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THE DISCHARGE OF ELECTRICITY THROUGH GASES.*

Although a wide variety of associated phenomena might be considered under the above title, it is proposed to deal only with the effects produced by the passage of electricity through gases at pressures of the order of a few mm. of mercury. The simpler types of discharge tubes operating on high voltages and associated with the names of Geissler & Crookes are well known. Such tubes are chiefly of scientific value, as the luminous effects produced from them are more interesting than useful. However, it is from such starting points and from a study of the conditions obtaining in the Geissler discharges that have come the many important and often useful developments in physical science.

We will consider the effects produced in a simple discharge tube between aluminium electrodes of 25 mm. in diameter and 300 mm. apart. As the gas pressure is progressively decreased by means of a rotary oil pump and the discharge from an induction coil is passed between the electrodes, effects are produced which can conveniently be considered under the following headings :—

(1) At pressures of the order of 50 to 100 mm. the discharge takes a sinuous spark like form.

(2) At pressures of the order of 10 mm. of mercury, a luminous column of light is visible from the positive electrode to within 40 or 50 mm. of the negative electrode. Between the end of this positive column, as it is called, and a luminous layer of gas surrounding the cathode is a dark space called after its discoverer "The Faraday Dark Space."

(3) At still lower pressures, the end of the positive column gradually recedes from the cathode towards the anode with a corresponding increase in the length of the dark space. At the same time, the cathode glow or luminous layer surrounding the cathode becomes wider and more diffuse, and recedes from the cathode forming the "Crookes" dark space.

(4) As the pressure is decreased to still lower values, no visible glow is produced from the gas, but the walls of the glass vessel enclosing the electrodes begin to fluoresce with a greenish-blue light.

We are concerned only with tubes exhausted to pressures giving effects similar to those described under headings Nos. 2 and 3.

Under ordinary conditions it is generally accepted that dry gases are good insulators, that is to say, that the application of a potential difference to two electrodes spaced some distance apart in a dry gas will not give rise to any current flow. If we make this test with very sensitive measuring instruments, it is found that even with an applied potential difference of only a few volts appreciable currents are obtained in a gas however carefully the experiment is conducted. These currents are due to the presence of a few ions which are found in all gases whether at atmospheric pressure or at the very low pressures obtained in the X-ray tube. The ionising influence is thought to be associated with penetrating radiations entering our atmosphere and known as cosmic radiation, while other ionising radiations from radio-active material present in the earth probably also play a part in causing this slight preliminary ionisation necessary to produce conduction in gases.

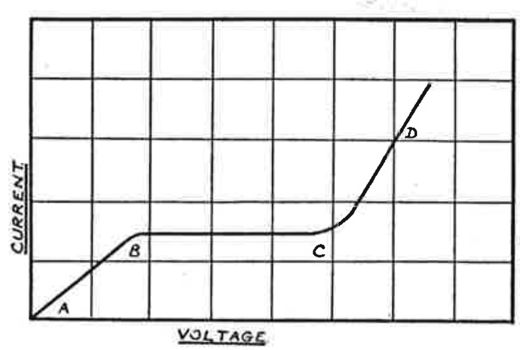

Fig. 1.

* *From a Lecture given before the Astro-Physical Section of the Preston Scientific Society on Friday, December 2nd, 1932, by J. N. Aldington, B.Sc., A.I.C., of Siemens Lamp Works, Preston.*

If the current/voltage characteristic of any gas is plotted it is found that a curve is obtained similar to that shown in Fig. 1.

The first portion of the curve (A—B) in which the current is proportional to the applied potential indicates a condition of the tube in which the number of ions being neutralised by the electrodes increases proportionately to the potential difference, less ions being lost at the walls of the vessel.

In the second portion of the curve (B—C) further increase in the applied potential produces no material change in the current. In this state all the ions being produced by the ionising influence are proceeding to the electrodes, none being lost at the walls of the vessel. In the very steep portion of the curve (C—D) the ions are now moving with such velocity that further ions are produced by their collision with neutral gas molecules. At a certain critical value of applied potential, the inner structure of the gas molecules is affected and luminous effects are produced in the tube. It has been found that the voltage necessary to produce these luminous effects in a gas discharge tube depends on several variables :—

(*a*) The nature of the gas.

