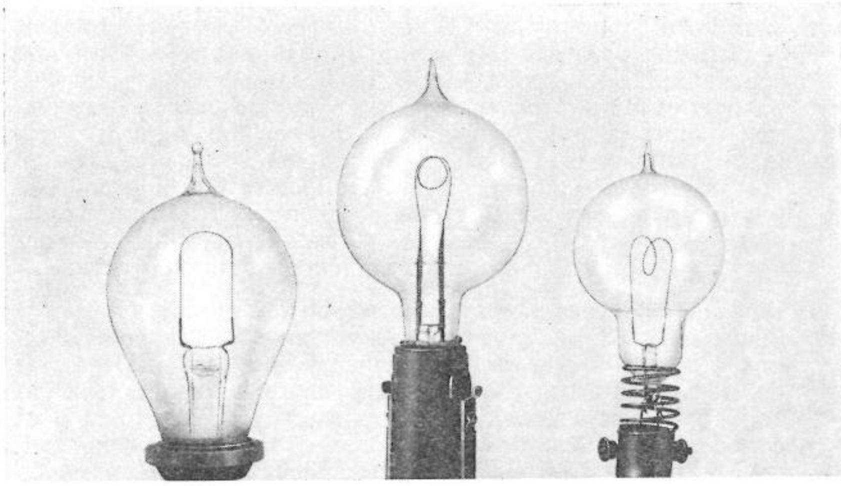


Figure 2
Early Carbon Lamps

1.5 Though some lamps employing tungsten filaments were made earlier, it was not until 1909 that the problem of making tungsten ductile, was first solved, enabling it to be drawn down through dies into a thin but tough filament. Tungsten possesses the highest melting point of any metal (3382°C). Thus tungsten filaments can be operated at considerably higher temperatures than those made from other metals and a very considerable advance in efficacy was secured, since this increases rapidly as the filament temperature is raised. Early tungsten filament lamps had the necessary length of filament wire arranged in a series of hairpin bends known as a 'squirrel-cage' formation. Examples showing this type of filament are illustrated in Figure 3.

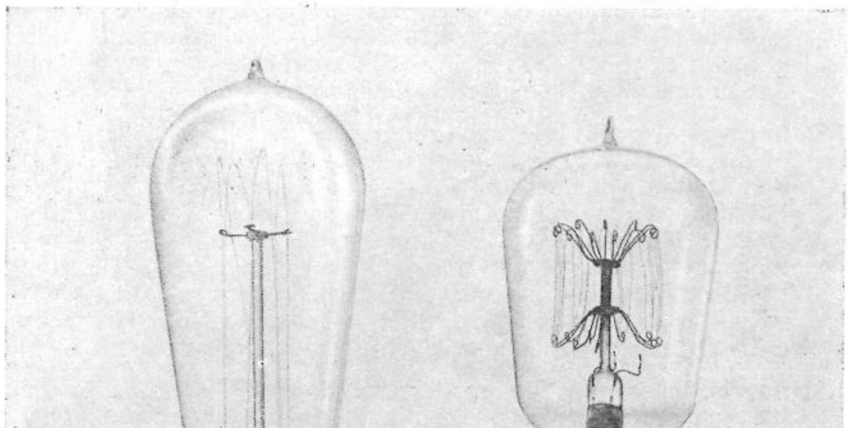


Figure 3
Early metal filament lamps

1.6 In 1913 the beneficial effect of filling the evacuated bulb with an inert gas such as nitrogen was discovered in America. The result was to retard the evaporation of tungsten from the filament, which was a major cause of lamp failure. An unfavourable accompanying feature was that convection currents in the gas carried heat away from the filament thus tending to cancel the advantage of the higher temperature of operation made possible in the gasfilled lamp. Due to restrictions during the 1914–18 war gasfilled lamps were not widely made in this country until after 1918, and about that time the principle of coiling the filament wire into a close helix was introduced. This greatly reduced the cooling effect of the gasfilling and enabled further increased efficacies to be obtained.

1.7 Due to its compactness and its high temperature, in the clear glass bulbs then employed the appearance of the coiled filament in operation gave rise to much more glare discomfort than was experienced with earlier lamps. Various methods of diffusing the light were used to reduce the glare and most of them resulted in an appreciable loss in efficacy due to absorption of light. In 1924 the present solution of the 'pearl' bulb was devised. This consists of etching the inner surface of the bulb and has the great advantage that the resultant light absorption is negligible. Also the outer surface remains smooth and therefore does not become dirty as it does when frosted on the exterior.

1.8 While minor developments continued, the next major improvement in the gasfilled lamp was introduced ten years later, in 1934. In the case of the lower wattage lamps, due to the fineness of the coiled filament, reduction in efficacy due to gas convection cooling was still significant. To minimise this the principle of coiled-coiling, Figure 4, was devised, giving a significant improvement in efficacy over a limited range of wattages (2.7 to 2.10).

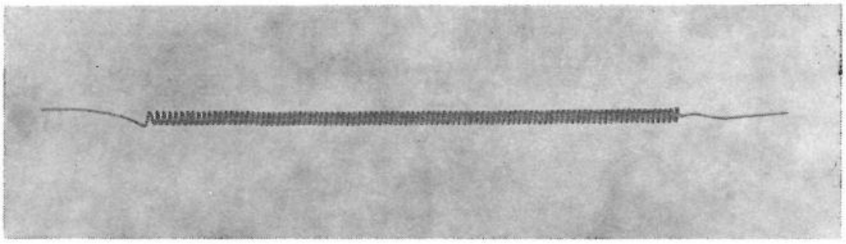


Figure 4
A coiled-coil filament

1.9 Both single and coiled coil lamps remain current in the general lighting service range. While changes have occurred in the interests of standardization and economy — such as the reduction in bulb size and in the number of different bulb sizes used — no further fundamental change has taken place.

1.10 In concluding this brief survey, however, mention must be made of a major development in the field of lamps for projection and floodlighting purposes. This took place in 1965 with the introduction of the tungsten-halogen lamp. The principle, detailed later (2.12 to 2.14) is the return of the evaporated tungsten to the filament by means of a halogen introduced into the gasfilling. This has the effect of enabling filaments to be run at still higher temperatures without impairing lamp life while obtaining still greater efficacy together with improved maintenance.

1.11 As yet, the application of the principle is limited because the halogen cycle i.e. redepositing tungsten on the filament, only occurs at operating temperatures too high for normal glass and much more costly quartz has to be used. Hence the original and now discontinued name "quartz-iodine lamps."

1.12 Thus, even after 90 years of development, continuing research is still producing improvements in incandescent lamp characteristics and performance. Indeed, during the preparation of this publication, tungsten-halogen lamps in a special hard glass have become available.

2 Modern lamp development and characteristics

2.1 Vacuum lamps
The life of an incandescent lamp filament, assuming that it is not mechanically or chemically imperfect, depends on how quickly the tungsten is evaporated. The rate of evaporation from each section of the filament depends partly on its temperature. If one mm of the filament length is thinner by a microscopic fraction than all the rest of it, its resistance will be higher and a hot spot will develop there. This raises the rate of evaporation from that small piece, the loss of evaporated material makes it still thinner, it becomes hotter still and so on with a cumulative effect until that part becomes so thin that it cannot support its own weight, and it breaks.

2.2 The rate of evaporation of the metal is retarded if pressure is exerted on the filament; the greater the pressure, the slower the evaporation. But in a vacuum lamp there is virtually no pressure because great pains have been taken to reduce it as nearly as possible to zero; for a given filament temperature the rate of evaporation is therefore high and the lamp has a comparatively short life.

2.3 Thus if a vacuum lamp is to have an acceptable life the filament must be run at a modest temperature not exceeding, say, 2100°C, but at such a temperature the efficacy of converting electrical energy into light is only some 9 lm/W. The light output decreases through life due to absorption by the evaporated metal which adheres to the bulb and becomes progressively more dense. Hence the blackened appearance of aged lamps of the old squirrel-cage type, now much reduced due to the use of coiled filaments and pear-shaped bulbs.

2.4 Gasfilled lamps
It has been indicated that the rate of evaporation of the filament is reduced if a pressure can be exerted on it. The practical way to achieve this is to fill the bulb with an inert gas which will have no chemical effect on the bulb or its contents. It is introduced only to retard filament evaporation.

2.5 Suppose then that we have a 'vacuum' lamp which has been filled with this gas mixture. The long wire of the filament has been bent into a series of hairpins or coiled in order to fit it into the bulb. When the lamp is switched on each part of the filament will become hot and will warm the gas surrounding it. The warm gas rises due to expansion and is replaced by cooler gas from below, thus setting up convection currents which carry heat away from the filament and transfer it to the bulb. From this it is dissipated due to radiation and by external air currents.
Experimental lamps have been made which when 'vacuum' light up brightly, but when 'gasfilled' glow only over the upper parts of the hairpin filament which are in a warm gas region; the lower parts, in cooler gas, do not glow at all. So far the idea of gas filling does not seem to have much promise.

2.6 Investigating the flow of gas past a hot wire, Langmuir found that immediately surrounding the wire there is a very thin layer of almost stationary gas, and it was only beyond a small but measurable distance from the wire that the gas moved strongly upward. (A somewhat similar phenomenon may be observed on a river; though the main stream runs quite swiftly, water close to the banks may be practically stationary).
The 'Langmuir layer' provided the solution to the problem of gas-filling. By coiling the filament into a tight spiral the stationary gas layer round one coil will join with the stationary layer round the next, and so on, and the gas will be prevented from flowing between the individual coils. So far as gas flow is concerned it must now pass round the outside of the helix; the filament has in effect become a comparatively short thick cylinder which offers much less surface area to be cooled by the gas than the long thin bent wire of the vacuum filament, Figure 5. Thus the gas carries away less heat, the filament becomes hotter, and since a pressure is now exerted on it, it can be designed to run at a higher temperature without evaporation causing early failure. And higher temperature means a more efficacious lamp, Figure 6.

The relative cooling effect with a closely or loosely coiled spiral is well illustrated by an ordinary electric fire with a damaged element. The closely coiled sections run brighter than sections where the coil is stretched out.

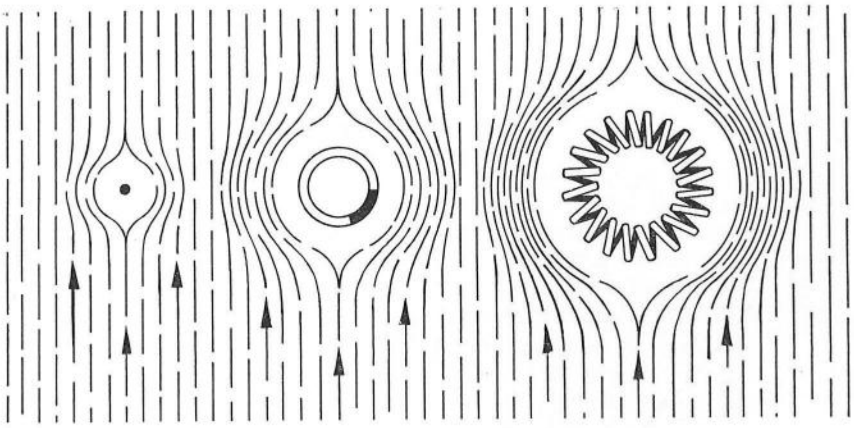


Figure 5
Flow of gas around straight, coiled and coiled-coil filaments

2.7 In some types of lamp gasfilling is inapplicable; for example in long tubular types where the filament must extend over the whole length and therefore cannot be tightly coiled. Another example is the 240V 25W lamp where the filament is so fine — it has such a large surface area in relation to its volume — that even with a tightly coiled filament the loss of heat to the gas outweighs the other advantages. But apart from such exceptions lamps for general lighting service are now invariably gasfilled because of the resulting gain in efficacy. For details of coiling techniques etc. (Appendix 1).

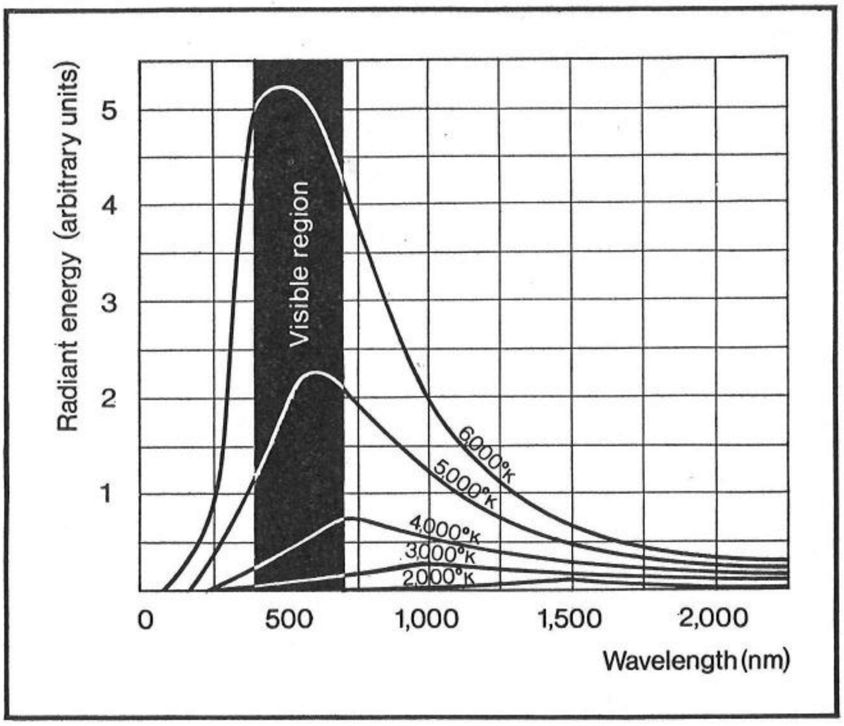


Figure 6
Characteristics of a filament at different temperatures

2.8 In the coiled-coil lamp the tight helical filament is coiled into a second helix, Figure 4, still further to reduce the heat loss and this results in still higher efficacy over a limited wattage range. In coiled-coil lamps the gas pressure is the same as in the single-coil type, and the filament temperature must remain the same if the lamp is not to have a shorter life. If the filament were left unchanged, however, the reduced loss of heat to the gas would result in a higher operating temperature. To prevent this the coiled-coil filament is given greater electrical resistance by making it longer. In the same filament diameter this would reduce the wattage of the lamp, but to retain the standard wattage ratings the coiled-coil filament is made with a slightly increased wire diameter. Thus the coiled-coil lamp has a greater mass of metal in the filament and it is from the extra metal that the additional light output is obtained.

2.9 The finer the filament wire is, the more effective is coiled-coiling in increasing light output, but the lower limit of lamp size to which it can be applied is set in the first place by the difficulties of manufacturing the complicated filament formation out of very fine wire, and in the second place in so treating or supporting the filament that it will retain its shape for a thousand hours at incandescent temperature. Thus in practice mains-voltage coiled-coil lamps are not made smaller than 40W, where the gain in light output is about 20% (Appendix 3).

The larger wattage lamps use thicker filament wire and the gain in light output by coiled-coiling is less marked. At 100W on mains voltage the gain is about 10%; at 150W it is a few percent and at still larger sizes it is negligible. Even so, coiled-coil filaments are used in many types of lamps intended to be used with an optical system to give accurate beam control, for the more compact dimensions of the coiled-coil assembly mean that more of it can be effectively concentrated at the optical focus. A few filaments are even triple-coiled for the same reason.

2.10 When a gasfilled lamp fails through filament fracture on lighting or while it is in operation, the gas may become ionized due to the arc and tungsten vaporisation across the fracture. Such ionization may result in the arc persisting long enough for a disruptive current to build up between the lead wires and sufficient energy to be released to shatter the seal and the bulb. The risk is higher in coiled-coil lamps due to the compact filament and closeness of the lead wires inside the bulb. In practice, all coiled-coil and most single coil gasfilled lamps have in-built protection in the form of small fuses located in the foot tube.

2.11 Tungsten Halogen Lamps

Tungsten halogen lamps have a halogen — iodine or bromine — added to the gas filling. The process taking place within the lamp differs in detail with the different additives but iodine is taken here as an example.

2.12 At temperatures above 250°C iodine combines with tungsten to form tungsten iodide, but at temperatures above 2000°C the the reverse reaction takes place and the tungsten iodide dissociates to form tungsten and iodine. Consider now what happens in an iodine-filled lamp where the envelope attains a temperature of, say, 300°C. When the lamp is switched on, filament material evaporates and would normally condense and adhere to the inner surface of the bulb, causing blackening; but the iodine combines with the tungsten near the bulb at the temperature in this region (250–500°C), forming tungsten iodide vapour and so keeping the inner surface clean. The vapour is circulated by convection in the hot gas and in due course approaches the filament, which has a temperature well over 2000°C. Here the vapour breaks down into iodine which is released for further clean-up action, and tungsten some of which is re-deposited on the filament. At a given filament temperature, this out-and-home cycle, Figure 7, much reduces the influence of evaporation on lamp life, and it is thus possible to use increased filament temperatures. Thus higher efficacy (about 20 lm/W) is obtained and the permanently clean interior of the envelope results in the light output remaining virtually constant throughout life. If each particle of evaporated tungsten could be made to return to the exact spot from which it originated, in theory the lamp might last for ever.

2.13 A further advantage of the halogen lamp stems from the fact that the lamp envelope must run hot and there is no need to be concerned with measures to reduce the effect of blackening. This means that the envelope can be made small; in the tubular types it is only about 12 mm in diameter. The very limited space inside the lamp provides insufficient room for strong convection currents to be set up in the gas filling, which accordingly has less cooling effect on the filament and so increases efficacy. At the same time,

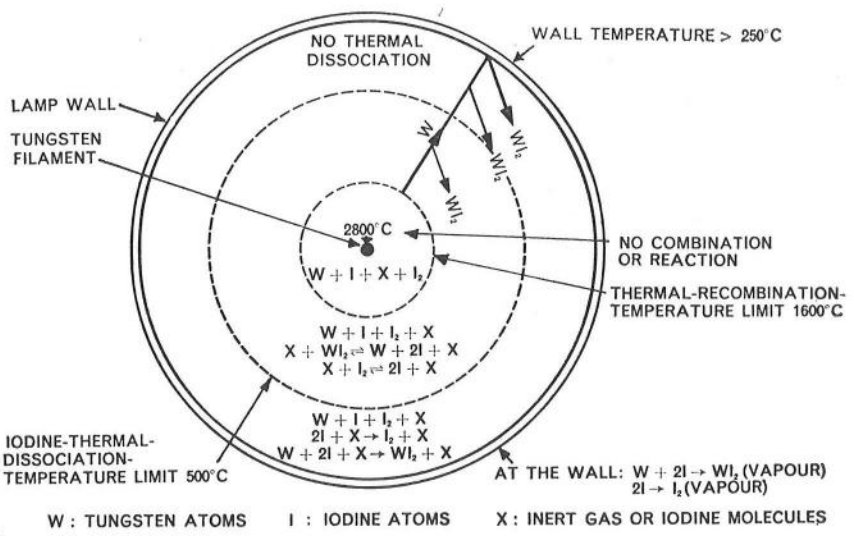


Figure 7
Mechanism of tungsten iodine cycle in an iodine lamp

with the much smaller quantity of gas required per lamp it is practicable to use the most advantageous gas for the purpose without its high cost being prohibitive. Thus in some lamps krypton or xenon may be used instead of the argon or nitrogen-argon mixture. The advantage of these rare gases is that they are both heavier and poorer thermal conductors. Also due to the smaller enclosed volume, a higher gas pressure can be employed.

3 General Lighting service Lamps

The above, which is shortened to GLS applies principally to the pear-shaped lamps listed in BS.161, but other types used domestically may be included, such as mushroom-shaped lamps (up to 150W).

3.1 Bulb finish
Some sizes of pear-shaped GLS lamps are available with three kinds of bulb finish — clear glass, pearl, and white, Figure 8. The two last are often given trade names by individual manufacturers, but the performance and appearance is similar.

3.2 Clear lamp bulbs have a smooth inner and outer surface and emit the maximum amount of light but do nothing to modify the brilliance of the filament. The larger sizes of clear lamp are likely to be mounted well above the normal line of sight in fittings which screen the filament from normal viewing angles, and so with them there may be no problem of glare, but in the smaller sizes such as are used domestically, it is generally preferable to use one of the diffusing bulb finishes. Clear lamps tend to give a 'hard' light; shadows are sharp, particularly shadows of nearby edges such as the top and bottom of lampshades; some streakiness of lighting may be apparent on a flat surface, due partly to internal reflections within the bulb and possibly to imperfections in polished reflecting parts of the lighting fitting. On the other hand, a clear lamp will best produce glitter and sparkle if this is desired — for example, in a crystal chandelier.

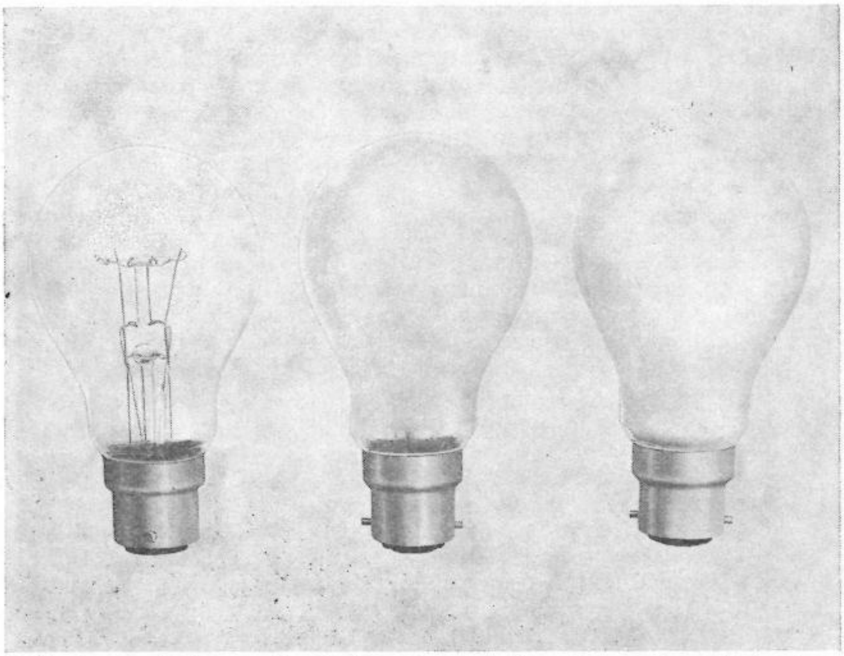


Figure 8
Clear glass pearl, and white, GLS lamps

3.3 In pearl lamps the inner glass surface is roughened by two applications of acid spray. The first application makes the glass brittle but breaks up the inner surface into countless minute prisms, The second acid application re-toughens the glass while retaining the characteristics of the surface, which refracts light in different directions, creating a degree of diffusion which conceals the brilliant filament, the light appearing to come from a bright patch on the bulb surface. Pearl lamps are standard up to 150W and they can be obtained in larger sizes. Due to the excellent transmission of the bulb the amount of light given by a pearl lamp is practically equal to that of a corresponding clear lamp, but shadow effects are softer.

3.4 White lamps have a smooth outer surface but a thin layer of very fine white powder — silica or titanium dioxide — is deposited on the inside surface. This gives almost complete diffusion of light within the bulb, which looks evenly bright all over. Shadow effects are therefore even softer than with the pearl lamp. The absorption of light by the powder coating results in the output of the white lamp being about 8% lower than that of a corresponding clear or pearl lamp.

3.5 Effect of bulb finish on light control

Effective control of light in a beam — even a fairly wide beam — depends on the source of light being concentrated as much as possible at the focus of whatever reflecting or refracting optical system is being used. For narrow-beam results a clear bulb is essential though the illuminated area may be slightly streaky as noted in 3.2; but with pearl and white lamps the effective source of light is at the bulb surface and with normal sizes of equipment this cannot all be at the optical focus, therefore close control is out of the question. However, for some applications a soft edged flood of light may best meet the requirement and pearl or white lamps in specular reflectors, or pearl fronted reflector lamps (4.1 and 6.4), may be effective for example in retail or exhibition displays.

3.6 Colouring

Coloured light is obtained from lamps which have been externally — or in some cases internally — sprayed with a colour pigment (6.5). With internal spraying there is of course no risk of the pigment being scratched off. Some lamps are also available with an external vitreous glaze of permanent colour which is virtually unscratchable.

