ENGINEERING SUPPLEMENT TO THE SIEMENS MAGAZINE

No. 131. APRIL, 1936.

SOME FURTHER ASPECTS OF THE ELECTRICAL DISCHARGE IN GASES & VAPOURS

(by J. N. Aldington, B.Sc., A.I.C., of the Siemens Lamp Works, Preston).

Gower Street, London, lighted with "Sieray" Electric Discharge Lamps.

General.

The commercial production of light by means of electric discharge lamps is an accomplished fact. There are probably in this country more than 10,000 lighting units employing Discharge lamps of one kind or another. In addition to these lamps, which are of the hot cathode type, there must be many thousands of cold cathode discharge tubes in use for decorative and advertising purposes.

Certain of the principles underlying the development of electric discharge lamps were outlined some two years ago in this Supplement.* During the past two years considerable developments have taken place not only in regard to the improvement of existing types of lamps, but also in the development of other types, some of which have already passed the experimental stage. In this short account of some of these developments it is proposed to describe certain of the principles of gaseous conduction in so far as they bear a relation to modern development.

Theoretical Considerations.

When a gas has an electrical potential applied to it there occurs a movement of electrons in a general direction towards the positive pole of the supply. These electrons tend to move with greater energy as the electrical potential increases. At a certain critical stage in that increase of potential, the gas begins to emit radiation. It is possible so to arrange the conditions that the emitted radiation will be of a single frequency

* *The Engineering Supplement of January, 1933.*

characteristic of one of the constituents of the gas to which the potential is applied. The radiation so produced may be of a wavelength in the ultra-violet range and thus not produce any response on the retina of the eye.

The voltage necessary to excite the atoms of a gas to produce radiation of a single frequency of the kind described above is called the resonance potential, and for each gas there is a certain critical value of this potential.

Further increase in the potential applied to the gas brings about eventually a condition in which the gas becomes conductive and emits radiation, some of which lies generally in the visible spectrum. This second higher potential is called the ionization potential. In the first case when resonance occurs, the electrons have not sufficient energy to ionise the gas, but have only enough energy to cause a disturbance of atomic structure sufficient to excite the most readily produced radiation. At the ionization potential the primary electrons, present in all gases, acquire sufficient energy to split up neutral gas atoms into further electrons and atomic residues called positive ions. The positive ions are simply the gaseous atoms which have lost an electron and thus have acquired a positive charge, and the electrons which have been separated from their parent atoms are called negative ions.

There is a further interesting state which can be acquired by a gas when under the influence of an electrical potential. Certain gaseous atoms can be so influenced by the movement of electrons in their vicinity that other electrons within the atom become raised to a condition of meta-stable equilibrium. In this condition the atom has not sufficient energy stored up within it to radiate that energy itself, but it is possible for it to give up that energy to another atom, thereby raising the second atom to a condition such that radiation can occur. This peculiar phenomenon is being utilised for lowering the striking voltage of certain electric discharge lamps. It is found, for example, that the voltage at which a neon tube will become conductive is decreased by mixing with the neon a very small percentage of some other gas, such as argon, and it is thought that this lowering of striking voltage is associated with the production of a meta-stable condition in the argon atoms.

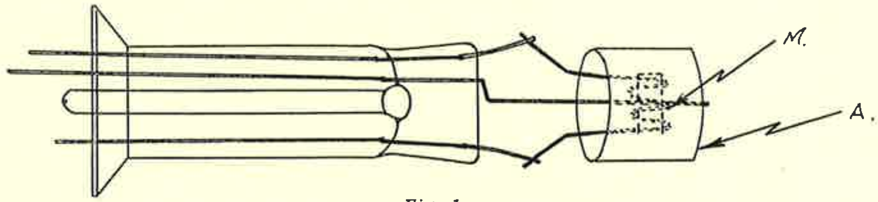

Fig. 1.

"Sieray" Red Floodlighting Lamps.

Certain of the above principles have been utilised in the design of the "Sieray" Red Floodlighting lamp. This lamp consists of a glass tube some 32 mm. in diameter and 610 mms. between the electrodes. The electrodes, which are of the form shown in Fig. 1, are mounted on ordinary lamp feet and sealed into the enlarged spherical ends of the tube.

