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LOW-WATTAGE MERCURY VAPOUR DISCHARGE LAMPS.

THE MODULATION OF THEIR LIGHT EMISSION BY LUMINESCENCE.

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On April 1st, 1937, two new high-pressure mercury vapour lamps were marketed, thus extending the range of this class of general purpose lamps by the introduction of a 125-watt and an 80-watt size. A photograph of the 125-watt size is reproduced in Fig. I.

The object of this article is to summarize briefly various considerations which led to the development of electric discharge lamps in general and more particularly those which led up to the recently marketed lamps referred to above.

General.

The electric discharge lamp has been known in commercial forms for at least 40 years. It is only during the past 7 years, however, that discharge lamps of compact form, high efficiency and long life, suitable for operation on ordinary supply mains voltages, have been available to the general public. Earlier types of discharge tube required voltages of the order of 2,000 to 10,000 volts for their operation, these voltages being generally supplied from a stray field transformer.

The current densities at which the sheet metal electrodes, common to ordinary neon signs, could be operated made it necessary to employ very low currents through the tubes themselves. For example, for a tube of 12 mm. diameter, a current not exceeding 30 milliamperes was in general use. Such low current values caused the luminous output per foot run of tube to be of an extremely low value and to be quite unsuitable for any other purpose than that of pure display.

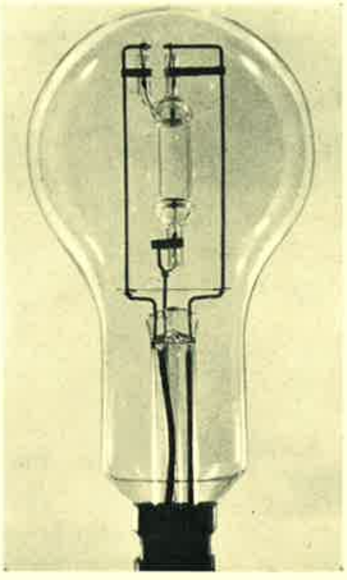

Fig. 1. New 125-watt high-pressure mercury vapour lamp.

Attempts to increase the current density in the cold cathode type of high-voltage sign tube led to rapid disintegration of the electrodes. The overall efficiences of such tubes were also not in effect greater than those obtained with the incandescent tungsten filament lamp.

In spite of the above-mentioned characteristics, it was the opinion of some of the people working on this aspect of the electrical discharge, that a discharge lamp would eventually be produced which would successfully compete with its forerunner, the tungsten filament lamp.

It was found that the cold cathode lamp could not be developed in high efficiencies and attention was therefore given to the development of a lamp operating with hot cathodes.

Some of the principles underlying the development of the many types of successful hot cathode discharge lamp known to-day have been described in previous articles in this journal. For the sake of completeness, however, certain features, common to most high-pressure discharge lamps, will be discussed in this article, especially in their relation to the recently introduced 80 and 125-watt Sieray discharge lamps. It will be convenient to consider these features under the following headings :—

(1) The envelope of the metal vapour discharge lamp.
(2) The electrode.
(3) The electrical characteristics.
(4) The nature of the light emission.

Under the heading (4) we will also consider the possibilities of modulation of this light by means of fluorescent powders.

Envelope of the Metal Vapour Discharge Lamp.

Early forms of electric discharge lamps utilised glass tubing whose main characteristics were that it could be bent into a variety of forms and that its co-efficient of expansion was such that the electrode lead wires could be sealed hermetically through its ends. The development of the high-pressure mercury vapour discharge lamp necessitated the production of new types of glass capable of withstanding the high thermal and electrical stresses produced in this lamp during the operation of the discharge arc.

Glasses similar to those sold under the trade name of "Pyrex" and "Monax" were first used in experimental Sieray lamps, and it was found necessary to use oxidised tungsten wires to produce an hermetic seal for the current leads through these early lamps. Although glasses of this type were found suitable from a mechanical point of view, they tended to darken rather rapidly during the first few hundred hours of the lamp's life, thus producing a diminution in the luminous output of the light source. The problem of developing more suitable hard glasses for the 400-watt mercury vapour discharge lamp was undertaken by certain glass technological laboratories with the result that these lamps are now made with bulbs which suffer little or no darkening at the temperatures which they attain in practice.