This method or indeed any other method (4.5) of producing coloured light from incandescent lamps involves absorbing the unwanted colours from the white light generated by the filament. In the case of the green sprayed lamp, for example, only about 20% of the generated light emerges from the bulb, the rest being absorbed by the pigment; in the case of blue-sprayed lamps, the absorption is such that only some 5% emerges. However, in the case of amber and pink coloured lamps the transmission is a good deal higher owing to the energy distribution characteristic of the incandescent filament, Figure 6.

3.7 Bulb shape

In GLS lamps the size and shape of the bulb, which in domestic wattages may be either 'pear' or 'mushroom', is dictated partly by considerations of good appearance and partly by the need to ensure that in normal operating conditions the hot gas rising from the filament becomes sufficiently cool to avoid raising the temperature of the glass or the capping cement above the safe working limit (3.8). In some of the larger lamps a mica or metal disc is inserted in the neck of the bulb to give additional thermal protection to the pinch seal and to the cap assembly.

In recent years on account of improved manufacturing techniques, and to minimize material, packing and transport costs, there has been an international tendency for bulb sizes to be reduced. In particular the mushroom shape of bulb permits adequate cooling of the gas even with a remarkably small bulb size.

3.8 Caps

The lamp caps most commonly used in this country (other than for projection purposes) are —

1. Bayonet — BC or B22
2. Small Bayonet — SBC or B15
3. Goliath Edison Screw — GES or E40
4. Edison Screw — ES or E27
5. Small Edison Screw — SES or E14
6. Miniature Edison Screw — MES or E10

The dimensional code of these and other caps is given in Appendix 2. For GLS lamps the caps used are BC, ES and GES.

BC caps allow quick and simple insertion and removal of the lamp from the lampholder but the electrical contact between lamp and lampholder in most designs depends on the pressure of small current-carrying plunger springs which can fail by overheating if misused. In British practice BC caps are normally used up to a maximum of 150W, ES caps for 150W and 200W, and GES caps for 300W and above. Screw caps enable the electrical connection to be made firmly and with increased area of contact, and the GES cap is of sufficient diameter to hold securely the large sizes of bulb. The design of the caps and their method of attachment to the bulbs must enable them to pass the torsion tests specified in BS.161, viz. 3 Nm (25 lb/ins) for BC and ES caps and 5 Nm (45 lb/ins) for GES caps. The insulation resistance between the shell of a BC cap and the current-carrying leads within it must be at least 50 megohms in order to comply. In the case of screw caps the insulation requirement does not apply since both shell and centre contact are connected within the lamp. Where ES or GES capped lamps are used therefore, lampholders so designed either that contact is not established until the lamp is screwed home sufficiently to render the cap untouchable, or with a shroud adequate to prevent the cap being touched at all during insertion, are preferable to avoid risk of shock. In this connection it should be noted that for compliance with IEE regulations the current-carrying shell or screwed part of a lampholder must be connected to the neutral pole of the supply. The capping cement now used is claimed safely to withstand a maximum temperature of 210°C, but in view of over voltage, high ambient and other unfavourable conditions it is prudent to work to a lower maximum — say 170°C — thus leaving a safety margin. BS.161 limits the average lamp cap temperature rise for common sizes of GLS lamp to between 125 and 135°C, according to lamp wattage.

3.9 Filament formation and supports

Most GLS lamps have a 'wreath' filament forming part of a circle in a plane at right angles to the lamp axis, but where the filament is too long to be accommodated in one plane it is formed into a series of V's.

Whatever its shape, the filament must be supported at the ends and at intervals along its length. The ends are welded or clamped to the current-carrying lead-in wires. Intermediate supports consist of molybdenum wires inserted into a glass stud formed on the end of the stem. The outer ends of the wires are formed into hooks or loops through which the filament passes, Figure 9. Molybdenum is used because it can withstand the temperature of the filament, possesses adequate strength in the fine gauge necessary to minimise heat loss and has some elasticity to soften shocks.

Each support wire causes local cooling of the filament and reduces the light output by about 1% therefore the number used is kept to a minimum. The maximum length of filament between supports depends on its mechanical strength to avoid sagging; this in turn depends on minute proportions of other metals added during preparation of the tungsten and on its molecular structure. The heat treatment of the filament both before and after it is coiled is of major importance also. The greatest care is therefore devoted to these matters during filament manufacture (Appendix 1).

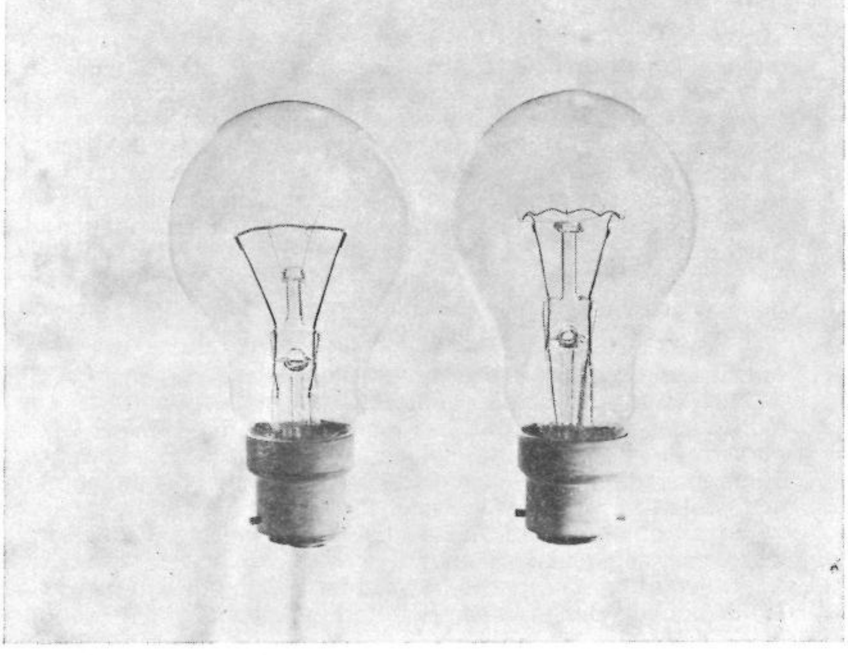


Figure 9
100 watt single coil and coiled-coil clear lamps to show filament supports

3.10 Starting Characteristics

The electrical resistance in ohms of a lamp when normally alight is given by $\frac{V^2}{W}$, but before the lamp is switched on the cold filament has a very much lower resistance. Therefore at the instant of switching-on an excess current will flow, generally up to about 14 times the normal value. As the filament heats, the current drops rapidly until after about 0.02 second for a small wattage lamp or 0.2 second for a large one, it reaches its normal value, Figure 10.

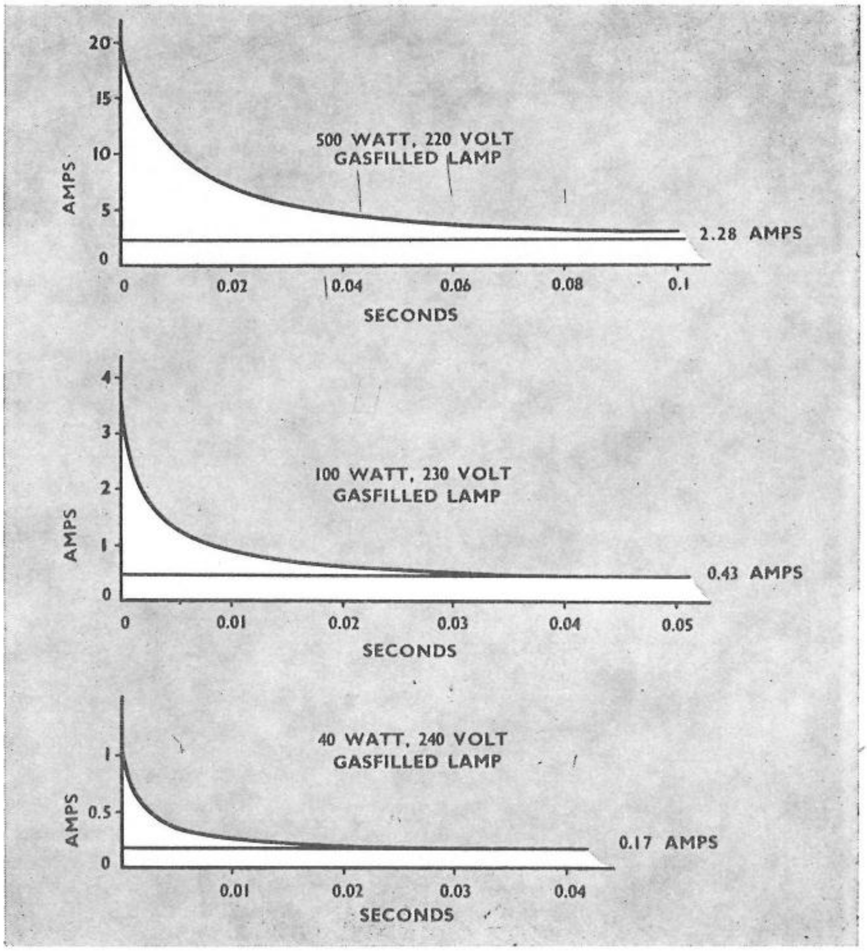


Figure 10
Graphs showing current surges at the instant of switching-on

The excess current does not persist long enough to cause most ordinary circuit breakers or fuses to operate, and it has generally been ignored by switch manufacturers since switches are more likely to fail when breaking a circuit than when making it; but in practise some short-break designs may not stand up indefinitely to the surges of repeated switchings.

It is a fallacy that it is more economical to leave an incandescent filament lamp alight than to switch it off for a short period. The cost of the surge current on switching again cannot possibly be as much as the cost of current saved by switching off, and in ordinary lighting usage the frequency of switching has no material effect on filament lamp life.

3.11 Luminous Output

BS.161 requires the initial efficacy (lumens per watt) of any individual lamp to be not less than 93% of the nominal value quoted in the standard, subject to a statistical allowance. Throughout life there is a gradual diminution of light output, and BS.161 requires that the value measured after 750 hours shall be not less than 85% of the initial. Changes in lamp wattage and current are negligible.

The value of light output to be used for lighting design purposes is the 'lighting design lumens' quoted in Appendix 3. This figure is the average output at 500 hours and approximates to the average throughout nominal life.

3.12 Lamp Life

While for very many years the nominal life of GLS lamps has been 1000 hours, not infrequently queries have arisen as to whether this is the optimum figure. In fact, such are the variations in users' requirements and in the prices which they pay for electricity and the costs of replacing lamps, that there can be no universal optimum life. The committee responsible for BS.161 is representative of a wide cross section of interests, and includes various government departments, professional institutions, organizations representing large users, electrical contractors, and the lighting industry. This committee has reviewed all the factors involved and has concluded that the long established life of 1000 hours should remain the standard rating.

Though rigid control and improvement of manufacturing processes leads to even greater uniformity in the lives of individual lamps, absolute uniformity is unattainable. In practice, if lamps are burned at their rated voltage and under other test conditions detailed in BS.161, the percentage remaining alight after various periods is approximately as shown in Figure 11.

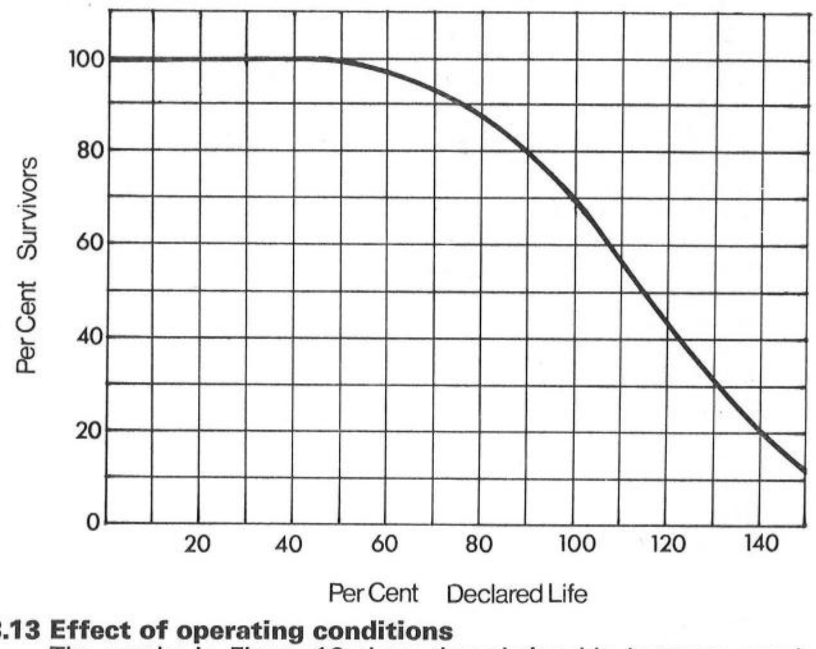


Figure 11
Typical survivor curve for GLS lamps

3.13 Effect of operating conditions

The graphs in Figure 12 show the relationship between supply voltage variation and gasfilled lamp performance.

1. *Voltage*

Within the normal range of supply voltage variations the change in light output is about 3.5% for each 1% change of voltage. The effect of voltage on life is more pronounced; 5% over-voltage will roughly halve lamp life and 5% under-voltage will roughly double it. If lamps are consistently found to fail early then the agreement between the rated lamp voltage and the actual voltage at the points concerned is the first thing to investigate. It might seem attractive deliberately to under-volt lamps (e.g. put 250V lamps on a 240V circuit) in order to secure increased life, until it is realized that by doing so the light output is reduced considerably more than the corresponding reduction in electricity consumed.

In general it is unwise and uneconomic to run a lamp at other than its rated voltage. There are exceptions; for instance under-volting is probably justified for an aircraft-warning lamp at the top of a high tower, where the labour cost and difficulty of renewing a lamp is great; and over-volting is regularly practiced for football floodlighting where the extra light output of over-run lamps allows fewer projectors to be used, on cheaper towers, which is a worthwhile exchange for renewing lamps for each season instead of after two years.

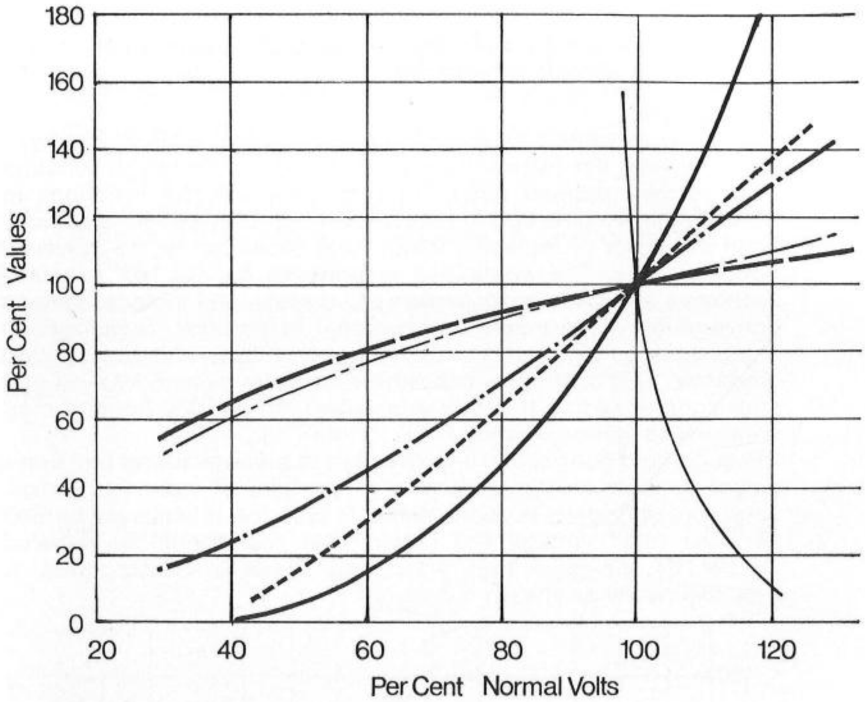


Figure 12
Typical characteristics of gas-filled GLS lamps on varying mains voltage

2. *Vibration*
The effect of vibration may be to shake together adjacent turns of the closely coiled or coiled-coil filament. If the turns touch while the lamp is alight they are likely to weld together, thus short circuiting a part of the filament so that the remainder is over-run and the lamp fails early. Due to the more complicated structure of the coiled-coil filament it may be rather more susceptible to vibration than the single-coil, but with special constructions the coiled-coil type can be at least equally robust. In conditions of severe vibration the rough service lamp may prove the most suitable.

3. *Burning position*
The normal burning position for GLS lamps is pendant, with the cap upwards. In this position the filament lies in the single-wire part of the loop formed at the end of the filament support wires. The tungsten evaporated from the filament of a gasfilled lamp is carried upwards by the hot gas and deposited in the neck of the bulb where it has minimum effect on the light output.
If gasfilled lamps are burned sideways or upside down the evaporated material will form an increasingly dark layer on the inside of the bulb vertically above the filament, and this will absorb some of the light. Also it is possible that parts of the filament may rest against the double wire part of the support loops; small portions of the filament may thus be short-circuited and a reduced life results.
For this reason, also because parts of the glass may otherwise become overheated, GLS lamps of 200W and above are designed for use only in the pendant position. However, for appearance or compactness or for some other good reason many lighting fittings for commercial and domestic applications are designed for lamps in upside-down or sideways positions, where other considerations outweigh some reduction in lamp life.
Vacuum lamps may be used in any position without materially affecting their performance. Whatever their position, the bulb will gradually darken more or less evenly all over.

3.14 Rough Service lamps

In Rough Service lamps a longer filament is retained in position by a greater number of supports than is used in a GLS lamp, also the filament spiral is slightly wider pitched to give more space between turns, Figure 37, thus giving a reduced weight of filament between adjacent supports. The 100W lamp is gasfilled but the 60W and 40W sizes are of the vacuum type because in their case gas filling would result in a lower light output (2.5 — 2.9). In all three wattages the Rough Service lamp operates at a slightly lower filament temperature than the corresponding GLS lamp, in order to give increased filament strength.

Approximate efficacies for 240V lamps are —

100W — 10 lm/W
60W — 8.5 lm/W
40W — 7.5 lm/W

Other ways in which the ill-effects of vibration may be countered include —

1. a change to a fluorescent or other discharge type of lamp;
2. fitting a vibration-damping device in the lamp suspension;
3. transform the supply to a lower voltage and take advantage of the more robust filament of the low-voltage lamp.

Much depends on the amplitude and frequency of the vibration, and it may be impossible to tell without trial which solution will be best in any particular case, but up to 100W the Rough Service lamp is the simplest alternative to try in an existing installation.

4 Reflector lamps

4.1 Reflector lamps are of two main types, 'blown glass,' Figure 13, and 'pressed glass.' In both, the shoulder part of the lamp is of paraboloidal shape and is internally mirrored so as to project forwards the light which is emitted in other directions. Being internal, the mirrored surface cannot become tarnished or scratched and so retains its reflectivity almost unimpaired to the end of life. In the blown glass type the complete bulb is blown to shape in a mould and the mirror finish is deposited inside, the deposit on the crown being prevented or subsequently dissolved away. In the floodlight version of the lamp, which gives a wide spread of forward light, a wreath filament is used centred round the focus of the mirror, and the crown of the lamp is fairly heavily frosted. In the spotlight version the filament is more concentrated and the crown frosting is lighter to give a narrower and more intense beam. In the 24V type a very strong concentration of light is achieved. Lamp life is normally 1,000 hours.

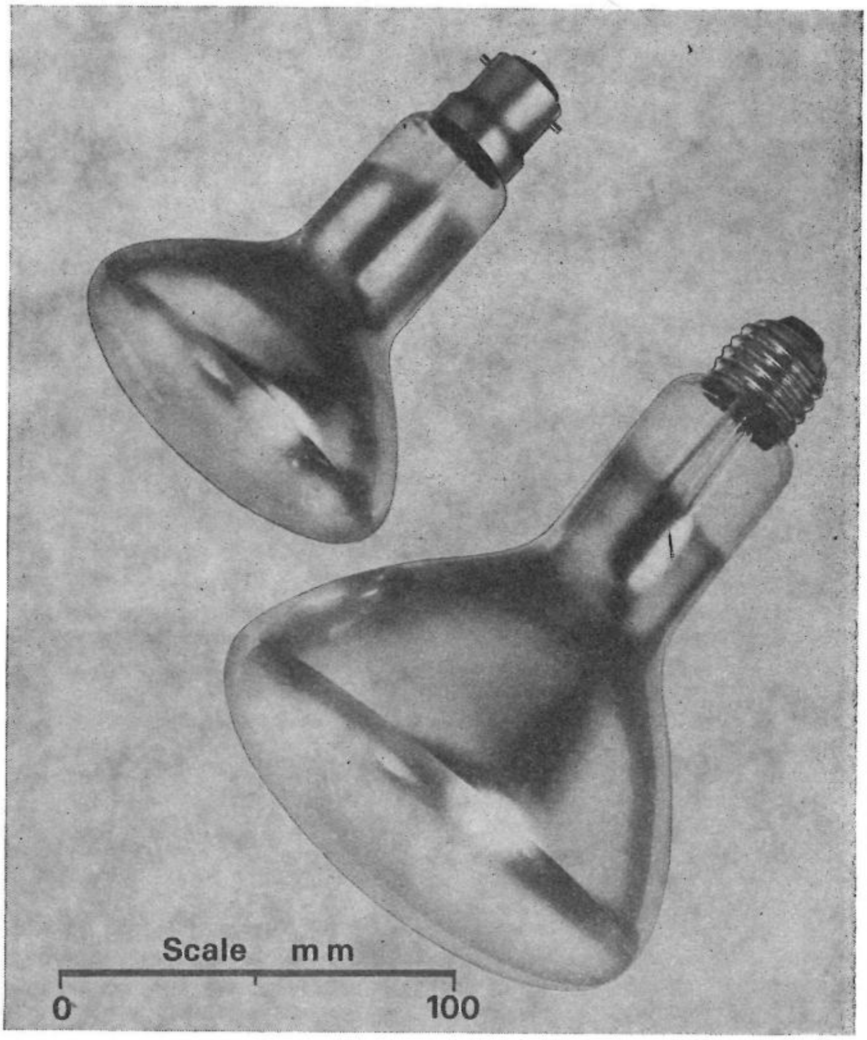
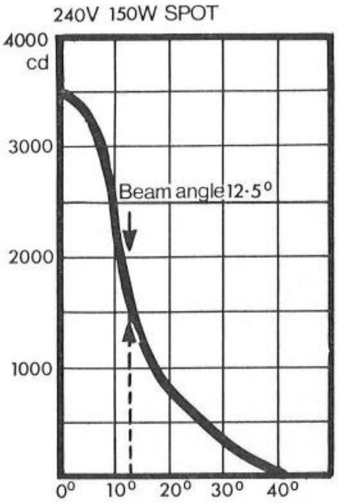
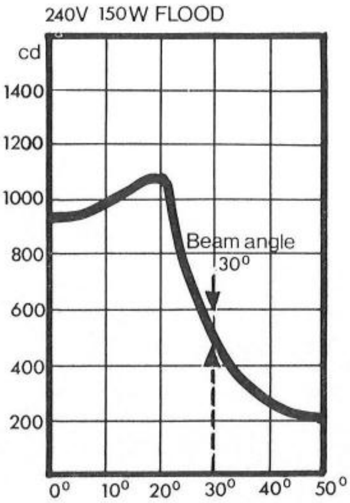
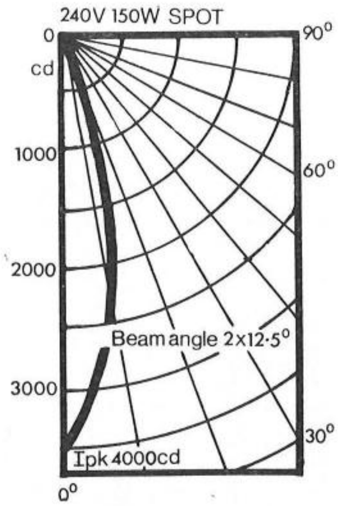
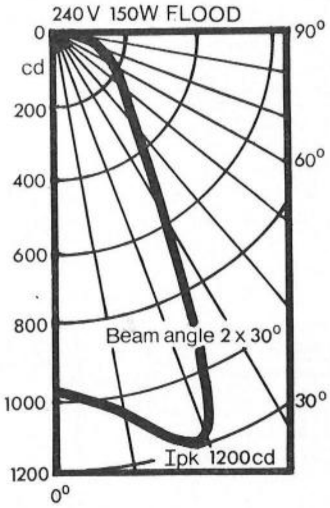


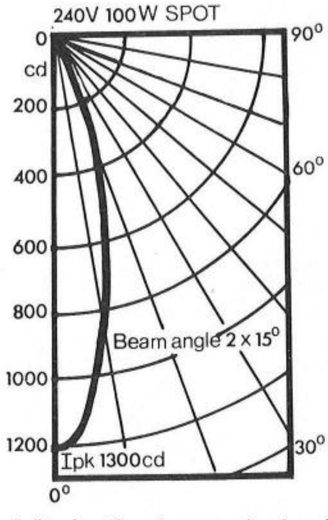
Figure 13
Blown glass reflector lamps











4.2 In the 'pressed glass' type, Figure 14, often referred to as the PAR lamp — followed by a number e.g. 38, indicating its diameter in eighths of an inch — the bulb is made from two hard glass pressings. The shoulder and crown are moulded separately under pressure and are fused together after the shoulder has been mirrored. This method enables a more accurate contour to be obtained, resulting in better beam control. In both the spotlight and floodlight versions the crowns are prismatic but have different configurations to produce the appropriate beam angles. The life of these lamps is nominally 1,500 hours and the hard (borosilicate) glass is resistant to thermal shock. The lamps can therefore safely be used out of doors unprotected, provided that the electrical connection to the cap is made weatherproof. Coloured light is obtainable from PAR lamps the crowns of which have been colour-glazed, or which have a dichroic filter (4.5).