The cylinder "A" is made from sheet nickel and is the auxiliary electrode used for initiating the discharge. The main electrode "M" comprises a rod of a sintered mixture of barium and strontium oxide enclosed within the tungsten helix. The complete lamp is of the form shown in Fig. 2, and has been thoroughly exhausted by a special process and filled with spectrally pure neon to a pressure of $1\frac{1}{2}$ mms. of mercury plus a very small amount of argon.

Fig. 2.

The "Sieray" red floodlighting lamp is designed for operation on A.C. mains only, and must be operated in series with a suitable choke coil designed to limit the current to three amperes. The tungsten helices are connected to two separate 4-volt secondary windings of a transformer, the primary of which is tapped in 5-volt steps from 200 to 260 volts. A resistance of 5,000 ohms connects together the two auxiliary electrodes for the purpose described below. The complete circuit arrangement is shown in Fig. 3, and the action of the lamp is as follows :—

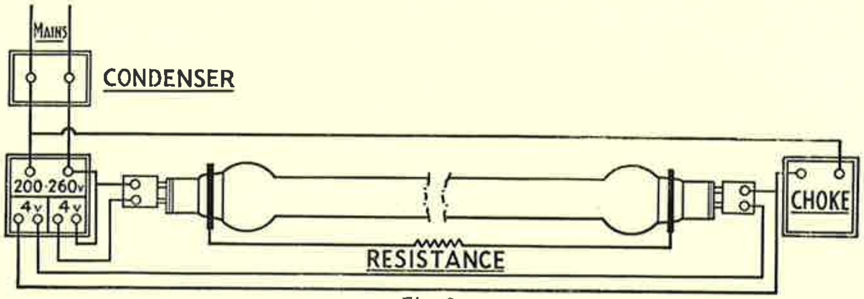

Fig. 3.

When the current is switched on, the tungsten helices are raised to a temperature of approximately

1000°C. Within about 20 seconds, the rods of alkaline earth oxides within the helices begin to emit electrons very freely. A glow discharge is, therefore, set up between each of these main emissive electrodes and the auxiliary electrodes which surround them. By utilising the gaseous mixture of neon plus a small percentage of argon, the meta-stable atomic condition described above is set up, and at a voltage of about 150 the whole of the 610 mms. of gas between the electrodes is rendered conductive and a current of three amperes begins to pass. The voltage drop across the main electrodes immediately falls to about 80—90 volts in which condition the tube requires approximately 200 watts and has a light output of about 2,000 lumens.

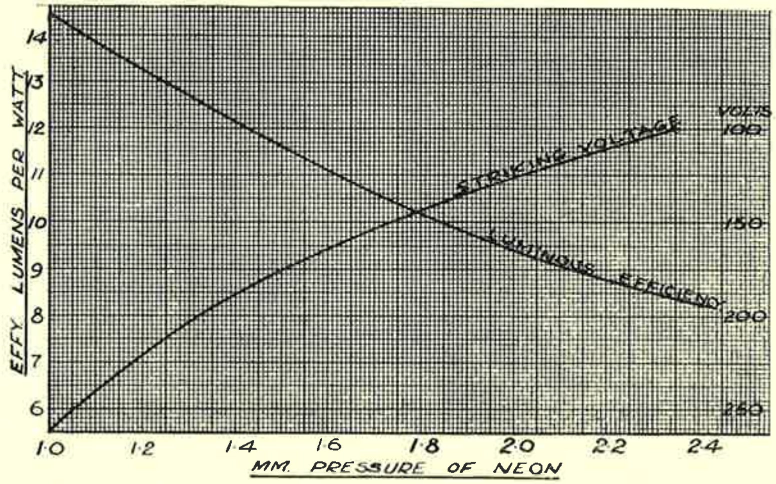

Fig. 4.

It is interesting to note the relation between the pressure of neon with which such lamps are filled and the efficiency in lumens per watt, and also the striking voltage of the lamp. The graph, shown in Fig. 4, depicts the relation between these quantities for the standard "Sieray" red floodlighting lamp.