At higher temperatures, however, even these greatly improved boro-silicate glasses suffered a certain amount of surface decomposition during the life of the lamp. Attempts, therefore, to reduce the overall dimensions of the arc tube to produce a more compact light source were rendered impracticable by this deleterious effect. It was necessary, therefore, to find a glass having improved characteristics. The most chemically-simple of all glasses and, therefore, the one most likely to have improved characteristics from this point of view was quartz or pure fused silica. Preliminary experiments showed that quartz could be operated at temperatures up to 1000° C. without showing harmful discolorations. The high transmission of quartz to ultra violet radiation (utilised for a number of years in ultra violet lamps) rendered this material additionally suitable for the envelopes of hot cathode high-pressure mercury vapour discharge lamps when used in conjunction with luminescent materials. It was, therefore, chosen as the material for producing the 80 and 125-watt Sieray discharge lamps, and attention was given to the production of an hermetic seal between the quartz and the current-carrying leads. This matter has been discussed previously in this journal at some length and the exact method of manufacturing the quartz metal seal of these new lamps will be described in the next section of this paper.

The inner tube of the 125-watt lamp is similar in appearance to that of the 80-watt lamp, but slightly different from it in size. It is worked up from transparent quartz tubing into the form shown in Fig. 2, which is a photograph of the interior of the 125-watt Sieray quartz lamp.

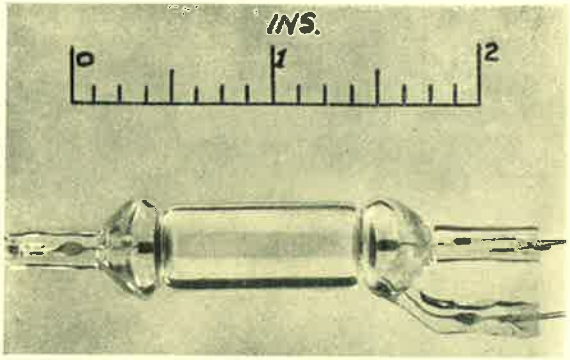

Fig. 2. Interior of the 125-watt Sieray quartz lamp.

Diaphragms, pierced with a small hole, are located in front of each main electrode and serve to confine spluttered electrode material to the ends of the discharge tube. The quartz interior is mounted inside a lamp bulb of standard shape and with a pearl finish. A photograph of a similar lamp, but with a clear bulb is shown in Fig. I. The auxiliary electrode is connected through one of the three lead-in wires of the lamp pinch through a high resistance (situated inside the lamp cap) to the opposite main electrode.

The following table itemizes the main features of these two new Sieray lamps :—

	80 watt.	**125 watt.**
Overall length ..	160±4·5 mm.	178±5·5 m.m.
Light centre length ..	120±4 mm.	133±5 m.m.
Bulb diameter ..	80±1 mm.	90±1 mm.
Cap	3-pin No. 121	3-pin No. 121
Initial Efficiency ..	38 lumens per watt.	40 lumens per watt.
Av. Effcy. over 1500 hrs.	30 ,, ,,	32 ,, ,,

Electrode.

The successful development of the hot cathode largely resulted from the work of Pirani of Berlin and American workers in this field, who made it possible for discharge lamps to be operated without the energy loss at the electrodes associated with the cold cathode.

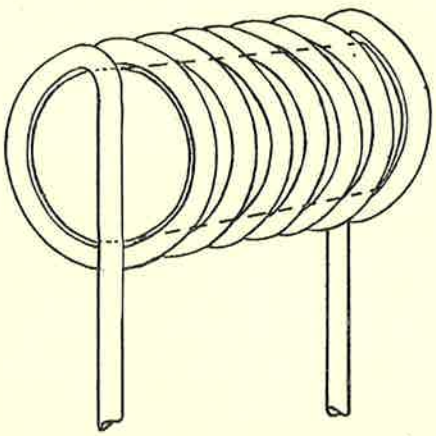

Fig. 3.