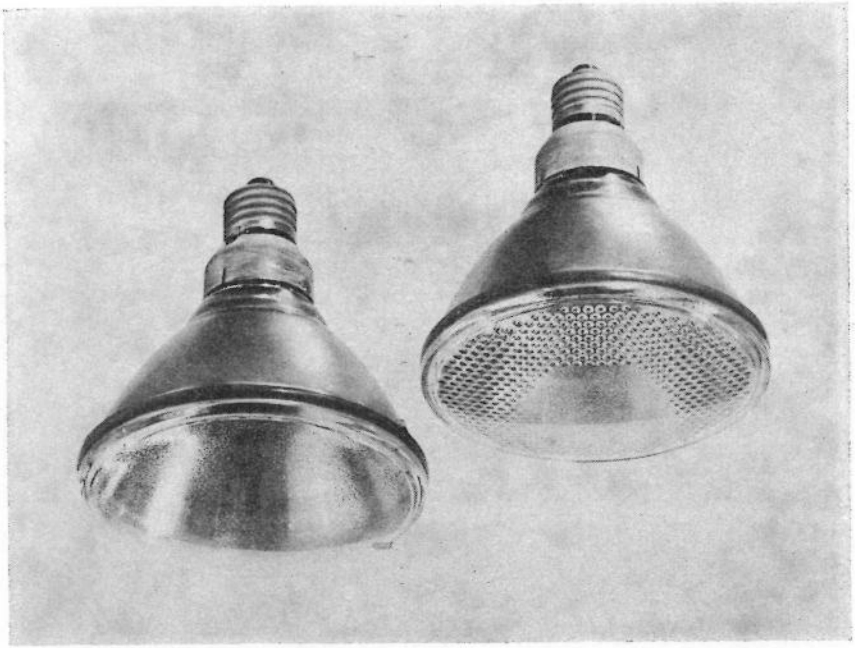
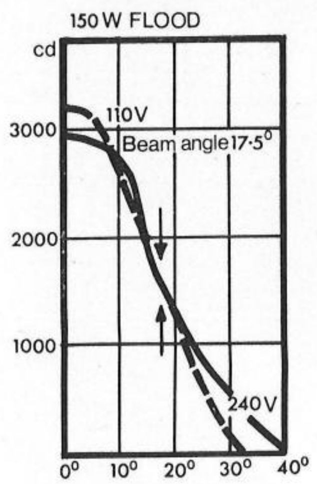
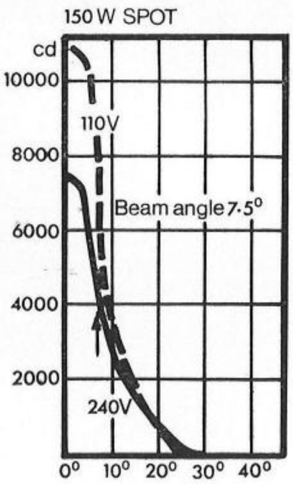
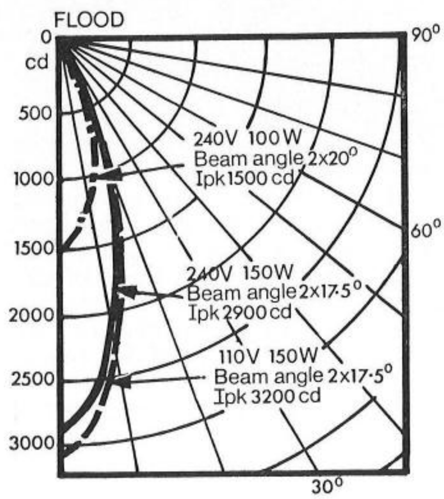


Figure 14
Pressed glass reflector lamps







4.3 Dichroic lamps

The property of a thin transparent film to produce optical interference has long been known. For example camera lenses are 'bloomed' to reduce internal reflections from the glass surfaces. If the film has a low refractive index and its optical thickness — (measured thickness) x (refractive index) — is made one quarter of the wavelength of light, then the light reflected from the film and from the glass beneath will be of almost equal intensity but because they are anti-phase they cancel each other and there is virtually no internal reflection.

Multi-layer interference coatings can be made more versatile. Instead of destroying reflections from the glass surface, they can be made selectively to strengthen them if alternate interference layers of materials with low and high refractive indices — such as zinc sulphide and magnesium fluoride — are used. These composite coatings will give a mirror-like reflection of radiations within a band of wavelengths, but will allow others to pass through almost unobstructed.

4.4 In the PAR 'dichroic cool' type of lamp the interference filter takes the place of the mirrored surface used in the normal PAR lamp. The filter projects the visible light forward in the usual way, but most of the infra-red heat radiated from the filament passes through the filter instead of being reflected with the light. The heat radiated forwards by the filament passes through the front face of the lamp, which is uncoated, but even so the total heat in the beam is reduced to about half its normal value. 'Dichroic cool' lamps may therefore have considerable advantages for display lighting of materials sensitive to heat such as flowers, foods and fabrics. They may also be useful in 'down lighters' for illuminating ordinary working or living spaces, where the unwanted concentration of radiant heat from ordinary incandescent lamps can cause discomfort.

It should be remembered that the space immediately behind the 'dichroic cool' lamp, which includes the lampholder and associated wiring, will become hotter than with the normal PAR lamp due to the heat which passes through the filter, and this must be allowed for in the design of the fitting. The total heat emitted by the lamp remains unchanged, only its distribution is modified.

4.5 PAR 38 lamps in the 150W rating are also available with the dichroic filters on the crown giving blue, green, red or yellow light which has purity of colour at an efficacy superior to that obtainable by the use of conventional colour filters. In these dichroic coloured lamps a multi-layer interference filter of appropriate composition and thickness is deposited on the inside face of the pressed glass front. This transmits a band of wavelengths corresponding to the colour required but is opaque to all other colours.

In the 100W rating PAR 38 lamps are obtainable with a silicone weatherproof colour filter coating on the face, in a nominally similar colour range. In both types the beam has a floodlight characteristic with an angular width of some 40° to half peak intensity.

5 Projector lamps

Classification

Within this category a great variety of lamps are available (Figure 16). Generally the envelope is smaller, the filament more concentrated and operated at a higher efficacy than that of the GLS type of similar wattage. Consequently the objective life is usually shorter.

Broadly these lamps fall into two classes; those whose principal use is in the illumination of an area by means of a beam of light, and those whose principal use is in equipment for the projection of still or moving pictures. The first category is strictly referred to as "lamps for projection" and the second "projector lamps," but commonly both categories are referred to under the latter name. However, in view of the great variety of lamps falling within these broad definitions, a more detailed classification has been found necessary. (Appendix 4). The most common classes are —

5.1 Class A1 — In wattages between 25 and 2000 and generally in tubular envelopes. The majority of this class must be mounted vertically cap down and have an objective life of between 25 and 100 hours. Although a hard glass is used, the safe envelope temperature limit is 500°C and most types in this class require forced draught cooling. In view of the accurate location of the light source needed to secure optimum performance of the equipment, many tvpes have pre-focus or other special caps uniformly positioned relative to the filament so that optimum performance is regained after lamp replacement (5.16). The crown of the envelope is frequently obscured by a coating or cap in order to stop stray light which would otherwise come through the ventilation apertures of the housing. In a few types the bulb is shaped and silvered so that the external optical system is simplified and maintained cleanliness of the internal mirror surfaces ensured.

A notable recent addition to this class is the tungsten-halogen type (2.11) which has the advantages of still greater efficacy, a whiter light, nearly 100% lumen maintenance, and smaller envelope dimensions are particularly valuable in optical equipment.

5.2 Class B1 — In wattages between 100 and 1000 this class is designed with spherical bulbs and screw caps fitted close to the bulb. The filaments are bunched to provide a concentrated source suitable for use in floodlights and stage lighting lanterns, where a relatively long life lamp is desirable. The objective life is 800 hours. Any orientation is permissible other than with the axis within 45° of the vertical cap up position. Forced cooling is not required but adequate ventilation is desirable in confined lanterns used indoors or in other high ambient temperature conditions.

5.3 Class B2 — In wattages between 500 and 2000 and with bunched filaments similar to those of Class B1, but in standard GLS type envelopes with GES caps. This type is suitable for operation in any orientation and has life and thermal characteristics similar to those of Class B1 except that the cap operates at a lower temperature because it is considerably further from the filament. Their application is generally similar to that of Class B1 but where the increased dimensions are acceptable.

5.4 Class CP — In wattages between 275W and 10kW this class includes a wide variety of lamps designed for photographic purposes, film and television studio lighting, particularly where the pictures are in colour. Most of the lamps in this class are designed to suit colour film balanced at 3200K or 3400K but are equally suitable for black and white. The majority are in spherical or short cylindrical form with all glass bases and bi-post contacts (Appendix 2). Filaments are in flat grid form and the class is limited in orientation to within 45° of the vertical, base downwards position. Twin filament lamps (Figure 15) are available in ratings of 1.25+1.25kW and 2.5+2.5kW which have been developed specially to meet the needs of television studios used for both colour and monochrome services. For monochrome shots normally only one filament or half power is used, but for colour — with its requirement of higher levels of illumination — the full power of the two filaments is brought into use, thus reducing the number of lanterns which would otherwise be needed. A further

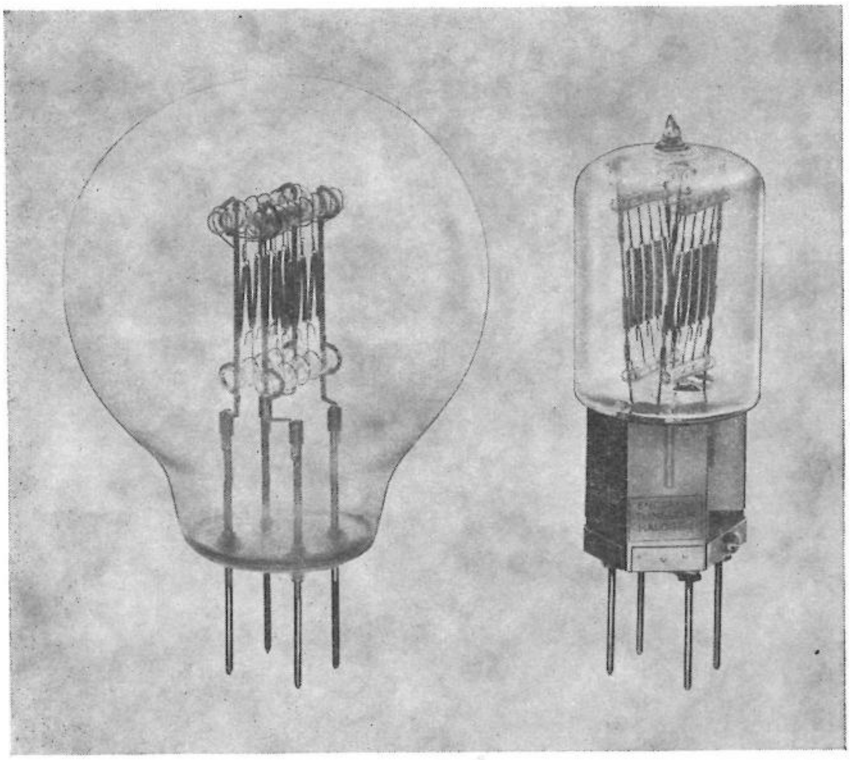


Figure 15
Twin filament studio lamps

feature of this construction is that the colour temperature of the light remains the same whether it is operated at half or full power, unlike the normal effect of dimmer control which is to lower the colour temperature of lamps held in check. Four contact pins are set in the all-glass bases of these lamps. Notable additions to this range are the tungsten-halogen lamps with both quartz and hard glass envelopes.

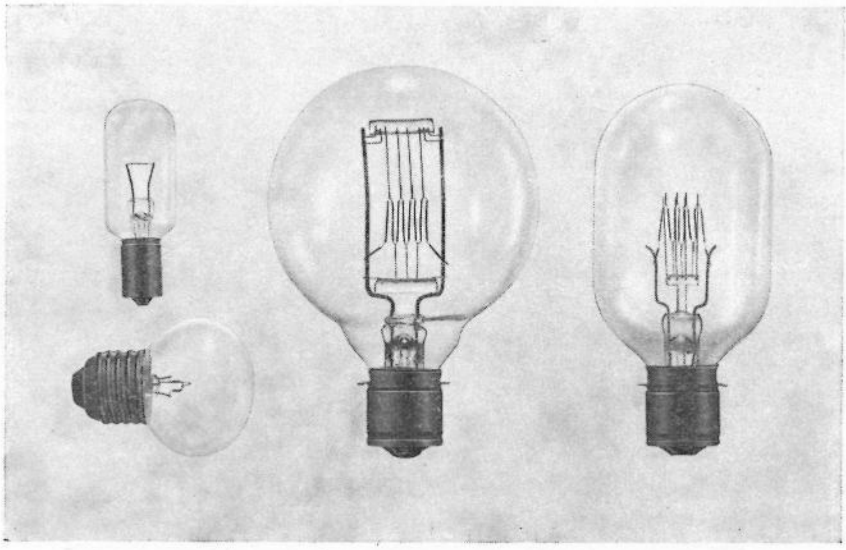
5.5 Class D — Formerly lighthouse lamps; now class L.

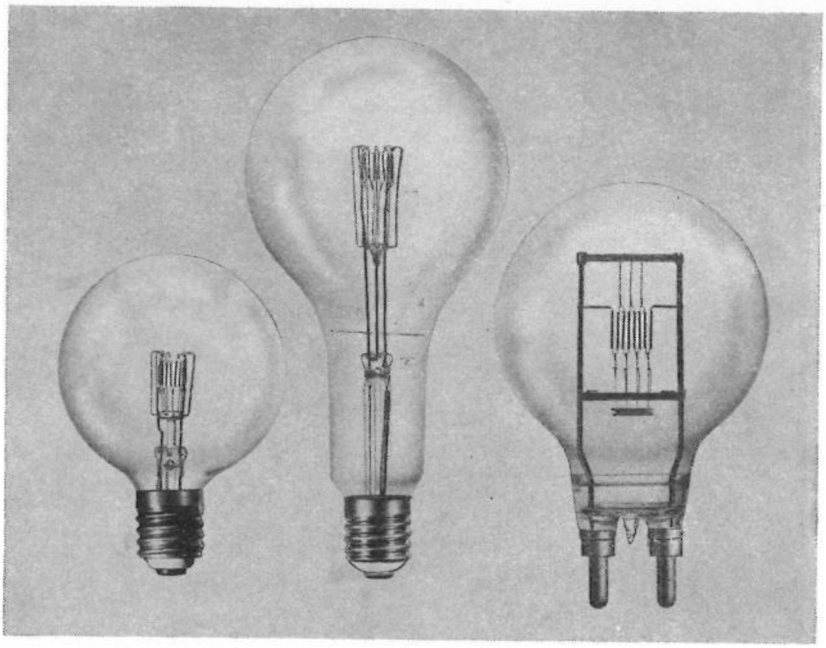
5.6 Class E — In 250, 500, 750 and 1000W ratings, these round bulb grid filament lamps are designed for use in epidiascopes. Class A1 lamps are now also used for this purpose.

5.7 Class F — In wattages between 24 and 100 and operating on 6 or 12 volts, this class is intended primarily for micro-projection, optical sound recording, and miscroscope illumination. The bulbs are round and usually fitted with screw caps. In most types the filament is made as small as possible to provide substantially a point source, while others have a transverse linear filament. All operate at a high efficacy and have an objective life of 100 hours or less. Some are designed for substantially cap-up operation, others are intended for any operating position other than within 45° of the cap-up position.

5.8 Class FL — In wattages from 250 to 2000 and in tubular glass envelopes, this class is designed with an extended linear filament and most have an objective life of 1000 hours. Made primarily for floodlighting applications requiring a broad fan shaped beam with the minimum of dispersion at right angles to the plane of the fan, this class has largely been superseded by the Class K tungsten-halogen linear types.

5.9 Class G — In wattages between 3 and 75 and operating on voltages between 2.5 and 10, this class is intended for sound track illumination in cine projectors. Some have axial and others transverse linear filament forms with objective lives of 50 or 100 hours. Operating position is limited according to type and many are fitted with pre-focus caps.





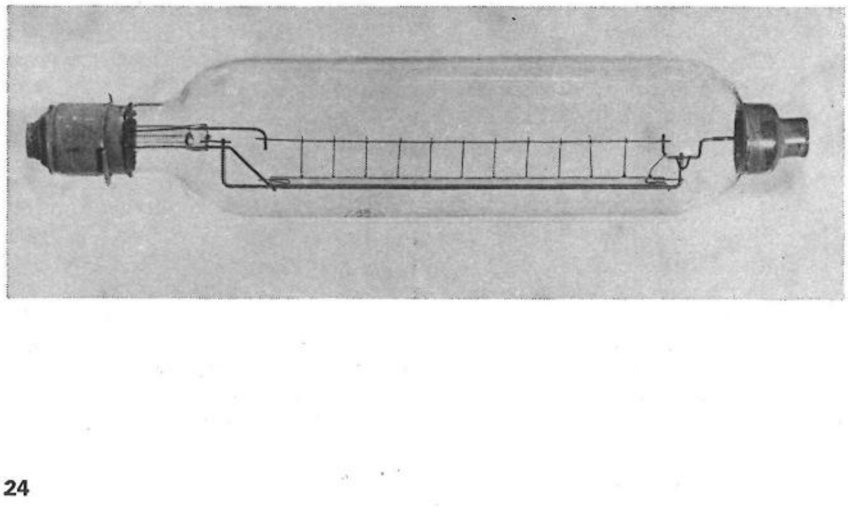


Figure 16
Representative projector lamps

5.10 Class K — In wattages between 500 and 2000 and for mains voltages, this class of linear tungsten-halogen lamp is designed primarily for outdoor floodlighting and studio applications. The objective life for most types is 2000 hours, but in the 1000 and 2000 watt ratings extra high efficacy lamps are available with rated lives of 250 and 200 hours respectively. The latter types may be used in any position and are intended for studio use with film balanced for 3200 K but the others are limited to horizontal operation. End contact ceramic sleeved caps are fitted, and while the small size of the lamps permits the use of very compact optical systems and floodlights, it is essential to ensure that the seal temperature does not exceed 350°C. Some types are available with frosted quartz tubes which avoid striations and give more uniform illumination especially when used with specular reflectors.

5.11 Class L — High wattage lamps made specially for lighthouse purposes.

5.12 Class R — This class comprises a small range of 6V lamps operating at 16A and employing a tungsten ribbon incandescent element. They were designed to replace the solid source parallel-coiled grid-filament types in certain scientific instrument applications such as optical pyrometers. The lamps have tubular envelopes and pre-focus or screw caps.

5.13 Class S — In 500W, 750W and 1000W ratings for mains voltages, this class is used for monochrome photographic and television studio work. The objective life is 100 hours. A flattened coil filament construction is used and the envelope is tubular with bi-post connections. This type is being replaced for television studio work by Class C.P. tungsten-halogen lamps.

5.14 Class T — In wattages from 100 to 1000 and for mains voltage operation this class of lamp with grid filament is designed for use in stage spotlights. Normally they are fitted with pre-focus caps and most should be used within 90° of the cap down orientation. The objective life is 200 hours. It is likely that this class of lamp will soon be available in tungsten-halogen types throughout the range of wattages.

5.15 Envelope Shapes

It will be noted from the illustrations and data (Appendix 4) that projector lamps assume a great variety of shapes. The principal considerations which have resulted in this variety are —

1. The need to ensure that glass and other parts are operated within safe temperature limits.
2. The requirements of accommodation within a lantern or lamp house of conveniently small dimensions.
3. Optical requirements of the associated mirror or lens system.

The majority of projector lamps rely on separate mirrors and lenses to produce the required directional and beam characteristics, but some incorporate a suitably contoured mirror reflector in the envelope. A few also have an externally silvered envelope, the area behind the filament forming an ellipsoidal reflector and that in front of the filament being a spherical reflector with a centre window of clear glass through which the reflected light from the rear mirror emerges, coming to a focus in the plane of the transparency to be projected and thus avoiding the need for any separate mirror or condenser lens.

5.16 Projector lamp caps

Though a variety of screw and bayonet caps are still fitted to some projector lamps, especially in the smaller sizes, it is very desirable to ensure that the filament is always in correct relationship with the optical system without having to rely on the judgment or skill of the operator to make it so. This object may be achieved by fitting the lamp with a pre-focus cap which, according to type, contains one or more slots, grooves or other features which engage with corresponding irregularities in the lampholder, and are designed so that the lamp cannot be inserted wrongly. In the optical apparatus in which these lamps are used the position and orientation of the holder is fixed or pre-set by the manufacturer, and the pre-focus cap on the lamp is constant in relation to the filament; thus lamp replacements can be fitted with confidence that no adjustment is required. Some of the larger projector lamps, such as are used in cinema studios, are not fitted with any cap, the internal supports being connected to two heavy external metal contact pins to which the supply connections are clamped. These bi-post contacts are pushed home into the sockets of a fixed holder, the whole assembly then being rigid and effectively pre-focussed.

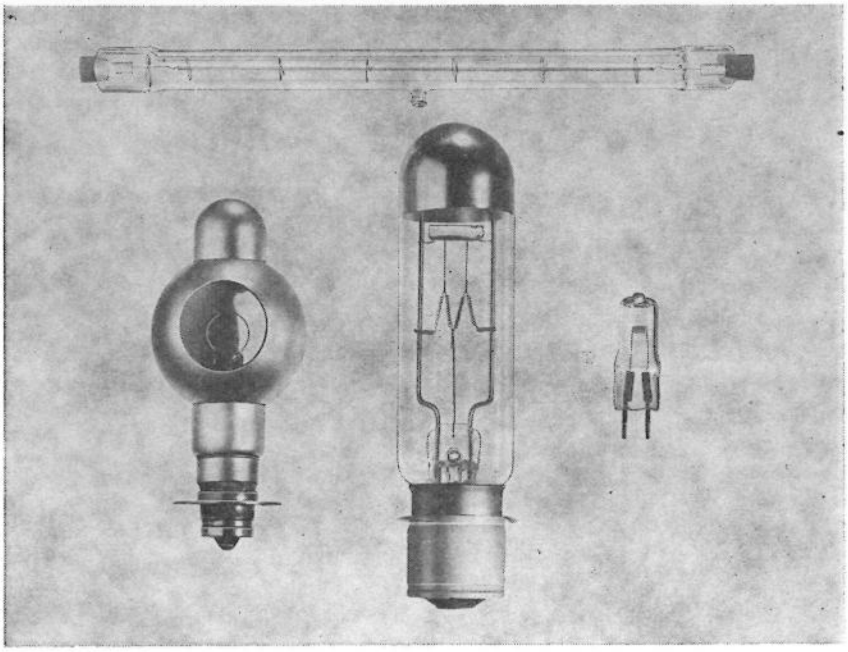


Figure 17
Tungsten-halogen projector lamps

5.17 Filament form

For projection purposes, in order to utilize the highest proportion of the light emitted by the lamp by means of mirrors and lenses of relatively small size, it is necessary to have the source area compact and in a form which will produce maximum flux in wanted directions. Thus generally for symmetrical beams the filament coils are arranged to form a square or rectangle more or less in one plane at right angles to the optical axis. In other cases, where a 'fan' shaped beam is desired and maximum control and concentration is needed only in one plane at right angles to that of the fan, the filament coil is linear. In a few examples, where the closest practical approach to the theoretical 'point source' is wanted, the coiled filament is V-shaped. Since for a given wattage the length of filament is related to the operating voltage, the overall size of the the source is a minimum at a low voltage, thus many projector lamps are designed for operation at voltages lower than that of the mains in order to achieve high beam luminances. The higher efficacies obtainable for a given life at lower voltages also contribute to the same objective.