It will be seen that with decreasing gas pressure the efficiency of the lamp increases, but the striking voltage also increases. It is found that a suitable compromise is obtained with a pressure of $1\frac{1}{2}$ mms. of neon at which the efficiency is of the order of 10—11 lumens per watt and the striking voltage is of the order of 150.

Standard Types of "Sieray" Street Lighting Lamps.

Considerable development has taken place in these types of lamp, not only with regard to improved efficiencies, but also with regard to their reliability on low-voltage circuits. All standard high-pressure metal vapour "Sieray" discharge lamps now employ the two-resistor method of connecting the auxiliary electrodes, as shown in Fig. 5.

This method of connecting the auxiliary electrodes has the advantage over previously used methods that both electrodes have the mains potential applied to the auxiliaries, thus ensuring good ionisation at both ends of the lamp immediately the circuit is closed. It is found that the standard "Sieray" lamps now have an average striking voltage of less than 150 volts A.C. The following table gives a list of "Sieray" lamps either on the market or shortly to be placed on the market, together with their initial efficiencies and through life efficiencies in lumens per watt. As a comparison, similar efficiency figures are given for a 500-watt tungsten filament gas-filled lamp :—

Lamp Input.	Initial efficiency.	Average efficiency up to 1,500 hrs.	Efficiency at 1,500 hours.
Watts.	L/W.	L/W.	L/W/.
150 (Mercury) ..	32	26	24
250 (Mercury) ..	36	31	29
400 (Mercury) ..	45	37	34
400 (Colour Modified)..	37	29	27
700 (Mercury) ..	50	40	38
500 (Tungsten Filament)	15·8	13·8 up to 1,000 hrs.	

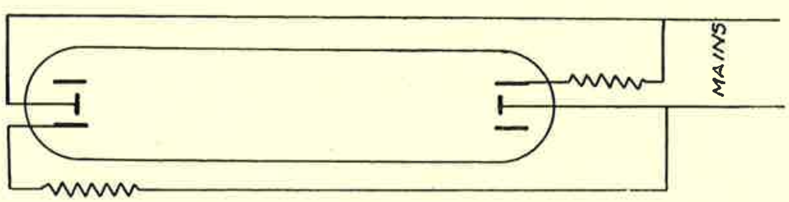

Fig. 5.

Besides these standard types of hot cathode high-pressure metal vapour discharge lamps, the Company has also developed a range of "Sieray" blue, green and primrose floodlighting lamps. These lamps are generally of the construction of standard "Sieray" electric discharge lamps, as shown in Fig. 6, but instead of the usual clear glass outer jacket, coloured outer jackets are used in order to absorb unwanted radiation and give efficient coloured light, substantially blue, green and primrose.

Fig. 7 shows transmission curves for the coloured glass used for these outer jackets.

It will be seen that the maximum transmission of these glasses is as follows :—

Colour.	*Wavelength of max. transmission to Tungsten light.*
Primrose ..	6400 Å. (no transmission below 5000 Å)
Green ..	5400 Å.
Blue ..	5000 Å.

This range of high pressure blue, green and primrose floodlighting lamps has a further point of difference from the standard high-pressure "Sieray" lamps, in that they are designed for operation at any angle without the necessity for any form of magnetic deflection to maintain the metallic vapour arc in the centre of the discharge tube. This very desirable feature has been achieved by operating the lamps at a somewhat lower vapour pressure than is usual in the standard "Sieray" lamps. It has been found possible to choose an internal vapour pressure such that very high efficiencies are still obtained with the further advantage, from a floodlighting point of view, that the lamps can be operated in any position or at any angle.

Fig. 6.

The following table gives the efficiency figures for these floodlighting lamps :—

Bulb.	Initial Efficiency.	Efficiency up to 1500 hours.	Efficiency at 1500 hours.
	L/W.	L/W.	L/W.
Primrose ..	22	18·5	17
Green ..	22	18·5	17
Blue ..	13	11	10

The above results are for lamps burnt horizontally.

Before the development of these lamps, the efficient production of coloured light by means of gas-filled lamps and colour screens was only of the order of 2—8 lumens per watt according to the colour ; it is thus evident that "Sieray" floodlighting lamps are extremely efficient from the point of view of colour floodlighting.

