ELECTRIC DISCHARGE LAMPS

By

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Research Laboratories of
The General Electric Co. Ltd. of England

THE GENERAL ELECTRIC CO. LTD. OF ENGLAND
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JULY, 1941

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A TECHNICAL ACCOUNT OF
"OSIRA" LAMPS AND "OSRAM" FLUORESCENT TUBES AND THEIR
OPERATING EQUIPMENT, MANUFACTURED BY
THE GENERAL ELECTRIC CO. LTD.

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CONTENTS.

PREFACE.

In the following pages an account is given of the various "Osira" and "Osram" Electric Discharge Lamps which are now available and of the equipment used to operate them. It is hoped that this technical description will assist engineers and others who use these lamps to a better understanding of what is, after all, a highly technical product. The object of Part I, which deals with a number of general aspects of Discharge Lamps, is to prepare the reader for the detailed account of the lamps themselves given in subsequent sections.

Part II deals with High Pressure Mercury Vapour Discharge Lamps. The outstanding operational feature of these lamps is the considerable change which takes place in the electrical and luminous characteristics between starting and fully-run-up conditions. This necessitates careful design of the gear as well as of the lamps, and it has been considered worth while to deal somewhat fully with this aspect. Parts III and IV deal with Sodium Vapour Lamps and Colour Floodlighting Lamps respectively, while Part V is given over to the most recent discharge lamp, the "Osram" 80-watt Fluorescent Tube, which is a natural development of the low pressure mercury vapour colour floodlighting lamps described in Part IV, and of the well-known "Osira" High Voltage Fluorescent Tubes which have been used for interior lighting for many years past. These latter tubes are not discussed here since they have been adequately described elsewhere. The new "Osram" Fluorescent Tube may well prove to be as important a contribution to illuminating engineering as was the incandescent filament lamp.

A summary of the important practical characteristics of the lamps described in Parts II to V is given in Appendix I. This includes a reference to the page of the text giving the detailed characteristics and should prove a convenient index. Spectral energy distribution data for all the lamps used for general illumination are given in Appendix II. No attempt has been made to deal with the illuminating engineering aspects of discharge lamps. This is an important and rapidly growing subject which could not be dealt with adequately in a publication such as the present one. The services of G.E.C. Illuminating Engineers, whose experience in the installation and utilisation of electric discharge lamps is unrivalled, are freely placed at the disposal of all who need advice on their illumination problems.

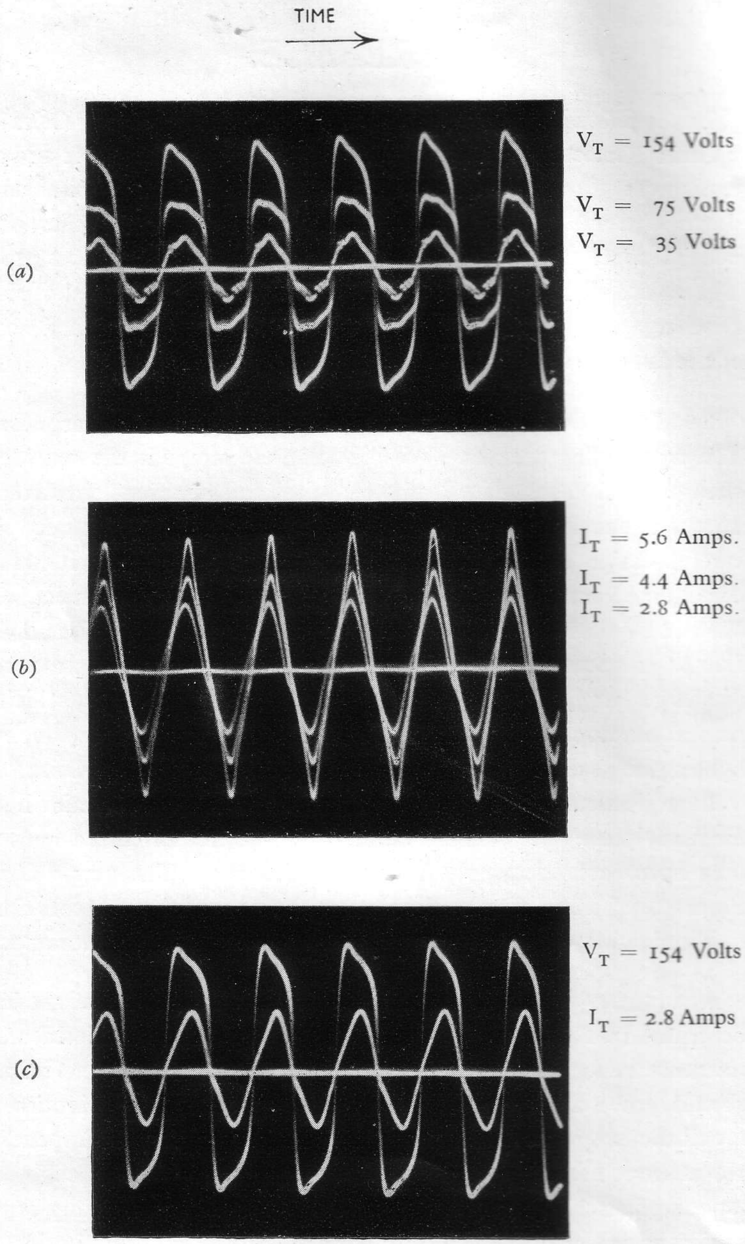


Fig. 3.—*Osira* 400*w. H.P.M.V. Lamp Voltage and Current Oscillograms.*

(*a*) *Tube Voltage at Three Stages During Running Up.*
(*b*) *Tube Current at Same Three Stages During Running Up.*
(*c*) *Tube Voltage and Current in Fully-Run-Up Condition.*

Part I—GENERAL.

The Production of Light.

Artificial light, in some primitive form—the flaming torch, the burning oil-fed wick—must have been one of the first needs of early man. For thousands of years the oil lamp had no serious rivals, and in its later developments it became a remarkably useful if somewhat inconvenient source of light.

As long as the only sources of steady electric current were voltaic cells or storage batteries, the arc between two slightly separated carbon pencils was limited in scope. With the coming of the dynamo, however, it became available for certain forms of public lighting; and when, in the early 'eighties of last century, the incandescent filament lamp began to be of practical use electric lighting entered an entirely new field. Since then the electrically heated filament, in a bulb either exhausted or containing rare gases, has been the basis of striking developments in what has become the science of illumination.

Within the last ten years research has brought the luminous discharge lamp, in which current passes through a gas or vapour contained in a tube or elongated bulb, from the stage of an interesting laboratory experiment to actual commercial use. The colour of the light thus given is governed largely by the nature of the gas within the tube and, in more recent discharge lamps, by the fluorescent coating used. The applications of this mode of electric lighting are rapidly increasing in number and variety and, in what follows, an attempt has been made to discuss the characteristics of the more important types of discharge lamps which are already in use in this country.

Even to-day, however, lamps considered as producers of light are very inefficient; much more energy is consumed than ultimately appears in the form of the light required. For this reason the primary object of those engaged in lamp research is the development of lamps which will produce useful light, not only most conveniently but also most efficiently.

The oldest illuminant, the sun, emits radiation corresponding to its effective surface temperature, which is in the neighbourhood of 5500°C. Early artificial illuminants, such as oil lamps and the candle, emit light owing to the incandescence of the carbon particles liberated by the incomplete combustion of their organic constituents. The same applies to the batswing gas flame. In modern coal gas lamps the light is emitted by the gas mantle which is heated to about 1650°C. by the almost non-luminous coal gas flame. Similarly, in the field of the carbon arc and filament lamps the emission of light is due to the high temperature to which their essential parts are raised.

It is thus clear that practical illuminants in the past have depended on what is now known as temperature radiation, that is the radiation emitted from heated solids. The characteristic of temperature radiation is that when analysed by a spectroscope it gives a continuous spectrum; in other words, there are no gaps in the range of frequencies or wavelengths emitted.

The radiation emitted from a discharge tube differs fundamentally from temperature radiation in that only certain wavelengths are emitted and the spectroscope shows each wavelength present as a sharply defined line, instead of a continuous band as in temperature radiation. When the number of lines is very large, however, they may be so close together as to appear almost continuous, except in powerful spectroscopes.

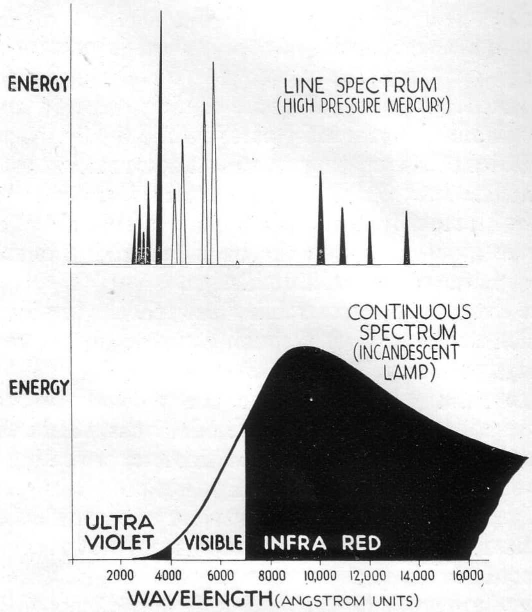


Fig. 1.—*Energy Distribution in Line and Continuous Spectra (not to same Scale).*

The lower portion of figure 1 represents the amount of radiation of each wavelength which is emitted by a hot filament. It will be seen that the amount of ultra-violet radiation is extremely small and that the energy radiated at each wavelength increases with the wavelength until a maximum is reached in the invisible infra-red. The peak moves towards the shorter wavelengths as the temperature is increased and at about 5500°C., the temperature of the sun, it occurs in the yellow green region. It will be seen that, since at all practical temperatures so much energy is wasted in the infra-red, temperature radiators are intrinsically inefficient, from the point of view of light production.

The upper portion of the diagram shows the corresponding energy spectrum of a high pressure discharge in mercury vapour. Here the energy is given out only at certain particular wavelengths and a far greater proportion of the radiated energy is emitted in the visible and ultra-violet regions of the spectrum than in the case of the hot solid. Also, as will be described later, the powerful ultra-violet lines in the spectrum may be transformed into useful light by means of fluorescence. It will be clear, therefore, that the electric discharge presents far greater possibilities of increased efficiency than temperature radiators such as the incandescent filament.

It can be shown that if it were possible to operate an incandescent lamp filament at 6200°C. so that the peak of the emission curve occurred in the green region of the spectrum at 5500A. where the eye is most sensitive, the luminous efficiency would be 84 lumens per watt—about seven times the efficiency of a modern 60-watt gasfilled filament lamp. If all the energy were radiated in the visible region to give a white light similar to sunlight and there was no loss in the infra-red or ultra-violet, then the efficiency would be about 230 lumens per watt. In actual practice, of course, the temperatures which can be used are limited not only by the melting point of the substances employed, but also by their rate of evaporation. All known bodies are vaporised at temperatures far below that corresponding to this optimum efficiency, so that even with tungsten, which, owing to its refractory nature is the most suitable of all the elements for lamp filaments, it is not possible to operate at temperatures much above 2500°C. It is for this reason that the maximum efficiency possible with any temperature radiator, consistent with reasonable life, is only of the order of 20 lumens per watt.

As has been stated, the radiation from discharges in gases differs fundamentally from temperature radiation in that only certain wavelengths are emitted and the important point is that these wavelengths are absolutely characteristic of the particular gas or vapour. Thus, in an electrically excited gas we are no longer necessarily under the restriction imposed on temperature radiators that only a continuous range of wavelengths must be emitted in which most of the energy is wasted in the invisible infra-red region. The possibility that a relatively high proportion of energy may be radiated in the visible range is now opened. On the other hand, many gases emit a large proportion of their spectrum lines in unwanted regions, so that only a few of those whose lines are suitably placed in the wavelength scale are of use as efficient light emitters.

We shall give later the distribution of energy in the spectra of a number of practical discharge lamps and it will be clear that in mercury as in other discharge tubes a large proportion of the input energy is wasted as heat. For this and similar reasons, the efficiency of even the best discharge lamps is only between about one-tenth and one-quarter of what one would expect from theoretical considerations. Nevertheless, recent discharge lamps enable much higher efficiencies to be obtained than are possible with practical temperature radiators. Also, as we shall see later, it is possible, by the use of luminescent material in conjunction with discharges, to obtain lamps of high efficiency giving light of extremely good colour rendering quality comparable with that of average daylight.

Historical Development of Discharges.

Although the gas discharge tube for purposes of advertisement and illumination is a very recent development, this source of light is historically much older than the more familiar tungsten filament lamp. Before 1800, experimenters, although they discovered many beautiful luminous effects, were not primarily interested in the luminous discharge as such. All their experiments were made with the object of studying the production or conduction of electricity in a partial vacuum; the light emitted was a pleasing, but entirely subsidiary, aspect of the phenomenon. From 1800 onwards, however, people began to take an interest in the discharge itself. Sir Humphry Davy investigated the different colours obtained by passing a discharge through partially evacuated vessels containing different vapours. Wollaston and Frauenhofer studied the discharge spectroscopically and showed that the spectra were materially different from that of sunlight. But it was the great experimental scientist Michael Faraday who, at the Royal Institution in 1838, first systematically studied the luminous discharge in gases at low pressure. In particular, he showed that the glow does not always extend continuously from one electrode to the other, but that dark spaces and striations sometimes appear. The dark space which occurs in the neighbourhood of the cathode at moderately low pressures still bears his name.

Faraday's experiments roused a widespread interest in discharge tube phenomena, and a further impetus was given to their study by the appearance of Rühmkorff's induction coil in 1851. For the first time a convenient and powerful source of high potential was thus made available and a little later a glass-blower of Jena named Geissler so perfected the technique of making up discharge tubes in a variety of attractive and spectacular forms that this type of demonstration tube has been known by his name ever since.

No practical use of discharge tubes was made until Moore began his researches on their value as illuminants in 1893, but it is true to say that such a use had long been foreshadowed and that Geissler's discharge tubes were among the earliest examples of artificial electric light. The first commercial installation of such a lighting system was carried out by Moore at Newark, New Jersey, U.S.A., in 1904. It consisted of a continuous tube 180 feet long and a high voltage transformer was used in place of the induction coil. An installation in the Court Yard of the Savoy Hotel, London, was erected a few years later. The gasfilling in these early installations was usually either carbon dioxide, which gives a whitish light, or nitrogen, which glows with a buff or golden colour. In each case the gas pressure falls during the life of the tube largely owing to chemical action between the gas and the electrode material and the light eventually fails unless some replenishing device for the gas is adopted. The automatic replenishers devised by Moore constituted his principal contribution to the problem. The whitish light from a carbon dioxide filled tube is a very fair approximation to daylight; such tubes, made into compact units, were developed in 1912 for colour matching and find continued use for this purpose at the present time.

So far only the common gases such as air, hydrogen, nitrogen, carbon dioxide, etc., had been used in discharge tubes, but further developments were made possible by the discovery of the group of inert gases (helium, neon, argon, krypton and xenon) by Rayleigh, and Ramsay and Travers. These gases are obtained by the fractional distillation of air. Helium is also obtained from certain minerals and from some natural gases.

The necessity for automatic replenishing devices, to overcome the gradual disappearance of the gasfilling in Moore tubes, was avoided by the use of these rare gases, which, owing to their chemical inertness, do not " clean-up " nearly so readily as the common gases. In particular, neon proved satisfactory and in 1910 Claude introduced large tubes filled with neon for display purposes. Their attractive red colour and higher luminous efficiency made them suitable for advertising and a further development lay at hand in the use of mercury as an addition to the rare gas ; this gave a bright blue colour to the discharge.

Tubes of a different type containing mercury and its vapour alone were developed by Arons in Germany and Cooper Hewitt in America which with suitable starting gear could be made to operate from comparatively low voltages. The luminous efficiency was fairly high but the light was completely lacking in red rays. Nevertheless, they have found many special uses, such as for studio lighting. Numerous attempts were made to improve the colour of the light emitted, and Wolke produced in 1912 an arc discharge lamp containing cadmium and mercury, which was somewhat better in this respect but for various reasons did not come into widespread use.

The most recent development is the hot cathode discharge lamp which allows a high intensity discharge to operate direct from the normal low voltage electrical supplies. Neon tubes of this type, for use as air beacons, were made in America in 1928 and work on similar lines has progressed in England and Germany where a wide range of such lamps, both gas- and vapour-filled, has been produced.

Mechanism of the Discharge.

Before discussing the later developments in electric discharge lamps and the great advances which have been made during the last few years, it is desirable to consider briefly the physics of the luminous discharge.

Each of the atoms of a material body is composed of a central positively charged nucleus round which circulate a number of elementary negative charges, or electrons as they are called. In normal circumstances, the negative charges just balance the positive charge on the nucleus, so that the atom as a whole is electrically neutral. If by some means an electron is removed from an atom the atom is left positively charged and is spoken of as a positive ion.

In a metal some of the electrons are free to move from one atom to another, so that if a potential difference is applied to the ends of a wire there will be a steady drift of electrons towards the positive end. This electron flow constitutes the observed current. The current passing through an ordinary 60-watt filament lamp corresponds to a flow of over a million million million electrons per second.

A discharge tube consists, in principle, of two electrodes, sealed into the ends of a glass tube containing a gas or vapour, generally at a pressure of a few millimetres. The gas consists of normal neutral atoms but, owing to the ionising action of cosmic radiation and traces of radioactive substances, a few ions are formed in each cubic centimetre of the gas every second. The number present is comparatively very small and they disappear, owing to recombination, at the same rate as they are formed.

When a potential difference is applied these primary ions begin to move towards the electrodes, the positives towards the negative electrode, or cathode, and the electrons towards the anode ; their velocities depend on the magnitude of the potential difference. This flow of ions constitutes a current so small that very special means have to be used to detect it.