The most common filament forms for projector lamps are —

1. *Grid filaments*

These are employed where the source must be very concentrated, with the maximum light output in one particular direction (as in optical lanterns and cinema projectors), Figure 18, forms C, H, J, K, L, M, and N.

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

In the monoplane grid filament, the limbs of the filament are in a single plane and a spherical mirror is usually employed behind the lamp in order to reflect back through the filament formation the light initially emerging in a rearward direction. This mirror is so adjusted that the reflected images of the limbs appear in the spaces between the actual limbs, thus giving in effect an almost 'solid' rectangular source.

In the case of biplane grid filaments the limbs are arranged in two parallel planes, one close behind the other and with the

Filament Forms

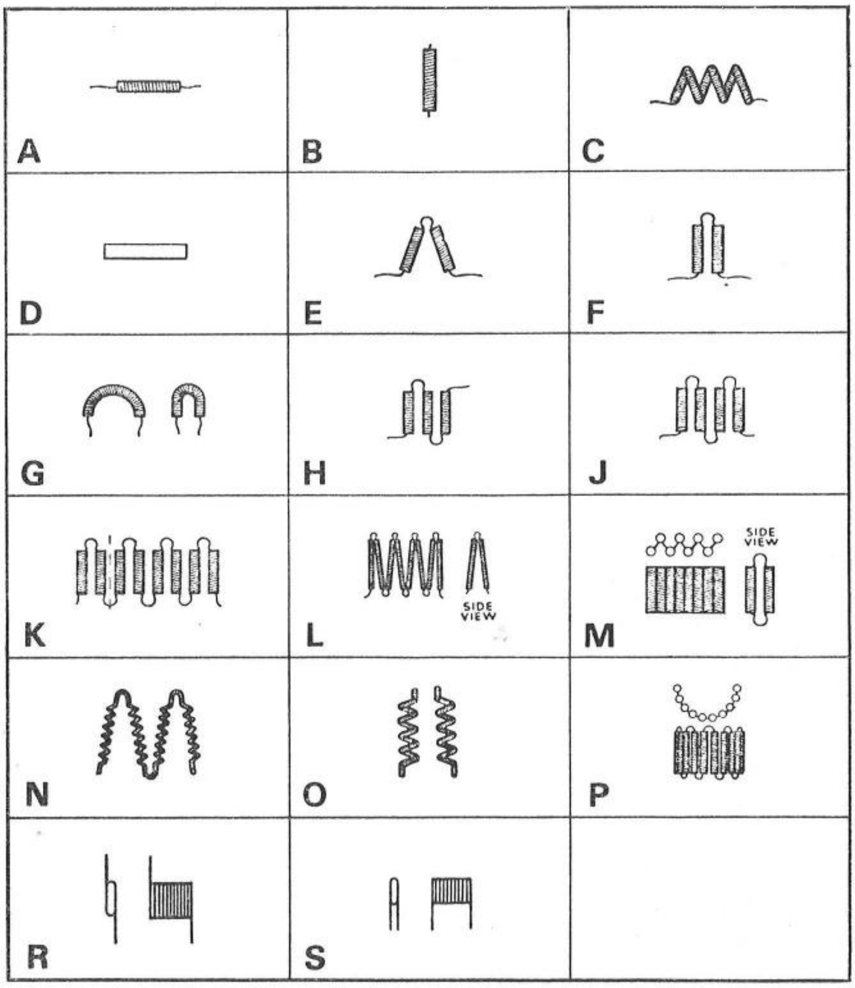


Figure 18
Projector lamp filament forms.

limbs in the second plane staggered in relation to those in the first, thus giving a similar effect to a monoplane grid with mirror.

2. *Solid source*
Formerly this type employed short filament coils arranged in parallel and with adjacent loops touching in order to achieve the highest uniformity of luminance and the highest mean filament temperature. This form has now largely been superseded by 'flattened mandrel' filaments in which a single continuous flat coil is used, Figure 18, forms D, R and S. Also in this category is included the tungsten ribbon construction used in Class R lamps.

3. *Bunched filaments*
Where a lamp is required to be used in conjunction with a paraboloid mirror to give a near-parallel beam of light (as in a long-range floodlight) the filament must be concentrated into as small a volume as possible and should be arranged to give approximately equal light intensity in all directions, Figure 18, form P.
In Class B1 and B2 projector lamps a 'bunch' filament is used. This consists of coiled tungsten wire bent into multiple V's or M's arranged vertically in a ring, thus forming a hollow cylinder of small dimensions.

4. *Linear*
This form, in which the filament coil is stretched out in a single straight line, Figure 18, forms A and B, is used principally to produce a broad fan shaped beam and with a suitable parabolic

trough shaped reflector. The beam divergence at right angles to the plane of the fan can be made very small. Most tungsten-halogen lamps fall into this category.
In extra-low voltage projector lamps, a short linear axial filament is employed very effectively in conjunction with a paraboloidal or ellipsoidal reflector to give a (narrow angle) symmetrical beam, particularly where the forward light is reflected back on to the mirror by crown-silvering on the bulb.

6 Miscellaneous filament lamps

In this category, covering all the types not mentioned in Sections 3, 4, or 5 the varieties are again numerous. The details which follow are grouped under headings descriptive either of the principal application of the types concerned, or according to similarity of form. Individual types described are those for which the demand is greatest. It cannot be exhaustive due to limited space, and because new applications continue to call for the design and production of new types. In spite of the great developments which have occurred and are continuing in the discharge lamp field, there remain a vast range of applications for which some form of incandescent filament lamp is still found to offer the best solution, both technically and economically.

6.1 Tubular envelope filament lamps

1. Single capped, Figure 19. The 25W lamp of this type is used for local lighting applications such as in sewing machine lights and small picture lighting brackets, and has a clear glass or externally frosted envelope. The 40W and 60W ratings are much larger and have an opal glass envelope with a pointed end. Their use is mainly in unshielded situations such as on wall brackets or multi-lamp pendants where some similarity to candles is desired, coupled with a low and even surface luminance.

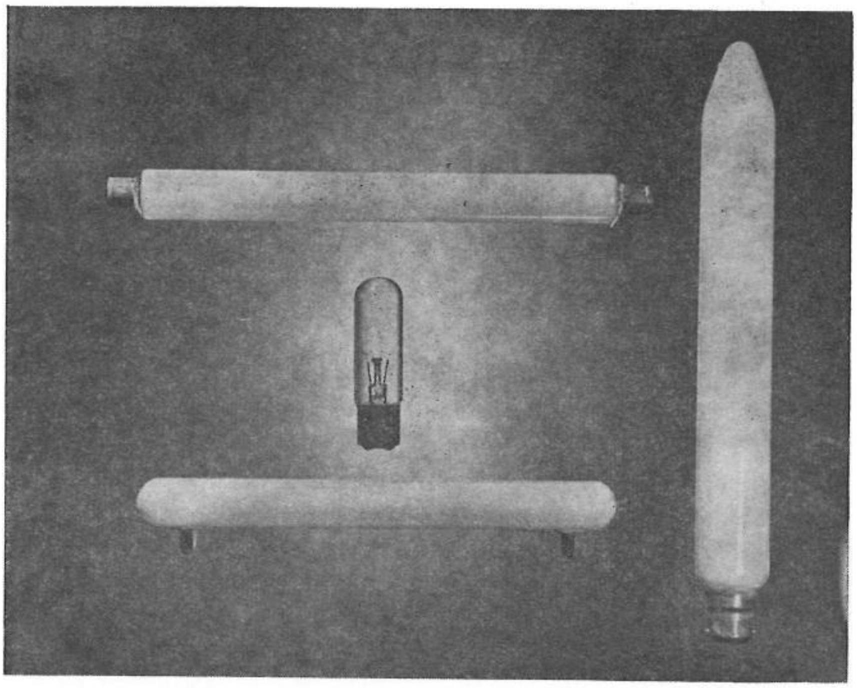


Figure 19
Tubular envelope filament lamps

Single-capped tubular lamp data
Table 1

Rated Watts	*Rated Voltages*	*Nominal Dimensions (mm)* Diameter	*Nominal Dimensions (mm)* Overall Length	*Cap*	*Finish*	*Approx. Lighting Design Lumens*
25	100–120 200–250	25–28	86 92 94	BC SBC SES	Clear	185
40	230–250	38	302	BC	Opal	240
60	230–250	38	302	BC	Opal	360

2. Double capped, Figure 19. In clear or opal tubular envelopes 25 mm in diameter, these lamps are made in 30W, 40W and 60W ratings. The more common patterns complying with BS.555, have centre contact S15s caps at each end and on the axis but an alternative type has side peg contacts permitting close in-line mounting. All are vacuum lamps with axial filaments and operate at an efficacy of about 8 lm/W with a rated life of 1000 hours for horizontal operation.
They are used mainly for show case and picture lighting but, owing to their much greater efficacy and cooler running, tubular fluorescent lamps are now generally preferred for such applications.

Double-capped tubular lamp data
Table 2

Rated Watts	*Rated Voltages*	*Caps*	*Nominal Dimensions (mm)* *Overall Length*	*Diameter*	*Nominal Lumens*
30	110–120 200–250	S15s	221 or 284	25	225
40	220–250	Side Peg	252	25	300
60	110–120* 200–250	S15s	221*or 284	25	500
60	220–250	Side Peg	252	25	500

* The 60W rating for 110–120V is not made in the 221 mm length.

6.2 Architectural lamps

These tubular vacuum lamps are made in a number of straight lengths and corresponding wattages. The envelopes are in white opal glass providing a substantially uniform luminance of about 2300 cd/m^2 (1.5 cd/in^2). The efficacy is some 5 lm/W and the rated life is 1000 hours. Due to their low surface brightness architectural lamps may be used unshielded in many situations without giving rise to glare. As the name implies, they may be used with good effect to outline architectural features, or for such applications as mirror framing for fitting rooms. When butted together their squared-off all glass ends and side peg contacts provide the illusion of a continuous line of light. As the luminance of all the lengths is similar it is possible to select sizes in a multi-lamp line to suit any overall length. Originally the range included curves but owing to the small demand these have been discontinued by most manufacturers.
While in the standard straight lamps the peg contacts are positioned with their centres 38 mm from each end face, in the 500 mm (60W) length a variation is available with a central contact two-pin cap (type S14d), thus leaving the lamp ends free from mechanical support or electrical connection, Figure 20.

Architectural lamp data
Table 3

Rated Watts	Rated Voltages	Nominal Dimensions (mm) Overall Length	Diameter
35	110, 120 230–250	305	30
53	110, 120 230–250	457	
60	110, 120 230–250	500	
75	110, 120 230–250	610	
110	230–250	915	
150	230–250	1220	

6.3 Decorative lamps

This classification covers lamps with specially shaped bulbs and those miniature lamps designed for multiple series operation for Christmas trees and similar decorative uses,
They are generally of relatively low luminance and intended for unshaded or partially shaded use. Their efficacy in clear or white bulbs is about 8 lm/W and their rated life 1000 hours. The principal types are —
1. Candle lamps, Figure 21 In 'olive' shaped bulbs, either smooth or twisted, with BC, SBC or SES caps. In addition to the clear glass versions, candle lamps are available with pearl, coloured or internally coated white bulbs. They have coiled-coil filaments and are gasfilled.

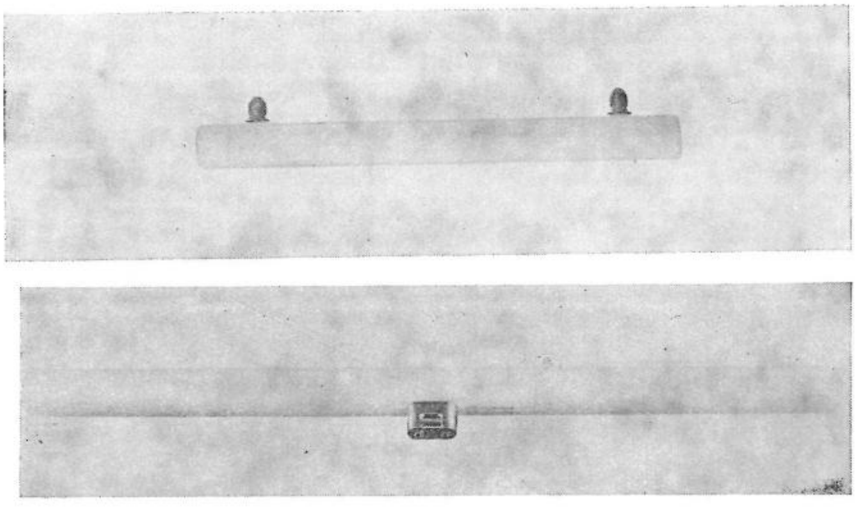


Figure 20
Architectural lamps

Candle lamp data
Table 4

Rated Watts	*Rated Voltages*	*Cap*	*Bulb Type*	*Nominal Dimensions * (mm) Overall Length*	*Diameter*
25	)	BC	(Plain	92	35
25	)110 120	ES	(Twisted	95	35
40	)200 220	SBC	(Plain	123	45
40	)230 250	or	(Twisted	123	46
60	)	SES**	(Plain	123	45
60	)		(Twisted	123	46

* These dimensions should be taken as a rough guide only. Different makes vary and the type of cap affects the length. Inside-white type dimensions are generally similar to plain.
** The 60W white type is not available with SES cap.

2. Round bulb lamps, Figure 21, these are made with either pearl, inside-white or coloured bulbs and their small dimensions and neat appearance go well with current designs of multi-arm pendant and bracket fittings having a shroud exposing only the round bulb, which is normally unshaded.

Round-bulb lamp data
Table 5

Rated Watts	*Rated Voltages*	*Cap*	*Nominal Dimensions (mm) Overall Length*	*Diameter*
25	200–220	(BC		
		(SBC		
	or	(ES	71	45
		(or		
40	230–250	(SES		

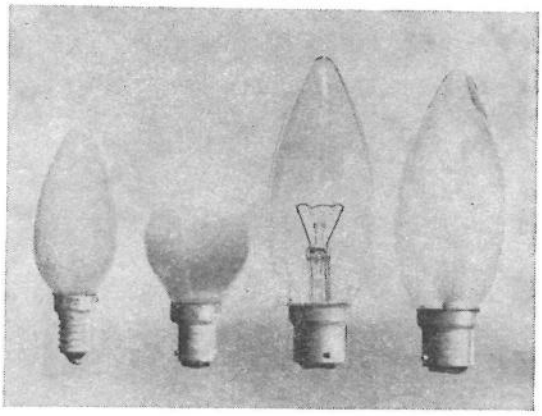


Figure 21
Candle and round bulb lamps

3. Christmas tree lamps, Figure 22. — These are normally supplied in multi-coloured sets with appropriate holders and flexible wiring ready for connection to 240V supplies. Some sets are supplied with flower petal or other designs of shade or decorative collars, usually of plastic. All are for series operation, and in many types should a lamp fail the remainder continue in operation due to the action of a cut-out in the base of the failed lamp. Some sets comprise 12 MES capped olive-shaped lamps each rated at 20V 3W, while others employ 20 or 40 LES capped or push-in wire contact lamps of very small size. For 20 lamp sets the normal rating is 12V 1.2W and for 40 lamp sets 6V 0.75W.

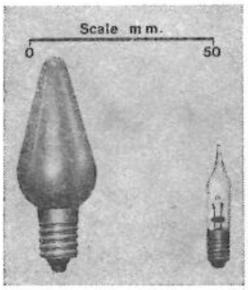


Figure 22
Christmas tree lamps

6.4 Mushroom Shape Lamps

In wattages between 40 and 150 these lamps offer for general domestic purposes an alternative shape to the equivalent pear shaped standard GLS range. They are of single or coiled-coil filament and gasfilled construction in internally white or pink coated bulbs giving substantially uniform luminance over the whole surface, Figure 23.

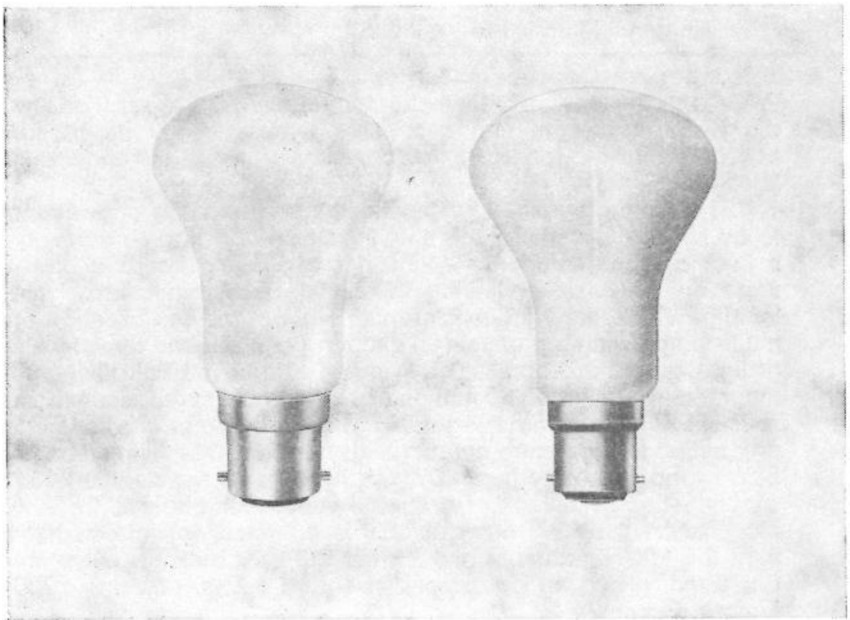


Figure 23
Mushroom shape lamps

In the 60W, 100W and 150W ratings an alternative is available in the same bulb shape and dimensions. This is made with a reflector coating on the conical inner surface of the bulb, which has a pearl crown window giving substantially greater intensity through the crown over a cone angle of about 140° and correspondingly less light in other directions. The downward axial illumination is thus increased by some 35% above that obtained from the standard mushroom shape lamp, Figure 23.

Mushroom Shape lamp data
Table 6

Rated Watts	*Rated Voltages*	*Nominal Dimensions* (mm)* *Overall Length*	*Diameter*	*Cap*	*Approx.† Nominal Lumens at 240V*
40	(200–210)	105	60	BC	380
60	(220–230)	105	60		640
100	(240)	105	60		1220
150	(250)	120	75		1860

* These dimensions are given as a guide to current practice (1970). BS.555 amendment No. 2 (1965) permits somewhat larger maximum bulb sizes.

† These lumen outputs are from BS.555. No lighting design values are yet published, but they approximate to those given for single coil lamps in Appendix 3.

6.5 Miscellaneous domestic lamps

While the majority of domestic requirements are satisfied by the GLS, mushroom and decorative lamps already described, certain others, though less common, are worthy of note under this heading.

1. Three-light lamps — For applications where it is convenient to be able to vary the amount of light from a fitting — normally a floor or table standard — to suit the differing needs of conversation, television viewing, reading, needlework etc., this lamp provides three different outputs without the complication of multi-lamp switching or special dimming control. The three levels of light output are obtained by having two coiled-coil filaments mounted in a common 80 mm diameter pearl bulb equipped with a special ES cap which has a third contact in the form of a separate ring between the centre contact and the shell. One filament is of 60W rating and the other 100W, each being for the normal 240V supply. Thus by means of a special switch-lampholder, for low illumination the 60W filament only is operated, for intermediate light the 100W filament only, and for full light both filaments are energized, giving an output equivalent to 160W, or some 1900 lumens, Figure 24.

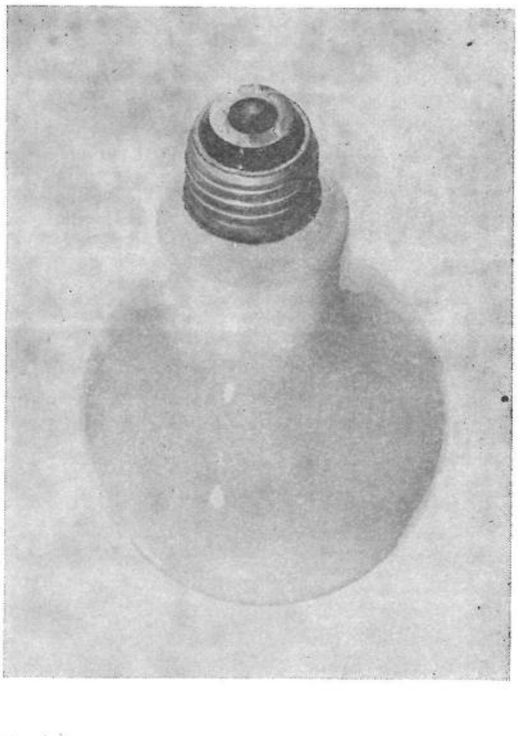


Figure 24
A three light lamp

2. Coloured lamps — For a variety of decorative effects, GLS type lamps are available with colour pigments internally applied to the bulb. Thus the colour is protected and the exterior of the bulb remains smooth. Externally coloured lamps with a glazed finish are also available (3.6). Standard wattages for coloured lamps are from 15W to 100W in red, blue, green, yellow, amber, pink and white. Whilst in the case of the first three colours the absorption of light due to the pigment is considerable, in the other colours the absorption is much smaller and the available light correspondingly greater. All wattages and colours are made in the standard GLS 60 mm bulb and are normally BC capped. In the 15W rating internally coloured lamps are also available in the pigmy sign type capped BC or SBC and in 28 mm diameter bulbs. In the 60W and 100W ratings GLS type lamps are also made in daylight blue clear glass designed to provide a degree of colour correction nearer to daylight.

3. Domestic equipment lamps — Many items of domestic equipment such as refrigerators, heaters, and cookers now have built-in lighting. Normal lamps are used in many of these, but for others due to space or service considerations special lamps are necessary. The more common of these are listed in Table 7.

Table 7
Equipment lamp data

Application	*Rated Watts*	*Rated Voltages*	*Bulb Shape*	*Colour or Finish*	*Nominal Dimensions (mm)*		*Cap*	*Notes*
					Dia.	*Overall Length*		
Refrigerators and Cookers	25	230–250	Tubular	Clear	28.5	61	BC	
	25	230–250	Round	Pearl	45	74	ES	
	40	200–250	Pear	Pearl	44	94	ES	
Oven Interiors	25	200–250	Tubular	Pearl	28	58	ES	For temperatures up to 260°C (500°F)
Large Oven Interiors	60	240–250	Pear	Clear	60	105	BC or ES	For temperatures up to 230°C (450°F)
Fire-glow	60	200–250	Pear	Flame or amber lacquer, glazed or flame colour glass	60	105	BC 3-pin BC or 2-pin special	Fire-glow lamps are also made in 15, 25 and 40W ratings, BC capped
Pilot	6) 10)	100–130 200–260	Tubular	Clear	19	48	SBC, SES or Candelabra	For indicator purposes.

6.6 Crown-mirrored display lamps

Although mirror reflector fittings are made to collect all the light which reaches the reflector and direct it into a narrow beam for spotlighting purposes, when a clear lamp is employed at least a third of the light emerges directly and therefore detracts from the concentration of light in the beam. With the crown-silvered lamp, the front half of the bulb, which is hemispherical, is internally aluminized giving it a highly specular mirror finish. Thus the light which would otherwise emerge uncontrolled is reflected back on to the reflector of the fitting and serves to reinforce the main beam; unwanted stray light is negligible, Figures 25 and 26.