In order to utilise the characteristic polar curve of these "Sieray" floodlighting lamps, a special floodlighting fitting has been designed, as shown in Fig. 8.

This floodlight is designed to accommodate "Sieray" floodlighting lamps in the horizontal position. The body is of heavy gauge lead-coated sheet steel, wired and reinforced at the joints. The reflector is of copper-backed mirror glass built up in strips on a sheet steel former and is of parabolic section. The top and front are covered by clear heat-resisting glass which slides in a channel formed in the end cheeks. The floodlight is complete with cradle for ground mounting. G.E.S. holder, watertight plug and socket for easy connection. Adjustment is provided on the lampholder for focussing. The exterior is finished aluminium cellulose. The beam spread is approximately 90° in the horizontal plane and 40° in the vertical plane.

Effect of Impurities in Gaseous Discharge Tubes.

As explained in the section devoted to theoretical considerations, there is a certain value of potential peculiar to each gas or vapour at which it becomes conductive. If a discharge lamp is filled with a mixture of gas or metallic vapours which have widely different values for this ionisation potential, then in general only one of the constituents will take any visible part in the electrical discharge. The selected gas will, of course, be that which has the lowest ionisation potential.

It is, therefore, necessary in designing and manufacturing discharge lamps to employ only pure gas or vapour fillings or else utilise mixtures, the ionisation potentials of which are of the same order. In the case of the Sieray "W" colour modified discharge lamp the three metals, mercury, cadmium and zinc, have values of ionisation potential which are sufficiently close to one another to allow each to contribute its appropriate spectral lines to the total radiation.

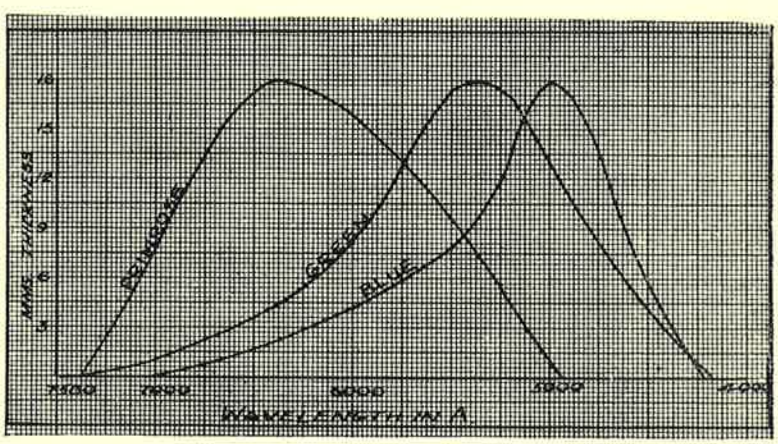

Fig. 7.

Similarly, in the field of cold cathode lighting, mixtures of gases, generally of the helium, neon, argon, series are used for producing bright colour effects, while the characteristic blue cold cathode discharge sign tube operates with a mixture of either mercury and argon or mercury and neon.

By means of a " U " tube containing neon at a pressure of about 4 mms. and a globule of mercury, it is possible to illustrate the effect produced when two materials, having rather different ionisation potentials, are used. At ordinary temperatures such a tube emits a blue light characteristic of low-pressure mercury vapour; when, however, the lower portion of the " U " tube is immersed in liquid air the mercury vapour in this portion of the tube is frozen out, i.e., its vapour pressure is reduced to a very low value, and the lower portion of the tube then emits a bright red radiation due to neon, while the upper limbs still emit blue light.

If it were possible to study the behaviour of an electron in its passage from the blue portion of the tube to the red portion, it would be found that in the blue portion it cannot acquire sufficient energy to ionise neon atoms. As soon as the electron had acquired sufficient energy to ionise the mercury present together with neon in the tube it would lose that energy by collision with mercury atoms, thus exciting them to produce their characteristic radiation. When, however, the mercury reached the lower portion of the " U " which no longer contained mercury vapour, it could then acquire sufficient energy to ionise the neon and thus cause the emission of the red radiation. Such an experiment is interesting as showing the complete suppression of the neon spectrum in the portion of the tube containing mercury.