In their passage through the gas, the ions continually collide with the neutral atoms in their track. At usual discharge tube pressures a collision will occur, on the average, about one hundred times in each centimetre of path. Various things, depending on the velocity of the impacting ion, may occur at the collision. As long as the velocity, and therefore the energy, of the ion is small, the collision is elastic. That is to say the ion rebounds from the atom, just as if both were perfectly elastic spheres ; their combined energy of motion is the same after as before the impact. If, however, the energy of the ion is somewhat greater than a certain critical value, energy is transferred from the ion to the atom, and this results in the displacement of one of the electrons of the atom to an exterior orbit. Any excess of energy over the critical amount needed for this shows itself as energy of motion, divided between the two particles. For each kind of atom there is a characteristic set of such critical energies, culminating in a value which corresponds to the complete removal of the electron from the atom. When an electron has been transferred to an external orbit, the atom is said to be in an excited state, while, when the electron has been completely removed, the atom is said to be ionised.

The energy which an electron possesses is generally denoted by the value of the potential difference through which it would have to fall in order to acquire that energy. The unit employed is the electron-volt, which is the energy gained by an electron in falling through a potential drop of one volt. The critical energies which we have just been discussing are accordingly expressed in these units and are therefore called excitation and ionisation potentials.

An ionising collision results in the formation of two new ions : the atom, now positively charged since it has lost an electron, and the free negatively charged electron which has been ejected from it. These new ions themselves move towards the electrodes and, on their way, generate others in a similar manner. Thus, if the applied voltage is sufficient to start the process, the number of ions present and the rate at which they are formed will rapidly increase and their flow will soon constitute a considerable current. Unless this current is limited by the nature of the external circuit, it will obviously continue to increase until it reaches values so large that the tube fails catastrophically.

It will be seen that the effective resistance of the tube decreases as the current increases, since more ions are formed by reason of the higher current. Similarly, if the current is limited by the external circuit, the tube voltage will, in general, be less the greater the value of the current allowed to pass. This is why discharge tubes are often spoken of as negative resistances, in contradistinction to metallic conductors, for which the potential difference increases with the current. It will also be seen that the potential required to start a discharge is greater than that required to maintain it.

Before leaving the question of how the discharge starts and the gas becomes conducting there is one further point to be considered, that is, the influence of the gas pressure on the starting voltage. It is easy to see that if the pressure is increased so that the atoms are relatively close together, fewer ionising collisions will occur, because the ions cannot gather sufficient speed between collisions unless the voltage is very high. On the other hand, if the pressure is reduced to a very low value, the atoms are so far apart that the chance of a collision becomes small. There will thus be some intermediate pressure at which the starting voltage will be a minimum.

If the discharge is initiated at about the lowest value of the starting voltage the pressure may be increased, while the tube is still operating and without extinguishing the discharge, to a value which would require a voltage many times the original voltage to restart the discharge. This is what actually happens in high pressure mercury vapour lamps, where the pressure of the gasfilling is only a few millimetres when the lamp is first switched on but builds up to a pressure of an atmosphere or more when the lamp is fully run up. As is well known, if the lamp is switched off momentarily while in the high pressure condition it cannot be restarted until it has cooled down, i.e. until the pressure has fallen to something close to its initial value.

The question now arises as to why the radiation from the discharge consists of fine lines when examined spectroscopically. We have seen that at collisions between atoms and ions, when the energy of the ion is greater than a certain critical value and less than the ionisation potential, the atom absorbs energy at the impact, i.e. becomes excited. It does not as a rule retain this excitation energy for any appreciable time but gives it up almost immediately in one of a variety of ways. The excited atom may strike the glass walls, in which case its energy is wasted as heat. Again, it may hand on its energy to other atoms either by exciting them or by increasing their velocity and in these instances too the energy may still ultimately appear in the form of heat. If, however, it does not collide either with other atoms or with the walls, it will emit its excitation energy in the form of radiation which may or may not be visible.

The law connecting the frequency υ of the light emitted in this way with the amount of energy E given up by the atom is one of the most fundamental in the whole of modern physics. It may be written—

$$E = h\nu = \frac{hc}{\lambda}$$

where h is known as Planck's universal constant, or the quantum of action, and c is the velocity of light. If λ is the wavelength in Angström units (1 A.= 10^{-8}cm.) and E, the excitation energy given up, is measured in electron volts, this becomes—

$$\lambda = \frac{12336}{E}$$

Thus, for example, the first excitation potential of the sodium atom is 2.1 volts and applying the above equation it is found that this corresponds to a wavelength 5890A., which is actually the wavelength of the sodium D lines.

In returning to normal from a highly excited state the atom may give up all its energy in one dose or it may return in a series of stages by way of various states of lower excitation. In this latter case it gives up its energy in a series of smaller doses, each corresponding to the energy difference between two states. These, by the fundamental equation, correspond each to a particular wavelength and therefore to a particular spectrum line.

It must not be imagined that the ways in which the atom can return to normal are entirely unrestricted. Actually, the possible paths open to it are governed by certain well-established laws known as "Selection Rules." Some of the ways are more frequently taken than others, and the intensity of a line is actually a measure of the number of excited atoms which return to the normal state by the particular path responsible for the line in question. The numbers of atoms returning to normal by any particular path, and hence the intensity of the particular spectrum line, are influenced by such things as tube current density, pressure of gasfilling, presence of other gases, etc. Thus in the low pressure mercury discharge about 60% of the input energy is emitted as the ultra-violet line at 2537A., and only about 1.5% is emitted in the visible region. In the high pressure mercury discharge, however, less than 1% of the input energy is emitted in the 2537 line, and some 10% is emitted in the visible part of the spectrum.

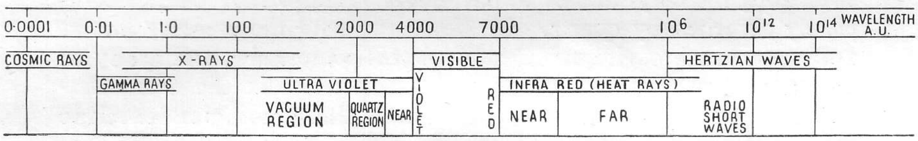
All the phenomena, which have taken so long to describe, are, of course, occurring simultaneously. Electrons and positive ions are moving about in all directions with huge velocities, the motion of the former having a bias towards the anode and that of the more ponderous positive ions towards the cathode. Every moment some of these ions are disappearing by recombination, chiefly when they strike the walls of the tube, while new ones, to take their place, are being formed by violent collisions with the millions of atoms present. Other atoms are being excited by less violent collisions and yet others are returning in various ways to states of lower excitation, thus emitting between them all the spectrum lines associated with the particular gas or vapour in the tube.

The Radiation Spectrum.

Radiation consists of electro-magnetic vibrations the frequency or wavelength of which determines its properties. Visible radiation, which comprises a relatively narrow range of wavelengths in the complete radiation spectrum, has the unique property of acting on the retina to produce the sensation we call light.

The unit of wavelength adopted for the visible and adjacent regions of the radiation spectrum is the Angström unit, which is one hundred millionth (10^{-8}) of a centimetre. On this scale the wavelength of violet light is about 4000 Angström units, which may be written 4000A., whilst that of deep red light is about 7500A.

The known radiation spectrum covers the enormous range of wavelengths from 10^{-4}A. to about 10^{14}A. This is shown in figure 2, in which the wavelength relationship of the different types of radiation is depicted diagrammatically. It should be realised that the different regions form a continuous wavelength or frequency scale and there are no sharp dividing lines between them; the properties of one region merge gradually into those of the adjacent regions.



THE RADIATION SPECTRUM

Fig. 2.—The Radiation Diagram (Wavelength Scale in Angström Units : 1 A.U. = 10^{-8} cm.).

Radiation of wavelength shorter than that of violet light, i.e. less than 4000A., is known as ultra-violet radiation. This name is applied to the whole spectrum down to wavelengths of a few Angström units, where the region of X rays commences. Below X rays occur the Gamma rays which are nothing more or less than "hard" X rays—that is to say X rays of short wavelength and high penetrating power emitted by radium and certain other radio active substances. Radiation of still shorter wavelength and of extreme penetrating power occurs in the so-called cosmic rays. This radiation appears to be produced in the outer atmosphere by fast particles of extra-terrestrial origin whose exact nature, however, is still somewhat in question.

At the other extremity of the visible spectrum, radiation of wavelength greater than 7500A. and extending to about 3×10^6A. is known as infra-red radiation (often referred to as "heat rays"). Above this region occur the wireless or Hertzian waves.

A brief survey of the different regions of the radiation spectrum will be helpful in showing how these are related. Cosmic rays are of very low intensity and have extreme penetrating power. The methods employed for their detection depend on the ionising effect produced by the rays in their passage through gases. The characteristic and well-known property of Gamma rays and X rays is the ease with which they pass through solid objects which are quite opaque to ordinary light. These rays exhibit strong photographic activity and excite fluorescence (see below) in suitable materials. Both these properties are regularly employed in their detection.

As the wavelength increases the penetrating power of the radiation decreases until the vacuum ultra-violet region is reached where the radiation is completely absorbed by a few cms. of air at ordinary pressure. Such radiation will affect a photographic plate, but the space between the source of the radiation and the plate must be virtually a vacuum and the plate itself must be treated to eliminate practically all the gelatine, which absorbs the rays before they can reach the silver salt. These rays also excite fluorescence under special conditions and the best known example of their use in this connection is in certain Osira Fluorescent Tubes containing neon, where the neon lines of wavelength about 740A. are responsible for the fluorescence.

As the wavelength increases still further, the penetrating power of the radiation increases again right up to the visible region. For example, the two strong mercury lines of wavelength about 1830A. are almost completely absorbed by quartz. On the other hand the mercury line at 2537A. passes through quartz readily, but is completely absorbed by an ordinary glass envelope. Another important line in the near ultra-violet mercury spectrum at 3650A. passes through a glass envelope without difficulty. All these wavelengths can be recorded on ordinary photographic plates and are capable of exciting strong fluorescence.

Passing through the visible spectrum the near infra-red is reached which it is possible to record photographically on special plates up to about 12,000A. Beyond the near infra-red it is necessary to employ other devices such as sensitive thermo-junctions, bolometers or radiometers to detect the radiation. Radiation of wavelength of the order of 10^6A. (0.1mm.), which may be regarded either as very long infra-red or as very short wireless waves, is difficult to detect. Bolometers and radiometers have been employed as in the case of shorter wave infra-red radiation, and it seems likely that modern developments will ultimately bring this region within the scope of short wave wireless technique.

The region from a few millimetres wavelength to about 10^{14}A. covers the well-known wireless waves, and radio valve detectors used for these waves are too familiar to need any mention here.

Fluorescence.

The phenomenon of fluorescence is of such importance in connection with modern electric discharge lamps that it is necessary to say a few words on the subject before discussing the lamps themselves.

When ultra-violet radiation falls on certain materials, these are sometimes seen to glow with a characteristic colour. In other words there is a transformation of invisible ultra-violet radiation into visible light. This phenomenon is known as fluorescence. Sometimes the fluorescent materials continue to glow for a time after the source of ultra-violet radiation has been cut off. This is known as phosphorescence; the term luminescence is used to describe both these phenomena. Sir George Stokes was one of the first workers to investigate luminescence in a fundamental way. In 1852 he discovered the important law of luminescence which bears his name. This simply states that fluorescent radiation is always of longer wavelength than the radiation which causes it.

The property of exhibiting luminescence is not confined to any particular class of substance. Actually nearly all substances fluoresce to some extent. However, the most important luminescent materials from the lamp point of view are the activated inorganic phosphors—so called because they all exhibit phosphorescence to a greater or lesser degree. These materials, although in powder form, all possess a crystalline structure, and their luminescent properties depend almost entirely on the presence of carefully controlled minute quantities of metallic impurities in the crystal lattice. The manufacture of fluorescent powders presents very difficult problems owing to the extreme care required to exclude all traces of accidental impurities. This becomes a serious difficulty owing to the fact that the powders have to be furnaced at a high temperature during manufacture.

The first commercial use of luminescent powders in discharge tubes in this country was made by Claude General Neon Lights Ltd., in 1933. These high tension fluorescent tubes were the forerunners of the new mains voltage fluorescent tubes described in a later section.

From the lamp point of view, luminescent powders may be divided into two classes :

(1) Those which are excited well by long wave U.V. (approx. 3650A.) ;

(2) Those which require short wave U.V. (approx. 2537A.) for their excitation.

Examples of class (1) are the well-known zinc sulphides and zinc cadmium sulphides activated by silver or copper. These powders, which are obtainable in a range of fluorescent colours from blue to red, are powerfully excited by the radiation from an Osira " black " glass lamp. (See Part II.) Some of these sulphides are strongly phosphorescent, although not so good in this respect as the alkaline earth sulphides. The latter, however, are of practically no interest for use in discharge lamps. Powders of class (2) comprise a range of compounds such as zinc silicate, zinc beryllium silicate, cadmium chlorophosphate, cadmium borate, magnesium tungstate, and many others, activated generally by manganese. These are not excited to any appreciable extent by the long wave U.V. radiation from Osira " black " glass lamps, but if placed inside a low pressure mercury vapour lamp, they are strongly excited by the powerful U.V. lines present in this discharge (see figure. 1).

The manner in which each of the above classes of luminescent material is ultilised in discharge lamps for modifying the colour and improving the efficiency will be discussed in later sections.

Practical Discharge Lamps.

Mention was made earlier of the negative resistance characteristic of discharges and of the need for limiting the current when the discharge has started. For direct current discharges this current limiting device usually takes the form of a simple resistance, which dissipates a considerable fraction (generally more than half) of the total watts consumed in the circuit. For alternating current discharges the current limiting device may be a choke coil and it is generally necessary to have a separate choke for each lamp. A properly designed choke coil consumes but little energy although the lagging current produced by its use lowers the power factor of the installation. As will be seen later, however, this can be remedied by the use of a compensating condenser in the circuit.

The appearance of a discharge excited by a.c. is different in detail from that presented by the d.c. discharge. To a first order of approximation, however, conditions inside a tube operating on a.c. of ordinary commercial frequencies are the same as when steady d.c. is used, except that the anode and cathode interchange each half cycle, the various parts of the discharge changing their positions in the tube with the change in polarity.

As with d.c., the voltage required to start the a.c. discharge is greater than that required to maintain it. Since the applied potential and current go through zero once each half cycle the discharge must extinguish and restart 100 times per second on a normal 50 cycle supply. This restarting of the discharge each half cycle requires a much lower voltage than the initial starting voltage, because the ions already present in the tube do not have time to disappear by recombinations, etc. in the very brief moment during which the current is zero.

Typical tube voltage and current oscillograms, at three stages during the running up of an Osira 400-watt high pressure mercury vapour discharge lamp, are shown in figure 3, page 4. It will be observed that the tube voltage and current, at any given time during the run-up period, pass through zero at the same instant (see for example figure 3(c) which shows the tube voltage and current in the fully-run-up condition). There is a slight phase shift of the tube voltage and current as the tube runs up, the final condition being slightly in advance of the initial. This is due to an increase in the tube voltage during the run up. It will be seen from figure 3(c) that the voltage rises steeply from zero to a peak which may be regarded as the restarting potential referred to above. The negative characteristic of the discharge is evident from the subsequent fall in the tube voltage while the tube current continues to increase to its peak value.

Perhaps the best known type of commercial discharge tube is the familiar so-called Neon sign. This consists of a long tubular envelope usually between 10 and 30mm. in diameter, with a simple metal electrode at each end. The electrode is generally of iron or nickel in the form of a cylinder about 2in. long by $\frac{1}{2}$in. in diameter. Tubes of this type require to be run with a high tension transformer which is often of the stray field type giving a high potential to start the discharge. The operating current rarely exceeds about 50 milliamperes, at which current the electrodes run cold. It is for this reason that these tubes are often referred to as cold cathode tubes. Increasing the current through a cold cathode tube would, of course, increase its light output, but the life of the tube would be seriously affected owing to disappearance of the gasfilling, which occurs rapidly if cold cathodes are overrun.

The trouble due to disappearance of the gasfilling, or as it is termed "gas clean up," can be obviated if the electrodes can be made to emit electrons freely. This is achieved by taking advantage of the electron emissive properties of heated alkaline earth oxides. One of the simplest forms of oxide electrode is shown in figure 4. It consists of a stick of sintered oxides surrounded by a spiral of tungsten wire through which a current may be passed to heat the oxide stick. In general it is not necessary to continue heating the electrodes once the lamp is alight, since the discharge itself maintains them at the requisite temperature. By the use of electrodes such as these, high currents of 50 to 100 times those used in neon signs, can be carried satisfactorily. Also, the watts lost at the cathode due to the cathode fall of potential, which is an inevitable accompaniment of a discharge, are considerably reduced by the use of oxide electrodes, as is the voltage required to initiate the discharge.

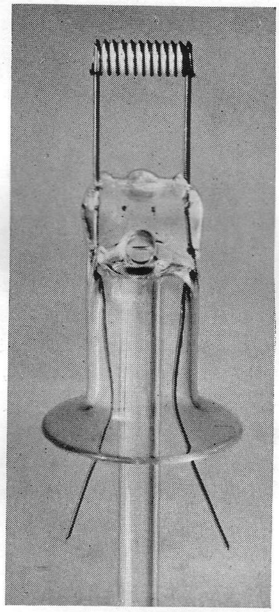


Fig. 4.—Heated Oxide Cathode.

Owing to the increased brightness and lower starting voltages which are made possible by hot cathodes, tubes giving an adequate light output and running directly on ordinary supply voltages have become a practicable possibility.

Of all the possible gasfillings for hot cathode discharge lamps, mercury vapour and sodium vapour are by far the most valuable. The vapour pressures of both mercury and sodium at ordinary room temperatures are too low to permit a discharge through lamps containing them to be started readily, so that these lamps usually contain, in addition to the mercury or sodium, a few millimetres pressure of argon or neon which enable the discharge to start at a reasonable voltage. The current passing through the rare gas heats up the tube, thus increasing the vapour pressure of the mercury or sodium. The spectra of the metal very soon suppresses that of the rare gas and dominates the discharge.

Discharge lamps may conveniently be divided into high and low pressure types according to the pressure of the gasfilling during normal operation. High pressure lamps, which invariably contain mercury as the main filling, always operate at low pressure when the discharge is first started, but the lamps are so designed that the vapour pressure of the mercury builds up to a final pre-arranged value (which may be many atmospheres in some lamps) as the temperature of the discharge envelope increases.