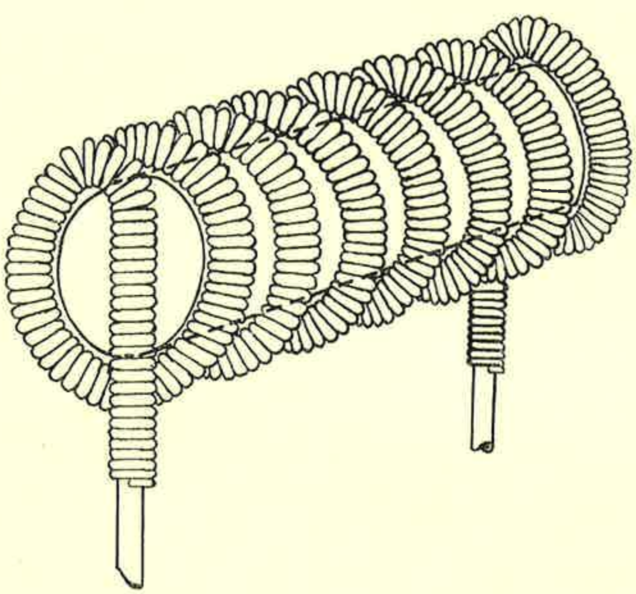

Fig. 4.

The emissive electrode or "hot cathode," as now used in most commercial forms of electric discharge lamp, consists of a short rod of alkaline earth material enclosed within a helix of tungsten wire which may be of simple structure, as shown in the diagram (Fig. 3), or may be of relatively complex arrangement, as shown in diagram Fig. 4.

It must be realised that these electrodes have to serve in alternate half cycles as anode and cathode. In the anodic half cycle the arc discharge plays on the surface of the tungsten helix, while in the cathodic half cycle the discharge locates about a spot produced on the surface of the highly emissive alkaline earth material.

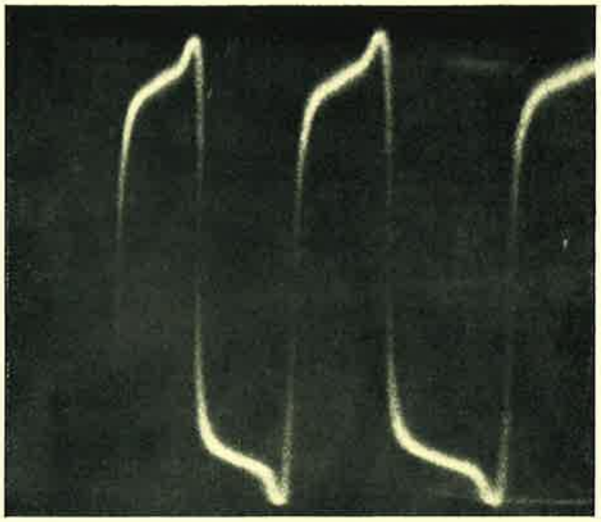

Fig. 5. Oscillogram of voltage wave.

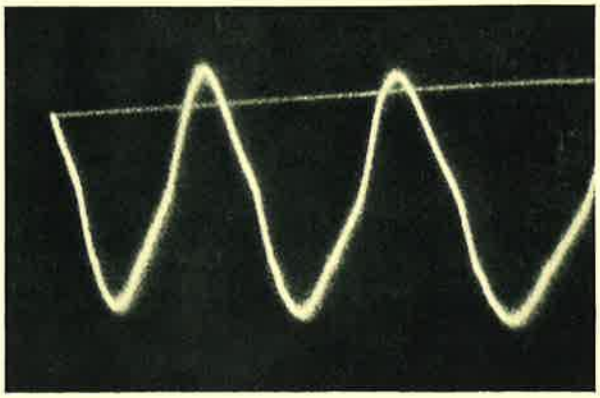

Fig. 6. Oscillogram of current wave.