Bearing in mind facts such as these it is obvious that considerable care must be taken in the manufacture of electric discharge lamps to ensure adequate purity of all materials used in their preparation.

The Use of Fluorescence.

In spite of the fact that electric discharge lamps can now be made at efficiencies two or three times those possible with tungsten filament lamps, it is still true to say that even the best commercial discharge lamp is a very inefficient converter of electrical energy into light. As it is known that some of the energy of electric discharge lamps is radiated in the ultra-violet as well as in the visible portion of the spectrum, workers in the electric discharge field have for some considerable time been experimenting with devices for converting some of this ultra-violet radiation into visible light. Different gases and vapours emit different proportions of their total radiation in the ultra-violet; hence it is desirable in work of this kind to select a radiator such as mercury vapour which gives a considerable proportion of its energy in the longer wavelength of ultra-violet. In the case of cold cathode tubes some success has already been achieved both in Europe and America in the utilisation of this ultra-violet for the production of visible light. For example, there are advertising signs now in evidence in some of our larger cities which employ glass tubes coated with fluorescent materials on their inner surfaces or embodied in their structure.

These tubes can be made to give a whole series of different tints, according to the nature of the fluorescent material which is used in their manufacture.

The actual discharge takes place through mercury vapour which provides the ultra-violet radiation necessary to excite the fluorescent material. The phenomena of fluorescence has received considerable attention recently, but its mechanism is still somewhat obscure. It appears, however, that when a substance of a particular chemical constitution is irradiated with a source of low wavelength some of the energy is absorbed and re-radiated at a higher wavelength than that of the absorbed radiation. Such substances are called fluorescent. Some fluorescent substances also have the power of storing up energy and emitting that energy for some time after the source of excitation has been removed. These substances are said to have the property of phosphorescence.

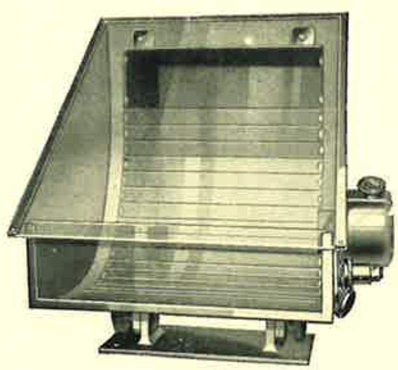

Fig. 8.

By means of a number of cold cathode discharge tubes some 2 feet in length and having a filling of mercury and argon and coated on their inner surfaces with fluorescent powders, it is possible to obtain a large series of different tints varying from orange-white through green to bright blue. Such tubes can also be used for showing the phenomena of phosphorescence, as with suitable powders there is a period of afterglow during which the characteristic fluorescent colours continue to be emitted after the tube has been switched out of circuit.

It has long been known that certain organic dyes, particularly those of the Rhodamine series, have the property of fluorescence to a very large degree. This property is well illustrated by an experiment as shown in Fig. 9.

" A " is a 400-watt high-pressure " Sieray " lamp, " B " is a lantern arranged to form an image of the arc on to the ground glass screen " C," " D " a glass prism containing Carbon Di-sulphide in order to disperse the light from the " Sieray " lamp into its several components. When the " Sieray " lamp is switched on and reaches full brilliancy, a series of images of the arc appear on the ground glass screen, each one corresponding with one of the characteristic spectral lines of mercury, the main ones being 5791, 5770, 5461 and 4359, the colour of these images being Yellow, Yellow, Green and Violet, respectively. When a glass cell containing a solution of the dye Rhodamine 6 GBS. is placed in the path of the light at XX, a broad band of red radiation having a wavelength between 6,000 and 7,000 10th metres appears on the screen. This additional red radiation is due to the phenomenon of fluorescence and is caused by the absorption of ultra-violet radiation from the discharge lamp and its subsequent emission as light of a lower frequency, i.e., in the red end of the spectrum. A further effect of placing the Rhodamine solution in the path of the light from the "Sieray" lamp is shown by the decrease in brightness of the green line on the ground glass screen. This decrease in brightness indicates absorption of visible light by the solution, and hence a considerable decrease in