Lamps of this type are made both for mains voltage and for 12V or 24V. The former has the advantage of direct mains operation, but for the narrowest spotlight beam the 12V or 24V ratings operated through a transformer are often preferred because the more compact filament results in still greater intensity and concentration of light. Whilst the mains voltage lamp is made with the normal bayonet cap, it is also available with a cap of the

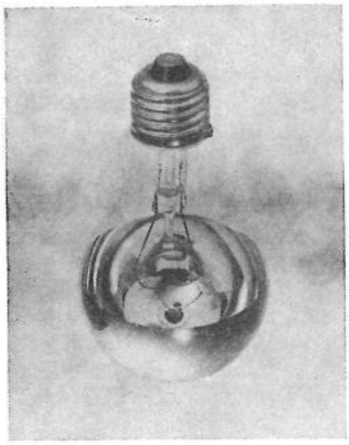


Figure 25
Crown-mirrored lamp

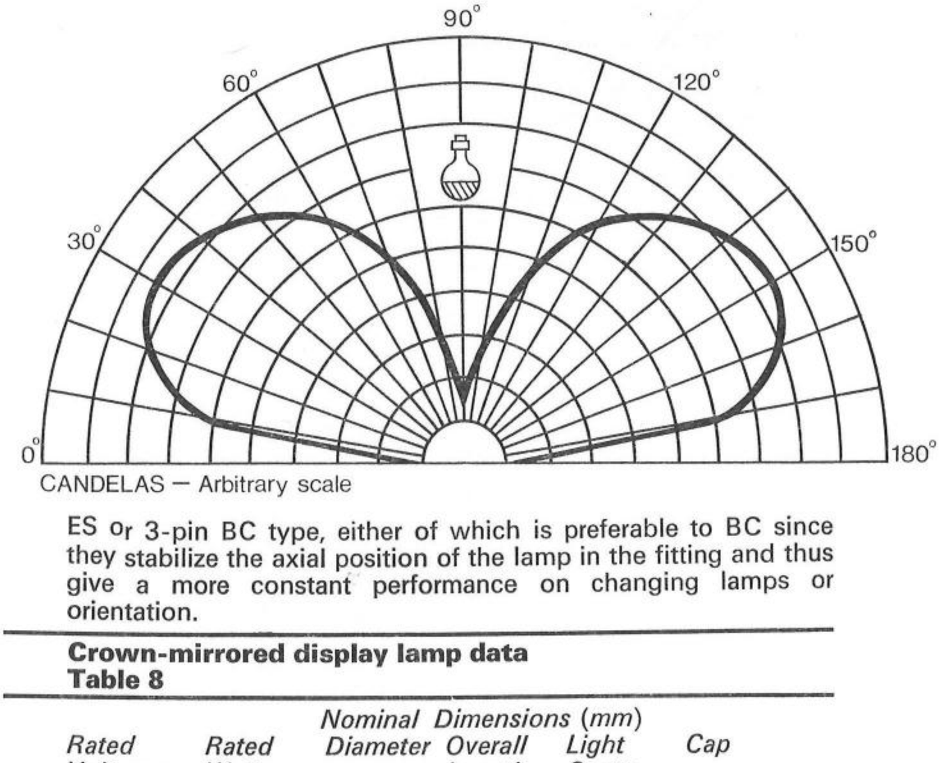


Figure 26
Typical light distribution curve for crown-mirrored lamp

ES or 3-pin BC type, either of which is preferable to BC since they stabilize the axial position of the lamp in the fitting and thus give a more constant performance on changing lamps or orientation.

Crown-mirrored display lamp data
Table 8

Rated Voltages	*Rated Watts*	*Nominal Dimensions (mm)* *Diameter*	*Overall Length*	*Light Centre Length*	*Cap*
240–250	100	60	105	75	3-pin BC
240–250	100	70	120	—	3-pin BC, ES or BC
240–250	100	68	125	90	3-pin BC
12	50	38	67	—	Bosch B20d
24	100	70	120	—	3-pin BC
24	150	50	83	—	Bosch B20d

6.7 Sign lamps

Whilst the majority of signs nowadays employ specially shaped high wattage fluorescent or neon discharge tubes, there remains a considerable use for small filament lamps in signs of other types, among which are drifting letter signs one of which may use 1000 or more small lamps. For clarity of outline and maximum legibility whatever the type of sign, close spacing to give continuity and sufficiently low brightness to avoid glare discomfort are necessary in this application. Though GLS or other lamps may be suitable in special cases, the lamp specially developed for sign use is the 15W "Pygmy" lamp, Figure 27. This is a small vacuum lamp with a zig-zag filament operating at a relatively low temperature to give it a high degree of reliability for a rated 1000 hour life.

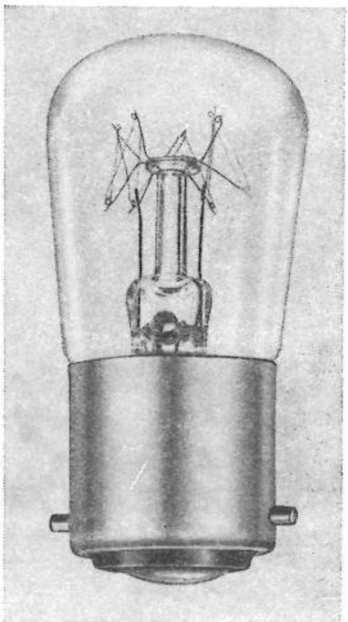


Figure 27
Pygmy sign lamp

In many cases pygmy lamps with clear bulbs are used without giving rise to glare discomfort but still lower luminance lamps are available with outside frosted, pearl, white and a full range of internally sprayed colour finishes.

Sign lamp data
Table 9

Rated Watts	*Rated Voltages**	*Finish*	*Nominal Dimensions (mm) Diameter*	*Overall Length*	*Cap*
15 or 25**	25, 50, 60	Clear	28	57	BC
	110–120			59	ES
	200–250			63	SBC
				65	SES
	110–120	Pearl or Coloured	28	57	BC
	200–250			63	SBC

* Low voltage sign lamps are not available with the full range of caps shown.
** Not available in low voltage.

6.8 Lamps for transport and traffic applications

On most trains and ships the filament lamp requirements are satisfied by normal mains voltage or low voltage GLS and other lamps already described, but there are many public transport applications where service conditions including vibration, permissible voltage, voltage variations, frequent switching, and the need to avoid pilferage necessitate the provision of special lamps designed with these considerations in mind. Details of the more common of these types for public transport, traffic control and marine navigation purposes are given in Table 10. All have a rated life of 1000 hours, Figure 28.

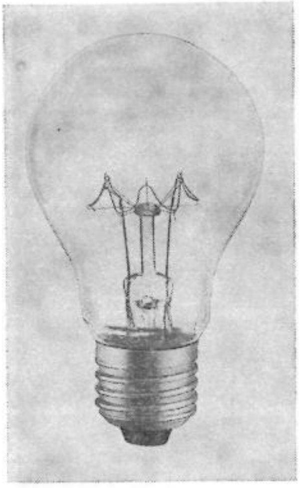


Figure 28
Traffic signal lamp

Table 10
Lamps for transport

Application	*Rated Voltages*	*Rated Watts*	*Nominal Dimensions (mm)* Diameter	*Overall Length*	*Finish*	*Standard Cap*	*Nominal Lumens*
Train Lighting	24	15	50	68	Clear or Pearl	BC	155
		20	50	68			220
		30	50	68			355
		30	55	92.5			355
Bus Interior Lighting	12	12	38	53	Pearl	BC	120
	24	12	38	53	Pearl	BC	110
Traffic Signals	230, 240 & 250	65	60	107	Clear	ES	510
Marine Navigation Lamps	110	40	66	150	Clear	BC or ES	370
	110	60	66	150	Clear		570
	220	40	66	150	Clear		345
	220	60	66	150	Clear		540

6.9 Commercial and private motor vehicle lamps

1. Such is the diversity of statutory requirements of vehicle lighting equipment and service considerations, that a very large number of different designs of lamp is necessary to cover them. Broadly, vehicle lamps may be classified under functions —

(*a*) To enable the driver to see the road without subjecting other road users to glare.
(*b*) To indicate the position and direction of the vehicle.
(*c*) To give warning of intention to turn or reduce speed.
(*d*) To light instruments and gauges.
(*e*) To warn the driver of functions needing attention, such as low oil pressure or battery charging circuit not operating.
(*f*) To light the interior of the vehicle.

2. Automobile lamps, Figure 29, for all these classes of duty are made for nominal supply voltages of 24V for the larger and heavy commercial vehicles, 12V for light commercial vehicles and most private cars, and 6V for a few cars and the majority of motor cycles and three-wheelers. In all cases due to the large percentage variation in battery voltage which occurs in service, and the need (for driving lights) to obtain the maximum amount of light from the power available, automobile lamps must be robust, reliable and of high efficacy. Fortunately the low operating voltage, calling for a relatively large diameter of filament wire, is favourable to these requirements. But in view of the vibration and road shocks, the filament and mount must be designed to be free from strong natural resonances which would give rise to early failure.

3. In lamps for headlights and spotlights a further important requirement is accuracy of filament position so that once the optimum relation between lamp and reflector has been established the lamp can be replaced without impairment of the beam and its training. These considerations result in lamps having a very closely controlled filament size and position relative to the cap, and to 'prefocus' caps. The flange is located precisely relative to the filament both axially and in orientation, and the holder design ensures that the lamp can only be inserted and held in the precise position originally determined for optimum performance. In the case of double-filament headlight lamps, this applies both to the main beam (higher wattage) filament on the axis and to the dipped beam filament which is offset in both planes to give a beam deflected both downwards and to the near-side in the same (fixed position) reflector.

4. The Tungsten-halogen version, with its advantages in higher efficacy and constant light output is made with a prefocus cap for 12V and 24V vehicle spot and fog lights so that it is interchangeable with the corresponding conventional glass bulb gas filled lamp.

5. On the other hand both for twin filament headlights and single filament spot and fog applications, sealed beam lamps on the lines of PAR 38 type (4.2) have been developed, and so great are the advantages of these in maintenance of initial performance and in complete control of beam characteristics ensured by the integration of filament, parabolic reflector and prismatic front lens, that this type is now fitted as standard equipment in most new vehicles. Figure 30 illustrates a sealed beam headlamp and shows the adaptor made to enable these lamps to be used as replacements in older headlights originally fitted with separate specular reflectors.

Sealed-beam automobile lamps
Table 11

Twin filament headlamps

Type No.	*Rated Voltages*	*Rated Watts*	*Nominal Diameter (mm)*
5702		50/37.5	145
7002		60/45	180
7005*		50/40	180
	12		
7010		75/50	180
7013		50/60	180
7014†		60/45	180

* For continental left-hand drive.
† For pre-1966 Mini conversions.

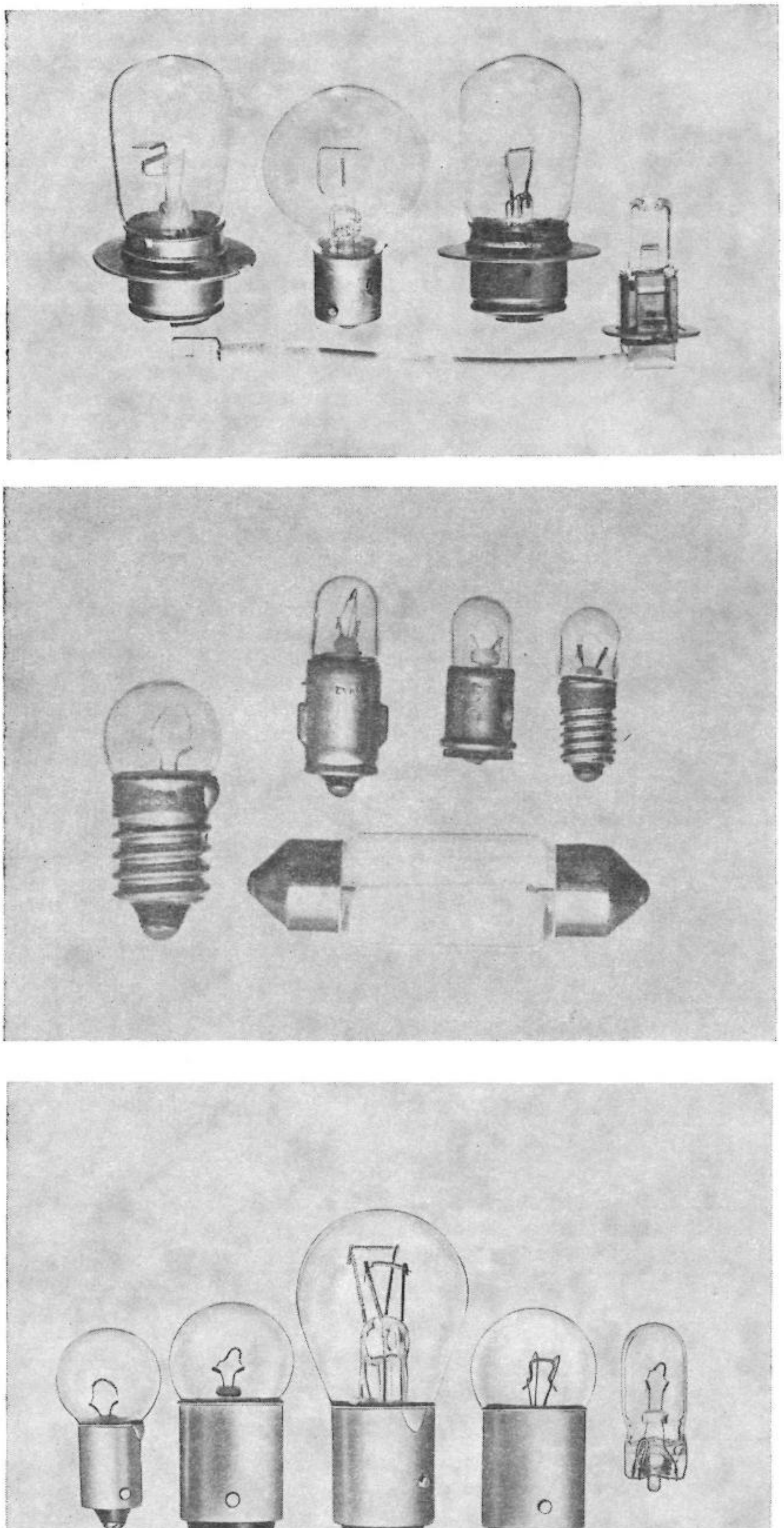


Figure 29
Selection of motor vehicle lamps

Sealed-beam automobile lamps
Table 11 (continued)

Single filament lamps

Type No. and Function	*Rated Voltages*	*Rated Watts*	*Nominal Diameter (mm)*
5700		37.5	145
5704 Spot		50	145
5706 Fog		50	145
5712		50	145
	12		
5717		100	145
5722* T.H. Fog		55	145
5723 T.H. Spot		55	145
7012		75	180
5707 Spot		50	145
	24		
5708 Fog		50	145

* With tungsten-halogen inner.

The types and ratings of other automobile lamps are too numerous for detailed listing here, but typical examples are illustrated in Figure 29. All automobile lamps have three or four digit type numbers used by all U.K. makers in common, and these are marked both on the lamp and its carton to assist in ensuring that the right replacement is obtained irrespective of brand name.

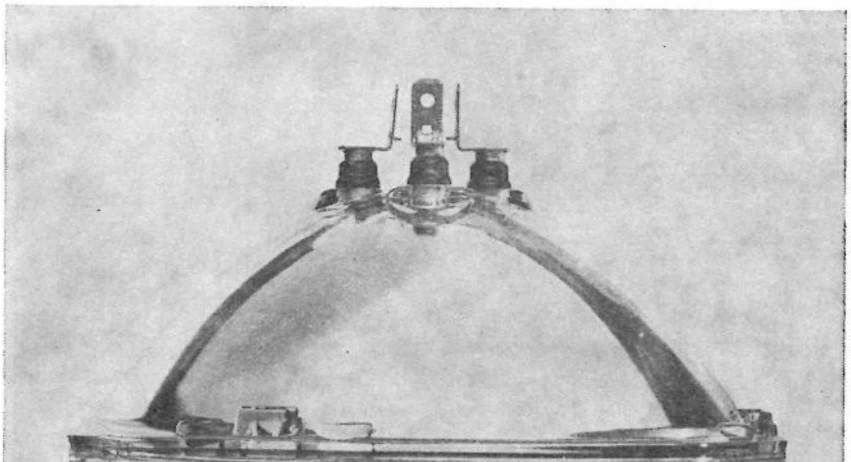


Figure 30
Sealed beam headlight

6.10 Lamps for photography

In addition to the CP type projector lamps for studio use (5.4), other lamps specially designed for photographic purposes include clear and pearl photoflood lamps, internal reflector lamps, enlarger lamps and tubular tungsten-halogen lamps. For studio purposes these lamps are designed to operate at the highest filament temperatures to secure the whitest light possible and the maximum light output for the wattage absorbed. These characteristics are only obtainable by the acceptance of short lamp life. Due to their design and arduous operating conditions, the possibility of disruptive failure is guarded against by the inclusion of internal protective fuses. All the lamps listed are suitable for operation in any position.

For enlarger negative illumination the maximum uniformity of luminance rather than the highest efficacy is required and accordingly enlarger lamps have bulbs internally coated with a white pigment giving a high degree of diffusion. Some enlarger lamps, however, are available in the high intensity class, giving increased enlarging speeds at the expense of lamp life.

The range of Class P, photographic and enlarger lamps, is given in Appendix 4.

6.11 Miners' lamps

Though mains lighting is being installed in an increasing number of British mines, battery-operated cap lamps are still necessary at the coal face, Figure 31. Lighting equipment actually carried by the miner must be as small and light as possible, but the dirty surroundings make it specially important that the small wattage available be used to convert electricity into light as efficiently as possible.

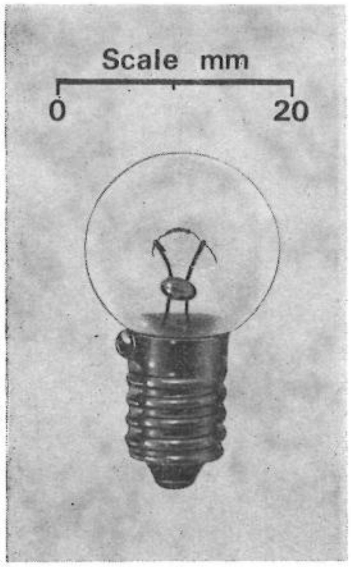


Figure 31
Miner's lamp

The National Coal Board now include only the following types in Category 1A.

Rating				
Volts	*Amps*	*Cap*	*Life (Hours)*	*Filling*
4.0	1.0	M.E.S.	200	Krypton
4.0	0.9	M.E.S.	250	Krypton

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

6.12 Infra-red lamps

1. A study of the energy distribution curve for incandescent tungsten (Section A, Fundamentals of light and its production, Figure 6) shows that by far the largest proportion of the energy radiated from the filament lies in the infra-red region of the spectrum. Figure 6, shows as well that by a suitable choice of filament temperature the infra-red wavelength at which the radiation is strongest can be selected within quite a wide band. Both of these properties are utilised in infra-red lamps which now have a great variety of applications for, like light, radiant heat can be beamed and concentrated by means of suitably shaped reflectors of bright metal or metallized finish.

2. For these reasons infra-red heating is used in the drying of paints, the softening of thermoplastics preparatory to shaping, the acceleration of chemical processes, driving off moisture, incubation and animal rearing, and for numerous other applications calling for a safe, clean and easily controlled form of heating.

Infra-red lamps are made in three types — blown glass integral reflector lamps with a choice of front finishes; pressed glass integral reflector lamps giving more accurate beam control and capable of unprotected service in the open due to the heat resisting glass used; and quartz tubular lamps for higher powers and for use with separate reflectors. The various types are illustrated in Figure 32, and their characteristics listed in Table 12.

Infra-red heating lamps
Table 12

Type	*Rated Watts*	*Rated Voltages*	*Nominal Dimensions (mm)* *Dia-meter*	*Overall Length*	*Front Finish*	*Cap*
Blown Bulb-Glass	150	110–120 240–250	111	150	Frosted or Red	ES
	250	110–120 240–250	125	180	Frosted, Red or Clear HR	ES
	275	100–130 200–250	126	178	Pearl or Red	ES or BC
	300	110–120 240–250	125	180	Clear HR or Red HR	ES
	375	110–120 240–250	125	180	Clear HR	ES
Pressed Glass	150	110–120 240–250	122	135	Red HR	ES

HR — Heat resisting glass (for thermal shock conditions).

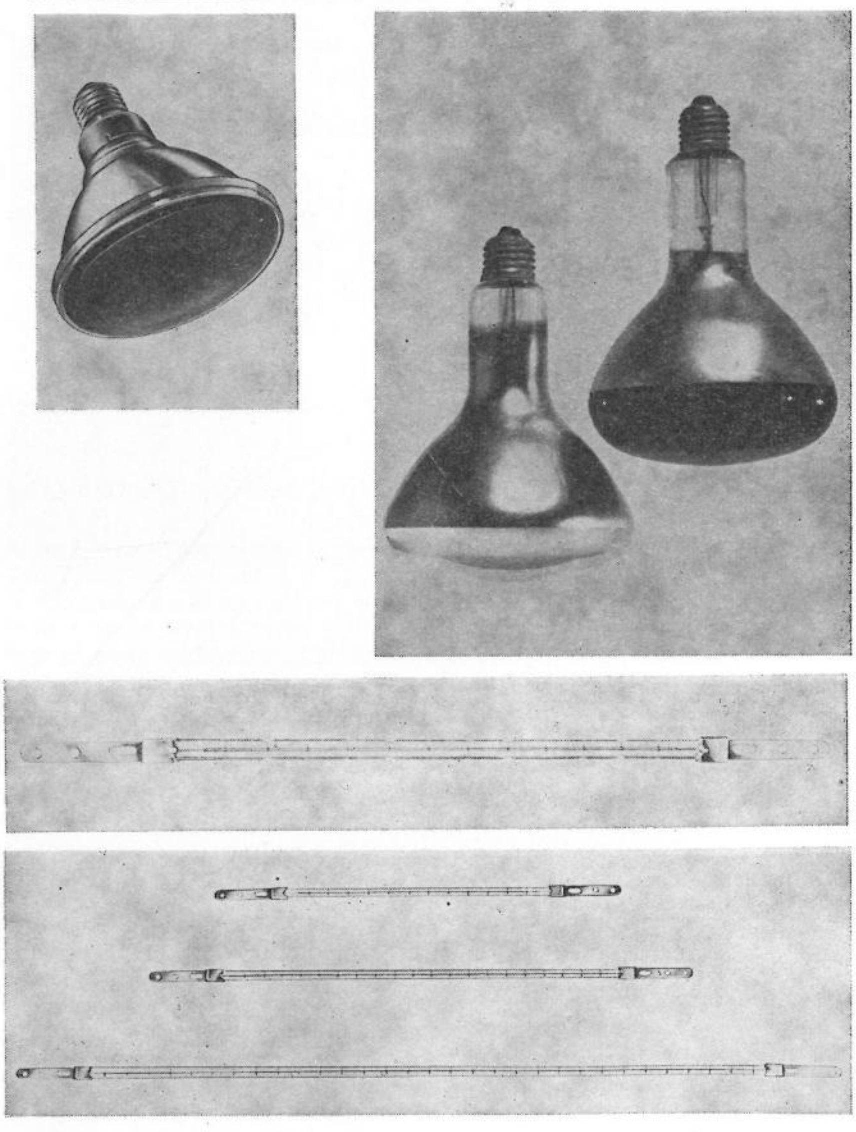


Figure 32
Infra-red lamps

Appendix 1
The manufacture of incandescent filament lamps

1 The first electric lamps were made by hand. Their performance relied greatly on the skills of the craftsmen who made them and on the materials used. Wide variations in light output and in life occurred and the number of lamps which could be produced was very limited. Since the last years of the 19th century with the constantly growing need for more and better lamps there have been successive improvements both in the purity and constancy of materials and in manufacturing techniques with the result that today the making of lamps is one of the most highly mechanized of mass production processes.

2 It might be thought that the ever increasing application of electric discharge lamps would have reduced the demand for incandescent filament types, but this has not proved to be the case. In fact it continues to grow, and the total annual production in the United Kingdom for 1969 reached the astronomical figure of 470 million lamps, of which some 310 million were in the GLS and similar types. The balance is composed of all other filament lamp types among which automobile type lamps predominate with an annual production of approximately 110 million.

3 With about 250 working days per annum, the U.K. production of GLS types alone thus averages about one million lamps per day. Keeping up with this enormous demand, while retaining an unexcelled standard of quality and performance, is no mean feat and one of which the lamp industry is justly proud. It must be realized that although almost two million GLS lamps are produced per working day, this quantity is divided among a great number of individual ratings and other variations such as bulb shape and finish, type of cap and type of filament. As an example, one major manufacturer produces in the mains voltage GLS range with ratings between 15 and 100 watts a total of 130 different lamps in the single coil filament category, plus an additional 21 different lamps in the coiled-coil category. And these numbers do not include similar ratings and types for export, fitted with ES caps, or specially branded lamps given other names by some large retailers, or as ordered by large users to discourage pilfering.

4 In the most highly automated manufacture a considerable number of skilled technicians are necessary to carry out running adjustments immediately any malfunctioning in a machine is detected, for with a group producing lamps at a rate of 2,000 to 4,000 per hour the number of rejects which would be produced otherwise would quickly constitute a serious loss.