(*b*) The gas pressure.

(*c*) The distance between the electrodes.

(*d*) The nature of the electrodes.

It will be useful to look at these effects separately and in some detail.

(*a*) *The Nature of the Gas.*

If a discharge tube is filled to the same pressure with the several gases, helium, neon, argon, hydrogen, nitrogen, it is found that a certain definite potential must be applied to the electrodes before luminous effects are produced in the tube, and this potential differs for the different gases, the particular order of P.D. depending on the pressure to which the tube is filled.

In general, the gases neon and then helium will produce luminous effects at lower voltages than the other gases ; while mixtures of gases in suitable proportions can be made to produce a value of striking potential in some cases less than that of the pure gas.

(*b*) *The Gas Pressure.*

If successive small amounts of gas are introduced into a highly exhausted tube producing pressures of say 1, 2, 3 and so on mm. of mercury, and the striking voltage of the tube is measured for each of these pressures, a curve of the form shown in Fig. 2 is obtained. It will be seen that the introduction of more and more gas causes a sharp decrease in the voltage of the tube until a certain minimum is obtained, after which, further increase in the amount of gas in the tube results in the striking voltage gradually increasing once more.

A curve of the general shape (Fig. 2) is obtained for all the permanent gases, although the particular values depend not only on the nature of the gas but on the distance between the electrodes, the electrode material and shape, and also on the size and shape of the containing vessel.

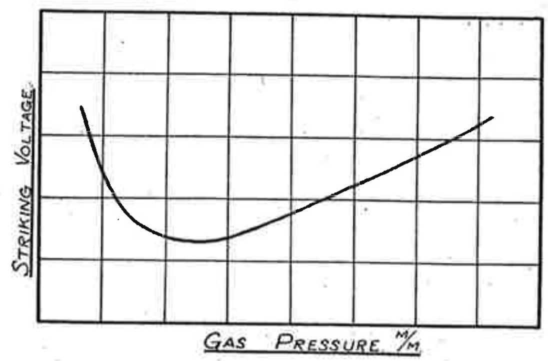

Fig. 2.

(*c*) *The Distance between the Electrodes.*

Varying the distance between the electrodes produces an effect very similar to that produced by varying the gas pressure, the explanation being that the striking voltage of a tube depends on the number of gas molecules between the electrodes. It is obvious that this number can be varied both by the gas pressure and by the electrode distance. It is thus evident that we can combine the effects produced by altering the gas pressure and the electrode spacing and draw a single curve by plotting striking voltage against the product P×S, "P" being the pressure of the gas in mm., and "S" being the distance between the electrodes in cms. A series of such curves for some of the common gases is shown in Fig. 3.

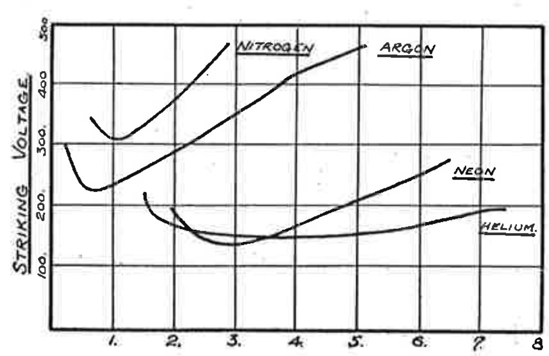

Fig. 3.

(*d*) *The Nature of the Electrodes.*

Changing the electrode material from iron to nickel or to aluminium produces but little effect on the characteristic of the tube, but if the electrodes are made of alkali metal a considerable decrease in the striking voltage is obtained. It has also been found that a similar decrease is produced if the electrodes are heated to incandescence.

We will now consider the distribution of electric force in a simple form of discharge tube when a small current is passing. A suitable tube for this purpose has plain aluminium electrodes, one of which is permanently fixed at one end of the tube and the other capable of movement to within a few mm. of the fixed electrode and away from it to a distance of approximately 200 mm. The tube has been highly exhausted and then filled with 5 mm. of neon containing a small amount of mercury vapour. A tube such as this can be operated on D.C. voltages between 200 and 400 volts, it being necessary to employ a high series resistance of the order of 10,000 ohms to prevent the characteristic of the tube altering during the experiments.