Stroboscopic examination of the arc of the high-pressure mercury discharge lamp reveals that this alternation between cathodic and anodic function of the electrode is of primary importance and largely governs the successful operation of the lamp during life. Figures 5 and 6 are oscillograms of the voltage wave and current wave forms, respectively. In each half cycle the lamp voltage rises to a value somewhat in excess of the mean voltage, then drops again as the electrode reaches full emission.

The electrodes of all types of Sieray lamps are designed to give a good performance in both the anode and cathode half cycles. In the case of the new 80 and 125-watt lamps, the actual electrode design can be seen from the enlarged photograph of an electrode, shown in Fig. 7.

Fig. 7. Enlarged photograph of electrode.

It will be noticed that the electrode consists of a coiled coil of tungsten which encloses a short rod of electron emissive material. The relative position of the electrodes of a 125-watt quartz lamp and their disposition within the quartz envelope are illustrated in Fig. 2. The illustration also shows clearly the third electrode in proximity to one of the main electrodes and used for producing preliminary ionization to assist in the reliable starting of the lamp on mains voltage circuits. The electrode proper terminates in a lead wire of molybdenum which, after preparation, is sealed through the ends of the quartz envelope in the following manner :—

Construction of the Seal. The electrode with its leading-in wire is inserted into a special pressing machine which flattens the leading-in wire over a length of about 3 mm. into the shape shown in Fig. 7. The machine is designed so that a continuous change in the wire thickness is obtained until it merges into a foil-like section. A further reduction in the thickness of the centre portion of the flattened wire is then obtained by erosion of the wire in a special acid bath. The electrode and leading-in wire with its foliation is then inserted into a constricted quartz tube sealed to the end of the lamp envelope. The lamp, complete with two electrodes inserted into capillary ends as described above, is sealed to an exhaust system and pumped to a low pressure, after which the quartz tube is caused to collapse on to the foliated surface, whereby an hermetic seal is produced which has been found to be satisfactory under extreme temperature gradients.

The third electrode, whose purpose has been described above, is finally sealed into the quartz envelope at the completion of the exhaust process. It consists of a wire of refractory metal, foliated as described above, and inserted into the exhaust tube of the lamp so that its tip reaches to with 1—2 mms. from the end of the adjacent main electrode. During the exhaust process, which consists of a thorough out-gassing of the quartz envelope and electrodes, a small measured quantity of mercury is introduced into the lamp sufficient to produce a pressure of about 10 atmospheres when the lamp is in full operation.

Electrical Characteristics.

All types of metal vapour discharge lamps require a series ballast to prevent the current through the lamp rising catastrophically. This ballast may be in the form of a choke coil, or, as in the case of the Sieray Dual Lamp, a filament which supplies useful light while limiting the current. It has become general practice to operate Sieray lamps in series with a suitably designed choke coil. The choke coils for the 80 and 125-watt Sieray lamps have been designed by Messrs. Siemens Brothers & Co., Ltd., Woolwich, in conjunction with the Lamp Factory, and are numbered Y 21 and Y 22, respectively. Both chokes are of the same overall dimensions and are tapped for all supply voltages from 200 to 260 volts. The tappings are brought out to terminal blocks and are numbered :—

+5, 0, 200, 210, 220, 230, 240, 250, 260 volts.

The choke impedance is practically constant over the normal working range, and in the case of the Y 22 choke, the lamp starting current is 1.42 times the normal lamp current. The corresponding figure for the Y 21 choke is 1.35. The chokes are of adequate dimensions and have a watt loss, under normal operating conditions, as shown in the following table for the extreme cases:—

Tappings.	**Approximate Choke Watts.** Y. 21.	Y 22.
0—260	8·0	5·3
0—200	9·0	6·0

As is common with all types of high-pressure metal vapour discharge lamp, the Sieray 80 and 125-watt lamps require a few minutes, after the lamp is switched into circuit, for the full light output to be obtained. Fig. 8 shows the run-up characteristics of a typical 125-watt Sieray lamp, operating on a Y 21 choke coil, and the curves show the changes in lamp current, lamp voltage, lamp wattage and efficiency with time.