Low pressure discharge lamps contain either mercury, sodium, or neon, and in all these types there is little change in the total pressure of the gasfilling between starting and fully-run-up conditions. Sodium lamps operate at much higher temperatures than do the other two, the tube wall temperature being close to 300°C. when the lamp is burning normally. The operating temperature of neon and mercury-filled low pressure lamps rarely exceeds 60°C., and is generally considerably lower.

Part II.—OSIRA HIGH PRESSURE MERCURY VAPOUR DISCHARGE LAMPS.

General Description.

High pressure mercury vapour discharge lamps of the types discussed here consist essentially of a discharge envelope enclosed in an outer bulb of ordinary glass. The discharge envelope may be of hard glass or of quartz according to the temperature which it attains during normal operation. Except where special precautions are taken as described later, glass lamps must be operated vertically to prevent the discharge touching the walls which would thereby become overheated.

The outer bulb absorbs all harmful ultra-violet radiation which the discharge envelope may allow to pass. The space between the discharge envelope and the outer bulb is either completely or partially evacuated to prevent undue loss of heat from the discharge and to keep the temperature as uniform as possible. The inner tube contains a rare gas such as argon at a pressure of about a hundredth of an atmosphere together with a carefully controlled quantity of mercury. The mercury

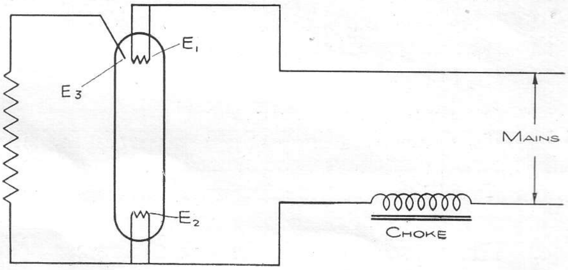


Fig. 5.—Auxiliary Electrode Principle.

is completely vaporised when the discharge is fully run up and the quantity is adjusted so that the voltage across the lamp terminals shall be between closely defined limits. The electrodes are similar in principle to that shown in figure 4, but no independent electrode heating is necessary.

In order to facilitate the starting of the discharge what is known as an auxiliary electrode is used. This consists of a piece of fine wire in close proximity to an electrode and connected through a high resistance R (figure 5) concealed in the lamp itself to the electrode at the other end of the lamp. Figure 5 shows the way in which the auxiliary electrode (E_3) functions. When the switch is first " made " the lamp receives the full voltage of the mains across the electrodes E_1 and E_2. Since the latter are not yet hot, the voltage is usually insufficient to start the discharge. However, it will be clear from the figure that the full mains voltage is also applied between the auxiliary electrode E_3 and the adjacent main electrode E_1. These are so close together that a glow discharge takes place between them, the current of which is limited to a few milliamperes by the resistance R. This glow discharge supplies sufficient ions to enable the main discharge to start.

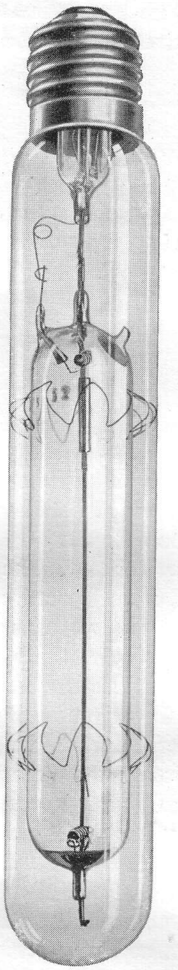


Fig. 6.—Osira 400w. H.P.M.V. Lamp.

As is the case with other discharge lamps operating on a.c. supplies the light intensity of h.p.m.v. lamps falls to a low value twice each cycle as the tube current passes through zero. Although the period of low intensity is very short a sensation of flicker is sometimes observed in rapidly moving objects viewed in the light from discharge sources. At low levels of illumination such as are normally used for street lighting the flicker, or stroboscopic effect as it is sometimes called, is not perceptible.

Even at higher brightness levels the effect is not objectionable except in certain cases where the lamps are used to illuminate moving machinery. In these cases the flicker can be largely eliminated by operating the lamps on multi-phase supplies as mentioned in Part V, page 57. Radio interference from h.p.m.v. lamps will rarely be experienced except possibly when the lamps are used in the immediate neighbourhood of a sensitive receiver. The inclusion of a simple filter will generally suffice to cure such interference.

250*w.* and 400*w.* Glass H.P.M.V. Lamps.

The first Osira high pressure mercury vapour lamp was put into operation on June 22nd, 1932, for street lighting in the G.E.C. installation in East Lane, Wembley. This was the first public lighting installation in the world to employ lamps of this type. The lamps used were the Osira 400w. h.p.m.v. lamps. The constructional details of the modern version of this type of lamp are shown in figure 6; the 250w. rating is similar. Technical data for both ratings are given in table 1.

The approximate distribution of energy throughout the spectrum is given in Appendix II.

TABLE I.

Technical Data for Osira 250w. and 400w. H.P.M.V. Lamps.

Lamp watts	250	400
Supply voltage	200–250 A.C.	200–250 A.C.
Efficiency in L/W Initial	36	45
Max. brightness of arc candles/cm.^{2}	150	150
Overall length mm.	290 ± 10	330 ± 8
Light centre length mm.	170 ± 8	190 ± 8
Arc length mm.	120	160
Diameter of outer bulb mm.	48 ± 3	48 ± 3
Cap	G.E.S	G.E.S.
Outer bulb	Clear	Clear

The discharge envelopes, which are filled with a predetermined quantity of mercury and a few millimetres pressure of argon, are made from a special hard glass which withstands the temperature of about 600°C. attained during operation. When the supply voltage is first switched on the mercury vapour pressure is only a small fraction of a millimetre corresponding to the ambient temperature. The discharge starts by means of the auxiliary electrode as described above.

As the lamp warms up more mercury is vaporised thus increasing the pressure and the luminous column, which in the low pressure condition practically fills the discharge envelope, becomes narrower and brighter. The lamp reaches full brilliancy when the mercury filling is completely vaporised; this takes about 4 or 5 minutes. The pressure of the mercury vapour when fully run up is approximately one atmosphere in the glass envelope lamps.

The circuit employed is extremely simple the only requirement being a choke coil, in series with the lamp to limit the current. Each lamp requires its own choke and a special choke is made for each lamp rating. A condenser may be placed across the mains to raise the power factor to the required value; without it the value would be only 0.6. The total losses in the choke coil and condenser amount only to 5 per cent., that is, 20 watts on the 400 watts which the larger lamp consumes. The electrical characteristics of the lamps and gear are discussed more fully in a later section.

The light source in these lamps is, of course, the narrow, bright column between the electrodes. The average brightness of this column, which is closely the same for both ratings of lamp, is approximately 120 candles per cm^2.* As would be expected, the column is brighter at the middle than at the edges, the values across the arc stream mid-way between the electrodes of the 400w. lamp varying, for example, as shown in figure 7. Towards the electrodes the column becomes slightly

* Compare with brightness of :—
Tungsten filament of 500 watt lamp = 500 candles per cm^2.
Pure carbon arc = 15,000 candles per cm^2.

narrower than it is at the middle and the brightness distribution is also somewhat altered.

An accurate description of the width of the column cannot be given, as its boundary is not clearly defined. The application of a common

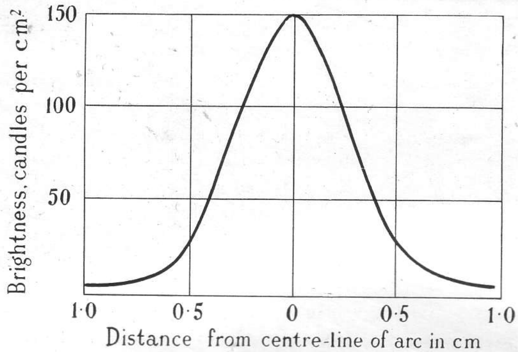


Fig. 7.—Distribution of Brightness Across Arc Stream of Osira 400w. H.P.M.V. Lamps (Internal Diameter of Tube = 30mm.).

definition employed for allied problems in illuminating engineering suggests that the edge of the column could be considered to be the point at which the brightness is one-tenth of the maximum. By this definition, as will be seen from figure 7, the width of the column in the 400w. lamp is approximately 12mm. and the corresponding width in the 250w. lamp is 9mm. It is interesting to note that when the lamps are viewed casually at close quarters, the effectively bright part of the discharge appears to be considerably narrower than the above figures suggest.

It will be seen that the light column of the 250w. lamp has dimensions three-quarters of those of the 400w. lamp. As the brightness is substantially the same for the two, the intensity in any direction and the light output will be functions of the projected area of light source and the intensity of the smaller lamp will be (0.75^2) or approximately half that of the larger.

The light distribution from the lamps compared with that of a 500w. tungsten lamp is shown in figure 8 as a polar curve in a plane containing the lamp axis, and has a form which would be expected from the shape of the source. The mercury discharge radiates more or less as though it were an incandescent solid, and the luminous intensity is therefore proportional to the projected area in any direction. If the lamp is considered to be in its usual position with the axis vertical, the curve shown refers to a vertical plane. The intensity is a maximum in a horizontal direction and falls off as the angle from the horizontal increases, having a low value in the direction of the downward vertical (if the lamp is considered to be burning cap-up) and zero in the opposite upward direction. The curve relates to a 400w. lamp giving 18,000 lumens, and to convert the values to those applying to the 250w. lamp giving 9,000 lumens, the ordinates should be halved.

The spectrum of a high pressure lamp differs a good deal from that of a low pressure one. Figures 9(a) and (b) compare the visible spectra of the two types. The green and yellow lines at 5461A. and 5770/91A. are much stronger in the h.p.m.v. spectrum than in that of the low

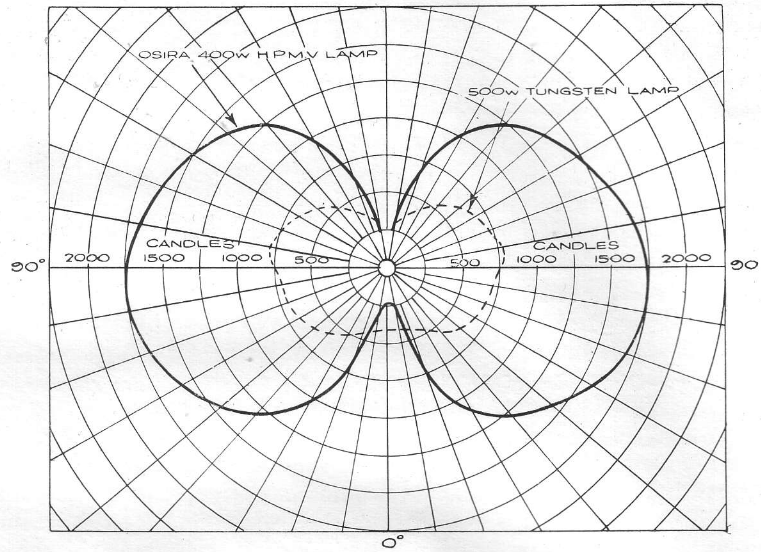


Fig. 8.—Polar Curve Showing Light Distribution in Vertical Plane for Osira 400w. H.P.M.V. and 500w. Tungsten Filament Lamps.

pressure discharge. The high pressure spectrum has in addition a background of continuous radiation and a number of fainter lines in the green, yellow, and red.

The colour of the light from the high pressure lamp may appear white, blue, blue-green, or green, depending on the condition of the observer's eyes, his distance from the lamp, the presence of other light sources, and the colour of the surroundings. It is a common experience that after a

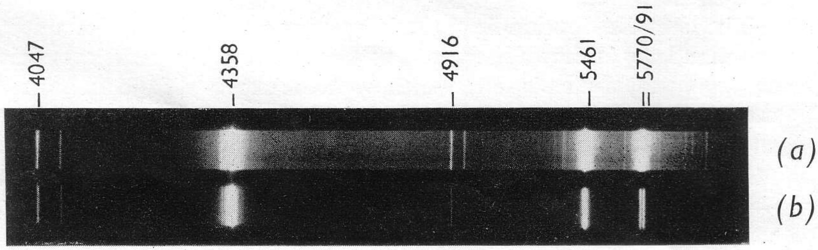


Fig. 9.—Mercury Vapour Discharge Spectra.
(*a*) *High Pressure.* (*b*) *Low Pressure.* (*Wavelengths in Angström Units.*)

few minutes in this light the eye adapts itself and the colour appears white, but blue-green is probably the best general description which can be given for comparison with other sources. The colour rendering of blues, greens, and yellows, under the light from the lamps is good, but red colours look brownish on account of the smallness of the red component in the radiation.

Early in the application of the lamps, some potential users were apprehensive of the colour effects produced, especially in shopping and residential areas. For most street-lighting and industrial purposes experience has shown that the colour of the lamps is no drawback. However there are some cases where the deficiency in red radiation from the lamp is a disadvantage.

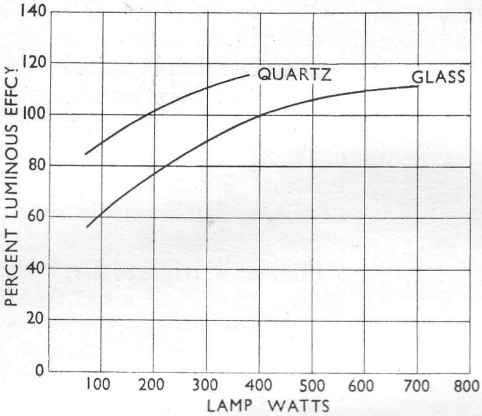


Fig. 10.—Wattage-Efficiency Relationship for Glass and Quartz H.P.M.V. Lamps (efficiency of 400w. lamp taken as 100%).

Colour modification has been achieved by the introduction of cadmium into the mercury, by the incorporation of a tungsten filament in the outer bulb of the mercury lamp itself and by the use of auxiliary tungsten-filament lamps. These methods can only be justified in circumstances where colour is of primary importance, since they involve a considerable reduction in the overall efficiency of the unit. A more successful method of colour modification of h.p.m.v. lamps is by the use of fluorescence. This method, which is described below, has been applied not only to the 400w. h.p.m.v. lamp, but also to the 80w. and 125w. quartz types.

80w. and 125w. Quartz H.P.M.V. Lamps.

In Osira 250w. and 400w. h.p.m.v. lamps the watts per cm. of arc are 20–25, and the operating pressure of the mercury vapour about one atmosphere. To obtain high efficiencies in lamps of lower wattage rating, it is necessary to increase the loading per cm. of arc and also the pressure.

This results in an increase of the operating temperature of the discharge envelope to a degree which even the special hard glass used in the 250w. and 400w. lamps is unable to withstand.

To overcome this the discharge envelope is made of quartz which, owing to its refractory nature, enables the diameter as well as the length to be reduced, thus making the lamp very compact. The advantage gained by the use of higher loading per cm. of arc and higher pressure, made possible by the use of quartz, is clearly shown by the curves in figure 10 which give the wattage-efficiency relationship for glass and for quartz h.p.m.v. lamps. Apart from the considerations mentioned above it is very desirable to keep the discharge envelopes of quartz lamps small on account of the high cost of this material. It is for this reason that 250w. and 400w. h.p.m.v. lamps are made from hard glass rather than quartz in spite of the gain in efficiency which quartz would give.

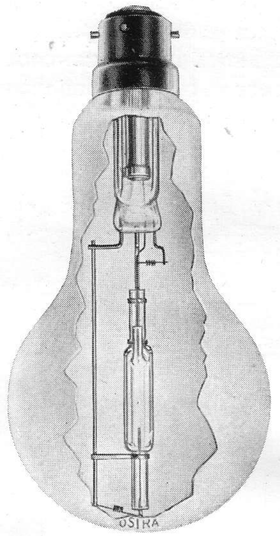


Fig. 11.—Osira 80w. and 125w. H.P.M.V. Lamps.

The first Osira quartz h.p.m.v. lamps were put on the market on April 1st, 1937. These comprised an 80w. and a 125w. lamp operating at a mercury vapour pressure of 5 to 10 atmospheres. Figure 11 shows the constructional details, and table 2 gives technical data of recent versions of these lamps, which are similar in principle to the glass types described above. It will be noted that the cap used is a 3-pin bayonet type the object of which is to prevent the lamp being inserted in a standard 2-pin socket by mistake. The time taken to reach full brilliancy is shorter than for the glass types being only of the order of 2 or 3 minutes. The spectral energy distribution data are recorded in Appendix II.

The spectra of the lamps are very similar to that shown in figure 9(a) for the 400w. glass types. The continuous background is somewhat stronger as are the feeble lines in the red region. It is noteworthy that in the very high pressure condition the discharge assumes some of the characteristics of a temperature radiator as is shown by the increase in the amount of continuous radiation emitted as the pressure increases.

The electrical characteristics of the lamps and gear are fully discussed in a later section.

TABLE 2.

Technical Data for Osira 80w. and 125w. H.P.M.V. Lamps.

Lamp watts	80	125
Supply voltage	200–250 A.C.	200–250 A.C.
Efficiency in L/W Initial ..	38	40
Max. brightness of arc candles/cm.^{2}	800	800
Max. brightness of bulb candles/cm.^{2}	60	60
Overall length mm.	160±4.5	178±5.5
Light centre length mm. ..	120±4	133±5
Arc length mm.	20	30
Diameter of outer bulb mm. ..	80±1	90±1
Cap	3-Pin B.C.	3-Pin B.C.
Outer bulb	Pearl	Pearl

400*w. Glass H.P.M.V. Fluorescent Lamps.*

Reference has already been made to the deficiency in red in the light from h.p.m.v. lamps and to the various ways in which colour modification of these lamps has been achieved. The method which is most generally employed utilises the phenomenon of fluorescence.

Owing to the high temperature at which h.p.m.v. lamps operate, it is not possible to apply the fluorescent powder to the discharge envelope as with low pressure fluorescent tubes. The fluorescent powder is applied as a thin uniform coating to the inside wall of the outer jacket and, in order to reduce still further the temperature of the coating, the outer jackets of h.p.m.v. fluorescent lamps are larger than those used for the normal lamps.