5 It is economical to devote a manufacturing group to the production of one particular lamp rating and type for as long a 'run' as possible, but with so many different ratings required changes are sometimes necessary in order to keep supplies balanced. Every change involves re-setting the machine, which operation requires the attention of the technicians for some hours or even days before the plant is running smoothly on the new type. The desirability of limiting the number of different lamps made in the interest of economy is thus apparent. It also explains the difficulty inherent in orders for 'specials' to suit individual customers, unless the quantity is sufficiently large to constitute an economic manufacturing run.
For lamps required in great quantities manufacturing processes and machines are now automated to a degree which leaves little for the operative to do other than inspect at various stages and pack the finished product, but types in small demand still involve a proportion of skilled hand work in manufacture and in certain cases hand processes predominate.

6 Lamp manufacture involves a great variety of techniques and processes between the raw materials and the final product. The glass envelope and internal parts of glass constitute one main section, the tungsten filament and other metal parts a second, the assembly, exhaustion and gasfilling a third.

Glass

7 Specialized and high purity glass is required for lamp making. Constant quality and characteristics are also essential, otherwise the setting of the automatic glass working machines and of the associated heating flames would be impossible. In use, the bulbs and other glass parts are subject to high temperatures, with rapid heating and cooling and with considerable temperature gradients between one part of the glass and another. Under these difficult conditions all the glass parts must retain adequate mechanical strength, remain free from even minute cracks and retain a perfect seal against the ingress of air. In addition, the bulb must be free from coloration or blemishes ('stones') and have high optical transmission. Molten glass has a strong tendency to absorb impurities from anything with which it comes into contact, and it is therefore essential not only to ensure purity of the sand and other ingredients in the mix but also that of the refractories used in the lining of the melting tanks.

8 Glass blowing by hand and mouth methods is an ancient craft, and some specialised lamp bulbs are still made in this way. The blower takes a gob of molten glass from the pot, on to the end of a metal tube, and by a combination of turning and blowing he forms it into a bulb. The shape and size of the bulb are finalized by putting the still plastic and roughly shaped bulb into a split mould which is then closed round it and the process of twisting and blowing is continued with the bulb in the mould, where it is cooled before the mould is opened sufficiently to retain its true form. The bulb is then withdrawn and cracked off at the neck from the end of the metal tube.

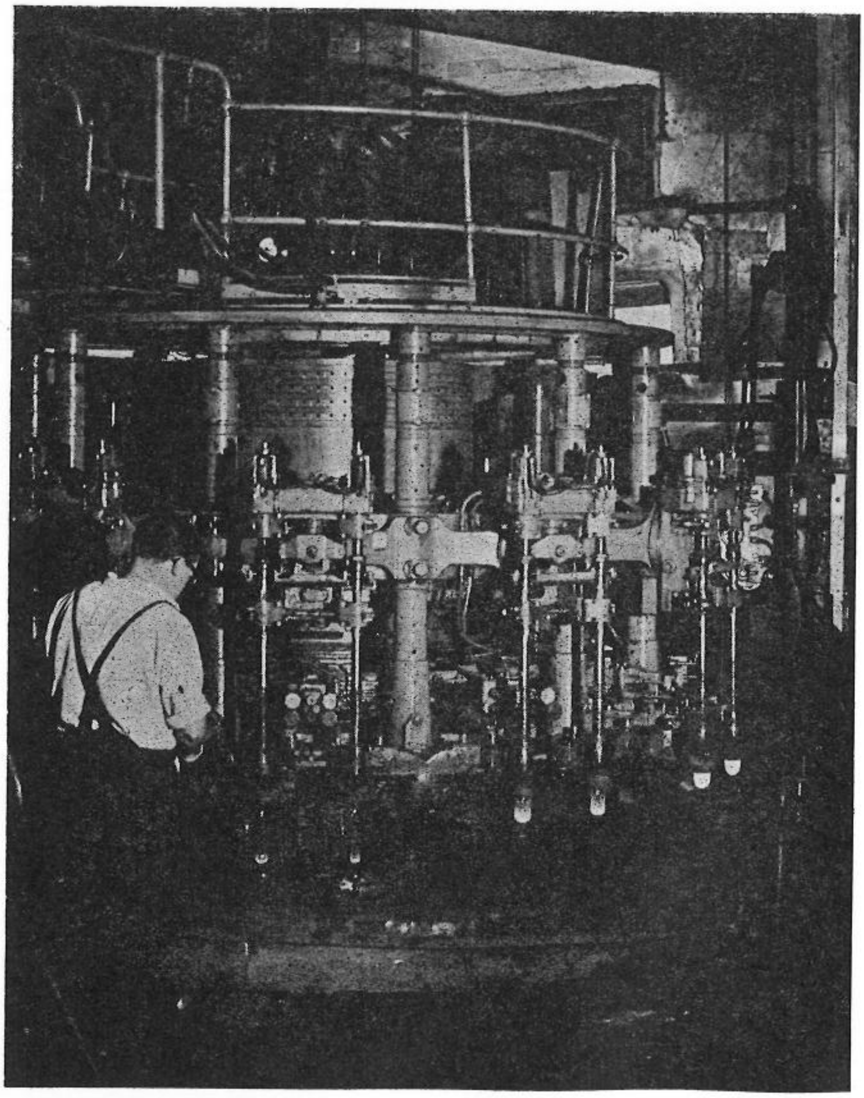


Figure 33
A Westlake Machine

9 For many years bulbs were made in quantity on Ohio and Westlake machines, Figure 33, which reproduced mechanically the motions of the manual glass blower. Most lamp makers had their own individual plant for producing the bulbs they needed. With the increasing quantities of bulbs required, however, the output of the old machines became inadequate, and an entirely new method of bulb production, employing what is known as the ribbon machine, was perfected in the USA and subsequently adopted in this country.

10 In the ribbon process, Figures 34 and 35, a continuous stream of molten glass issues from an orifice in a reservoir tank fed from the melting pot and maintained at a closely controlled temperature. The stream of glass falls between two rollers, Figure 36, which serve to thicken up the 'ribbon' of glass at short intervals and below which the ribbon falls on to a moving band which conveys it away to meet a similarly progressing endless chain of blowheads above and another of moulds below the moving band carrying the glass ribbon. In the conveyor band are holes corresponding with the thickened portions of the ribbon, the position of the blowheads above and the moulds below. As the roughly blown bulbs form below the band, the split moulds close round them, Figure 37, and the blowing process is completed while all is moving forward. As they progress, the moulds are rotated and the smoothness of the bulb is ensured by means of a cushion of steam between the glass and mould. After a sufficient distance has been traversed for the bulbs to set, the mould heads open and the bulbs are cooled further in the open until they reach the cutting off position and after annealing pass to the ribbon lifter where they drop away from the band on to a rotating disc. The blowheads and moulds, both mounted on continuous chain-link bands, traverse back to the start and repeat the process in endless succession.

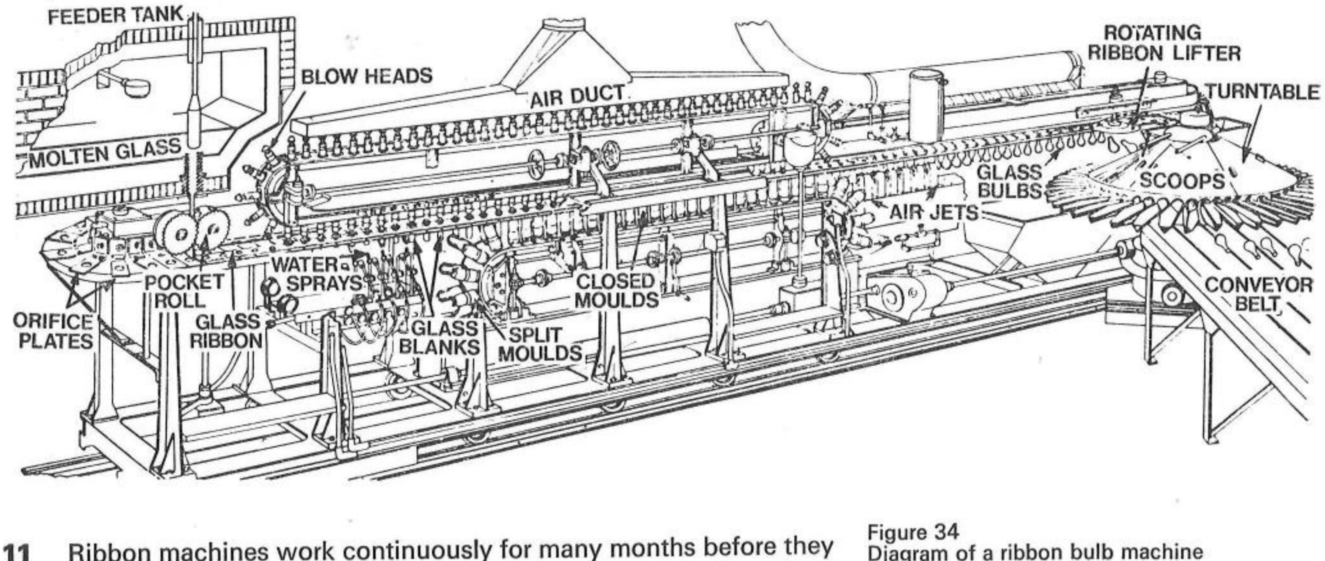


Figure 34
Diagram of a ribbon bulb machine

11 Ribbon machines work continuously for many months before they have to be closed down for maintenance, and such is the rate at which they manufacture bulbs that a single plant, situated near Doncaster, equipped with five ribbon machines is serving the whole UK lamp making industry together with a considerable part of the European requirement and some more distant overseas demand.

12 Bulbs made as described are in clear glass, and for the majority which are required in 'pearl' finish, the inner surface of the bulb is etched by a spray of hydrofluoric acid. After a second spray of acid which has the effect of re-toughening the glass, left brittle by the first etch, the pearl bulbs are washed to remove all traces of acid and dried by hot air.

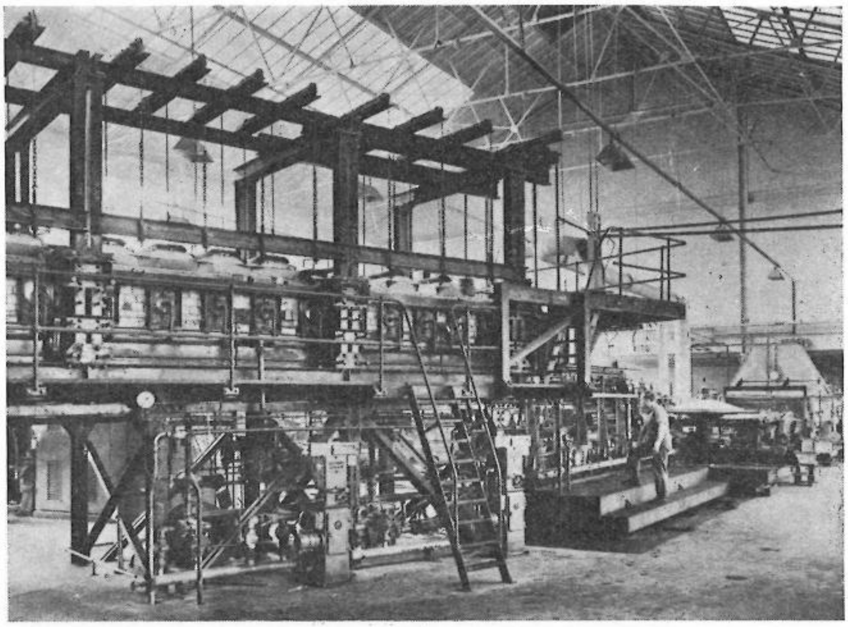


Figure 35
General view of ribbon bulb machine

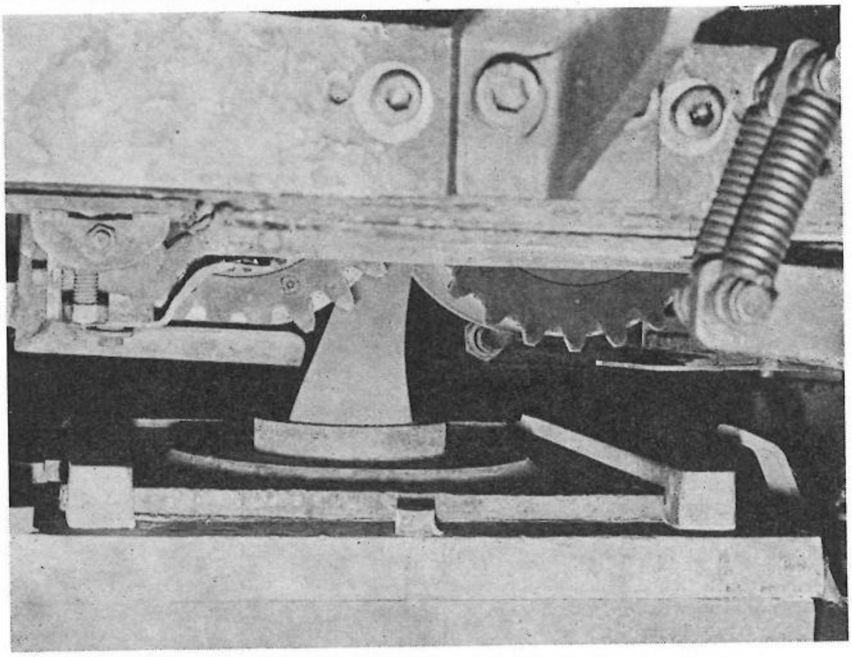


Figure 36
The ribbon of glass

13 In addition to the bulb, lamp manufacture requires glass for forming the foot tube and exhaust tube, and rod or 'cane' for the filament support stem. These are produced by extruding the molten glass through dies and after cooling in a long continuous length the rod or tube is cut into convenient lengths for loading into the flanging and mount machines.

Filaments

14 Tungsten in powdered form is obtained from the tungstates of calcium, iron and manganese which are the principal ingredients in mineral ores known as scheelite and wolframite. The transformation of the powdered metal into a coherent ductile rod capable of being drawn out into the fine wire needed for lamp filaments is laborious, and the basic techniques of the method still employed are those discovered in 1909 (1.5).

15 From the chemical extraction and refining processes practically pure tungsten powder in correctly graded and proportioned grain sizes to give maximum strength, is poured into a long narrow steel mould holding about 1.3 kg of the powder. The bar of powder is subjected to great pressure hydraulically to compact

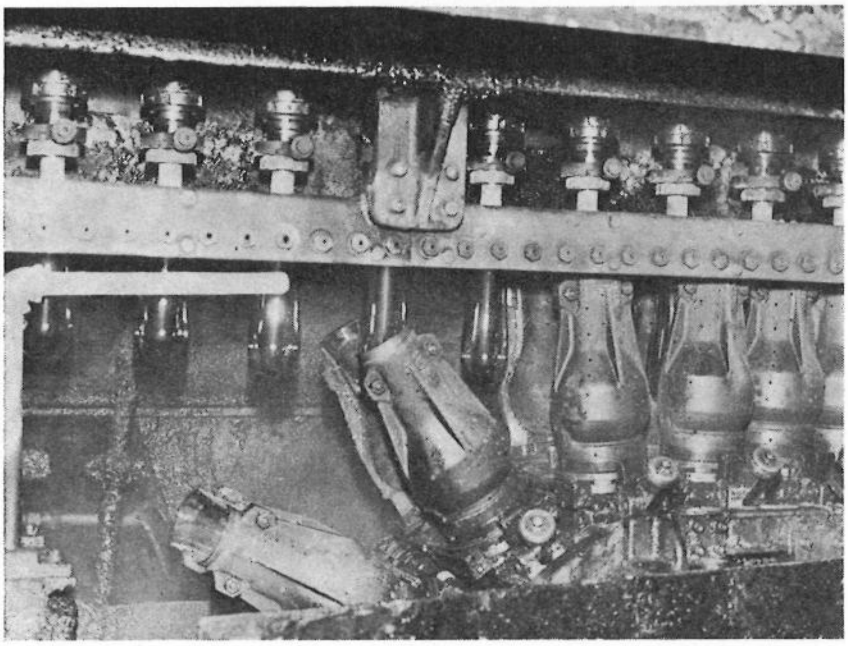


Figure 37
The split moulds

it and on release it is removable with care in one piece to the sintering furnace. This contains a hydrogen atmosphere to prevent oxidation when a heavy electric current is passed through the tungsten bar, thus raising it to a temperature approaching the melting point and still further compacting the rod into solid metal. Swaging by mechanically rotated hammers follows, with the rod starting at about 1400°C and gradually cooling as it elongates and assumes a round cross section.

16 At this stage drawing processes take over. The first draws are through steel dies taking the tungsten rod down in diameter to a fairly fine wire, each draw reducing the diameter only by a few percent and being preceded by passage through an annealing oven. The later and final stages of filament drawing are through diamond dies, diamond being about the only material capable of enduring the intense stresses involved in dies of the minute sizes necessary. Here again, the filament wire, now elongated to many kilometres and wound on steel reels, is annealed by heating before and often after each draw to restore the maximum ductility, and to prevent crystallisation.

17 The diameter of the tungsten filament wire for a GLS 240V lamp is about 0.014mm for the 15W rating, or 0.042mm for the 100W, so it will be realized that to illustrate the actual drilled diamond is impractical. However, Figure 38 reproduces the photograph of greatly enlarged models in perspex of two such dies and shows the contour of the die orifice. The drilling of the diamond to give these contours and the necessary dimensional accuracy is in itself almost a miracle. Because of the difficulty of measurement, the correctness and grading of the finished filament wire is checked by weighing measured lengths and the maximum variation permissible in weight is about 2%, which corresponds to about 1% in wire diameter — in other words in a 15W filament there is a diametral tolerance of only 0.00014mm, or a quarter of the mean wavelength of visible light!

Filament coiling

18 Because the diameter and turn spacing of coiled filaments influence the rate of heat dissipation, the maintenance of luminous efficacy and lamp life demand great accuracy in coiling, and in the mandrel wire round which the coil is formed. The spacing of individual turns is only about half the filament wire diameter and control of the rate of progression of the mandrel wire, which determines the turn spacing, must be correct and constant within 1%. To ensure accuracy in the coil diameter, the hardness and

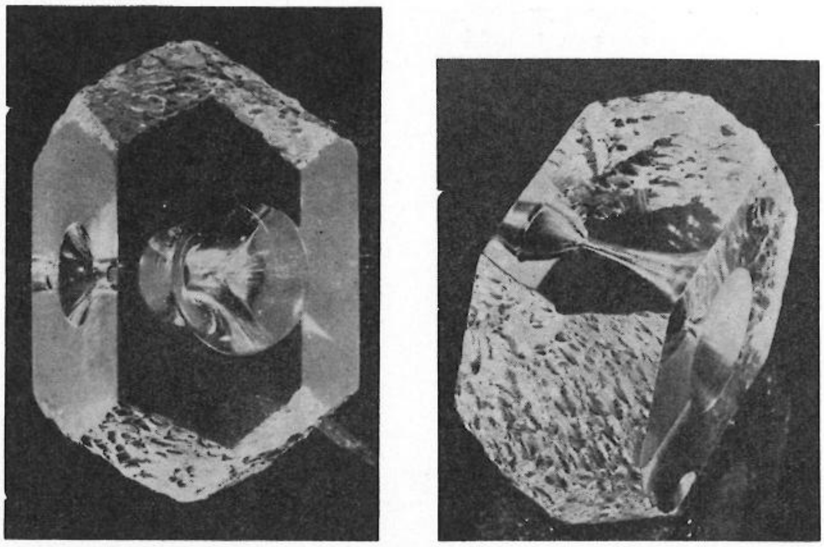


Figure 38
Enlarged models in perspex of two diamond dies

the tension in the filament wire during winding must also be controlled to similarly fine limits, and microscopes mounted on the winding heads are necessary for checking the process.

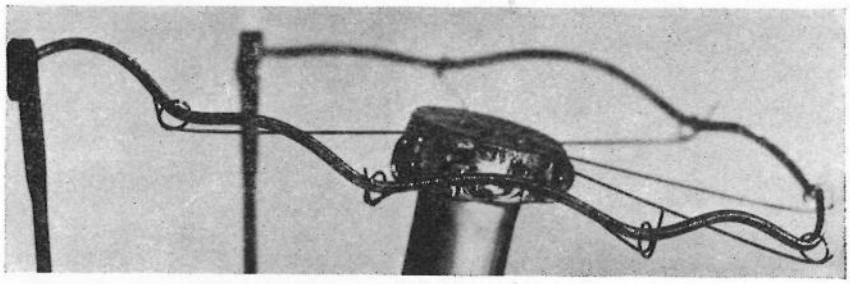


Figure 39
A single-coil filament assembly

19 For a coiled-coil filament, the primary coil — still on its mandrel wire — is re-coiled on a second mandrel wire of larger diameter. In the second coiling a further complication arises because this must be gapped at intervals so that only the small diameter primary coil is clamped in the flattened ends of the lead-in wires. A section of a coiled-coil filament is shown in Figure 4.

20 Following the coiling process the filament, still on the mandrel wire(s), undergoes an annealing heat treatment in a hydrogen atmosphere. After cutting into the precise length for each filament the mandrels are then dissolved out in acid, followed by a further heat treatment to eliminate any trace of residual embrittlement. Before the finished filaments are released for incorporation, a proportion from each batch is put through microscopic inspection, measurement and test to ensure that all are within the required limits. Should the samples be found to include any which are outside the specification, the whole batch is withdrawn for examination and regrading or rejected as necessary.

Filament supports

21 The thinnest molybdenum wire of adequate mechanical strength is used to limit the heat loss from the filament, (3.9). Improvements in the mechanical strength of tungsten filaments at incandescent temperature have tended to reduce the number of supports necessary for single coil filaments, but due to the considerable reduction which coiled-coiling makes in the effective length of filament not more than two intermediate supports are necessary compared with six or seven usually in the single coil high voltage GLS lamps. Figure 39 shows the closed loop construction of the supports in a single coil filament assembly.

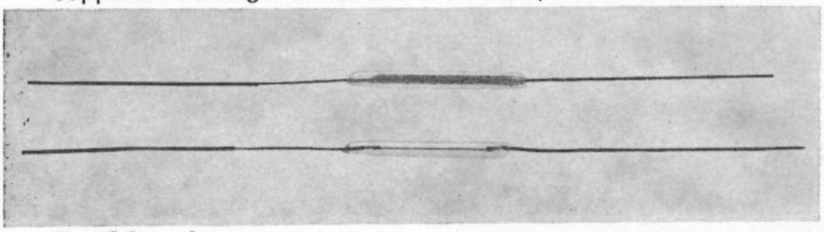


Figure 40
Part of a lead-in wire incorporating fuse.
(a) Example of long established encapsulated wire fuse two per lamp i.e. one per lead-in wire.
(b) Example of more modern Ballotini filled fuse fitted into one lead-in wire only.

Lead-in wires

22 Where the lead-in wires, which carry the current from the outside to the inside of the lamp, pass through the glass they must make a completely air-tight seal at all temperatures. They must therefore have the property of being wetted by the molten glass and must also have the same coefficient of expansion with temperature as the glass, for otherwise when heated they would either burst the glass seal, or would expand less than the glass, leaving a gap through which air could pass. Platinum has this characteristic and though used for this purpose in early lamps, its very high cost has prevented its continued use and since no other single metal has the required physical and electrical characteristics, a composite wire has to be employed. This consists of nickel-iron wire with a copper sheath, the proportions of the metals being so arranged that when drawn to the required size the overall coefficient of expansion equals that of glass.

23 Economic considerations demand that the copper-clad composite wire be kept short, and in any case it is not suitable inside the lamp, for which part nickel or molybdenum have the necessary properties. The composite portion is therefore limited to the short length in the glass seal outside which it connects with the fuse and thence via a length of copper to the cap contact, Figure 40. Thus from the cap to the filament there is a four part lead — copper, fuse, composite wire, and nickel — and these components are cut to length, assembled in sequence and hydrogen flame-welded together automatically. The same machine also flattens the free end of the nickel wire and turns the flat section over to form a hook ready to receive and clamp round the end of the filament.

A fuse on a lead-in wire is one of the safety devices employed by lamp makers and is so designed that it will blow immediately ionisation occurs, i.e. when the gas-filling becomes capable of carrying a current.

Stem making

24 The next step is the manufacture of the 'stem,' or glass and lead-in wire assembly on which the filament will be mounted. The stem consists of four parts —

(*a*) a glass stem tube, one end of which is flared out to form a surface for sealing to the glass bulb, Figure 41 ;

(*b*) a glass exhaust tube, through which, after sealing, the lamp is first evacuated, scavanged, and then filled with the final gas ;

(*c*) a glass rod or 'cane' which will carry the molybdenum filament supports, and

(*d*) the lead-in wires, Figure 42.