It will be seen that under normal working conditions the full light output is reached in approximately 5 minutes. When these lamps are switched out of circuit, they require a period of approximately 3 minutes before the arc will restrike, and after this restriking period full light output is reached in a much shorter period—of the order of 3 minutes. Fig. 8 also shows the behaviour of a typical lamp from the period of being switched into circuit, run-up to full brightnes, the circuit interrupted for 5 seconds and re-made, the period of darkness before the lamp restrikes and the time elapsing before full light output is again obtained.

The Nature of the Light Emission.

Considerations of the nature of the light emission from electric discharge lamps have led to discoveries of the first importance regarding the nature of matter itself. In this short account of some of the more important aspects of this subject it will be necessary for us to limit our attention to considerations of those properties of the radiation from 80 and 125-watt quartz lamps which are, or may become, of commercial importance.

Light Emission from the Quartz Interior Tube of 80 and 125-watt Sieray Lamps. The radiation from a Sieray quartz interior tube is extremely rich in those wavelengths commonly described as the ultra-violet region. When the lamp is first switched into circuit, it emits very low wavelength ultra violet radiation, producing intense erythemal effects. For this reason it is important that Sieray Q.H. type lamps should not be operated if the outer bulb becomes accidentally broken. A warning to this effect is enclosed in the carton of each lamp, as supplied by the makers. When the quartz tube has reached its full light emission, after a period of approximately 5 minutes, the lower wavelength ultra violet radiation is absorbed to some extent by processes occurring in the highly ionized metal vapour and there is a shift in the point of maximum energy radiation in the direction of decreasing frequency.