Since the ultra-violet radiation emitted by h.p.m.v. lamps is largely of long wavelength, the fluorescent materials employed are the zinc and

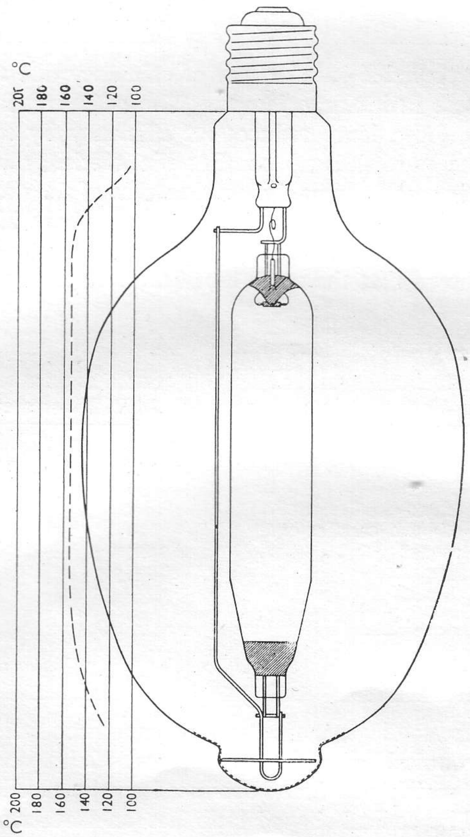


Fig. 12.—*Osira* 400*w. H.P.M.V. Fluorescent Lamp.*

zinc-cadmium sulphides (see section on fluorescence). The fluorescent powder used in the 400w. fluorescent lamp is slightly yellowish in colour, and therefore tends to absorb a certain amount of blue light from the discharge. To counteract this a little cadmium is used with the mercury. The cadmium supplies some useful red light, but its chief purpose is to compensate for the blue light absorbed by the coating.

TABLE 3.

Technical Data for Osira 400w. H.P.M.V. Fluorescent Lamp.	
Lamp watts	400
Supply voltage	200–250 A.C.
Efficiency in L/W. Initial	38
Max. brightness of arc candles/cm.² ..	150
Max. brightness of bulb candles/cm.² ..	50
Percentage red lumens*	Approx. 5
Overall length mm.	335±75
Light centre length mm.	195±10
Arc length mm.	150
Diameter of outer bulb mm.	165±3
Cap	G.E.S.
Outer bulb	Isothermal Fluorescent

There is no appreciable gain or loss of efficiency due to the use of fluorescent powders in h.p.m.v. lamps. The cadmium in the special inner tube in the 400w. lamp reduces its efficiency by some 12–14% below that of the normal lamp so that the efficiency of the 400w. fluorescent lamp is correspondingly less than that of the non-fluorescent type. However, for many industrial purposes where high efficiency combined with a reasonable degree of colour rendering is called for, experience has shown that the small sacrifice in efficiency is more than justified.

TABLE 4.

Technical Data for Osira 80w. and 125w. H.P.M.V. Fluorescent Lamps.		
Lamp watts	80	125
Supply voltage	200–250 A.C.	200–250 A.C.
Efficiency in L/W. Initial	38	40
Max. brightness of arc candles/cm.² ..	800	800
Max. brightness of bulb candles/cm.²	10	15
Percentage red lumens*	Approx. 5	Approx. 5
Overall length mm.	178±5.5	233±7
Light centre length mm.	123±5	167±6
Arc length mm.	20	30
Diameter of outer bulb mm.	110±1.5	130±1.5
Cap	3-Pin B.C.	G.E.S.
Outer bulb	Fluorescent	Fluorescent

Figure 12 shows diagramatically the constructional details and table 3 gives technical data for the present Osira 400w. h.p.m.v. fluorescent lamp which was first introduced to the public on December 1st, 1937. The conical shaped bulb has an isothermal contour—designed to give as uniform a temperature as possible over its surface. The actual distribution of temperature attained while burning in free air with an ambient temperature of 20°C. is shown in figure 12.

* This represents the lumens transmitted by a Wratten No. 25 red filter expressed as a percentage of the total lumens. On the same scale daylight has a red ratio of about 12% while the value for tungsten lamps is about 20%.

80w. and 125w. Quartz H.P.M.V. Fluorescent Lamps.

Osira 80w. and 125w. Quartz h.p.m.v. fluorescent lamps were marketed about a year after the 400w. type—actually on February 1st, 1939.

The general properties of these lamps are similar to those of the 400w. glass type described above. Owing to the higher loading per centimetre length of arc, there is already more red present and the colour correction required is not so great as for the 400w. type. It is, therefore, possible to get the necessary additional blue light from a blue fluorescing powder mixed with the red fluorescing powder, thus avoiding the use of cadmium and the consequent reduction in efficiency which cadmium brings.

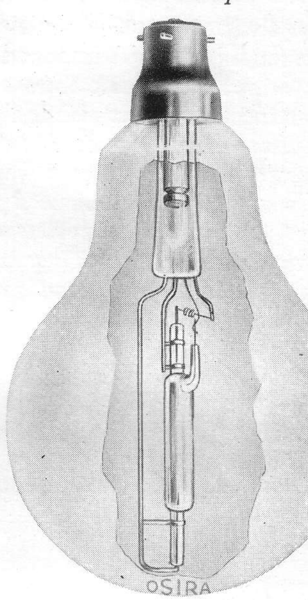


Fig. 13. Osira 80w. H.P.M.V. Fluorescent Lamp.

The outer bulbs are larger than those used for the corresponding non-fluorescent types and the comparative smallness of the discharge envelope enables a satisfactory temperature distribution to be obtained with a spherical bulb. Figure 13 shows the constructional details of the Osira 80w. h.p.m.v. fluorescent lamp. The 125w. lamp is similar in construction but is fitted with a screw cap instead of the 3-pin bayonet cap shown in the photograph. As already mentioned the function of the 3-pin cap is to prevent the lamp being inserted in a standard 2-pin socket by mistake.

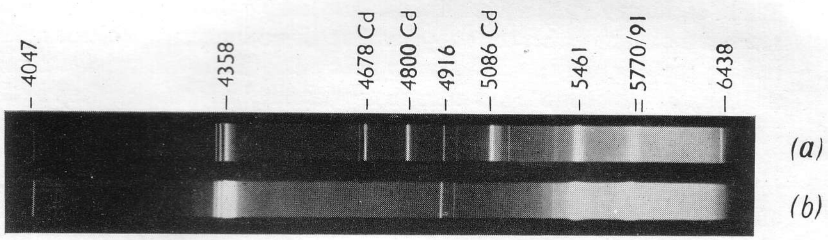


Fig. 14.—Spectra of Osira H.P.M.V. Fluorescent Lamps.
(*a*) *400w. H.P.M.V. Fluorescent Lamp.* (*b*) *80w. and 125w. H.P.M.V. Fluorescent Lamps.* (*Wavelengths in Angström Units*).

Technical data for both lamps are given in table 4. Typical spectra of 400w. and 125w. h.p.m.v. fluorescent lamps are shown in figure 14. The additional lines due to cadmium may be clearly seen in the spectrum of the 400w. lamp, figure 14(a). Energy distribution data for both lamps are given in Appendix II.

80w. and 125w. " Black " Glass Lamps.

The discharge envelopes of these lamps are identical with those of the corresponding lamps described in the previous section. The outer bulb, however, is made from a special " black " glass which absorbs almost completely the visible light from the lamps while allowing the near ultra-violet radiation, in which the high pressure mercury vapour discharge is so rich, to pass freely. These " black " glass lamps form very convenient and efficient sources of this radiation for exciting fluorescent advertising posters and fluorescent shop window displays, theatrical effects, etc. They have also proved invaluable for certain types of A.R.P. lighting and are used extensively for the sorting of linen in laundries where the linen is marked with an invisible ink which fluoresces under the lamp. Osira " black " glass lamps have recently been used for an important method of surfacing metal where the usual Prussian Blue mixture is replaced by a solution of anthracene in paraffin oil and the " high " spots observed by fluorescence.

The electrical characteristics of the lamps and method of operation are, of course, identical with those of the corresponding lamps described above. The dimensions of the outer bulbs for both wattage ratings are the same as for the 125w. non-fluorescent h.p.m.v. lamp (see table 2, page 24). The percentage of the input energy emitted in the different spectral ranges is given in Appendix II.

Factors Affecting Osira H.P.M.V. Lamp Design.

The lamp or arc voltage in h.p.m.v. lamps is controlled by the amount of mercury vaporised. The value chosen takes into account a number of requirements, some of which are conflicting, and a compromise has to be made between these.

It is desirable to make the lamp voltage high in order that the choke should be small and the overall power factor correspondingly improved. There is, however, an upper limit to the lamp voltage since, when this reaches a certain value, the supply voltage is no longer capable of maintaining the discharge and the lamp goes out. Thus the voltage across the lamp has to be made low enough to withstand any sudden drop in the supply voltage likely to be experienced.

A further consideration is that, from the manufacturing point of view, it is desirable to select a lamp voltage such that the lamp watts are least affected by the inevitable slight variations which occur in manufacture. Generally speaking it may be said that the lamp voltage is made as high as possible consistent with the lamp being able to withstand a sudden drop in the supply voltage of 30 volts. The design of the choke then has to take into account the spread of lamp voltages obtained in manufacture so as to arrange that the resulting uniformity in performance is as great as possible.

Figure 15 shows typical curves connecting lamp volts and watts for a 250w. 230v. Osira h.p.m.v. lamp operating on different supply voltages representing 20v. overload and 20v. underload conditions. The full straight lines show the sudden voltage drop in the mains which will just allow the lamp to remain alight. The broken straight lines on the figure represent the overall power factor obtained, using the recommended condenser. The curves show that the lamp watts are

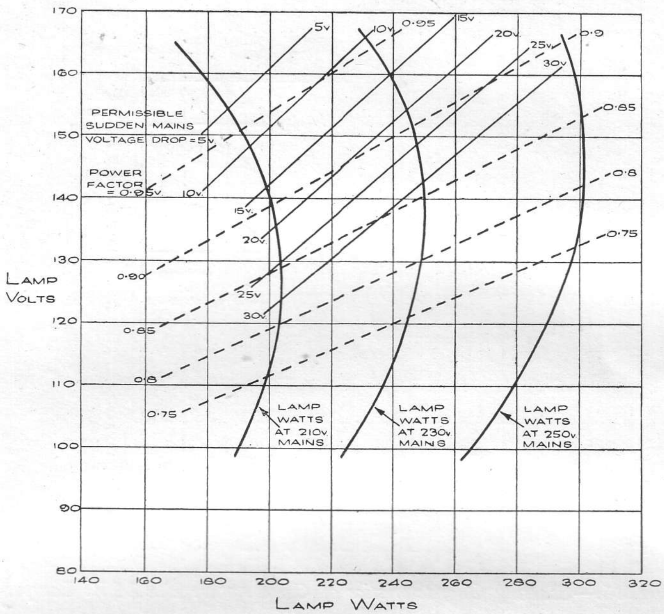


Fig. 15.—*Relation between Lamp Volts and Watts at Different Mains Voltages for Osira 250w. 230v. H.P.M.V. Lamps.*

practically constant for lamp voltages between 130 and 145, which is the kind of spread which occurs in practice. The permissible sudden voltage drop for the worst case (lamp volts = 145) will be seen to be approximately 30 volts, while the power factor for the worst case (lamp volts = 130) is about 0.8.

Starting Characteristics.

The lamps reach full brilliancy when the mercury filling is completely vaporised. The time required to reach this condition and for the current, wattage, etc., to reach their final values is from 1 to 5 minutes according to the type of lamp, ambient temperature, etc.

If the current is interrupted after the lamp is fully run up the latter will not restart immediately, but only when most of the vapour has re-condensed ; this will normally take 3 or 4 minutes. In normal a.c. supplies, of course, the discharge current passes through zero each half-cycle. The period of zero current is, however, so short that ions present in the discharge have not time to disappear, so that the discharge readily restarts in the next half-cycle. Typical starting charactistics for the 400w. 230v. lamp and the 125w. 230v. lamp are shown in figures 16 and 17. Tables 5 and 6 give electrical data in the starting and running conditions with and without power factor condensers for average 250w., 400w., 80w. and 125w. lamps respectively. It should be noted that the

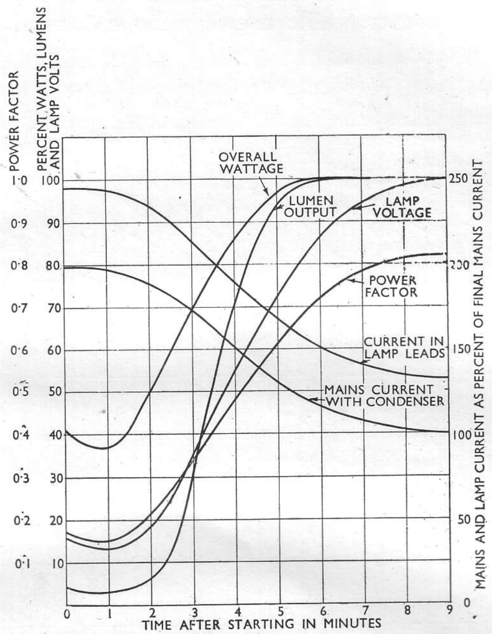


Fig. 16.—Starting Characteristics of Osira 400w. H.P.M.V. Lamps.

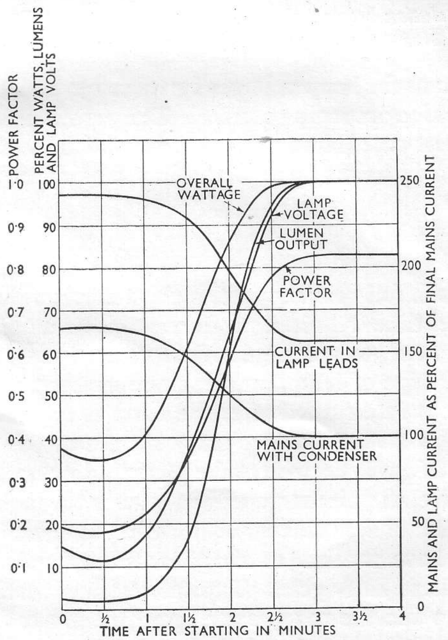


Fig. 17.—Starting Characteristics of Osira 125w. H.P.M.V. Lamps.

lamp current, whether condensers are used or not, is the same as the mains current without condensers.

Figures 18 and 19 indicate how variations in supply voltage affect factors such as wattage, current, permissible sudden mains voltage drop,

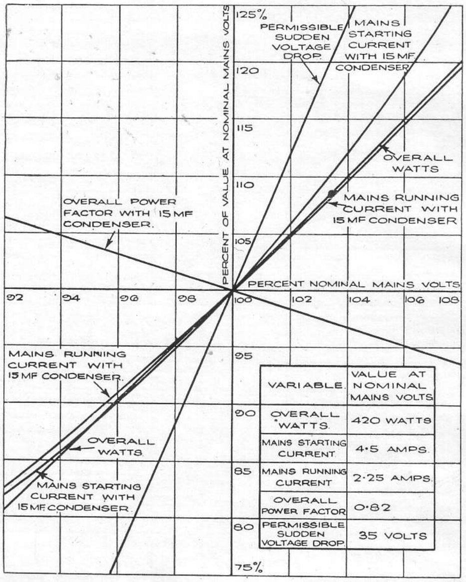


Fig. 18.—*Effect of Variation of Mains Voltage on the Electrical Characteristics of Osira* 400*w. H.P.M.V. Lamps.*

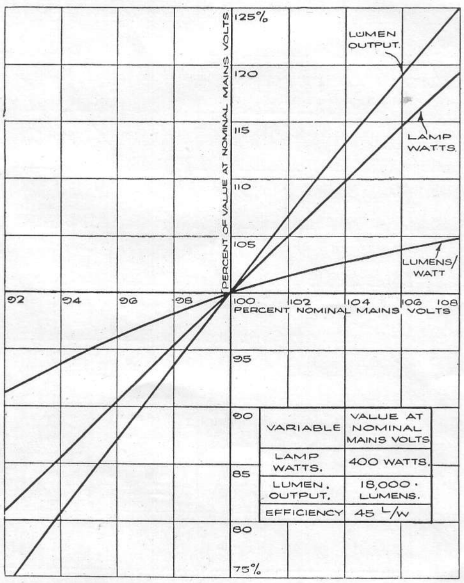


Fig. 19.—*Effect of Variation of Mains Voltage on the Lamp Characteristics of Osira* 400*w. H.P.M.V. Lamps.*

lumen output, lamp efficiency and power factor for a typical 400w. 230v. lamp, while figures 20 and 21 give similar details for a typical 125w. 230v. lamp.

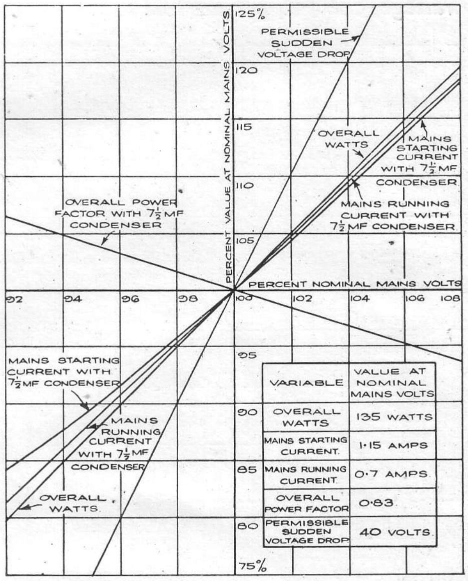


Fig. 20.—Effect of Variation of Mains Voltage on the Electrical Characteristics of Osira 125w. H.P.M.V. Lamps.