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

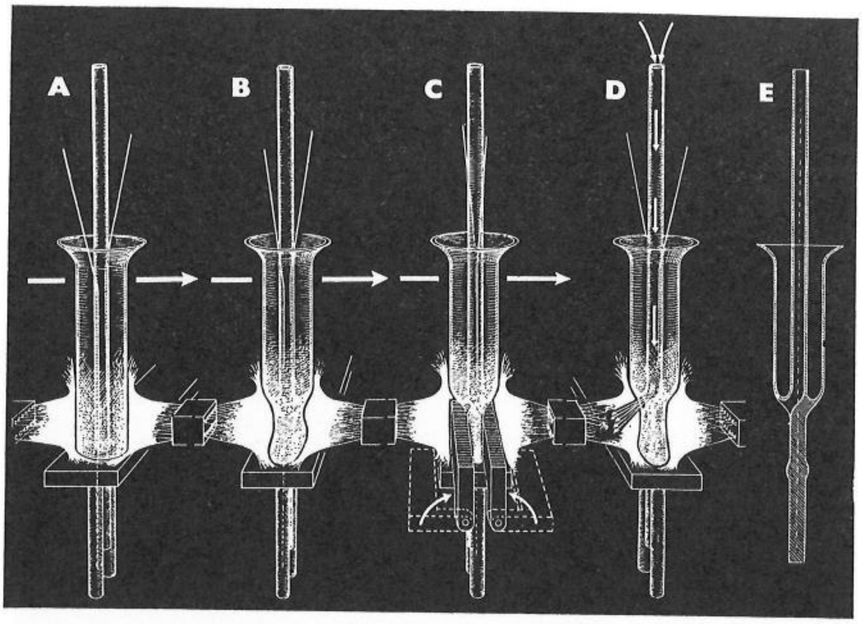


Figure 41
The formation of the flange

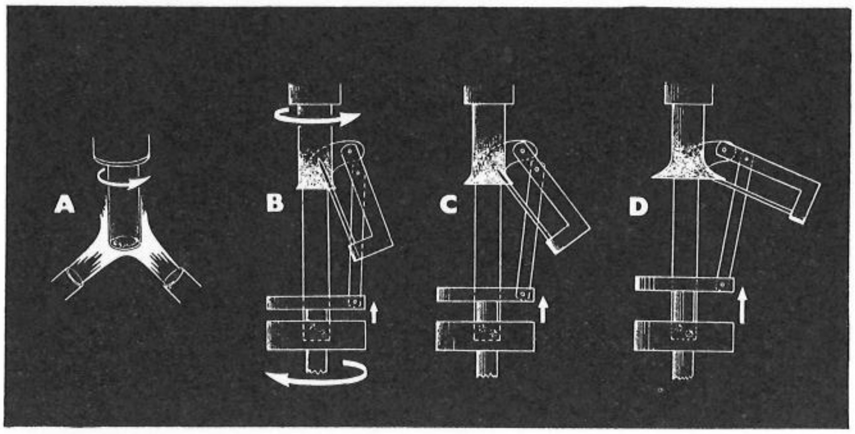


Figure 42
Formation of the stem assembly

Filament mounting

26 This operation is also performed automatically. The filaments are laid out on a tray from which they are picked up one at a time by a vacuum chuck and the ends are fed into the loops of the lead-in wires, where they are clamped. On the same machine the end of the glass cane is softened, the molybdenum filament supports inserted, and their looped ends wrapped round the filament, Figure 43. The last operation on the mount machine is the addition of a chemical known as a 'getter' to reduce the level of impurities inside the bulb. In this instance it is phosphorous with which the filament is coated by dipping or spraying.

Sealing

27 The mounted stem is fed up the neck of a glass bulb, and gas jets adjusted to fuse the bulb neck to the flared end of the stem tube. Critical adjustment of jets is necessary to prevent excessive strain in the glass and to ensure a perfect seal. The weight of the discarded lower part of the bulb neck causes it to fall away as the sealing process is completed.

Pumping

28 Formerly both vacuum and gasfilled lamps were exhausted of air by means of special pumps capable of reducing the internal pressure to the equivalent of at least 0.001mm on the mercury barometer scale. Pumping to this degree of vacuum takes some time, and, in the case of gasfilled lamps with present manufacturing speeds a different method has largely superceded it. Pumps are still

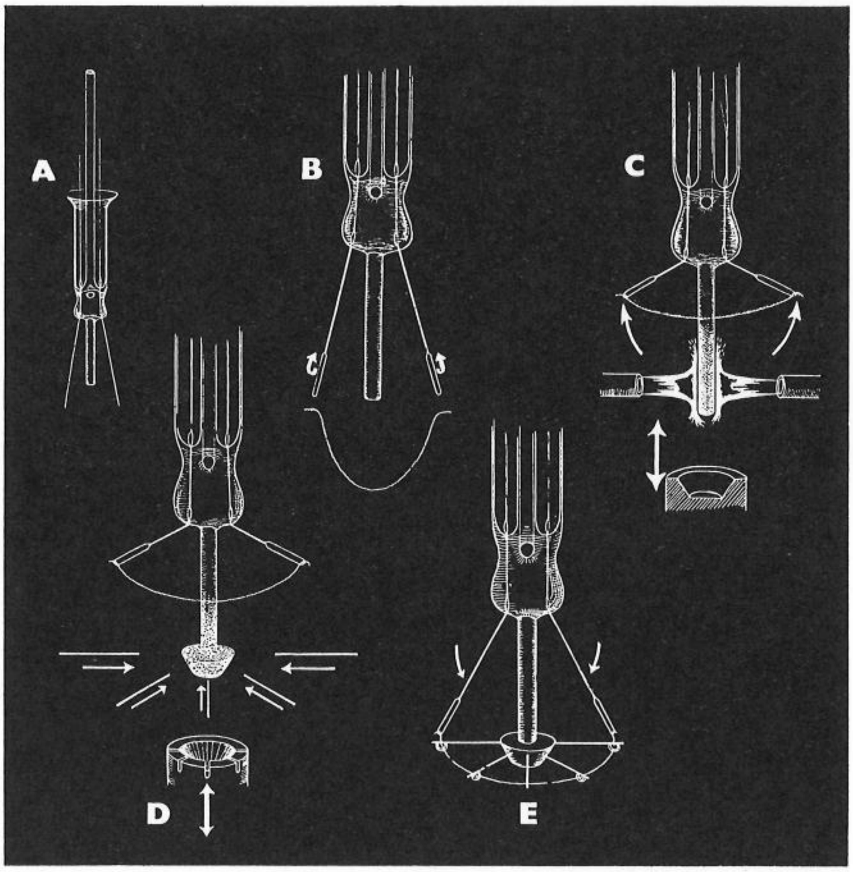


Figure 43
The filament mounting process

used to produce a rough vacuum, which can be achieved very rapidly. Flushing gas is then admitted and the bulb re-pumped. This flushing process is repeated so that on final gasfilling, the residual oxygen concentration is no more than 5 to 10 parts per million. At an internal pressure a little below atmospheric the exhaust tube is sealed off, and residual oxygen molecules are cleaned up by chemical combination with the getter which is flashed off by the passage of an electric current through the filament.

29 For most lamps the filler gas is a mixture of argon and nitrogen. A complete absence of both oxygen and water vapour is essential to prevent oxidation of the filament as this would seriously shorten its life. A single drop of water in a cylinder of filler gas sufficient to make half a million lamps would result in all failing to achieve their rated life!

30 With the filled pressure in the lamp when cold about 90kN/m^2, or 80% of atmospheric pressure, due to the temperature rise in operation, the gas pressure in operation is equal to or a little above atmospheric pressure. This constitutes a working compromise between thermal loss and the inhibition of flashing. On samples from each batch of lamps, the purity of the gas filling is checked by passing a high frequency electric discharge through the bulb, the colour of the resultant glow indicating the presence or absence of impurity.

Capping

31 The cementing of the cap to the bulb is a minor mechanical operation, but if faulty it can cause a great deal of annoyance and some danger. A system by which the cap is mechanically fixed to the glass without reliance on the cement has been developed for some lamps operating at high temperature; projections in the cap interlock with recesses in the glass seal, and once fitted the cap cannot become detached without breaking the glass.

Lamp Making Groups

32 The less the lamp components are handled and the quicker they can be assembled, the less chance there is of contamination. Modern practice is therefore to group the necessary machines together into a unit so arranged that each assembly operation follows quickly on the previous one. Five rotary automatic machines operating in sequence turn the various components into finished lamps —

(*a*) *The flanging machine* forms the flange on the foot or stem tube, Figure 41.

(*b*) *The pinch machine* assembles into the stem the exhaust tube, the cane and the lead-in wires and clamps all together by flattening the end of the stem tube, Figure 42.

(*c*) *The mounting machine* forms a stud at the end of the cane, inserts the filament supports and the filaments, and clamps the filament ends in the hooked ends of the leads, Figure 43.

(*d*) *The sealex machine* welds the flanged stem, carrying the completed filament and support assembly, to the neck of the bulb, Figure 44, exhausts, scavanges and gasfills the lamp and seals off the exhaust tube, and finally lights the lamp for a second or two to volatolize the phosphorus getter.

(*e*) *The capping machine* adds the previously cement-coated caps, with the lead-in wires threaded through holes in the contact plates. The lead-in wires are trimmed to length and soldered over. The capping cement is heat-cured while the cap is held in close contact with the glass. After a short period alight, the completed lamp passes to the final inspector and wrapping position. Figure 45 shows a general view of a lamp-making group.

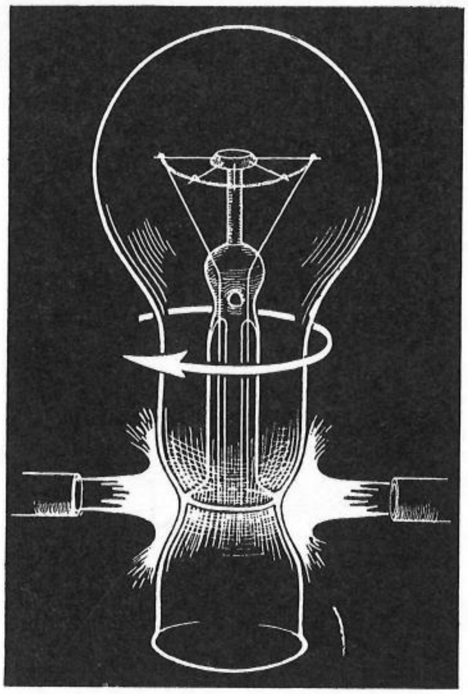


Figure 44
The sealing-in process

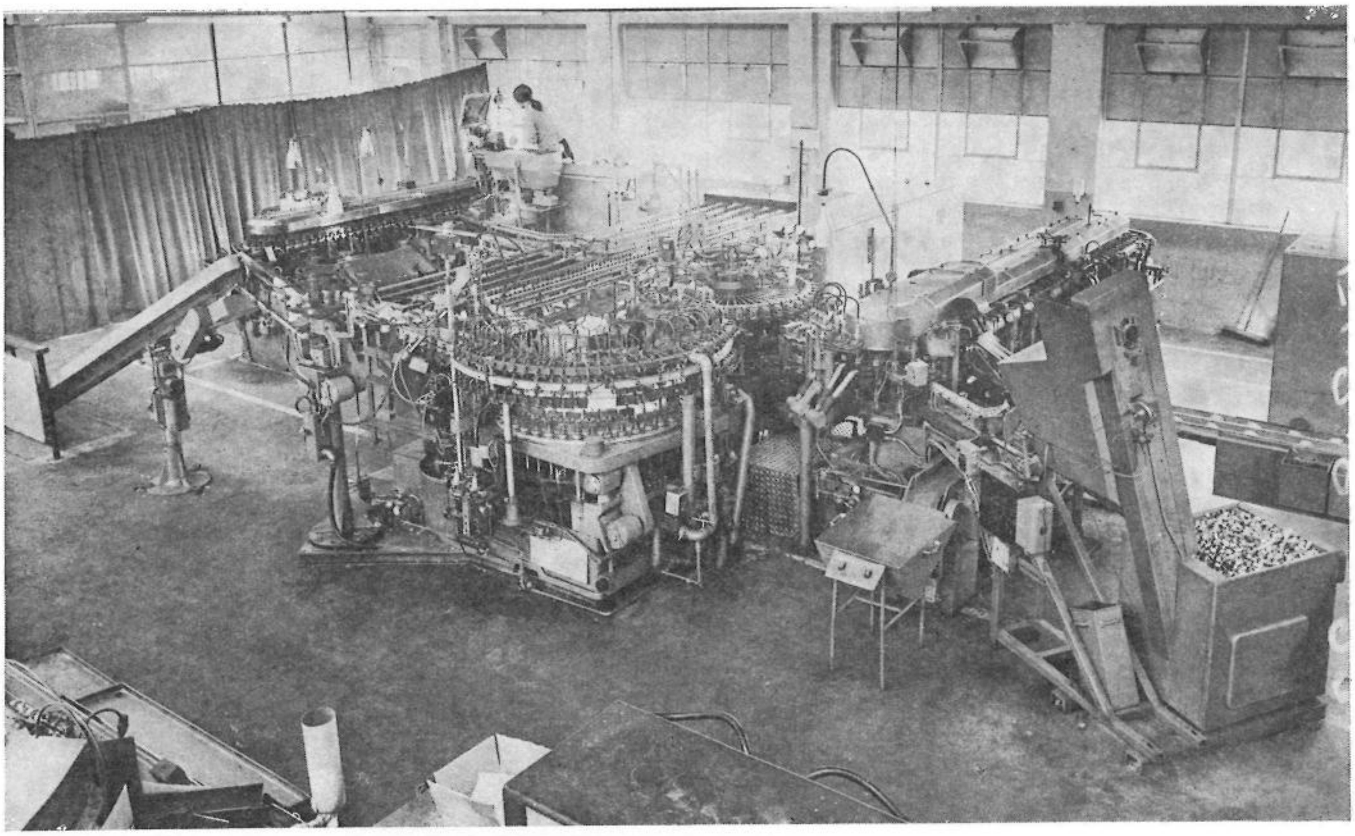
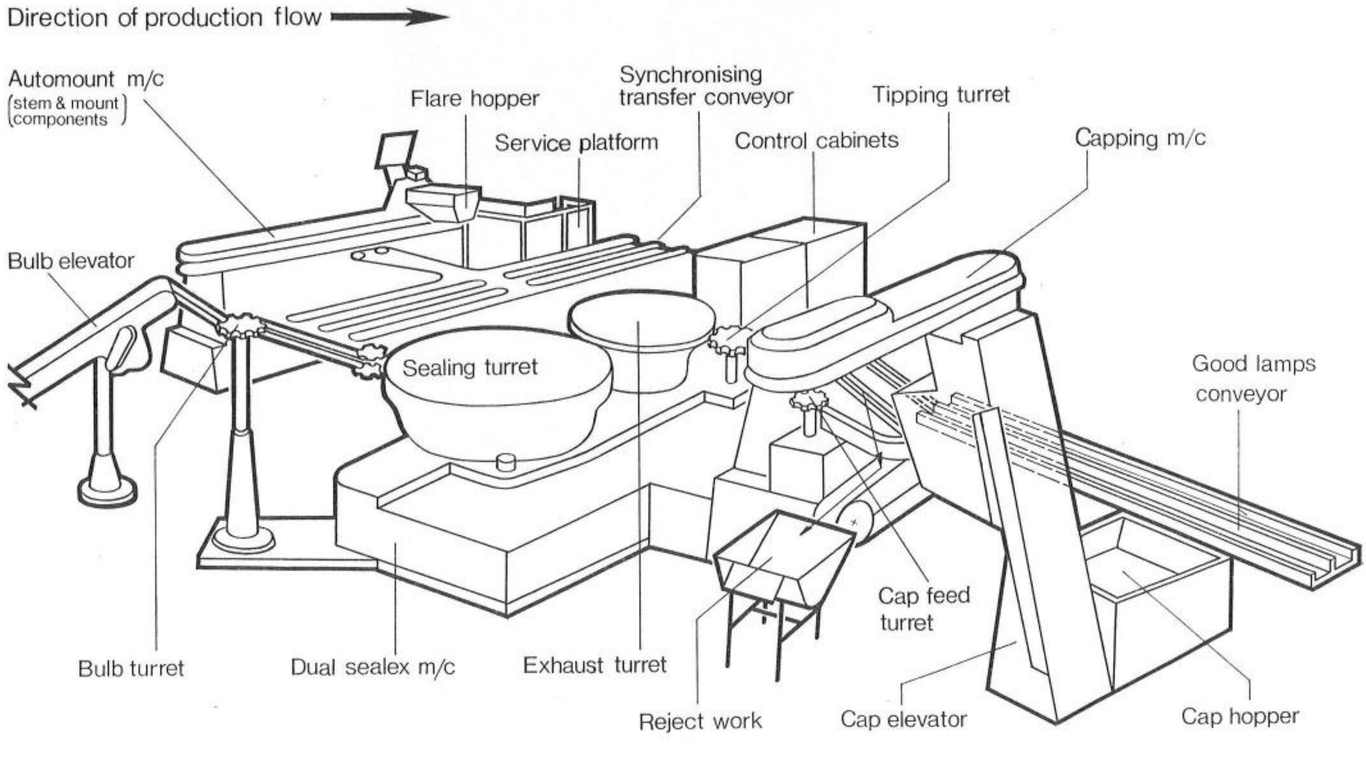


Figure 45
The Sealex Machine (top) and diagram showing production flow



Appendix 2
Lamp cap designations

1 Relatively broad cap-designations such as BC (Bayonet Cap) and ES (Edison Screw) have come to be widely used for general descriptive purposes, and will no doubt continue to be so used, but a much more detailed nomenclature is necessary for a complete indication of the cap design and dimensions.
In outline, the system now internationally recognized is —

2 The principal part of the designation code, which ensures interchangeability and fit of the cap in the holder consists of one or more capital letters followed by a number —

B — Bayonet
BA — Bayonet automobile (short catch pins)
BM — Bayonet for mining lamps
E — Screw thread
F — Single contact pin or post, the other terminal being the shell of the cap
G — Two or more contact pins or posts
K — Flexible wire connections
P — Prefocus cap, in which a precise relation between filament and cap is maintained
R — Recessed contact
S — Shell
SV — Shell with a conical end (as on festoon lamps)
T — Telephone indicator lamps
W — A capless construction in which contact is made to the lead-in wires

The number immediately following the letter(s) indicates the principal dimension, usually the shell diameter, of the cap in millimetres. Exceptions are after F where the pin diameter is indicated, and after G where the spacing of the pins is indicated.

3 Where it is necessary to give dimensions other than the principal one, a number preceded by an oblique stroke indicates in millimetres the axial length of the cap. A further number preceded by x indicates that the skirt of the cap (the part nearest the glass) has a diameter different from that indicated by the first figure following the letter(s). Thus a designation E27/25x30 indicates an Edison screw cap with a screw diameter of 27mm, an overall axial length of 25mm, and a skirt spun out to 30mm diameter.

4 A lower case letter following the main capital indicates the number of contact plates, pins or other connections not counting the shell where this forms one of the contacts —

s — one contact
d — two contacts
t — three contacts
q — four contacts
p — five contacts

Thus B22d indicates a bayonet cap with a 22mm diameter shell (standard BC) and two contact plates.

5 Following the letters and preceded by a hyphen, a single number indicates the number of locating pins or lugs, and this may be followed in brackets by the angular spacing of the pins or lugs in the plane at right angles to the cap axis. Thus B22d-3 (90°/135°) indicates a BC cap with three locating pins the angles between the pins being 90°, 135° and 135°.

6 Caps whose coded designations are otherwise identical in this system, but which are not completely interchangeable because of differences in some feature not covered, are differentiated by adding the capital letter X, Y or Z. Thus an SBC automobile lamp with pins in different planes so that they can only be inserted in the holder one way round (to ensure that the appropriate filament is connected to its intended circuit, as in combined stop and tail lamps) has the code BAY15, while one in which the same purpose is achieved by means of different lengths of pin is coded BAX15.

Note: Dimensions given in cap designations are normally in mm and without fractions or tolerances. They should therefore be regarded as approximate values, Figure 46.

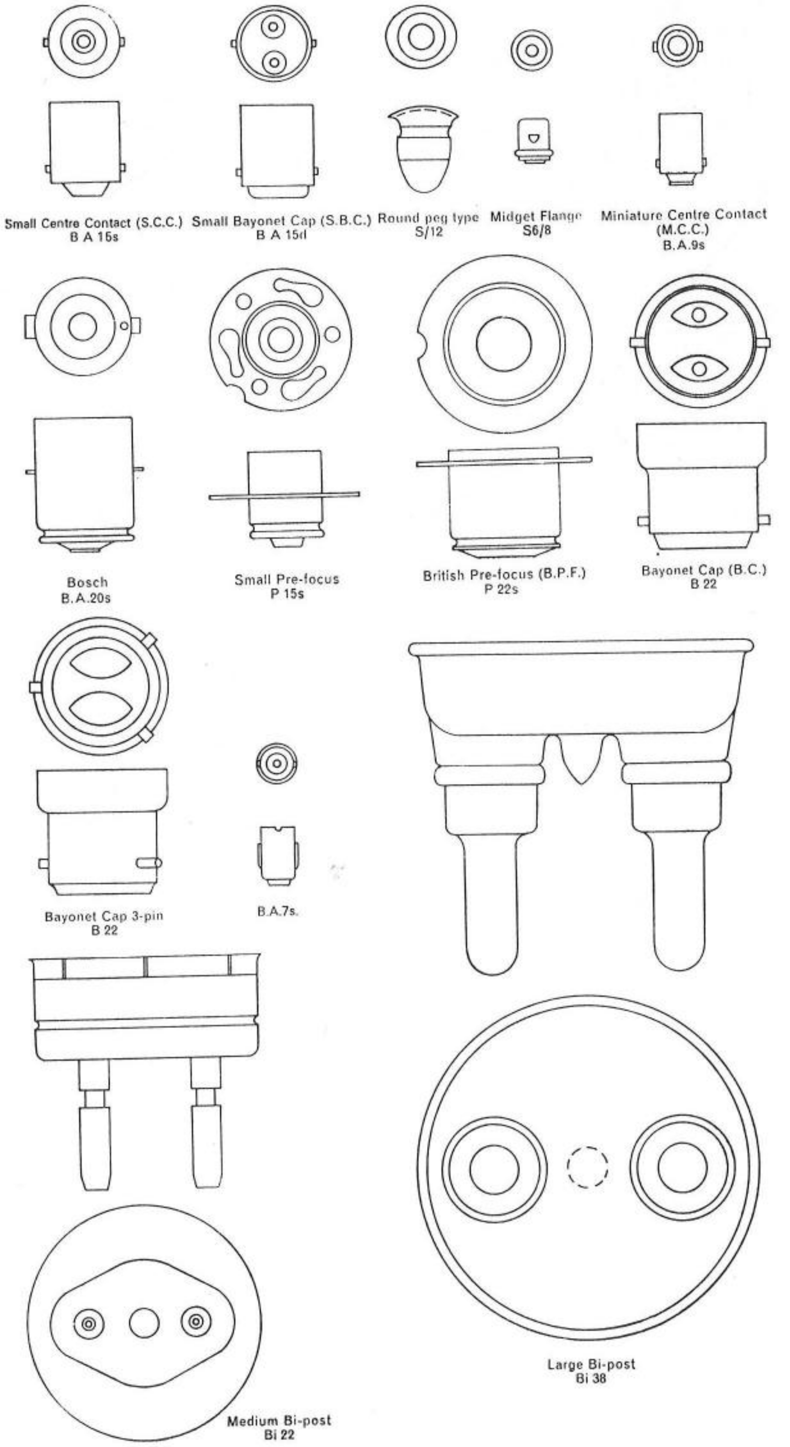
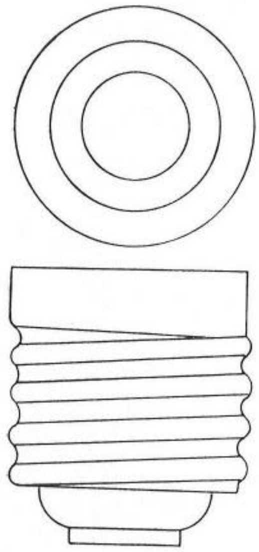
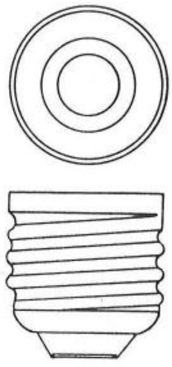


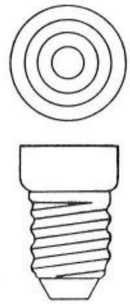
Figure 46
Typical Lamp Cap bases. Note :—The international standardised basic code designation for each type is given under each diagram (codes in brackets do not apply other than in English speaking countries).