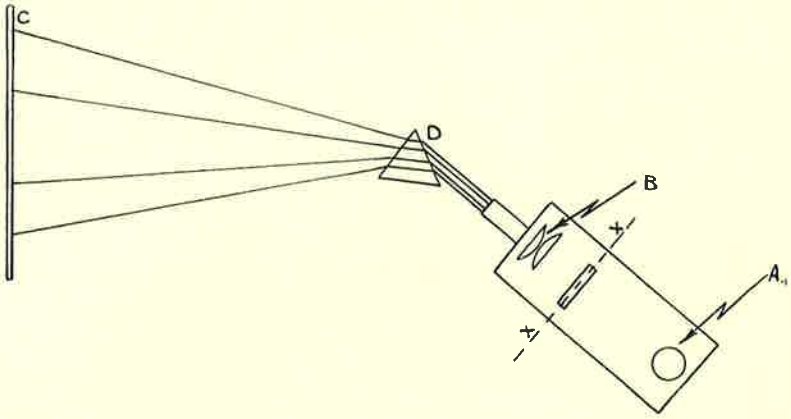

Fig. 9.

efficiency of the transmitted light. From a practical point of view, therefore, the use of Rhodamine solutions for improving the colour of the radiation from high-pressure "Sieray" lamps entails a considerable sacrifice in luminous efficiency which must be weighted against the gain in the resultant colour of the radiation.

Extremely High Pressure Lamps.

Ordinary commercial high-pressure metal vapour discharge lamps, such as the "Sieray" 250 W. and 400 W. mercury and colour modified lamps, operate at a pressure of half to one atmosphere. It was observed many years ago that the effect of increasing the pressure of the gas or vapour through which an electrical discharge is passing was to cause a shift of the energy maximum toward the higher wavelength end of the spectrum, or in other words, to cause a lowering of the frequency of the radiation. At higher pressures also, lines in the spectrum, which at lower pressures are hardly visible, become of considerably increased intensity and thereby contribute to alter the colour distribution of the resultant radiation. From theoretical considerations it would appear that the ultimate effect of increasing the pressure of the gas or vapour through which an electrical discharge is passing would be to cause such a restriction of the electronic vibrations that the normal spectral lines would be widened so that the actual radiation would be indistinguishable from that of an incandescent solid. In other words, the effect of increasing the pressure in a discharge lamp to many times that found possible hitherto would be to produce a lamp whose spectrum was no longer characteristic of the material through which the discharge was passing. With increasing pressure the spectra of different gases and vapours would thus become much more nearly similar to one another until ultimately at extremely high pressures the radiation would be of a continuous nature.

In the usual type of high-pressure electric discharge lamp the arc voltage drop per millimetre of distance between the electrodes reaches a limiting value of the order of 0.75 volts per millimetre. A new type of lamp is in course of development and is designed to operate at pressures such that the arc voltage per millimetre of distance between the electrodes is of the order of 5—30 volts per millimetre.

A lamp of the above experimental type and having an arc length of 10 mms. was demonstrated in Preston on the 22nd November, 1935, to the Astro Physical Section of the Preston Scientific Society. The lamp operated from the supply mains and the discharge occurred through mercury vapour, the pressure of which gradually increased to a certain equilibrium value at which the lamp voltage drop was 15 volts per millimetre of arc length. This extremely high pressure "Sieray" lamp was approximately 1 inch in overall length and $\frac{1}{2}$ inch in outside diameter, the arc being restrained inside a specially designed quartz thimble. It was evident from objects viewed in the light from this lamp that the radiation was much richer in red than the light from the ordinary high-pressure "Sieray" lamp. It is not new to produce lamps which work with a vapour pressure greater than one atmosphere. The problem is rather one of so designing the lamp that it can operate safely at these extremely high pressures and, at the same time, have a reasonable lumen maintenance through life. The problem is one which is exercising the minds of research workers in the various electric discharge lamp laboratories both on the Continent and in this country. The value of such lamps is to be found in their very high intrinsic brilliance and the small physical dimensions of the light source which should render them of particular use for projector work.