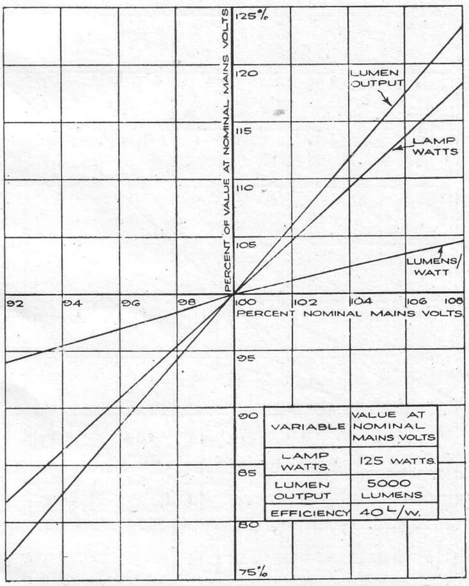


Fig. 21.—Effect of Variation of Mains Voltage on the Lamp Characteristics of Osira 125w. H.P.M.V. Lamps.

Chokes.

When the lamp is first switched on, the lamp or arc voltage is only of the order of 20 volts and the current passing is almost entirely dependent on the impedance of the choke. By suitably designing the choke, therefore, the starting current may be arranged to have any one of a wide range of values consistently with correct final lamp wattage. The use of a very high starting current must be avoided as this may give rise to trouble in the lamps themselves and in the cables ; if the starting current is too low the time taken to reach the maximum brightness may be excessive. Care must be taken to see that the choke is designed to be safe thermally at the overloads likely to arise in practical installations, and also that its wattage loss is not excessive. In keeping with these requirements the dimensions should be as small as possible.

The chokes used for Osira h.p.m.v. lamps are of the shell type construction with fixed air-gap. Tappings are provided at 5v. steps, there being one choke for the 185v. to 230v. and another for the 215v. to 260v. range. Adjustment at the Works to within $\pm 1\frac{1}{2}\%$ (which is equivalent to about $\pm 2\%$ in lamp wattage) is made by a patented method of coil shift. The design enables a rigid and robust construction to be obtained, which ensures that the electrical adjustment is maintained in service. The 5v. tappings enable selection to within $\pm$ 2.5v. to be made for practically all normal supplies. This allows close control of the lamp wattage Special care has to be taken in the choke design (e.g. in the choice of iron circuit, number of turns in coil, dimensions of air gap, etc.) in order that the required currents both in the starting and in the fully-run-up conditions may be accurately obtained for all supply voltages.

Two different types of chokes are made for each wattage rating. The standard protected type is an air-cooled choke with ventilated castings in which provision is made for conduit entry. The second type of choke is designed to withstand more arduous service conditions. This is enclosed in a sheet steel container and is waxfilled. The choke is particularly robust, well insulated for service conditions, and able to withstand higher ambient temperatures than the standard protected type. Under normal ambient conditions it may be mounted in a horizontal position with terminal block uppermost without danger of extrusion of the waxfilling. Photographs of the above types of chokes are shown in figure 22. The dimensions of the chokes are given in table 7.

A combined lamp and choke fitting is made in which a special choke is housed in a canopy above the lamp. The canopy is filled with the same type of wax as is used for the ordinary waxfilled chokes and a special terminal arrangement is provided under the canopy lid.

The chokes shown in figure 22 are designed for 50 cycle a.c. supplies. For supplies of other frequencies it is sometimes possible to adapt the 50-cycle types but in other cases special chokes are necessary.

The wiring diagram is given in figure 23 while the tappings to be used are given in table 8, for 80w., 125w., 250w. and 400w. lamps.

TABLE 5.

Starting and Running Electrical Data for 250w. and 400w. Osira H.P.M.V. Lamps.

Mains voltage (actual) at unit.	Osira Lamp in use.	Installation without condensers.				Installation with G.E.C. condensers.			
		Mains and lamp current and wattage at starting (excluding switching surges).		Average running conditions.		*Mains current and wattage at starting (excluding switching surges).		Average running conditions.	
				Mains and lamp current in amps.	Power factor.			*Mains current in amps.	Power factor.
		amps.	watts.			amps.	watts.		
200	200–210v.	3.5	100	2.3	0.55 to 0.6	2.75	100	1.7	0.8 to 0.85
210	250w.	3.5	100	2.3		2.5	100	1.6	
220	220v. 250w.	3.25	95	2.1		2.25	95	1.4	
230	230v. 250w.	3.5	95	2.0		2.5	95	1.4	
240	240–250v.	3.25	90	1.9		2.25	90	1.3	
250	250w.	3.0	85	1.9		2.0	85	1.3	
200	200–210v.	5.5	160	3.6		4.25	160	2.7	
210	400w.	5.25	155	3.6		4.0	155	2.6	
220	220v. 400w.	5.0	150	3.4		3.75	150	2.4	
230	230v. 400w.	5.5	155	3.0		4.5	155	2.3	
240	240–250v.	5.0	150	2.8		4.25	150	2.1	
250	400w.	4.75	145	2.8		3.75	145	2.0	

*Lamp current same as in installation without condensers.

TABLE 6.

Starting and Running Electrical Data for 80w. and 125w. Osira H.P.M.V. Lamps.

Mains voltage (actual) at unit.	Osira Lamp in use.	Installation without condensers.				Installation with G.E.C. condensers.			
		Mains and lamp current and wattage at starting (excluding switching surges).		Average running conditions.		*Mains current and wattage at starting (excluding switching surges).		Average running conditions.	
				Mains and lamp current in amps.	Power factor.			*Mains current in amps.	Power factor.
		amps.	watts.			amps.	watts.		
200	200–210v.	1.3	35	0.85	About 0.5	0.85	35	0.5	About 0.85
210	80w.	1.25	35	0.85		0.8	35	0.5	
220	220v. 80w.	1.25	35	0.8		0.7	35	0.45	
230	230v. 80w.	1.35	40	0.75		0.8	40	0.45	About 0.9
240	240–250v.	1.25	40	0.75		0.7	40	0.4	
250	80w.	1.2	40	0.75		0.65	40	0.4	
200	200–210v.	1.85	45	1.3		1.25	45	0.85	0.8 to 0.85
210	125w.	1.8	45	1.3		1.15	45	0.85	
220	220v. 125w.	1.75	45	1.15		1.05	45	0.7	
230	230v. 125w.	1.7	45	1.1		1.15	45	0.7	
240	240–250v.	1.6	45	1.05		1.05	45	0.65	
250	125w.	1.5	45	1.05		0.95	45	0.6	

*Lamp current same as in installation without condensers.

TABLE 7.

Dimensions of Chokes for Osira H.P.M.V. Lamps.

Wattage.	Type.	Overall width.	Overall length.	Overall projection.	Weight.
		in.	in.	in.	lb.
400	Standard protected	$4\frac{1}{8}$	$6\frac{5}{8}$	6	$12\frac{1}{2}$
250		$4\frac{1}{8}$	$5\frac{5}{8}$	6	$9\frac{1}{2}$
125		$3\frac{5}{8}$	$4\frac{5}{8}$	$4\frac{3}{4}$	$4\frac{1}{2}$
80		$3\frac{5}{8}$	$4\frac{1}{8}$	$4\frac{3}{4}$	$4\frac{1}{2}$
400	Wax-filled	$5\frac{3}{4}$	$6\frac{1}{8}$	$6\frac{1}{2}$	$20\frac{3}{4}$
250		$4\frac{3}{4}$	$6\frac{5}{8}$	$5\frac{1}{4}$	$14\frac{1}{2}$
125		$4\frac{3}{8}$	$5\frac{3}{4}$	$4\frac{5}{8}$	$7\frac{3}{4}$
80		$4\frac{3}{8}$	$5\frac{3}{8}$	$4\frac{1}{4}$	$7\frac{3}{4}$

Choke Coils for Use with Osira H.P.M.V. Lamps.

Fig. 22(a).—Waxfilled Type.

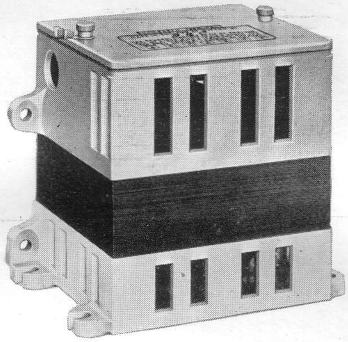


Fig. 22(b).—Standard Protected Type.

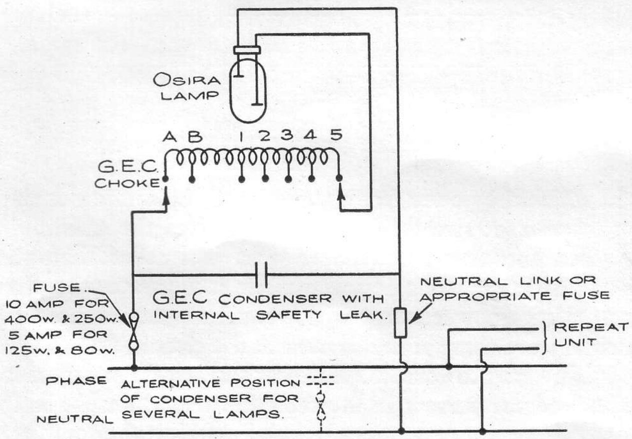


Fig. 23.—Wiring Diagram for Osira H.P.M.V. Lamps.

TABLE 8.

Choke Tapping Schedule for Osira 80w., 125w., 250w. and 400w. H.P.M.V. Lamps.*

L type choke for 200, 210 and 220v. supplies.	H type choke for 230, 240 and 250v. supplies.	Tapping.
185	215	B and 1
190	220	A and 1
195	225	B and 2
200	230	A and 2
205	235	B and 3
210	240	A and 3
215	245	B and 4
220	250	A and 4
225	255	B and 5
230	260	A and 5
Tapping should be chosen corresponding to average mains voltage at unit.		

* The special tapping schedule for horizontal burning h.p.m.v. lamps is given in table 11, page 38.

Power Factor Correction.

The overall power factor of the complete lamp, choke and condenser unit will depend on the size of the condenser used. Figure 24 indicates

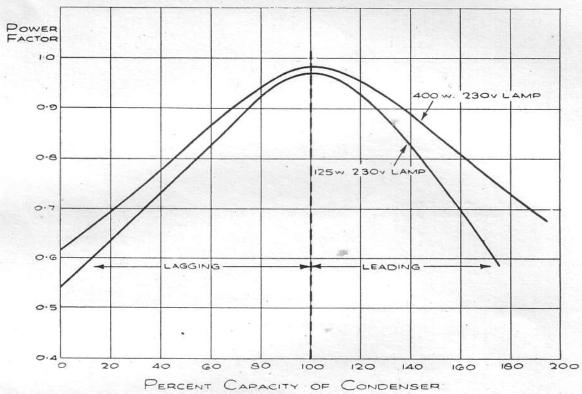


Fig. 24.—Relation between Condenser and Power Factor for Osira 125w. and 400w. H.P.M.V. Lamps.

the way in which the power factor varies with the condenser size, taking the 100% condenser size to be that which gives the maximum power factor. When the actual condenser used is smaller than the 100% value, the phase angle is lagging, and when it is greater the phase angle is leading. Unity power factor is not generally achieved owing to the nonsinusoidal wave form of the current in the circuit.

When it is desired to correct the power factor of a group of lamp and choke units, and the current in the cable between different lamps is not important, a single condenser can be used equal to the total capacity of the individual condensers which would be required for correction at each unit. The single condenser arrangement is generally cheaper and occupies less space, but if some of the lamps of the group are not switched on, a low leading power factor may result owing to the capacity per unit being then too great. It is therefore generally wise not to group for power factor correction more lamps than are on any one separately switched sub-circuit.

It is usually desired to operate Osira h.p.m.v. lamp installations at a power factor not less than 0.8. The data in table 9 gives the capacity necessary to correct single units to any power factors between 0.7 and 0.95. The value required for a group of lamps may readily be determined from the table. If a condenser of the calculated capacity is not available the nearest standard size should be used. For frequencies other than 50 cycles the condenser required will be greater or less according as the frequency is less or greater.

TABLE 9.

Capacity of Condensers for Power Factor Correction of Osira H.P.M.V. Lamps.

Lamp watts.	Mains volts.	Capacity in microfarads to give the following power factors:					
		0.7	0.75	0.8	0.85	0.9	0.95
80	200–220	5.0	6.0	7.0	8.0	9.0	10.5
	230–250	4.0	4.5	5.5	6.5	7.5	9.0
125	200–220	7.0	8.5	10.0	11.5	13.0	15.5
	230–250	4.0	5.5	7.0	8.0	9.5	11.0
250	200–220	10.0	12.5	15.0	18.0	21.0	24.5
	230–250	7.0	9.0	11.0	13.5	16.0	19.0
400	200–220	12.0	16.5	20.5	24.5	29.5	35.5
	230–250	8.0	10.5	14.0	17.5	21.5	25.5

The condensers employed to correct the power factor of Osira h.p.m.v. lamps are of very high quality, impregnated with a special jelly of high dielectric constant thus reducing their physical dimensions, and are provided with a safety leak resistance. When a unit is switched off the condenser is automatically discharged through the resistance and danger from shock is thus eliminated.

Direct Current Operation.

Osira h.p.m.v. lamps may be operated on 200–250v. d.c. supplies but a resistance of suitable size must be used in place of the choke. The approximate values of the resistance required for the various h.p.m.v. lamps on different mains voltages are given in table 10. The resistor should be capable of carrying the high starting current without overheating (see tables 5 and 6, page 34). It is advisable to have a wattmeter in the circuit, and to adjust the resistor until the correct lamp watts are recorded.

TABLE 10.

Resistances for Osira H.P.M.V. Lamps on D.C.

Mains volts.	Lamp voltage rating.	400w.	250w.	125w.	80w.
		ohms.	ohms.	ohms.	ohms.
200	200–210	23.5	39.0	79.0	123.5
210	200–210	26.5	43.5	88.0	137.5
220	220	29.0	46.5	95.0	150.0
230	230	31.0	51.0	103.0	164.5
240	240–250	33.5	55.5	112.5	179.0
250	240–250	37.0	61.0	123.5	195.0

The lamp must be connected in the circuit so that the upper electrode is the cathode or negative electrode. It should be noted that the upper electrode is connected to the centre contact of the cap where this is of the screw type. The starting is not as reliable as on a.c., and no guarantee as to life and performance of lamps operated on d.c. can be given.

Although the lamp efficiency is not appreciably affected by d.c. operation, the overall efficiency is approximately half what it is on a.c.

Horizontal Burning.

For certain purposes it is desirable to be able to operate the lamps horizontally. In horizontal burning, however, a special problem arises since the luminous arc is bowed upwards by the convection currents in the discharge. As a consequence, the temperature of the upper side of the discharge tube is increased considerably and the hard glass discharge envelope may be destroyed. The arc column can be brought back to the centre of the lamp by means of an electro magnet operating at the same frequency as the lamp current. The lamp will then operate at normal efficiency and normal life. Osira 400w. fluorescent lamps may not be operated horizontally.

In the G.E.C. system the coil of the magnetic deflector is fixed in position above or below the lamp and connected in series with it. If placed above the lamp the wire used for the deflector coil is covered with

TABLE 11.

Choke Tapping Schedule for Standard Osira H.P.M.V. Lamps burnt horizontally with magnetic deflector.

400w. H chokes Mains volts.	400w. L chokes Mains volts.	250w. H chokes Mains volts.	250w. L chokes Mains volts.	Tapping.
218	188	214	188	B and 1
223	193	220	193	A and 1
228	197	226	197	B and 2
233	202	232	202	A and 2
239	207	238	206	B and 3
244	211	244	211	A and 3
250	216	249	215	B and 4
255	221	254	220	A and 4
261	226	259	224	B and 5
266	231	264	229	A and 5

asbestos to withstand high ambient temperatures in the fitting. The use of a series magnetic deflector rather than a parallel one leads to a more robust construction and a lower wattage loss in the coil. It also avoids the use of an auxiliary condenser which is necessary in the latter arrangement to correct the phase angle of the current in the parallel deflector. Table 11 gives the special choke tapping schedule for use with lamps burnt horizontally in conjunction with a magnetic deflector. Lamps are available which operate without a magnetic deflector but the efficiency of these is lower than that of normal lamps.

Owing to the refractory nature of the quartz envelope of Osira 80w. and 125w. h.p.m.v. lamps, these may be run in a horizontal position without a magnetic deflector. The performance of quartz lamps operated in this way appears to be substantially unchanged although there is a slightly greater tendency for a sudden drop in the supply voltage to extinguish the lamp.

Part III.—OSIRA SODIUM VAPOUR LAMPS.

General Description.

Osira sodium vapour lamps operate with a low pressure of sodium vapour, and in this respect they are quite different from the h.p.m.v. lamps described in Part II. They are, however, similar to h.p.m.v. lamps in that a high operating temperature is necessary to produce a high luminous efficiency. The h.p.m.v. lamps operate at a temperature of 600°–800°C., whereas sodium vapour lamps require a temperature of some 300°C. Even at this temperature the sodium vapour pressure is still small, being only of the order of one-hundredth of a millimetre. The neon and low pressure mercury vapour lamps discussed in Parts IV

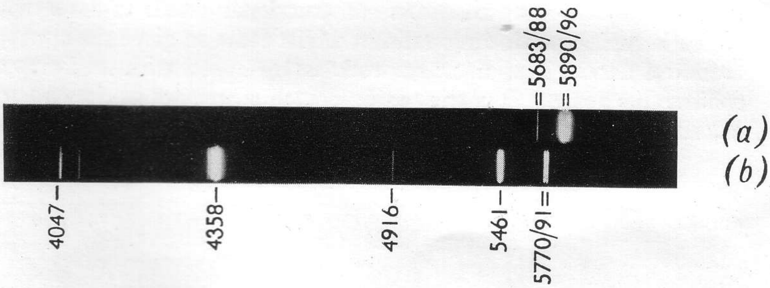


Fig. 25.—(a) Spectrum of Osira Sodium Vapour Lamps. (b) Spectrum of Low Pressure Mercury Vapour Discharge for Comparison. (Wavelengths in Angström Units.)

and V operate at a temperature of only some 20°C. above ambient and the filling pressure is of the order of a few millimetres.