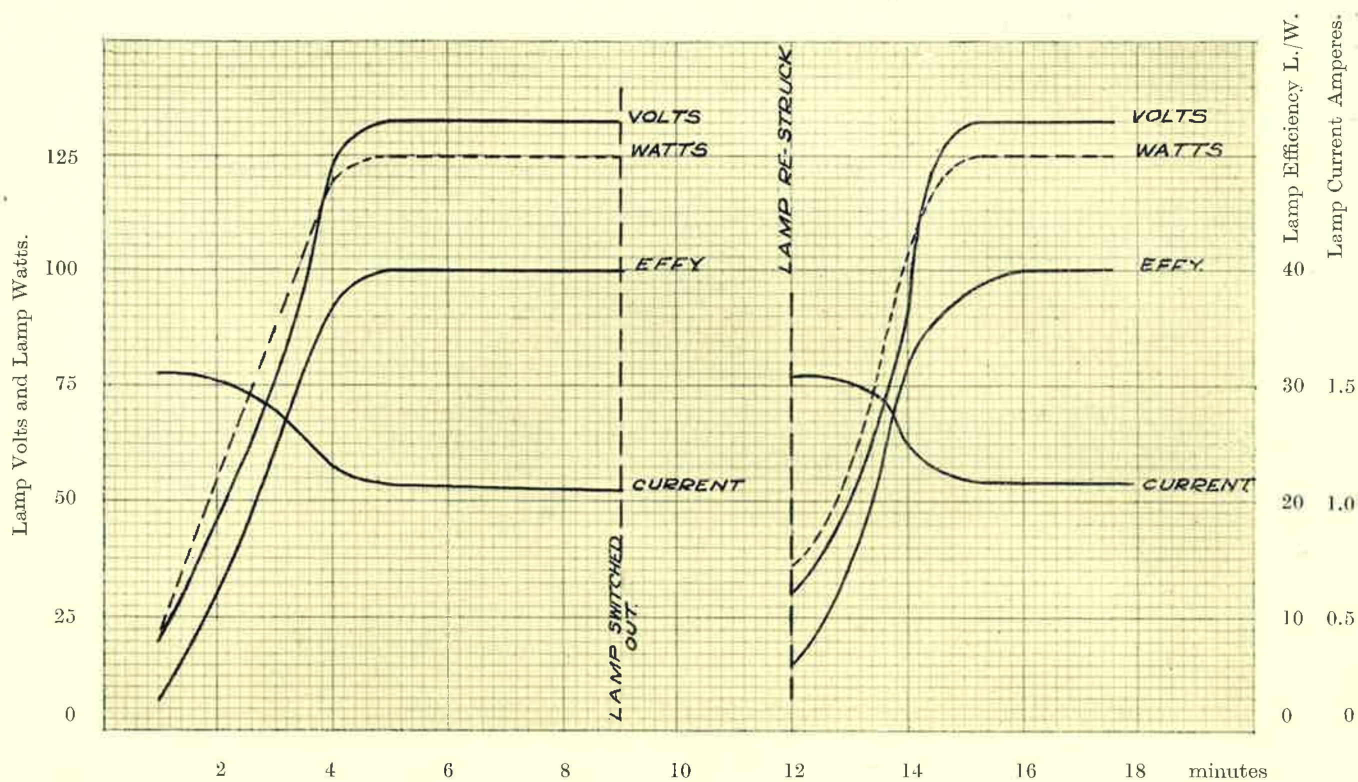

Fig. 8. Characteristics of 125-Watt Sieray Lamp, Type Q.H.

Under these conditions, the principal wavelengths at which light is emitted are :—

Angstrom Units.	
5790	Yellow
5461	Green
4960-4916	Blue-green
4358	Violet
4075-4047	Violet
3650	Ultra-violet
3132	,,
2967	,,
2804	,,
2653	,,
2537	,,

There is also a definite background of continuous radiation extending from the remote ultra-violet through the visible spectrum into the infra red. This spectrum is shown in Fig. 9.

Light Emission from the 80 and 125-watt Sieray Lamps complete with Pearl Outer Bulb. When analysed by means of a prism or spectroscope, the light from the complete 80 and 125-watt quartz lamps is similar to that described above, but little or no radiation below a wavelength of 3000 Angstrom Units is emitted. Radiation of wavelengths below this value is absorbed by the outer glass bulb, the erythemal value of the emitted light being quite low. The visible radiation is of a pleasing bluish-white colour when the source is being viewed directly. The colour composition of the light, however, is of such a nature that coloured objects, other than those of pronounced yellow, green or violet body colours, suffer considerable distortion. For many purposes, where adequate illumination is the most important factor, such colour distortion is of little or no importance, and the high efficiency of these new Sieray quartz lamps renders them of particular value for side street lighting, factory lighting, small flood-lighting installations and the like. Where good colour discrimination is essential, a combination of these lamps with tungsten filament lamps can be used to produce adequate colour rendering combined with a reasonably high efficiency of light production. Tungsten filament lamps should be used in combination with quartz lamps to give approximately the same total luminous output from each type of light source, as shown in the table below :—

One 80-watt Sieray Lamp, type Q.H.	Light output 3,040 L.
Two 100-watt Gasfilled Tungsten Filament Lamps.. ..	Light output 2,400 L.

A suitable combination for the 125-watt Sieray lamp would be :—

One 125-watt Sieray Lamp Type Q.H.	Light output 5,000 L.
Two 150-watt Gasfilled Tungsten Filament Lamps	Light output 4,000 L.

The above combination of Sieray lamps and gas-filled tungsten filament lamps will give a mixed light having a colour composition reasonably close to that of daylight. The overall efficiency of these combinations is of the order of 22 lumens per watt.

Investigation is proceeding into the production of a better light composition from Sieray quartz lamps on the lines of the well-known Sieray Dual Lamp, and also in other directions which are discussed in the following section.

Luminescent Powders.

When light is incident upon a body, in general some of the light is reflected from the body unchanged, while some proportion of the light is absorbed by the body and becomes transformed into heat energy. In the case of certain substances, however, there is a third possibility, *i.e.*, some of the light is absorbed and re-emitted as light of a different wavelength. This class of phenomenon is termed "fluorescence."