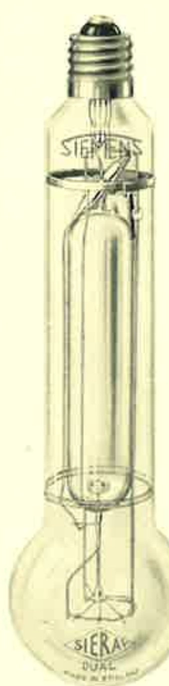

Fig. 10.

The "Sieray-Dual" Lamp.

It is considered a disadvantage by some users of discharge lamps that they require auxiliary electrical gear in order to stabilise the lamp at its designed wattage. The " Sieray-Dual " lamp has been designed to provide a high efficiency light source which is entirely self-contained. It consists of an electric discharge tube of the ordinary high-pressure type mounted in an outer glass envelope which has been exhausted and filled with argon. In the enlarged spherical end of the outer envelope is mounted a 500-watt tungsten filament which is connected in series with the high-pressure electric discharge tube. When a potential is applied to the terminals of the lamp, the arc tube strikes up and operates with a voltage drop across its terminals of approximately 20 volts. Meanwhile the 500-watt tungsten filament, running in series with the arc tube, is designed to operate at its rated current. Within about 5—10 minutes the metal fillings in the discharge tube volatilise and the voltage drop across the tube increases to some 130 volts. Soon after this state is reached the thermal switch, situated in the outer envelope, closes and cuts out a portion of the tungsten filament equivalent to the arc tube voltage. The lamp is then operating at an efficiency of approximately 25 lumens per watt and consists of a discharge tube loaded to about 275/300 watts and a filament operating at an efficiency designed to give a life of about 1,500 hours. The light from the " Sieray-Dual " lamp contains approximately 8 per cent. of red radiation, and is quite suitable for most ordinary lighting purposes. The high efficiency of 25 lumens per watt also enables the user to effect a considerable saving in energy for a given light output.

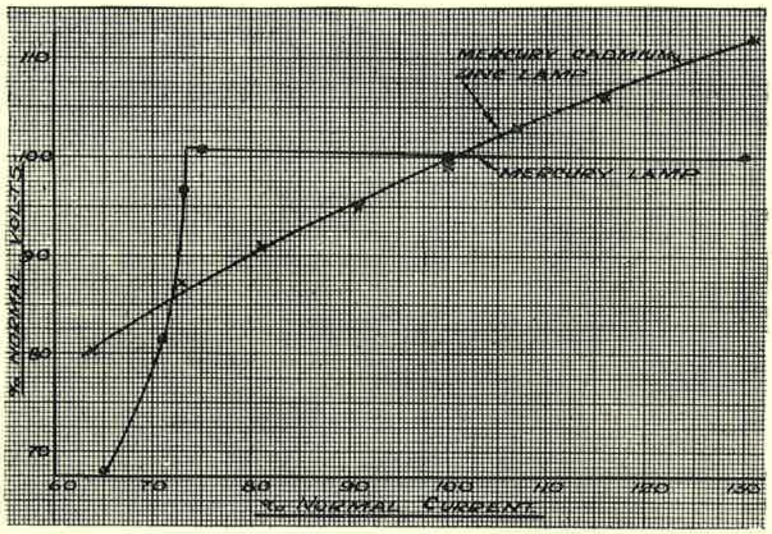

Fig. 11.

Fig. 10 shows the general appearance of the standard 500-watt " Sieray-Dual " lamp. The position of the bimetal switch situated opposite the upper end of the discharge tube can be clearly seen, together with the third connection to the filament which enables an appropriate portion of the filament to be cut out of circuit.

During the development of the Dual lamp it soon became obvious that there was a possible disadvantage in operating a filament taking only one half the mains voltage in series with an arc discharge tube taking the other half of the voltage. This disadvantage is due to the fact that with the saturated vapour type of mercury discharge tube the shape of the voltampere characteristic is similar to that shown in curve 1 of Fig. 11.

