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SOME CHARACTERISTIC CURVES FOR GASES AT LOW PRESSURES.

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A LARGE amount of data on the potential required to produce and to maintain a discharge through gases under varying conditions of pressure has been published by numerous observers. The data upon the value of the current strength of the discharge and the effect of varying potential, pressure and spark length upon the magnitude of the current are more limited.

Townsend in his book on Ionization by Collision has gathered much of the available data on the relation between potential gradient and current. The data there presented and discussed apply to a different phase of discharge than the one described in this article. Townsend discusses the currents produced in a gas by the action of some agent like X-rays or ultraviolet light. The sweeping of the ions thus formed out of the ionized region constitutes the current, the current values produced in most cases lying far below the saturation value.

The term characteristic curve used here is similar to the technical term as applied to a dynamo or similar electrical device and merely shows in a graphic way the relation between current and potential under a stated condition.

The problem as it appeared to the author at the inception of the experiments resolved itself into several questions of a rather simple character. Given a luminous discharge at low pressure between two electrodes: what effect will changing the potential produce? To what extent will a characteristic curve be modified by altering the gas pressure and the distance between the electrodes? What effect will altering the size of the cathode have on the characteristic curve? To what extent will these be modified if a diaphragm with orifices of different sizes be placed in different parts of the discharge path? What, quantitatively,

will be the effect of a constriction in the path of the discharge? So far as the author is aware the term characteristic curve used in the sense previously stated was first applied to gases by Kauffman.¹ The discussion is theoretical for the most part and the experimental data very limited. In 1901 Rieche² studied the relation between potential and current in gases under low pressures, but considered particularly the effect of a magnetic field on the characteristic curves. Both Warburg and Tamm have made experiments on the relation between current and potential for pressures of the order of atmospheric pressures and have stated their results in empirical formulæ. It may well be doubted whether their formulæ could be extrapolated to pressures of the kind used in a Geissler tube. In fact the observations recorded in this paper indicate that much larger currents are obtained at lower potentials as the pressure approaches the critical value, than would be anticipated from their formulæ. A digest of the experiments by Warburg and by Tamm is given by Sir J. J. Thomson in his *Conduction of Electricity through Gases*, pages 501-502. Two articles by Zeleny³ constitute a comprehensive extension of the subject. His account of the variation of current and potential for the lower pressures is very brief. Mention is made of the fact that between pressures of 1 and .01 cm. large variations of current are produced with small changes in potential. The present article is concerned with pressures lying wholly within such limits. In a paper recently published by the author,⁴ it appears that currents of considerable magnitude may be secured if the cathode is of generous dimensions. The apparatus used in this experiment is fully described in the previous article and will be but briefly mentioned here. A plate made up of ten concentric brass rings separated by an insulating material served as a cathode. The face of the cathode was in a horizontal plane and had a total conducting area of 85 sq. cm. The anode consisted of a hemisphere of Pt (of 1 mm. radius), mounted on a vertical brass rod. The brass rod was covered with a thin glass envelope leaving only the hemisphere exposed. The anode was capable of adjustment vertically and was always symmetrical with reference to the cathode. The discharge apparatus was contained in a bell jar of approximately 10 liters capacity. Measurement of the current which passed through any or all of the rings which together make up the cathode could be made. In the present case the rings were usually connected in parallel. The potential difference between the

¹ Gottingen Nach., 1899, p. 243.

² Annal. d. Phys., 1901, 4, p. 292.

³ J. Zeleny, *PHYS. REV.*, 25, p. 305, 1907; 26, p. 129, 1908.

⁴ *PHYS. REV.*, Mar., 1912, p. 188.

electrodes was produced by 450 storage cells and regulated by means of a cadmium-iodide-amyl-alcohol resistance. Potential was determined by means of a Weston voltmeter with multiplier in series and current measured directly with a Siemens and Halske milliammeter. The experiments may be grouped under four heads and will be taken up in that manner.

I. The characteristic curves between the sphere and plane for different pressures and for distances ranging from 1 to 4 centimeters.