If the tube electrodes are brought within about 40 mm. of one another and a potential difference of 300 volts applied to the electrodes, conduction will be established and a luminous glow produced in the tube. The electrodes can then be separated to a distance of 200 mm. when the tube will show a bright positive column having the characteristic blue colour of the mercury spectrum extending from the anode to within 30 mm. of the cathode.

No luminous effect is produced between the end of this column and the cathode, with the exception of a narrow red luminous layer of gas surrounding the cathode and called "The Cathode Glow." As tbe anode is brought progressively nearer to the cathode, the positive column decreases in length without any decrease taking place in the length of tbe dark space, or in the nature of the cathode glow. When the anode approaches to within 30 mm. of the cathode, the positive column illumination entirely disappears and we then have the effect of a luminous layer of gas surrounding the cathode, no other glow proceeding from the tube. In certain of the devices to be described later the tubes will be operating in the latter condition, *i.e.*, with only visible cathode glow, while other devices are so designed that the chief luminous effects are produced from the positive column. If the distribution of electric force in a tube such as that described above is measured, a curve such as that shown in Fig. 4 is obtained.

It will be seen that as we proceed from the anode along the uniform positive column a constant drop in potential is obtained for each unit length of column, but near the end of the positive column, adjacent to the cathode, the electric force rapidly falls off and becomes very small in the "Faraday Dark Space."

In the layer of gas adjacent to the cathode, there is a very large fall in potential which has been called "The Cathode Fall." It is evident that if the two electrodes of a discharge tube are brought to such a distance that no positive column glow is obtained, then the striking voltage of the tube will not be very different from the cathode fall in potential; and that if means can be found by which the "cathode fall" can be reduced then discharge tubes can be made which will operate on low voltages.

It has been shown that the cathode fall of potential is caused by the accumulation of positive ions in the neighbourhood of the cathode, and that any means which serves to facilitate the emission of electrons from the cathode, so neutralising the excess of positive ions, has the effect of reducing the value of the cathode fall. Such means are found in the alkali metals which emit electrons very freely under positive ion bombardment, while certain of the alkaline earth oxides and rare earth oxides and metals, when heated to temperatures of the order of 1,000°C., have this property of electronic emission to a high degree.

In the main the facts outlined above have become known as the result of pure research. The results so obtained have made possible many developments in the practical application of electrical discharges in gases. Consideration of these developments will be limited to one or two types of cathode glow devices operating without visible positive glow, while in the field of positive column tubes only the simplest types will be mentioned.

(1) *Cathode Glow Devices.*

Lamps. (*a*) The ordinary Osglim type of lamp, having a consumption of only a few watts, and having a striking potential of about 160 volts, is familiar to all of us. For such devices the common metals, nickel or iron, form suitable electrodes. These are spaced at a distance of 2 or 3 mm. apart, a neon filling being used at such a pressure that the minimum striking potential is obtained. A high series resistance

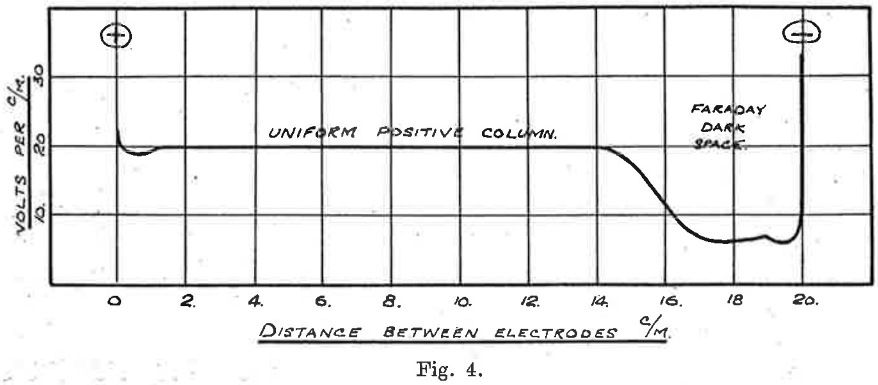

Fig. 4.

is incorporated in the cap of all such devices to limit the current and prevent destructive ionisation taking place.