The spectrum of the discharge through sodium vapour is exceedingly simple, consisting for all practical purposes of only two closely placed lines in the yellow region at 5890A. and 5896A. (see figure 25). As might be expected from its spectrum the luminous efficiency is high, although considerably less than the theoretical maximum for light of the same colour.

The efficiency of a sodium vapour discharge falls off rapidly as the current density is increased above a certain optimum value. The lamps must, therefore, be operated at relatively low currents, consequently the wattage dissipation is small in relation to the surface area involved. For this reason the discharge tube must be very effectively insulated to conserve the heat for vaporising the metallic sodium. Effective heat insulation is achieved by operating the discharge tube in a double-walled vacuum flask.

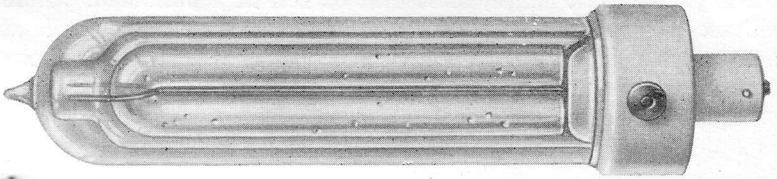


Fig. 26.—Osira Sodium Vapour Lamp.

As the length of the discharge path is increased the fraction of the total input energy dissipated in the luminous column increases, whereas that dissipated at the electrodes (which does not affect the light output) remains constant. Thus designs have tended towards long discharge paths operating from medium voltages and, for compactness, the long discharge tube is made U-shaped.

Construction, Characteristics and Operation.

Osira sodium vapour general lighting lamps are made in three wattage ratings, viz. 45w., 85w. and 140w., all of which are similar in general construction. Figure 26 shows constructional details of the 45w. lamp which is typical of all three ratings, whilst table 12 gives the appropriate technical data. The discharge tube is U-shaped with its limbs a few millimetres apart. It carries oxide-coated electrodes at the ends of the U, although these cannot be seen in the photograph. The discharge

TABLE 12.

Technical Data for Osira 45w., 85w. and 140w. Sodium Vapour Lamps.

Lamp watts	45	85	140
Supply voltage	100–250 A.C.	100–250 A.C.	100–250 A.C.
Lamp current, amps.	0.6	0.6	0.9
Efficiency in L/W. Initial	55.5	71.1	71.5
Max. brightness of arc candles/cm.^{2}	9	9	9
Overall length mm.	250 ± 20	425 ± 20	540 ± 25
Light centre length mm.	140 ± 10	230 ± 10	280 ± 10
Diameter of outer bulb mm. ..	50 ± 2	50 ± 2	65 ± 2
Cap	B22/S Ceramic	B22/S Ceramic	B22/M Ceramic

envelope is made from a flashed or two-ply glass, the outer layer being an ordinary soda glass, and the inner layer a thin flashing of a special glass designed to withstand attack by hot sodium vapour over long periods. Such glasses are characterised by a low silica content and a high purity. As in h.p.m.v. discharge lamps the hot cathode electrodes are heated solely by the discharge even during the starting period, so that two connections only are necessary to the ceramic bayonet cap, which is attached to the free ends of the U.

Surrounding the U-tube is a double-walled vacuum flask, carefully designed to give high thermal insulation. This is fitted at its open end with a ceramic ring bearing a slot through which the inner discharge tube can be slipped. The corresponding portion of the ceramic cap fits into the slot, where it can be locked into position by means of a small spring-loaded plunger. For transport the inner tube is packed separately from its vacuum flask in a special fire-proofed wrapper in order to avoid any risk of fire, which might arise through the metallic sodium from a broken lamp coming into contact with moisture. Because of this risk the inner tube should never be packed in an ordinary wrapper.

Since the inner U-tube is removable from the vacuum flask, it can be replaced on failure without the expense of replacing the latter. It is not, however, recommended that one flask should be used for more than 3 inner lamps, on account of the gradual deterioration of the vacuum with consequent reduction in the heat insulation properties of the vacuum flask.

Referring to table 12 it will be seen that the 45w. and 85w. lamps differ from one another only in length, whilst the 140w. lamp is greater both in length and diameter than the 85w. type. Distributed uniformly along the lamps are droplets of sodium metal and, in addition to the sodium, there is a filling of neon at a pressure of a few millimetres. This is to assist starting, since sodium is solid at room temperature and, as stated above, has a very low vapour pressure. The pitchfork support arranged between the limbs of the U-tube acts also as an external auxiliary electrode and facilitates starting.

The lamps are suitable for a.c. and not for d.c. supplies, and must only be used in conjunction with the special G.E.C. equipment. For each wattage rating there is one lamp only for all mains voltages as variations in the supply voltage are taken care of in the auxiliary equipment. The lamps are operated from stray-field, step-up, tapped auto-transformers, a separate transformer being required for each lamp. The transformers are designed with an open circuit secondary voltage of some 470–480 volts at their rated primary voltage and are so arranged that, by virtue of the stray-field effect, the secondary voltage falls as the transformer is loaded and the lamp is stabilised at its correct operating current. As with other low pressure discharges sodium lamps may be restarted immediately after the supply is interrupted.

It is important to use the correct tappings to suit the actual average mains voltage during burning hours and not necessarily the nominal voltage of the supply. Table 13 gives the transformer type for each lamp, the mains voltage range and the essential transformer-tapping data for different average mains voltages.

TABLE 13.

Transformers and Power Factor Condensers for use with Osira Sodium Lamps on 50 Cycle A.C. Supplies.

Lamp Watts.	Actual Average Mains Voltage.	Transformer Type.	
45	180–200	LL	For 45w. and 85w. Lamps
45	190–210	L	
45	210–230	H	
45	230–250	HH	
85	190–210	LL	
85	200–220	L	
85	220–240	H	
85	240–260	HH	
140	190–210	LL	For 140w. Lamps
140	200–220	L	
140	220–240	H	
140	240–260	HH	

Average Mains Voltage.

	Transformer Type / Connect phase to terminal	LL Type for 45w. lamp	L Type for 45w. lamp	H Type for 45w. lamp	HH Type for 45w. lamp
45w. lamp	2	175–185	185–195	205–215	225–235
	1	186–195	196–206	216–225	236–245
	B	196–206	206–215	226–235	245–255

	Transformer Type / Connect phase to terminal	LL Type for 85w. lamp or LL Type for 140w. lamp	L Type for 85w. lamp or L Type for 140w. lamp	H Type for 85w. lamp or H Type for 140w. lamp	HH Type for 85w. lamp or HH Type for 140w. lamp
85w. and 140w. lamps	2	185–195	195–205	215–225	235–245
	1	196–205	206–215	226–235	246–255
	B	206–215	216–225	236–245	256–265

Lamp Watts.	Capacity in mfd. to give the following power factors. 0.7	0.75	0.8	0.85	0.9
45	20.0	21.5	23.0	—	—
45	18.0	19.0	19.5	—	—
45	16.0	17.0	18.0	—	—
45	13.5	14.0	15.0	—	—
85	16.0	17.0	19.0	21.0	23.0
85	14.0	16.0	17.0	18.0	20.0
85	11.5	12.0	13.0	14.0	16.0
85	9.0	10.0	11.0	12.0	13.0
140	27.0	29.0	32.0	35.0	38.0
140	24.0	26.0	29.0	32.0	34.0
140	18.0	20.0	21.5	23.0	25.0
140	15.0	16.0	18.0	19.0	22.0

Figure 27 shows the complete wiring diagram for Osira Sodium Lamps. The neutral lead must always be connected to terminal 3 of the auto-transformer and the lamp leads to terminals A and 5. C is the power-factor correction condenser the measured values of which to correct the power factors of each lamp to between 0.7 and 0.9 are given in table 13. Condensers of the precise values given in the table are not necessarily available and the nearest standard size should be used. A

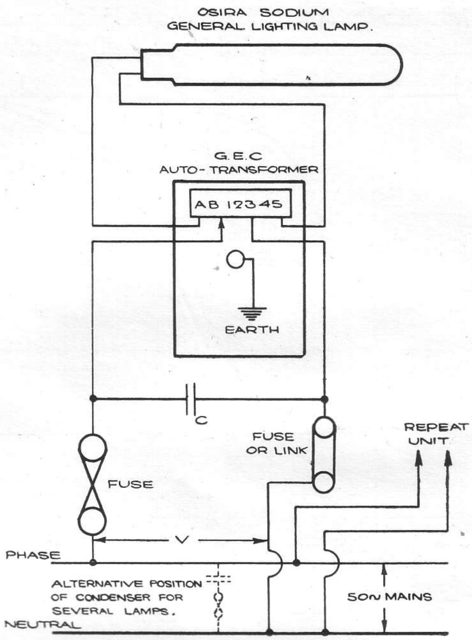


Fig. 27.—Wiring Diagram for Osira Sodium Vapour Lamps.

single large condenser for a group of lamps may be used and care must be taken to connect the condenser across the mains and not across the lamp or any other part of the circuit. The uncorrected power factor is only about 0.3.

Radio interference will rarely be experienced except perhaps where the lamps are operated from overhead wiring and are hung on non-conducting posts. The inclusion of a simple filter will generally suffice to remove such interference. The 85w. or 140w. lamps must always be operated horizontally, or with the cap end tilted upwards at an angle not greater than 20° to the horizontal. This is necessary to prevent the sodium accumulating at one end ; should this happen the remainder of the lamp would operate as a neon instead of a sodium discharge, with a consequent large reduction in efficiency. It is also important to prevent molten sodium from running to the capped end of the lamp where it might cause failure due to attack of the glass in the neighbourhood of the seal wires. For the same reason lamps should not be shifted after they have been in operation until they have cooled sufficiently for the sodium to solidify. In operating the lamps horizontally they should be placed so that one limb of the bend is above the other. The 45w. lamp is much shorter than the other two ratings and may be burnt in any position between the horizontal and the vertical provided the cap end is uppermost.

Colour, Efficiency and Life.

The discharge, on first switching on, shows the characteristic red colour of neon but this gradually changes to a bright yellow as the lamp warms up and the sodium melts and then partially vaporises. Figure 28

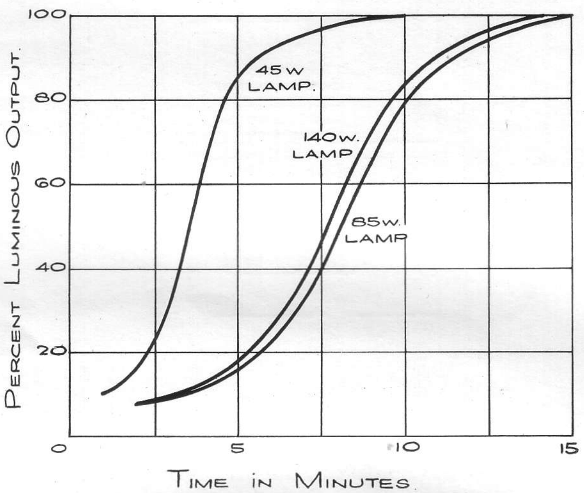


Fig. 28.—Luminous Output of Osira Sodium Vapour Lamps During Warming-up Period.

illustrates the rise in luminous output during the warming-up period. It will be noted that the 45w. lamp attains maximum light output in about 7 minutes while the other two ratings require approximately 12 minutes. As mentioned above, the visible radiation from the lamp is practically monochromatic, i.e. occurs nearly all in two powerful lines in the yellow part of the spectrum (see figure 25). Colours are therefore distorted when viewed under sodium light and appear as a monochrome of varying brightness.

Unlike the mercury discharge, which is rich in ultra-violet radiation, the sodium discharge generates or emits practically none. It is thus not possible to modify the colour of sodium lamps by means of the fluorescent materials described in Part I. Attempts have been made to utilise the well-known organic dye, rhodamine, which is excited by sodium light to give a red fluorescence. The method is interesting from an academic point of view but has proved to be of little practical significance owing to the considerable loss in efficiency and the relatively small gain in colour. Another difficulty is that rhodamine, in common with other fluorescent dyes, fades more or less rapidly. Also, since it does not withstand high temperatures, it cannot be applied to the lamp itself but only to an independent support such as the reflector or fitting

The relevant photometric data for the three ratings are given in table 12, while the approximate energy distribution is given in Appendix II. Figure 29 shows the effect of changes in mains voltage on the lamp watts and light output and figure 30 gives the polar distribution of light from the bare lamp.

Final failure may be due to a number of causes. Firstly the cathode may lose its emissive coating resulting in a gradual rise of the starting voltage to a value greater than the transformer will provide. Secondly

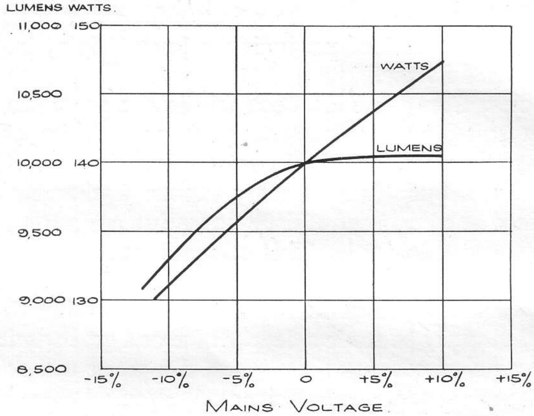


Fig. 29.—Effect of Variation of Mains Voltage on the Efficiency of an Osira 140w. Sodium Vapour Lamp.

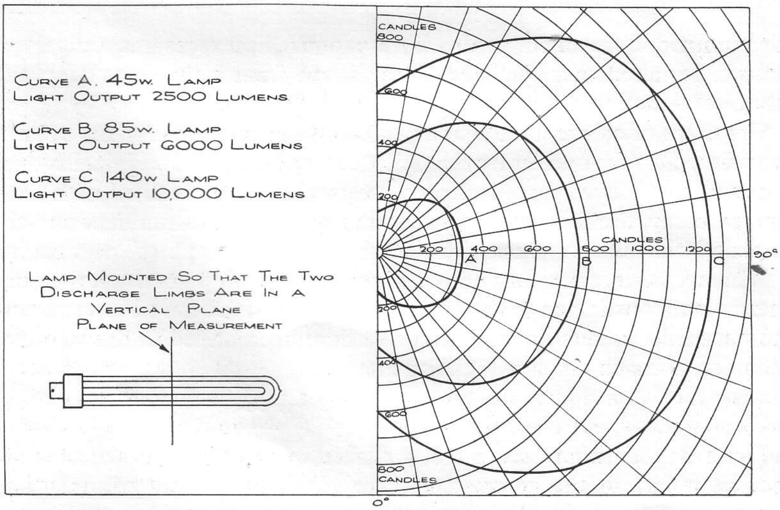


Fig. 30.—Polar Curve Showing Light Distribution in Vertical Plane for Osira Sodium Vapour Lamps.

the light output may fall to an uneconomic figure due either to migration of the sodium to one end of the lamp or to blackening of the inner discharge tube caused by sodium vapour attack. Very substantial improvements have been made in recent years, however, in the resistance of glasses to sodium vapour and the reduction in efficiency due to this cause is now relatively small. A third possible cause of failure, viz. glass-cracks, is one which seldom occurs.

Part IV.—OSIRA COLOUR FLOODLIGHTING LAMPS.

General Description.

Colour floodlighting using tungsten filament lamps in conjunction with suitable coloured filters has been in use for many years. The low efficiency of this method of producing coloured light, however, considerably restricted its use.

It will be clear from what has been said in the preceding pages, that discharges in suitable gases present great possibilities of producing coloured light of exceptional vividness at relatively high efficiencies.

The pale blue colour of the mercury vapour discharge, for example, may be obtained at efficiencies of from 12–45 lumens per watt according to the type of lamp employed. This colour is made up of a few lines in the blue and green regions of the spectrum as shown in figure 9(b). By the use of blue or green filters or coloured tubing the pale blue colour of the light may be made a deeper blue or a green and in the latter case, by using fluorescent uranium glass, the green colour is obtained with little or no reduction in efficiency. Even when a blue filter is used to obtain a darker blue light the efficiency is still from 4 to 10 times that of a tungsten lamp and blue filter giving approximately the same colour.

At the other end of the visible spectrum red and yellow light may be obtained from neon and sodium vapour discharges respectively at efficiencies about 2 to 5 times that possible from a tungsten lamp and filter combination giving similar colours.

A system of colour floodlighting utilising hot cathode discharge lamps was placed on the market by the G.E.C. in 1932. In the original system the lamps employed were low pressure discharge lamps filled with neon and mercury, the former giving a characteristic orange-red light and the latter a pale blue or green light according to the type of glass tubing employed. More recently both sodium vapour lamps and high pressure mercury vapour lamps of the types already described have been successfully used for colour floodlighting and have been added to the standard range of Osira colour floodlighting lamps.

Range of Colours Available.

Osira floodlighting lamps are available in the following colours :— red, light blue, light green, dark blue, dark green and yellow. The red or neon-filled floodlighting lamps are rated at 150 and 400 watts. The blue and green lamps are either 100w. and 250w. low pressure

TABLE 14.