It has been found that in general the violet and ultra-violet portions of the spectrum are most active in producing flourescence. Among the substances which have been known for some year to exhibit this property, some of the most interesting are quinine compounds and other organic substances, such as fluorescein, rhodamine and eosin. Many mineral substances have also been known for a considerable time, such as Bolognian phosphorus or calcium sulphide, willemite and other minerals which fluoresce brilliantly when exposed to violet or ultra-violet radiation.

The phenomenon of fluorescence only continues so long as light is incident on the active substance. There is, however, a class of substance which continues to emit light after the incident light has been removed, and this light may or may not be of the same colour as that which was emitted when the original light was incident upon it. This phenomenon is called "phosphorescence." Prominent among phosphorescent substances are the sulphides of calcium, barium and strontium, and among substances of more recent development zinc cadmium sulphide occupies a prominent position.

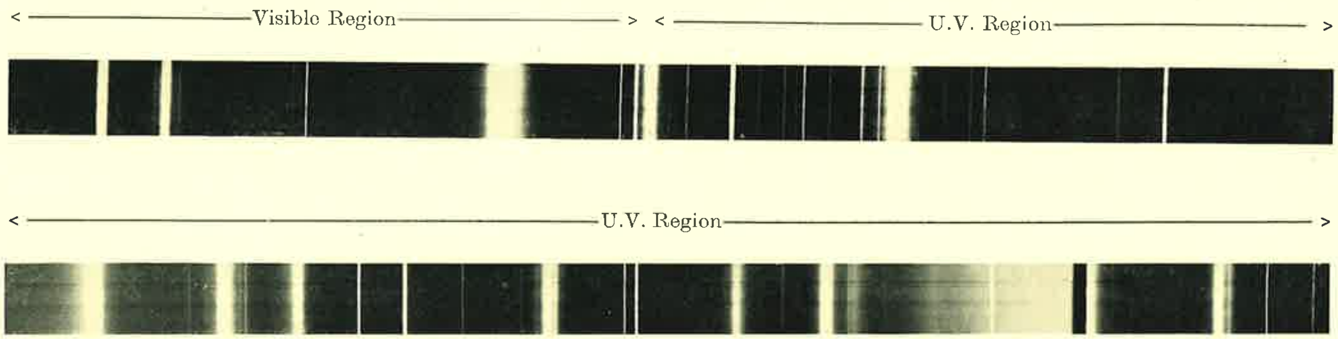

Fig. 9. Spectrum of the new high-pressure mercury vapour lamps.

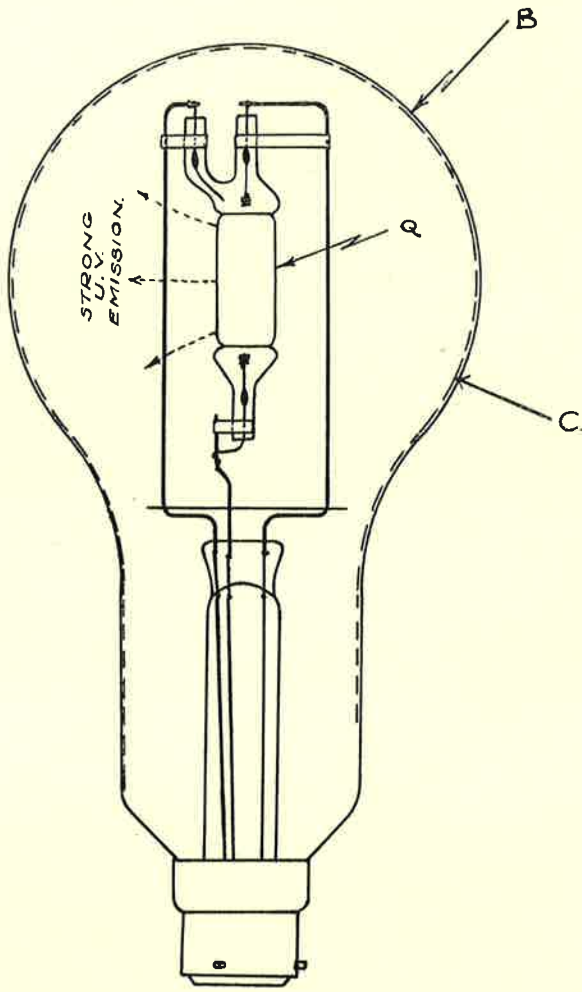

Fig. 10. Diagrammatic representation of the construction of the new high-pressure Sieray Quartz lamps.