It is evident that if the filament is run in series with such a discharge tube at normal current, then any rise in the supply voltage will not cause an increase in the arc tube voltage and, therefore, the whole of such increase in the supply will be thrown on to the series filament. Assuming then that the filament takes about half the supply voltage, it is obvious that the effect of the mains fluctuations will be twice as great as in the case of an ordinary tungsten filament lamp, and since the life of a tungsten filament varies approximately as the 14th power of the voltage the effect on life of these changes is very considerable.

This possible defect in the design of the Dual lamp was, however, overcome by utilising a mixture of mercury, cadmium and zinc in the arc tube, thus producing a volt-ampere slope similar to that of curve 2, Fig. 11.

It has been found possible to produce in the discharge tube a sloping volt-ampere characteristic very similar to the slope of a tungsten filament lamp, hence in the event of the mains voltage supply to the dual lamp increasing, the arc tube voltage also increases and prevents excessive over-running of the filament.

Fig. 12 shows the distribution of voltage between the arc tube and the filament of two Dual lamps.

The first lamp has a mercury filling in the arc tube and the second lamp has a filling of mercury together with a little cadmium and zinc. It will be seen that whereas in the case of a change in the mains voltage the mercury arc tube voltage remains substantially constant and the filament associated with the mercury tube increases 10 per cent. in voltage for a 5 per cent. increase in mains voltage, this effect is practically eliminated in the case of the filament running in series with the mixed metal vapour arc.

Another interesting feature of the " Sieray-Dual " lamp is the relation between the re-striking time of the arc tube and the re-opening time of the bi-metal switch after a period of operation. It is evident that in the event of the arc tube re-striking before the bi-metal switch has re-opened, the whole of the mains voltage will be thrown across the working half of the tungsten filament with consequent damage. It has, however, been found possible to arrange that the temperature at which the arc tube will re-strike is considerably lower than the temperature at which the bi-metal switch re-opens, and hence, whether the Dual lamp operates in free air or enclosed in a lantern, the bi-metal switch will always open and leave the complete filament in series with the arc tube before the arc tube re-ignites.

Lower wattages of Dual lamps are in process of development, and it would appear that lamps of this type will play no mean part in the future of electric discharge lighting. It has also been found possible to design Dual lamps for operation on D.C. mains ; these lamps are at present being tested under various operating conditions. The production of a discharge lamp for commercial operation on D.C. mains will enable districts still without A.C. to have the advantage of this latest form of high-efficiency light source.

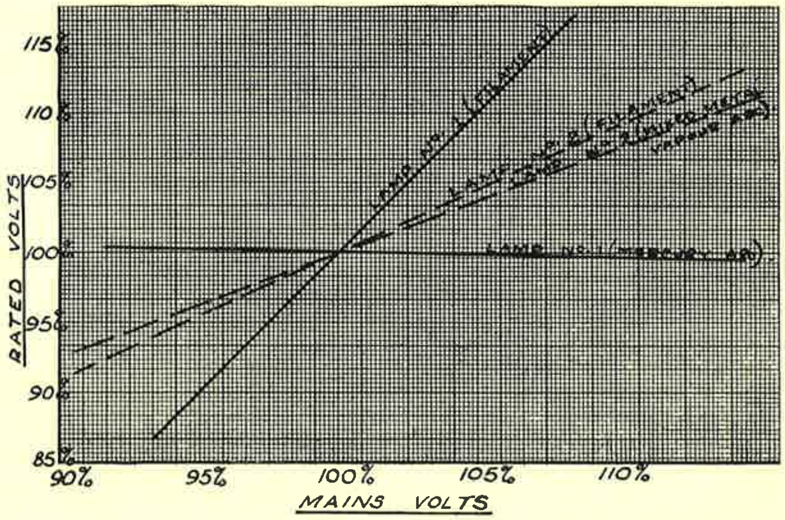

Fig. 12.

It has been the object of the foregoing account of some further developments in electric discharge lamps to show the dependence of any developments on pure research. Each new step which is taken entails the application of already known phenomena to a new purpose. It is too early to forecast by what precise means still more efficient light sources will be produced. It does, however, appear probable that they will be electronic rather than truly incandescent in nature.

Philco Radio Works, Perivale, illuminated with "Sieray" Electric Discharge Lamps.