Technical Data for Osira Colour Floodlighting Lamps.*

Colour	Red		Light Blue		Light Green		Dark Blue		Dark Green	
Lamp watts	150	400	100	250	100	250	100	250	100	250
Supply voltage	200–250 A.C.		200–250 A.C.		200–250 A.C.		200–250 A.C.		200–250 A.C.	
Lamp current, amps.	2.5	6.0	2.5	6.0	2.5	6.0	2.5	6.0	2.5	6.0
Efficiency L/W. Initial	10.0	11.0	12.5	15.0	12.5	15.0	5.5	6.5	9.5	11.5
Max. brightness of arc candles/cm.^{2}	2.0	3.7	1.8	3.0	1.8	3.0	0.8	1.3	1.4	2.3
Overall length mm.	690 ± 10	1180 ± 19	690 ± 10	1180 ± 19	690 ± 10	1180 ± 19	690 ± 10	1180 ± 19	690 ± 10	1180 ± 19
Arc length mm.	480	920	480	920	480	920	480	920	480	920
Diameter of tubular part mm.	37 ± 1.5	37 ± 1.5	26 ± 1.5	26 ± 1.5	26 ± 1.5	26 ± 1.5	26 ± 1.5	26 ± 1.5	26 ± 1.5	26 ± 1.5
Diameter of bulbous part mm.	55 ± 5	65 ± 4	55 ± 5	65 ± 4	55 ± 5	65 ± 4	55 ± 5	65 ± 4	55 ± 5	65 ± 4
Cap	3-Prong	2-Prong	3-Prong	2-Prong	3-Prong	2-Prong	3-Prong	2-Prong	3-Prong	2-Prong
Bulb	Clear	Clear	Clear	Clear	Light Green	Light Green	Blue	Blue	Green	Green

*Technical Data for 250w. and 400w. H.P.M.V. and 85w. Sodium Vapour Floodlighting Lamps are given in Table 1, page 20, and Table 12, page 40 respectively.

mercury vapour lamps or 250w. and 400w. horizontal burning high pressure mercury vapour lamps. In the former lamps the dark blue, light green, dark green and dark blue colours are obtained from lamps with appropriately coloured bulbs. The corresponding colours using h.p.m.v. lamps are obtained at relatively high efficiencies by means of coloured glass screens mounted in the floodlight. The h.p.m.v. lamps employed are identical with those already described (see page 19). The yellow floodlighting lamp is identical with the 85w. sodium vapour lamp already described (see page 40).

Constructional Details and Method of Operation.

The 400w. neon filled and the 100w. mercury filled floodlighting lamps are shown in figure 31. The 150w. neon lamp is the same length as the 100w. mercury filled lamp but of larger diameter, while the

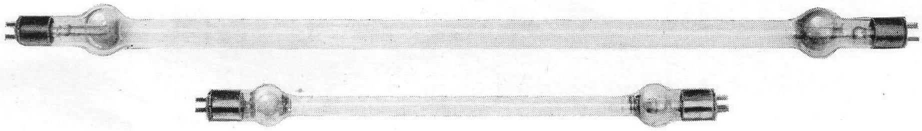


Fig. 31.—Osira Colour Floodlighting Lamps. (a) 400w. Neon-filled Lamp. (b) 100w. Mercury-filled Lamp.

250w. mercury lamp is the same length as the 400w. neon lamp but of smaller diameter. The relevant technical data are given in table 14.

Each Osira low pressure colour floodlighting lamp requires a filament heating transformer and the usual choke to operate the tube at the correct wattage. The 400w. and 250w. lamps have in addition a small Tesla or high frequency coil operated from the filament heating transformer the purpose of which is to start the discharge. The filament heating transformer and Tesla coil are mounted in the floodlight housing, while the choke can be placed in any convenient position between the floodlight and the control board. The chokes are supplied with tappings to operate from 50 cycle a.c. supplies between 200 and 250 volts, but can be adapted if required for supplies of certain non-standard frequencies. Table 15 gives the choke tapping schedule for neon and low pressure mercury vapour floodlighting lamps. The corresponding data for h.p.m.v. and sodium vapour floodlighting lamps will be found in tables 11 and 13 respectively.

TABLE 15.

Choke Tapping Schedule for Osira Low Pressure Floodlighting Lamps.

Supply voltage	Tappings for Red Tubes		Tappings for Blue and Green Tubes	
	150w.	400w.	100w.	250w.
190	215 and 0	2 and 3	215 and 5	1 and 3
200	215 and 0	2 and 3	225 and 0	2 and 4
210	215 and 5	1 and 3	235 and 0	1 and 4
220	225 and 0	2 and 4	235 and 5	2 and 5
230	235 and 0	1 and 4	245 and 0	1 and 5
240	235 and 0	2 and 5	245 and 0	2 and 6
250	245 and 5	1 and 5	255 and 15	1 and 6

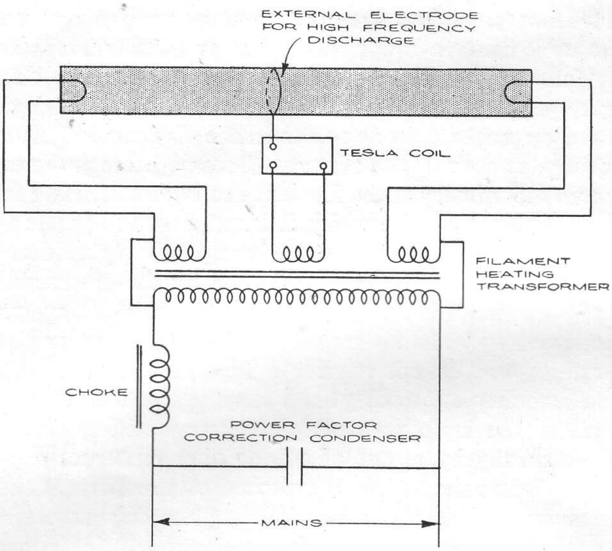


Fig. 32 (*a*).—*Circuit Diagram for 250w. and 400w. Low Pressure Colour Floodlighting Lamps.*

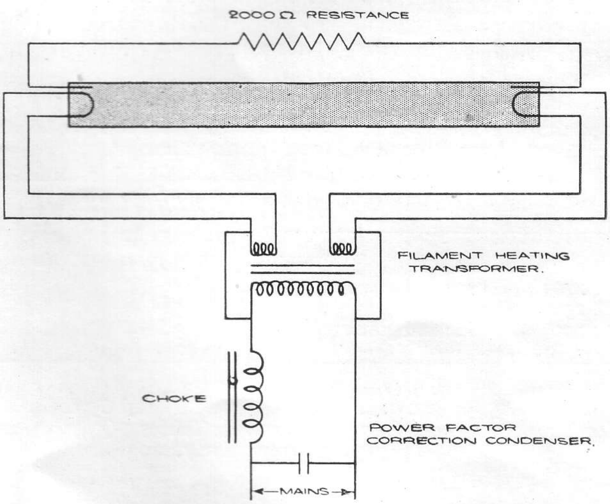


Fig. 32 (*b*).—*Circuit Diagram for 100w. and 150w. Low Pressure Colour Floodlighting Lamps.*

Figure 32(a) shows the circuit diagram for the 250w. and 400w. lamps while figure 32(b) is the circuit diagram for the 100w. and 150w. low pressure lamps. Apart from the starting arrangements the circuits are identical. When the supply is switched on the filaments heat up and practically full mains voltage is applied across the lamp. The Tesla coil in figure 32(a) operates and produces a high frequency discharge by means of the external electrode shown in the diagram. This starts the main discharge as soon as the filaments become heated whereupon the voltage across the primary of the filament heating transformer falls to the operating voltage of the tube which is insufficient to operate the Tesla coil. The filament heating voltage is correspondingly reduced but the residual heating together with that supplied by the discharge itself, is sufficient to keep the cathodes at the correct operating temperature.

The 100w. and 150w. lamps are shorter than the 250w. and 400w. low pressure ratings and do not require a Tesla discharge to start them. Instead, an auxiliary electrode placed close to the filamentary cathode at each end of the lamp is used. The two auxiliary electrodes are connected externally by means of a 2000 ohm resistance as shown in figure 32(b). When the supply is switched on the filaments heat up as described above and at the same time a glow discharge takes place between each filament and its auxiliary electrode. This enables the main discharge to pass whereupon the auxiliary discharges extinguish since the lamp voltage is insufficient to maintain them.

The uncorrected power factor of Osira colour floodlighting lamps is approximately 0.3, but this can be improved to approximately 0.8 by the use of suitable condensers, as shown in table 16. As with other discharge lamps a single larger condenser to correct a group of lamps may be used.

TABLE 16.

Capacity of Condenser for Power Factor Correction of Osira Low Pressure Floodlighting Lamps.

Lamp Wattage	Capacity to give power factor of approx. 0.8
400 watts red	80 mfd.
250 ,, blue and green	80 ,,
150 ,, red	30 ,,
100 ,, blue and green	30 ,,

The capacity for 250w. and 400w. H.P.M.V. and 85w. Sodium Vapour Floodlighting Lamps are given in Tables 9 (page 37) and 13 (page 42) respectively.

Part V.—OSRAM FLUORESCENT TUBES.

General Description.

The first low pressure fluorescent discharge tubes to be employed for lighting purposes in this country were the well-known Osira High Voltage Fluorescent Tubes. These tubes are the forerunners of the new lamp described in this section. Although Osira high voltage fluorescent tubes have found a wide field of application for interior illumination the need for high voltages to operate them is for many purposes a disadvantage. Research has therefore been directed towards the development of low pressure fluorescent tubes which will operate directly from normal supply voltages. The Osram 80w. mains voltage fluorescent tube was made available to the general public early in 1940. This lamp, which is described fully below, is shorter, and wider in diameter, than most high voltage fluorescent tubes. Also it operates with hot cathodes at a much greater current density then the high voltage tubes and with correspondingly increased brightness.

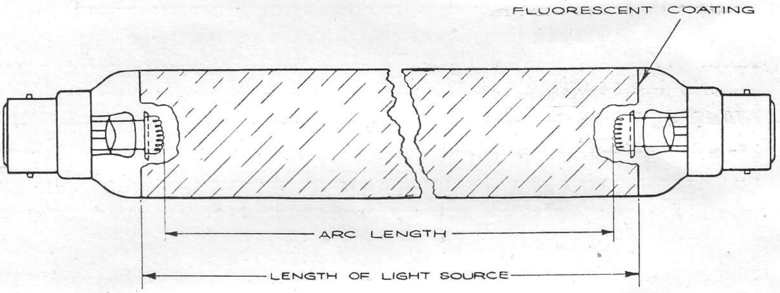


Fig. 33.—*Osram 80w. Fluorescent Tube.*

In h.p.m.v. fluorescent lamps the fluorescent powder is applied to the inside wall of the outer jacket, which is made as large as practicable in order to keep the temperature of the powder as low as possible. Owing to the much lower operating temperature of the low pressure mercury vapour discharge, however, it is possible to apply the fluorescent powder to the inside walls of the lamp itself and in contact with the discharge where full advantage of the ultra-violet radiation can be taken. About 60% of the input energy of the l.p.m.v. discharge goes into the ultra-violet lines of mercury at 2537A. and below. Since all the highly efficient fluorescent powders of class (2) (see page 15) are powerfully excited by these wavelengths, it will be clear that the use of fluorescent powders in conjunction with the l.p.m.v. discharge presents great possibilities of improved efficiency and colour.

Constructional Details and Method of Operation.

Figure 33 shows diagrammatically the constructional details of the lamp. The relevant technical data are given in table 17. The filamentary electrodes are oxide coated and have metal fins attached which help to reduce the voltage drop when the electrode is acting as anode.

The electrodes are mounted on short glass pinches which are sealed into the ends of the long tubular envelope. Since the filaments require to be heated independently during the starting period both leads are brought out to a standard bayonet cap at each end.

TABLE 17.

Technical Data for Osram Fluorescent Tube.	
Tube watts	80
Supply voltage	200–250 A.C.
Tube current, amps.	0.8
Efficiency in L/W. Initial ..	35
Max. brightness candles/cm.^{2} ..	Approx. 0.5
Overall length ins.	60+1, 60–0.5
Arc length mm.	1445±10
Length of Fluorescent Coating (Light Source) mm.	1455
Diameter of tube mm.	38±1.5
Caps	2-Pin B.C.

Each Osram fluorescent tube requires a series choke to limit the current to the required value. The chokes used are similar to those shown in figure 22 for the Osira 80w. quartz h.p.m.v. lamp, and the tapping schedule is the same as given in table 8, page 36, for h.p.m.v. lamps. A somewhat cheaper version of the standard protected type of choke, tapped in 10 volt steps instead of the usual 5, is also available.

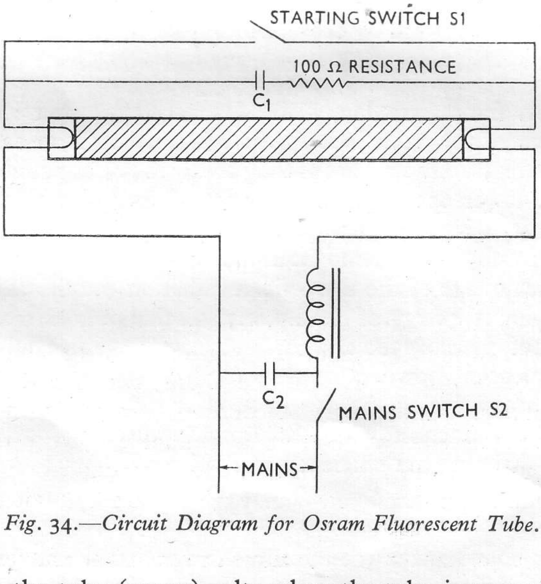


Fig. 34.—Circuit Diagram for Osram Fluorescent Tube.

Although the tube (or arc) volts when the tube is operating are only about 115 the actual starting potential is well above ordinary supply voltages. For this reason some device is necessary to initiate the discharge. The principle of the method employed is shown in the circuit diagram in figure 34. The choke is connected in series with the two filamentary electrodes and a hand-operated starting switch S1. If the mains switch S2 is closed with the starting switch open nothing happens, since the supply voltage is insufficient to start the discharge, particularly with the electrodes unheated. If, however, the switch S1 is now closed for a few moments, the electrodes heat up and on opening S1 a momentary high voltage is induced across the tube terminals which, since the electrodes are hot, enables the discharge to start. Once the current is passing through the tube the discharge itself maintains the electrodes at the required temperature. In practice it would, of course, be very inconvenient to have to operate two switches to start the tube and a special glow discharge starting switch is used which operates automatically when the supply voltage is switched on.

Figure 35 is a photograph of the glow starting switch. The switch is, itself, a small discharge tube of the negative glow type, the electrodes of which form the switch contacts. The envelope is filled with helium at a reduced pressure. The electrodes are bimetallic strips—that is to say they are made from strips of metals of different coefficients of expansion welded together, so that when heated they bend and touch.

When the device is first switched on the contacts of the glow switch are open and the mains voltage starts a glow discharge between them. This heats them up and they bend over until the contacts close, whereupon the current passing through the filaments increases from approximately 100 m.a. to about 1.3 amps, causing them to become bright-red hot. Meanwhile the bimetallic electrodes of the glow switch are cooling down since, with the contacts closed, the glow discharge between them is short circuited. After a few seconds the switch contacts open and the resulting induced voltage across the tube causes the discharge to start easily; this is facilitated by the fact that the tube electrodes have become heated. The voltage across the tube when it is running is not sufficient to restart the glow in the switch. No energy is consumed by the latter, therefore, while the tube is operating. All the above, which takes so long to describe, happens within a few seconds of closing the main switch, so that the delay in starting the tube is negligible. Since the pressure of the mercury vapour never rises above a fraction of a millimetre the tube, unlike h.p.m.v. lamps, may be restarted immediately after switching off.

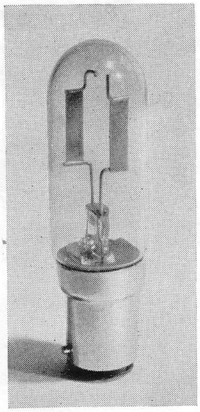


Fig. 35.—Glow Starting Switch. Overall Length, 70mm. Diameter of Bulb, 20mm.

The starting voltage depends to some extent on the ambient temperature and increases somewhat as the temperature falls. Starting trouble may, therefore, arise if the tube is erected in a position where a low ambient temperature is likely to be experienced. It is for this reason that the tubes are not recommended for outdoor burning. It is difficult to specify accurately what is the lowest ambient temperature which will permit of satisfactory operation, owing to variation in the supply voltages and to the inevitable small variations in the tubes themselves. It would appear that below about 5°C. slow starting, or even complete failure to start, may sometimes occur, particularly if the supply voltage is below its nominal value.

The complete circuit diagram for the tubes is shown in figure 34. The power factor condenser C_2 has a capacity of 7.5 mfd. giving an overall power factor of about 0.9. With no correction the power factor is only about 0.5. Table 18 gives the capacity required to correct each tube and choke unit to power factors between 0.7 and 0.95. For groups of tubes a single larger condenser may be used the value of which is obtained from the table as mentioned before. The nearest standard capacity to that determined from the table should be used. The small condenser C_1, the function of which is to suppress any radio interference which the tube may cause, has a capacity of 0.05 mfd. A 100 ohm resistance is connected in series with the radio suppression condenser to prevent the condenser discharging across the contacts of the glow switch and welding them together.

TABLE 18.

Capacity of Power Factor Correction Condensers for Osram 80w. Fluorescent Tubes.

Mains Volts	Capacity in microfarads to give the following power factors.					
	0.7	0.75	0.8	0.85	0.9	0.95
200–220	4.5	5.0	6.0	7.0	8.0	9.5
230–250	4.5	5.0	6.0	7.0	7.5	9.0

Figure 36 shows the effect of variation of the mains voltage on the characteristics of Osram 80w. fluorescent tubes. As the mains voltage increases the tube current increases and the voltage across the tube decreases, since the increased tube current results in more ions being formed in the gas and this reduces the effective resistance of the discharge path.

It will be seen that the tube watts increase at a slower rate than the tube current and that, although the lumens increase with the mains voltage, the efficiency actually falls by about ½ per cent for a 1 per cent increase in mains voltage. The change in lumens brought about is very small being only about 1¼ per cent for a 1 per cent change in mains voltage.