Signs. (*b*) Small cathode glow sign tubes for operating on ordinary mains voltages have been developed at the Preston Lamp Works. Signs are being made having a maximum of about 10 letters per tube, and the complete device measures 15 × about 1½ inches, and so far is arranged for operation on A.C. mains only.

Neon Valves. (*c*) In the neon valves developed at the Preston Works for relay operation in traffic signal devices, the cathode area has been made relatively large so that the device is capable of passing currents of the order of 40 to 50 m.a. without damage.

A typical neon valve has a breakdown potential of 260 volts D.C., and when breakdown occurs will allow 40 m.a. to flow through a 4,000-ohm resistance connected in series.

Experimental tubes have been made which have a breakdown potential of 120 volts D.C. and will pass 10 m.a. through a series resistance of 4,000 ohms. It is anticiapted that many more uses will be found for such valves when once their characteristics are fully understood.

(2) *Positive Column Tubes.*

Under this heading can be included both the cold cathode tubes, and also the more recent hot cathode tubes.

Cold Cathode Tubes. (*a*) These tubes, familiar to all of us in neon signs, are capable of a wide variety of physical form. The discharge takes place between electrodes generally of iron or nickel situated one at each end of the tube, and the illumination is produced from the positive column. Various gas mixtures are used to produce the different colours, the dominant colour being given by the gas or vapour with the lowest ionisation potential. The intensity of illumination per unit area of glow is relatively low because the current through the tube is limited by the electrodes. Attempts to increase the current in cold cathode tubes leads to local heating effects and excessive cathode splutter. As the cathode fall of potential is of the order of 150 volts, the tubes require high voltages for their operation and, in general, each tube of a sign has an independent transformer.

Hot Cathode Tubes. (*b*) The development of hot cathodes as a result of the work of Pirani and others has made possible positive column tubes carrying currents 50 to 100 times greater than those used in cold cathode tubes. The electrodes of these devices are coated with mixtures of alkaline earth oxides and have a very high electronic emission when heated to temperatures of about 1,200° C. The cathode fall is generally only a few volts and hence the tubes are suitable for ordinary mains voltages. The initial heating of the electrodes is generally carried out by auxiliary heater coils, but when the tube is running, the main discharge current is sufficient to maintain the electrodes at a suitable temperature. The use of metallic vapours such as those of sodium, cadmium, magnesium, etc., has resulted in still further increases in the efficiency of these tubes. Although the colours at present being obtained leave much to be desired when compared with daylight, very little disadvantage is felt when the tubes are used for such purposes as street lighting. One or two street lighting installations are at present being tried out in this country using sodium vapour tubes, and these are undoubtedly the forerunners of considerable developments in this field.

During the lecture demonstrations were made of various types of discharge tube. A simple tube as described in the earlier part of the lecture was exhausted to various pressures and excited by means of an induction coil. A movable electrode device was used for illustrating the complete disappearance of the positive column at distances of the order of 30 mm., under which condition there was no glow in the "Faraday Dark Space."

Various types of cathode glow tubes were shown, including cathode glow lamps of the familiar commercial pattern ; while considerable interest was excited by two Sign Tubes with plain electrodes in the form of the words "SIEMENS LAMPS."

One or two types of cold cathode positive column tube filled with neon were demonstrated, followed by two types of high intensity hot cathode tubes. In one type of hot cathode tube the cathodes were heated by a low-tension supply, the arc discharge being set up immediately the main 230 volt A.C. supply was switched on to the tube. Tubes of this type were exhibited having a filling of neon which gave a red glow, and neon-mercury which gave a blueish-white glow.

A similar tube was then demonstrated containing neon and sodium-vapour. Part of the lecture room was floodlighted by this tube, which gave practically monochromatic illumination and which had a current consumption of only 0.4 amps. at 120 volts and operated at very high efficiency.

In conclusion, a discharge tube was shown having a filament running in parallel with the arc, and it was pointed out that by this means, and using a controlled mixture of mercury and neon, the resulting light approximated very closely to white light.

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