Balmaines luminous paint is composed of a mixture of some of these alkaline earth sulphides and will continue to glow for some hours in a dark room after exposure to sunlight. This, and similar substances, have been used for a number of years for coating the dials of luminous watches and compass instruments.

A certain amount of confusion has been occasioned by the indiscriminate use of the terms " phosphorescence " and " fluorescence." The term " luminescence " is now coming into favour to include both the above phenomena, more especially where the emitted radiation is in the visible portion of the spectrum. It is generally found that the radiation emitted by the active substance is of a longer wavelength than that of the incident radiation. This fact was embodied in the well-known law enunciated by Stokes. A consideration of the quantal energy contents of the primary and secondary radiations leads us to expect the same result.

Luminescent powders, as now prepared on a commercial scale, are very much more efficient than those which were known even 5 years ago. This is the result of very intensive research work carried out in recent years. These powders are already being used commercially in high-voltage low-current discharge tubes for the production of a variety of pastel tints. In this method the luminescent powder is coated on the inner surface of the glass tube through which the discharge takes place and is activiated both by the ultra-violet radiation and by actual bombardment with gaseous ions.

In the case of high-pressure Sieray quartz lamps, experimental work is being carried out on the application of fluorescent powders and powder mixture to the inner surface of the glass bulb within which is mounted the mercury vapour lamp. A diagrammatic representation of such an arrangement is shown in Fig. 10.

A quartz lamp "Q" is mounted inside a glass bulb "B" on the inner surface of which is a coating "C" of luminescent powder. The coating is of such a nature as strongly to absorb ultra violet radiation from the quartz lamp and re-emit it as visible radiation which may cover some or all parts of the visible spectrum. In order to produce a satisfactory colour modulation, it is necessary to use luminescent powders which will fill up those portions of the spectrum which are deficient in the visible radiation from the mercury lamp. The powders are, therefore, required in the main to supply red and blue light in which the mercury discharge is deficient, as can easily be seen by reference to the spectrum produced in Fig. 9. Most substances which are capable of luminescing in the light from the mercury vapour lamp, emit a band type of spectrum. The human eye is much more sensitive to yellow light than it is to red light and hence the visual effect of red luminescence is to produce a dominating orange-yellow tint. As mercury light is already very rich in yellow and green lines, one of the effects of producing colour modulation by means of red luminescing powders is to give to the total light emitted from the luminescent lamp a distinctly yellow hue. For this reason it has been found necessary to use, in combination with powder luminescing in the red and orange portions of the spectrum, powders which also luminesce strongly in the blue. The use of the blue luminescent powders is made additionally necessary because of the fact that the powders used for supplying the red light have a pronounced yellow body colour and hence a definite absorption in the visible, which is usually in the blue.

A further fact which has emerged is that the density of the powder coating must not in general exceed that at which it cuts off more of the initial visible light than it supplies by transformation of the ultra violet.

It can thus be seen that a definite limit is set to the amount of colour modulation which can be produced by these luminescent powders, owing to the nature of the light which they emit. Nevertheless, it has been found possible, by the use of these powders, to increase the proportion of red in the light radiated from a 125-watt Q.H. lamp to 7 per cent. from its original value of 2 per cent., and yet maintain an efficiency of 40 lumens per watt.

Conclusion.

The development of improved electric discharge lamps both from the point of view of efficiency and colour is receiving attention in many laboratories. As a result of this, the number of types of lamp is ever increasing. It will be interesting to see whether in the future the electric discharge lamp will become a serious rival to the tungsten filament lamp or whether its use will be confined to certain important, but limited, applications. We venture to predict for it an ever expanding market.

Siemens Electric Lamps & Supplies Limited, London.