Goliath Edison Screw
(G.E.S.)
E 40



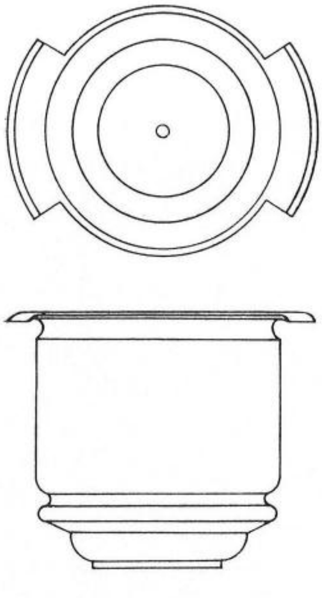
Edison Screw (E.S.)
E 27



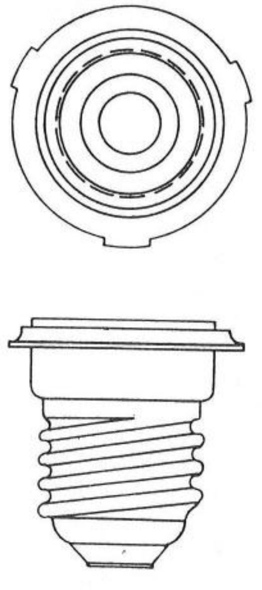
Small
Edison Screw (S.E.S.)
E 14

Miniature
Edison Screw
(M.E.S.)
E 10/13

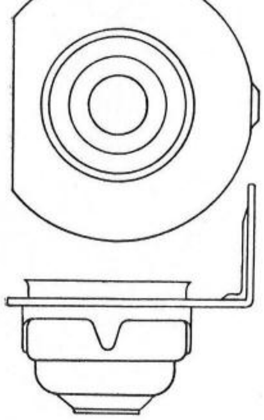
Lilliput
Edison Screw
(L.E.S.)
E 5/8



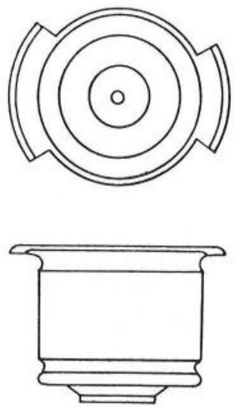
Large Pre-focus
P 40s



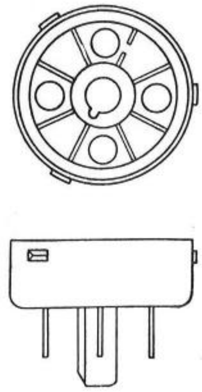
3 fin Pre-focus



**Bell & Howell
Pre-focus
S 26s**



Medium Pre-focus
P 28s



4 pin Base
G 17q

Appendix 3

General lighting service lamp Data

Rated average life . . . 1000 hours

Rated Watts	Lighting design lumens at 240V (1): Single Coil	Lighting design lumens at 240V (1): Coiled-Coil	Dimensions (mm): Overall Length	Dimensions (mm): Diameter	Dimensions (mm): Light Centre Length	Standard Cap	Standard Bulb Finish
25	200	—)				)	
40	325	390)	105 ±3.5	60±1	75	) BC	Pearl
60	575	665)			(Nominal)	)	
100	1160	1260)				)	
150	1960	(2)	160 ±4.5	80±1	120 ±5	BC or ES	
200	2720	—	161.5±4.5	80±1	121.5±4	ES	)
							)
300	4300	—	233 ±7	110±1.5	178 ±4	)	)
500	7700	—	233 ±7	110±1.5	178 ±4	)	) Clear
750	12400	—	300 ±9	150±1.5	225 ±8	) GES	)
1000	17300	—	300 ±9	150±1.5	225 ±8	)	)
1500	27500	—	335 ±9	170±1.5	250 ±8	)	)

Notes: (1) Other standard voltage ratings are 210, 230 and 250V.
(2) A 150W coiled-coil lamp will shortly be included in BS.161 with the following characteristics —

Lighting Design Lumens at 240V	2040
Overall Length (mm)	125±3.5
Diameter (mm)	68±1
Light Centre Length (mm)	90±5
Standard Cap	BC or ES
Standard Bulb Finish	Pearl

Appendix 4

Projector lamp data

Class and Reference Number	Rated Watts	Standard Voltages	Dimensions (mm) Maximum Diameter	Maximum Overall Length	Nominal Light Centre Length	Cap	Nominal Lumens	Objective Life (hours)
A1/165	25	25	19	52	20	BA15s	450	100
A1/17	50	8	33/44	96	47	P30s	—	25
A1/202	50	8	31	96	47	P30s	—	25
A1/219	50	12	26	78	35	BA15s	1200	25
A1/220	50	12	11.5	44	30	G6.35	1400	50
A1/225	50	240	26	67	35	B15s	675	100
A1/229	50	8	For relevant data see page 64			GZ6.35	—	50
A1/224	75	12	41/50	96	44	P35s	—	15
A1/230	75	12	For relevant data see page 64			GZ6.35	—	50
A1/186	100	12	26	78	35	BA15s	2800	25
A1/193	100	12	26	78	29.5	BA21s-4	2800	25
A1/203	100	12	41/50	95	44	P35s	—	25
A1/215	100	12	11	44	30	GY6.35	3000	50
A1/209	100	12	11	45	24	2-pin Ceramic	3000	50
A1/217	100	12	33	90.5	39.7	G17q	1800	300
A1/135	100	24	26	78	55	BA15d	2200	100
A1/4	100	12, 115, 240	26	135	55.5	P28s	1650*	25
A1/21	100	115, 240	26	78	35	B15s	1650*	25
A1/45	100	12	11.5	45	18	PG22	3000	50
A1/121	100	115, 240	26	78	35	B15d	1650*	25
A1/41	100	12	41/50	95	44	P35s	—	25
A1/231	100	12	For relevant data see page 64			GZ6.35	—	50
A1/18	150	21.5	39	81	39.7	G17q	—	25
A1/184	150	21.5	39	91	39.7	G17q	—	25
A1/194	150	21.5	48	86	39.7	G17q	—	25
A1/210	150	21.5	39	91	39.7	G17q	—	25
A1/211	150	21.5	39	91	39.7	G17q	—	25
A1/221	150	21.5	39	91	39.7	G17q	—	15
A1/212	150	24	33	103	39.7 max	G17q	4100	25
A1/216	150	24	13.5	50	32 max	G6.35	5000	50
A1/167	150	115, 240	26	90	35	B15s	2700*	25
A1/175	150	115, 240	26	135	55.5	P28s	2700*	25
A1/24	150	120, 125	42	81	39.7	G17q	—	15/25
A1/168	150	115, 240	26	90	35	B15d	2700*	25
A1/182	150	240	30	76	33.5	G17q	2700	25
A1/232	150	15	For relevant data see page 64			GZ6.35	—	50
A1/234	150	15	11.5	45	30.0	G6.35	4650	50
A1/238	150	240	30	76	33.5	G17q	—	25
A1/26	200	115, 240	26	90	35	B15s	4000*	25
A1/5	250	50, 115, 240	33	135	55.5	P28s	5200*	50
A1/223	250	24	13.5	55	33	G6.35	8500	50
A1/235	250	24	12.5	56	32	PG22	8500	50
A1/6	300	115, 240	33	135	55.5	P28s	6900*	25
A1/37	300	115, 240	28	105	35	B15s	6900*	25
A1/178	300	240	33	103	39.7	G17q	6900	25
A1/201	300	240	33	103	39.7	G17q	—	25
A1/183	300	115, 240	31	81	35	B15s	6900*	25
A1/226	375	30	For relevant data see page 64			R7s	7200	1000
A1/227	420	120	For relevant data see page 64			R7s	11000	75
A1/7	500	115, 240	33	135	55.5	P28s	11400*	25
A1/8	500	115, 240	66	135	55.5	P28s	11000*	50
A1/237	500	240	13.65	76	44.5	American Polarised 2-pin Ceramic	12500	50

Class and Reference Number	Rated Watts	Standard Voltages	Dimensions (mm) Maximum Diameter	Maximum Overall Length	Nominal Light Centre Length	Cap	Nominal Lumens	Objective Life (hours)
A1/47	500	115, 240	33	130	59	P38s	11400*	25
A1/180	500	240	33	103	39.7	G17q	11400	25
A1/205	500	240	33	103	39.7	G17q	—	25
A1/228	600	120, 240	For relevant data see page 64			R7s	16250*	75
A1/233	650	240	22.5	63	36.5	Special Polarised Bi-pin	16500	50
A1/187	750	110	51/39	140	55.5	P28s	18000	25
A1/52	750	115	37	153	81	P39s	19500	25
A1/53	750	115, 240	39	135	59	P46s	18000*	25
A1/9	750	115, 240	39	140	55.5	P28s	18000*	25
A1/206	750	115, 240	39	118	39.7	G17q	—	25
A1/30	750	115	64	140	55.5	P28s	16500	100
A1/57	1000	115, 240	66	240	120	E40	23000*	100
A1/58	1000	115, 240	66	140	55.5	P28s	25000*	25
A1/59	1000	115, 240	39	140	55.5	P28s	25000*	25
A1/91	1000	115, 240	39	135	59	P46s	25000*	25
A1/188	1000	115, 240	66	245	87	P40s	23000*	100
A1/199	1000	115, 240	39	118	39.7	G17q	25000*	25
A1/207	1000	115, 240	39	118	39.7	G17q	—	25
A1/208	1200	115	39	118	39.7	G17q	—	10
A1/218	2000	240	66	245	87	P40s	48000	100
B1/1	100	115, 240	82	125	76	E27	900*	800
B1/2	250	115, 240	82	125	76	E27	3100*	800
B1/7	250	115, 240	82	130	55.5	P28s	3100*	800
B1/3	500	115, 240	132	190	115	E40	7250*	800
B1/8	500	115, 240	122	175	108	E40	7500*	800
B1/4	1000	115, 240	132	190	115	E40	16500*	800
B1/15	1000	115, 240	135	200	84	P40s	16500*	800
B2/1	500	115, 240	132	275	202	E40	7250*	800
B2/2	1000	115, 240	152	309	225	E40	16500*	800
B2/5	1000	240	132	250	180	E40	18000	800
B2/6	1000	240	132	211	140	E40	18000	800
B2/3	1500	240	172	344	250	E40	26000	800
B2/7	1500	240	172	344	235	E40	29000	800
B2/8	1500	240	172	348	212	P40	26000	800
B2/4	2000	240	172	344	207	P40	42000	200
E/5	250	240	85	113.5	70.0	E27	4500	100
E/1	500	115, 240	105	145.0	60.0	P28	10300*	100
E/3	500	115, 240	105	145.0	85.0	E27	10300*	100
E/4	500	115, 240	100	140.0	55.5	P28	10300*	100
F/17	24	6	39	65	10±2**	B15d	410	100
F/10	24	6, 12	39	65	10±2**	E14	410	100
F/3	24	12	39	65	10±2**	B15d	440	100
F/23	30	6	39	69	10±2**	E27	450	200
F/56	30	6	40	70	7±2**	E27	425	200
F/26	30	6	39	65	10±2**	E14	450	200
F/74	30	6	36	63	45±1.5	E14	510	100
F/52	48	6	37	65	49±2	E14	800	100
F/58	48	6	40	65	7±2**	E14	675	200
F/59	48	6	40	70	7±2**	E27	675	200
F/81	48	6	39	63	41±0.5	P30s	675	200
F/75	48	8	41	68	45±2	E14	900	100
F/4	48	12	52	81	40±3	E14	950	100
F/13	48	12	52	78	38±5	E27	950	100
F/38	48	12	40	65	40±3	B15d	850	100

** Measured from crown of bulb

* Value for 240V rating

Class and Reference Number	Rated Watts	Standard Voltages	Dimensions (mm) Maximum Diameter	Maximum Overall Length	Nominal Light Centre Length	Cap	Nominal Lumens	Objective Life (hours)
F/76	50	12	40	72	33±0.25	BA20s	950	50
F/77	50	12	40	70	48±3	E14	950	50
F/40	100	6	61	95	55±5	B22	2000	100
F/14	100	12	62	91	55±5	E27	2250	100
F/63	100	12	62	98	37±0.5	P28s	2250	100
FL/4	250	115, 240	58	310	—	E27	3250*	1000
FL/1	500	115, 240	92	365	—	E40	7250*	1000
FL/2	1000	115, 240	92	405	—	E40	18000*	1000
FL/6	1000	115, 240	92	430	—	P40 Special	18000*	1000
FL/3	2000	240	92	430	—	P40 Special	45000	200
G/1	0.75	4	25.5	51	28.5±0.5	P30s	30	50
G/19	0.75	4	16.5	50	31.8±0.8	BA15s	30	50
G/27	0.75	4	16.5	50	28.5±0.5	P30s	30	50
G/29	0.75	4	16.5	50	28.5±0.5	P30s	30	50
G/31	0.75	4	25.5	51	28.5±0.5	P30d	30	50
G/33	0.8	6	18.5	74	31.5±0.5	PX28s	25	100
G/4	1.0	6	16.5	42	21.5±0.5	BA15s	80	100
G/5	1.0	6	16.5	50	28.5±0.5	P30s	80	100
G/40	1.0	6	16.5	57	28.5±0.5	P30s	80	100
G/46	2.0	6	26	52	36.0±0.5	BA15d	190	100
G/39	3.0	2.5	16.5	50	28.5±0.5	P30s	50	100
G/8	4.0	8	26	78	44.5±0.5	BA15s	650	100
G/9	4.0	8.5	26	78	44.5±0.5	BA15s	680	100
G/30	5.0	6	18.5	54	28.0±1.0	BA15s	525	100
G/45	5.0	6	19	54	23.0±0.25	P30s	450	100
G/10	5.0	10	26	78	37.3±0.5	P30s	1050	100
G/22	6.0	4	26	52	31.5±1.0	BA15s	400	100
G/23	6.5	5	26	78	41.0±0.5	P30s	600	50
G/13	7.5	10	26	78	37.3±0.5	P30s	1650	100
G/14	7.5	10	26	78	40.5±0.5	BA15s	1650	100
T/8	100	240	51	69	35	B15d	1200	200
T/3	250	240	82	124	55.5	P28s	4250	200
T/1	500	115, 240	102	140	55.5	P28s	9500*	200
T/7	500	240	96	140	55.5	P28s	6750	1000
T/2	1000	240	132	200	87	P40s	20000	200
T/4	1000	240	39	155	89	P28s	20000	200
T/6	1000	240	102	140	55.5	P28s	20000	200
T/9	1000	240	39	125	55	Gx9.5	23000	400

* Value for 240V rating

Class and Reference Number	Rated Watts	Standard Voltages	Dimensions (mm) Maximum Diameter	Maximum Overall Length	Nominal Light Centre Length	Cap	Nominal Lumens	Objective Life (hours)
CP LAMPS — COLOUR PHOTOGRAPHY								
CP/1	275	115, 240	61	110	—	B22d or E27	7500*	5— 8**
CP/2	500	115, 240	82	166	—	B22d or E27	14000*	15—20**
CP/3	1000	115, 240	151.5	309	—	E40	28000*	20—30**
CP/4	1500	115, 240	171.5	344	—	E40	42000*	25—50**
CP/14	10000	115, 240	272	440	254	G38	280000*	200
CP/20	2500+ 2500	240	154	228	143	GX38q	†BF117000 ‡SF 55000	100
CP/23	650	240	32	110	55	GX9.5	16800	75
CP/24	1000	240	32	110	55	GX9.5	26000	120
CP/29	5000	115, 240	75	280	165	G38	135000*	300 at 45°
CP/30	1250+ 1250	240	60	220	143	GX38q	†BF 53000 ‡SF 25000	150 at 45°
CP/32	2500+ 2500	240	70	220	143	GX38q	†BF117000 ‡SF 55000	150 at 45°
CP/33	650	115, 240	39	131	63.5	G22	16000*	50—70**
CP/34	2000	115, 240	66	247	127	G38	52000*	100
CP/35	5000	115, 240	121	378	165	G38	130000*	150
CP/39	650	240	32	140	63.5	G22	16800	75
CP/40	1000	240	32	140	63.5	G22	26000	120
CP/41	2000	240	39	210	127	G38	55000	200
CP/42	2000	240	154	246	127	G38	52000	100
CP/43	2000	240	40	135	70	GY16	52000	200

†BF — Both Filaments ‡SF — Single Filament * Values for 240V rating
Note: ** The smaller life refers to 240V, larger life to 115V

Class and Reference Number	Rated Watts	Standard Voltages	Dimensions (mm) Maximum Diameter	Maximum Overall Length	Nominal Light Centre Length	Cap	Nominal Lumens	Objective Life (hours)
CLASS P1 PHOTOGRAPHIC LIGHTING LAMPS FOR MONOCHROME & COLOUR FILM BALANCED FOR 3400° K (PHOTOFLOOD TYPES)								
P1/1	275	115, 240	61	110.0	—	BC or ES	8300*	3
P1/2	500	115, 240	82	166.0	—	BC or ES	15000*	6
P1/3	250	30	61	110.0	—	ES	8250	5
							Peak Intensities	
P1/5	275	115, 240	97	141.5	—	BC or ES	3300*	3
P1/6	375	240	97	141.5	—	BC or ES	13000	4
P1/7	500	115, 240	112	160.0	—	BC or ES	8000*	6
							Nominal Lumens	
P1/8	250	30	For relevant data see page 64			R7s	8000	12
P1/9	650	115	For relevant data see page 64			R7s	21000	12
P1/10	650	115	For relevant data see page 64			R7s	21000	15
P1/11	800	240	For relevant data see page 64			R7s	24500	12
P1/12	1000	240	For relevant data see page 64			R7s	33000	15
P1/13	650	240	23	65	36	G6.35	20000	15
P1/14	650	240	14·5	65	40±2	G6.35	20000	15
P1/15	1000	240	23	65	36	G6.35	32000	12
P1/16	850	115	23	65	36	G6.35	28000	15
P1/17	1250	240	23	80	—	GY9.5	40000	15

Class and Reference Number	Rated Watts	Standard Voltages	*Dimensions (mm)* Maximum Diameter	Maximum Overall Length	Nominal Light Centre Length	Cap	Nominal Lumens	Objective Life (hours)
CLASS P2 PHOTOGRAPHIC LIGHTING LAMPS FOR MONOCHROME & COLOUR FILM BALANCED FOR 3200° K								
P2/1	500	115, 240	89	183.5	—	ES	11000*	100
P2/2	1000	240	133	274.0	—	GES	22000	100
							Peak Intensities	
P2/3	500	115, 240	126.5	165.0	—	ES	3000*	100
P2/4	500	240	127.5	182.0	—	BC or ES	7200	12
P2/5	500	115, 240	127.5	182.0	—	ES	12000*	12—20**
							Nominal Lumens	
P2/6	650	115	For relevant data see page 64			R7s	17000	100
P2/7	1000	115,240	For relevant data see page 64			R7s	26000*	200
P2/9	2000	240	9.5	334.5	—	Fa4	58000	200
P2/10	625	240	For relevant data see page 64			R7s	15500	200
P2/11	800	115, 240	For relevant data see page 64			R7s	21600*	250
P2/12	1250	115, 240	For relevant data see page 64			R7s	33500*	200
P2/13	800	240	For relevant data see page 64			R7s	20000	50
P2/14	800	240	For relevant data see page 64			R7s	20000	50
P2/15	625	240	For relevant data see page 64			R7s	16250	75
P2/16	650	240	23	65	—	G6.35	17500	50
P2/17	1000	240	23	65	—	G6.35	28000	50
CLASS P3 — PHOTOGRAPHIC ENLARGER LAMPS								
P3/1	75	240	69	128.5	—	BC	690	1000
P3/2	100	240	69	128.5	—	BC	1000	1000
P3/3	75	115, 240	61	110.0	—	BC or ES	1150*	100
P3/4	150	115, 240	69	129.0	—	BC or ES	2500*	100
P3/5	100	240	61	108.5	—	BC	1500	100
P3/6	275	240	66	121.0	—	BC or ES	8800	3
P3/7	300	240	92	183.5	—	ES	5250	100
P3/8	500	115, 240	151.5	308.0	—	GES	7500*	1000

** The smaller life refers to 240V, the larger life to 115V   * Values for 240V rating

Class and Reference Number	Rated Watts	Standard Voltages	*Dimensions (mm)* Max. Clearance Length ±1.6	Nominal Contact Length	Max: Pip Protubce. from Bulb Axis	Max. Diameter	Cap	Nominal Lumens	Objective Life (hours)
CLASS K PROJECTOR LAMPS — TUNGSTEN-HALOGEN TYPES PRIMARILY USED FOR FLOODLIGHTING									
K/1	500	115, 240	117.6	114.2	10.2	12	R7s	9500	2000
K/2	750	240	178.1	174.1	10.2	12	R7s	14500	2000
K/3	750	240	189.1	185.7	10.2	12	R7s	14500	2000
K/4	1000	115, 240	189.1	185.7	10.2	12	R7s	21000	2000
K/5	1500	240	254.1	250.7	10.2	12	R7s	32000	2000
			Overall Length						
K/6	2000	240		334.5	10.2	12	Fa4	44000	2000

Lamp Reference Number	*DIMENSIONS (mm)*			
	B	*C*	*D*	*E*
A1/226	77 max.	73.6±1.6	12.5	13.0
A1/227	64 max.	60.3±1.6	12.5	13.0
A1/228	91.8 max.	88.4±1.6	12.5	13.0

Lamp Ref. Number	*DIMENSIONS (mm)*								
	A	*B*	*C*	*D*	*E*	*F*	*H*	*J*	*L*
A1/229	1±0.05	6.35±0.25	7.5 min.	49.7±0.3	24.85	42 max.	18.0±0.5	8.2±0.2	2 max.
A1/230	1±0.05	6.35±0.25	7.5 min.	49.7±0.3	24.85	42 max.	18.0±0.5	8.2±0.2	2 max.
A1/231	1±0.05	6.35±0.25	7.5 min.	49.7±0.3	24.85	42 max.	18.0±0.5	8.2±0.2	2 max.
A1/232	1±0.05	6.35±0.25	7.5 min.	49.7±0.3	24.85	42 max.	18.0±0.5	8.2±0.2	2 max.

Lamp Reference Number	*DIMENSIONS (mm)*			
	D Maximum	*E Maximum*	*B Maximum*	*C* ±1.6
P1/8	10.2	12	78.3	74.9
P1/9	11.4	15	78.3	74.9
P1/10	10.2	12	125.1	121.7
P1/11	11.4	15	78.3	74.9
P1/12	10.2	12	125.1	121.7
P2/6	11.4	15	78.3	74.9
P2/7	10.2	12	189.1	185.7
P2/10	10.2	12	189.1	185.7
P2/11	10.2	12	117.6	114.2
P2/12	10.2	12	189.1	185.7
P2/13	11.4	15	78.3	74.9
P2/14	12	13.5	93.5	90.2
P2/15	10.2	12	119.5	112.4

Appendix 5
List of British Standard Specifications for tungsten filament lamps, caps, and holders

B.S. No.	*Title*
52	Bayonet lamp caps, lampholders and BC adaptors (lampholder plugs).
98	Dimensions of screw lamp caps and lampholders (Edison type).
161	240V Tungsten filament general service electric lamps.
469	Electric lamps for railway signalling.
495	Lamp caps and lampholders for double capped tubular lamps.
535	Bulbs for miners' electric lamps.
555	Tungsten filament miscellaneous electric lamps.
841	Lamp caps and lampholders for architectural lamps.
867	Traction lamps (series burning).
941	Filament lamps for automobiles and cycles.
1015	Exciter lamps.
1050	Visual indicator lamps for use in telephone and telegraph switchboards, and for allied purposes.
1075	Studio spotlight lamps.
1164	Dimensions of prefocus lamp caps and lampholders.
1298	Lamp caps and holders for festoon lamps for voltages not exceeding 50.
1546	Electric lamps for lighthouses.
1929	Screw threads and external dimensions of lamps for endoscopic and diagnostic instruments.
E18	Aircraft landing lamps.
2G181	Electric lamps for aircraft.
G193	Aircraft lampholders.
AU40	Motor vehicle lighting and signalling equipment.

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