Osram fluorescent tubes are intended primarily for operation on a.c. The series choke has a resistance of only a few ohms and on d.c. it is no longer capable of limiting the tube current to the required value. On d.c. the current will tend to rise to very large values and the tube may be destroyed unless special precautions are taken. Operating the tubes on d.c. is not recommended but if it is desired to do so for any special purpose a suitable resistance must be used in series with the choke. The function of the choke in this case is merely to provide the inductive voltage kick to start the discharge. The resistance required will depend to some extent on the supply voltage. For a 230v. supply the resistance

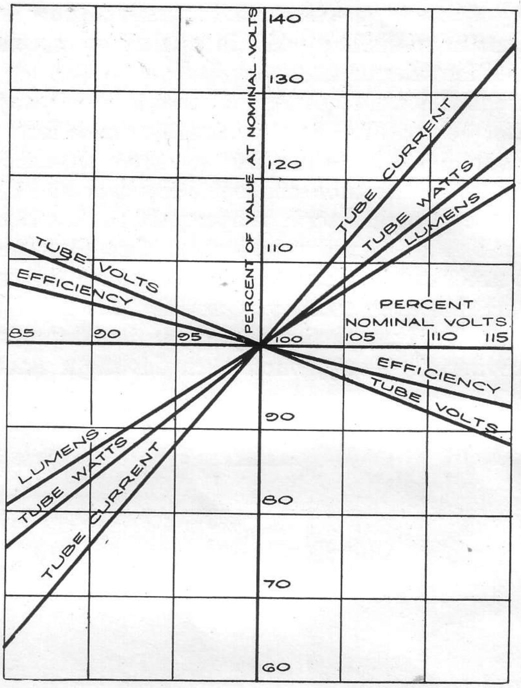


Fig. 36.—Effect of Variation of Mains Voltage on the Characteristics of Osram Fluorescent Tube.

should be approximately 140 ohms, and this should, of course, carry the tube current of 0.8 amp. without overheating. The glow switch may be found rather slow in acting on d.c. or may even fail to start the tube and an independent hand-operated switch of the 5-amp. tumbler type, for example, may have to be used instead.

Diffusion of the mercury from the anode to the cathode end of the tube (or electrophoresis as it is called) will take place on d.c., with the result that after a few hours burning the light from the anode half of the tube is likely to be seriously reduced. This may be remedied temporarily by reversing the polarity. The tube efficiency before electrophoresis takes place will not be affected on d.c. but the overall efficiency of the unit will be approximately 50% of that obtained on a.c. owing to the loss in the resistor. The efficiency on d.c. falls off rapidly as electrophoresis develops.

Stroboscopic Effect.

Reference has already been made to the tendency of discharge tubes operated on single-phase a.c. supplies to show multiple stationary images of rapidly moving objects illuminated by them. The reason for this is that on a.c. the light falls to a low value each half cycle as the current passes through zero and a moving object tends to disappear for a brief instant at the position in space it occupies when zero current occurs. This property of showing stroboscopic images is of great importance for examining parts of machinery while in motion and special tubes have been developed for this purpose.

In tubes used for normal lighting purposes, however, any pronounced stroboscopic or flicker effect is objectionable and efforts are made to reduce it to a minimum. In the Osram fluorescent tube this is done by careful design of the tube and operating gear and also by taking advantage of the phosphorescent property of the fluorescent powder, which continues to glow during the instant of zero current. For most purposes the stroboscopic effect in modern discharge lamps is negligible and causes no inconvenience even at high levels of illumination. Instances occur, however, particularly where the lamps are used in the vicinity of moving machinery, where even this slight amount of flicker

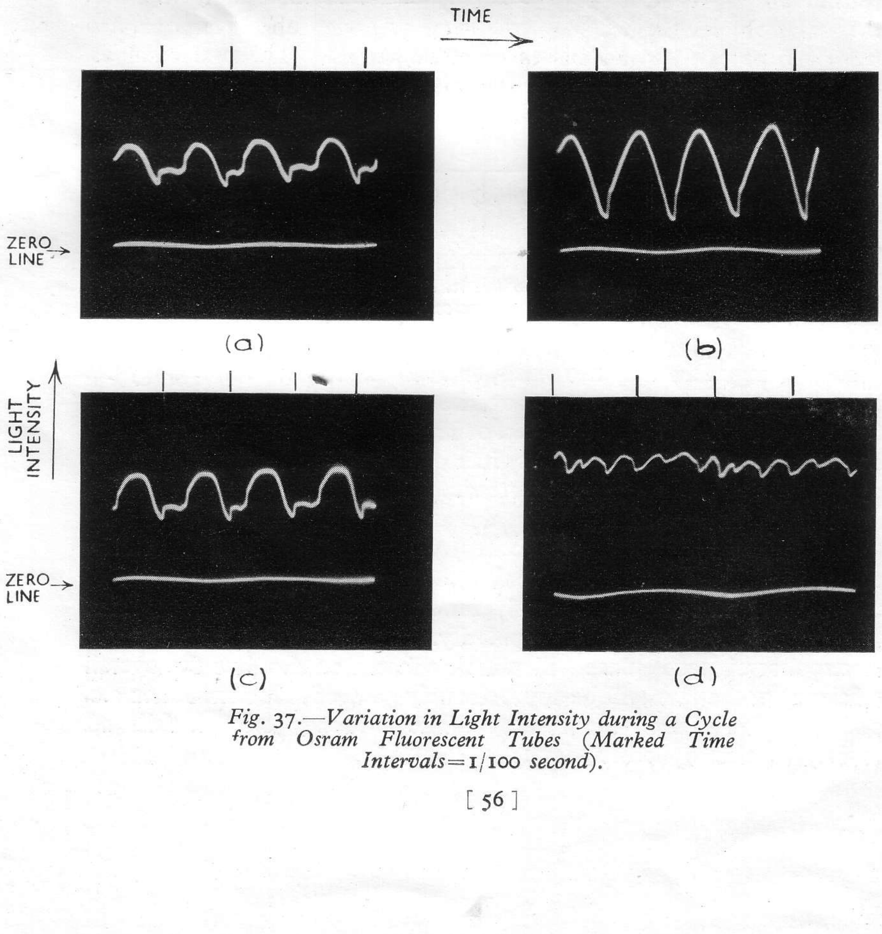


Fig. 37.—*Variation in Light Intensity during a Cycle from Osram Fluorescent Tubes (Marked Time Intervals* = 1/100 *second).*

is objectionable. This, as already mentioned, can be eliminated by operating the lamps on multi-phase supplies so that the zero currents and therefore the light minima occur in different lamps at different times. The mixed light from the lamps operated in this manner is practically free from stroboscopic effect.

Another method of reducing stroboscopic effect which is applicable to low pressure mercury vapour lamps and which is very useful where only a single-phase supply is available is to operate the lamps in pairs, preferably in the same fitting, with the usual choke of one of the lamps replaced by a capacitative reactance. An advantage of this arrangement is that the lagging current in the choke-controlled lamp is balanced by the leading current in the capacitatively-controlled tube, resulting in an overall power factor of practically unity. Figure 37(a) shows oscillograms of the light intensity from a pair of Osram fluorescent tubes operated in this manner. Figure 37(b) shows the wave form obtained when both tubes are operated inductively. For comparison, figure 37(c) shows the result obtained when two tubes are operated on two phases of a three-phase supply with a phase displacement of 120°, while figure 37(d) shows the variation in intensity of the mixed light from three tubes operated on a three-phase supply. It will be clear from these curves that the variation in light output during a cycle is very considerably reduced by the use of the special circuit described above, the result obtained being about the same as if the tubes were operated from two phases of a normal three-phase supply. The best result is, of course, obtained by operating the tubes in groups of three on normal three-phase supplies as shown in figure 37(d).

Spectral Energy Distribution.

Spectral energy distribution of the radiation emitted by the Osram fluorescent tube is given in Appendix II together with that of a similar tube without fluorescent coating for comparison. Some 60% of the input energy goes into the ultra-violet lines at 2537A. and below although, of course, these short wavelengths are not radiated by the tube. Approximately 20% of the input energy of the fluorescent tube is radiated in the visible region of which just under 1.5% is made up of the four well-known mercury lines. The rest of the input energy is dissipated either in the infra-red region, as radiated energy which accompanies the light, or by convection and conduction of heat in the tube itself (see Appendix II). The total energy radiated amounts to about 60% of the input energy (20% visible light plus 40% infra-red) compared with 85% in a tungsten filament lamp. This fact and also the high luminous efficiency, accounts for an important characteristic of the new fluorescent tube, namely that the amount of heat accompanying the lumens is only about one quarter of that from a tungsten filament lamp of equal wattage. The energy lost as heat at the tube itself by conduction and convection tends to remain at ceiling level and is largely removed by the normal ventilation of the room.

Colour, Efficiency and Life.

The colour of Osram 80w. fluorescent tubes, which is, of course, determined by the fluorescent coating, has been chosen very carefully to give an effect approximating to noon sunlight. Figure 38 is a graphical representation of the luminosity distribution throughout the spectrum compared with that of noon sunlight. The heights of the rectangles enclosed by the full lines are proportional to the total amount of light in each wavelength band radiated by the tube. The colour of the tube when alight is creamy white and the colour rendering properites of the light are excellent—very much better than those of ordinary incandescent filament lamps.

It is not possible to obtain satisfactory colour rendering by the use of a single fluorescent powder since all known powders give bands of light with a well defined maximum in some region of the visible spectrum but are deficient in light from other regions. To overcome this difficulty the fluorescent coating comprises a number of different powders selected

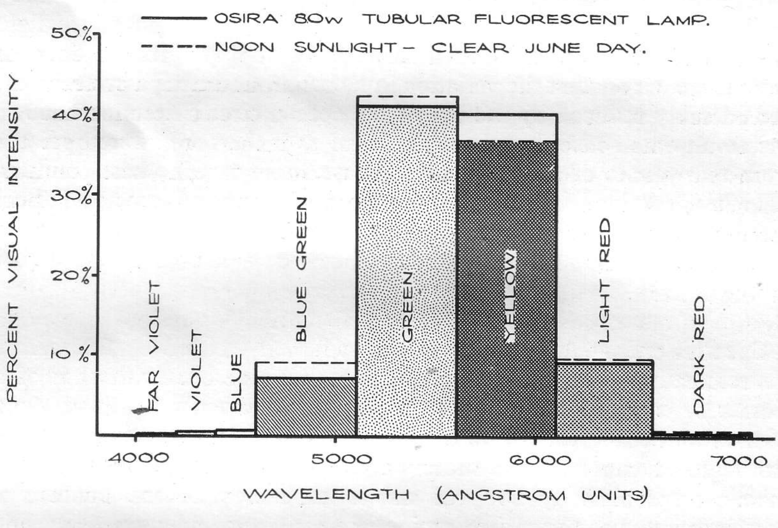


Fig. 38.—Luminosity Distribution of Osram Fluorescent Tube compared with that of Noon Sunlight.

so that their emission bands occur in complementary regions of the visible spectrum. The proportions of the component powders present in the mixture are adjusted to give the desired luminosity distribution throughout the spectrum. The resultant light contains all the wavelengths in the visible spectrum required to give an exceedingly agreeable natural white light highly reminiscent of sunlight. Figure 39 shows a spectrum photograph of the light from the tube compared with that of noon sunlight. The spectrum of a l.p.m.v. discharge without fluorescent coating is also shown alongside for comparison. The apparent fall in intensity in the green about 5000A. shown in (a) and (b) is due to the characteristics of the photographic plates which are very insensitive in this region.

The efficiency of the tube is determined largely by the intensity of the powerful mercury line at 2537A. which is mainly responsible for exciting

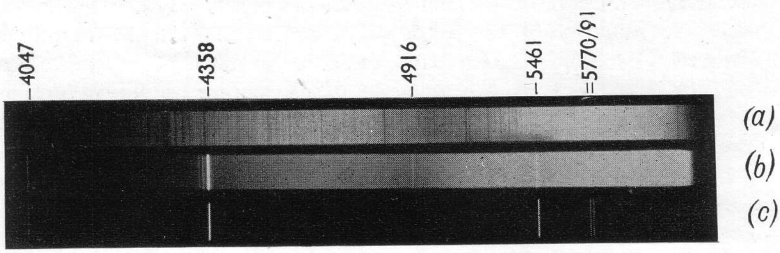


Fig. 39.—(a) Spectrum of Noon Sunlight. (b) Spectrum of Osram Fluorescent Tube. (c) Spectrum of similar Discharge without Fluorescent Coating. (Wavelengths in Angström Units.)

the fluorescent coating. The intensity of the 2537A. line is influenced by the vapour pressure of the mercury which in turn is controlled by the temperature at which the tube operates. It is clear, therefore, that in a given tube the efficiency will to some extent depend on the temperature of the surrounding air. The tube has its rated efficiency when burning unenclosed with an ambient temperature of 20°C. At lower ambient temperatures the efficiency would be somewhat lower, but this would tend to be offset when the tube is enclosed in a fitting. At higher ambient temperatures the efficiency versus temperature curve is rather flat up to about 40°C., so that under all normal conditions it may be taken that the rated efficiency will be achieved.

As already mentioned the running voltage of the Osram 80w. fluorescent tube is 115 volts. This is made up of a potential drop of about 15 volts in the immediate vicinity of the cathode, and a uniform drop of 100 volts along the positive column. The fall of potential at the cathode, and hence the wattage loss at the cathode, is independent of the length of the tube while the positive column potential drop, and therefore the positive column watts, is directly proportional to the length of the column of light. If the length of the tube is decreased, therefore, the percentage loss at the cathode increases and the efficiency falls. The curve in figure 40 shows the way in which the efficiency varies with the length. It will be seen that above 5 ft. the efficiency increases very slowly as the length increases, and the efficiency of the 5-ft. tube is only about 2% below the value obtained with very long lengths. It has been assumed that the conditions as regards current density, etc. are identical for the different lengths of tube. It must not be supposed that one tube must necessarily be less efficient than another just because it is shorter. If the current density and other conditions are not the same in the two tubes other factors may arise which compensate for the difference in length and the shorter tube may actually be the more efficient.

Apart from failures due to accidental occurrences such as glass cracks, etc. the ultimate failure of the lamps is caused by exhaustion of the

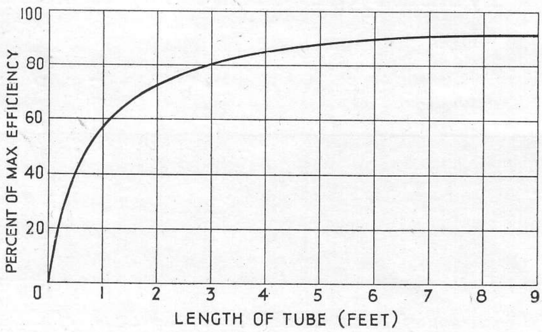


Fig. 40.—Relation between Efficiency and Length of Tube.

electron emissive material on the filamentary electrodes, which is disintegrated slowly throughout life. A momentary greater loss occurs each time the tube is switched on and for this reason excessive switching, as on flashing circuits for example, should be avoided.

APPENDIX I.

Summary of Important Characteristics of Osira and Osram Electric Discharge Lamps.

Discharge Lamp	Supply voltage	Efficiency L/W initial	Capacity in mfd. to correct to 0.8 power factor.	Operating gear required (excluding Power Factor Condensers)	For further particulars see page
250w. H.P.M.V. Glass	200–250 A.C.	36	10.5–13	Tapped choke	20
400w. H.P.M.V. Glass		45	12.5–18		20
80w. H.P.M.V. Quartz		38	5–6.5		24
125w. H.P.M.V. Quartz		40	6.5–9		24
400w. H.P.M.V. Fluorescent ..		38	12.5–18		26
80w. H.P.M.V. Fluorescent ..		38	5–6.5		26
125w. H.P.M.V. Fluorescent ..		40	6.5–9		26
80w. H.P.M.V. "Black" Glass ..			5–6.5		28
125w. H.P.M.V. "Black" Glass ..			6.5–9		28
45w. Sodium	100–250 A.C.	55.5	15–20	Leakage reactance Auto-transformer	40
85w. Sodium		71.1	15–20		
140w. Sodium		71.5	20–30		
85w. Sodium Floodlighting		Same as 85w. Sodium Lamp above.			
100w. Floodlighting	200–250 A.C.	12.5–5.5*	30	Tapped choke, filament heating transformer and starting resistance.	47
150w. Floodlighting		10	30		
250w. H.P.M.V. Floodlighting ..	Same as 250w. and 400w. H.P.M.V. Lamps above.				
400w. H.P.M.V. Floodlighting ..					
250w. L.P.M.V. Floodlighting ..	200–250 A.C.	·15–6.5*	80	Tapped choke, filament heating transformer and Tesla coil.	47
400w. L.P.M.V. Floodlighting ..		11	80		
80w. Fluorescent Tube		35	6	Tapped choke. Starting switch and radio interference suppressor.	52

*This efficiency range includes low pressure mercury vapour lamps of different colours, viz. light blue, dark blue, light green and dark green.

APPENDIX II.

Distribution of Energy throughout the Spectra of Osira and Osram Electric Discharge Lamps.

The table below gives the approximate distribution of energy throughout the spectra of the various Osira and Osram electric discharge lamps discussed in the previous pages. This is expressed as the per cent of the input watts radiated in the far ultra-violet, near ultra-violet, and visible regions of the spectrum. The remainder of the input energy is radiated in the infra-red or dissipated as heat at the lamp and fittings by conduction and convection.

Approximate Energy Distribution of Osira and Osram Electric Discharge Lamps.

Discharge Lamp.	Per cent of input energy radiated by the lamp.			Infra-red, conduction and convection losses.
	Below 2600A.	2600A. to 4000A.	4000A. to 7500A.	
250 and 400w. H.P.M.V. Plain	All wavelengths in this band are, of course, absorbed either by the discharge envelope or the outer bulb.	3	10	In all the lamps the remainder of the input energy is dissipated as heat either by direct infra-red radiation from the discharge itself and the heated lamp parts, or by direct removal of heat from the lamp by conduction and convection.
400w. H.P.M.V. Fluorescent		1	9	
80 and 125w. H.P.M.V. Plain		4.5	12	
80 and 125w. H.P.M.V. Fluorescent		1	12	
80 and 125w H.P.M.V. "Black" Glass		3.5	0.01	
Sodium Lamps		Very small	8.5	
100 and 250w. L.P.M.V. Floodlighting		0.5	1.5–2.0	
150 and 400w. Neon Floodlighting		Very small	1.5	
80w. Fluorescent Tube		0.5	13	
80w. L.P.M.V. tube without Fluorescent coating for comparison with above		0.5	1.5	

In h.p.m.v. fluorescent lamps, the energy distribution inside the visible wavelength band is, of course, different from that of the corresponding non-fluorescent lamp, since the fluorescent lamp gives more orange and red light. The values given in the table for the near ultra-violet band (2600A. to 4000A.), radiated by fluorescent lamps are only rough estimates, since the thickness of the fluorescent coating influences to some extent the amount of this radiation emitted by the lamp.

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