II. Effect of changing the area of the cathode on the characteristic curves.

III. Effect of the introduction of thin diaphragms with apertures of different dimensions in the path of the discharge.

IV. Effect of a constriction. Length of constriction. Size of constricted portion. Location of the constricted portion.

I. EFFECT OF DISTANCE AND PRESSURE UPON THE CHARACTERISTIC CURVES.

The cases studied experimentally in this connection were taken with the full cathode plate, 85 sq. cm., and with the anode at distances of 1 cm., 2 cm., 3 cm. and 4 cm. under various conditions of pressure. These are represented graphically in Figs. 1 to 12. In Figs. 1-4 the results obtained for air are given and in a general way are typical. Figs. 5 to 8 are for hydrogen and Figs. 9 to 12 for carbon dioxide. The form of the characteristic curve is the same for each gas. For hydrogen lower potentials than those necessary for air sufficed, while higher potentials were required for carbon dioxide. The apparatus as constructed made it possible to study the distribution of current density over the cathode. This was done in some cases, but has been discussed in a previous paper. The usual method of procedure was as follows: A discharge was produced, usually by making the sphere negative and then reversing the polarity of the electrodes, the current was raised to the maximum value and allowed to run for 10 or 20 minutes. The current was then reduced by increasing the resistance in the circuit by small steps. Frequent measurements were made upon the potential and current. These are represented in the graph. Many measurements were made at other pressures but are not incorporated in the figures. It may be noticed that for the lower pressures two current values are possible for the same potential, but the distribution over the plate differs in the two cases. When the current has the least value, the resistance in the circuit is a maximum and the potential difference between the electrodes exceeds the minimum value. The discharge is then confined to a limited portion of the cathode.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

Fig. 12.

Should the pressure be above the critical value the discharge will be confined to the inner zones; should the pressure lie below the critical value, to the outer zones. When the resistance of the circuit is decreased the potential falls, the current increases and the luminosity spreads out over the plate. After the entire plate is functioning, decreasing the resistance causes a rise in current accompanied by a rise in potential between the electrodes. The increase in current density after this stage is reached is not uniform over the plate, but is greatest over the outer zone. It may be noticed that for the higher pressures, the largest currents obtained do not require a potential exceeding the minimum value. It was observed in such cases that the minimum discharge occurred between the inner zones and the anode and as the current increased the discharge spread over the cathode but never reached the edges of the plate. Near the critical pressure, as the current was diminished and the luminosity ceased to cover the cathode an unstable condition existed in which the luminous patch moved about over the plate. In general, while the redistribution takes place there is an unstable condition and the branch of the curves representing the smaller values of the current has a region of instability. This is particularly true for hydrogen which presented an anomaly. In obtaining the hydrogen curve the current

was decreased in the usual manner. This was accompanied by rise in potential when the discharge drew in toward the center of the plate. At a certain stage, as the current was decreased the potential also fell, passing through an unstable region, but with further decrease in current the potential rose in a perfectly normal manner. This gives rise to the peculiar kink in the hydrogen curve in this region. Modification of the current control, by altering the batteries and control resistance indicated that it was not an error due to some peculiarity of manipulation but occurred each time under the same condition of pressure and potential. No explanation of this is vouchsafed. The hydrogen was prepared in a Kipp apparatus by the use of C.P. acid on aluminium turnings and was purified and dried. No similar kink was found for either air or carbon dioxide.

Before leaving this phase of the subject it may be of interest to indicate the extent to which the condition of the cathode surface influences the characteristic curve. In the experiments just described, care had been taken to have the cathode smooth, free from scratches and clean. The smooth cathode was covered with a handful of brass turnings and filings. These were spread out in such a manner as not to decrease materially the distance between the electrodes but served to give a rough surface. The characteristic curve was modified but slightly. The apparent effect was to increase the range of instability. The roughening of the plate had in general no effect on the form of the characteristic curve or on the numerical values which relate potential and current. The empirical formulæ based on measurements for high pressures and which connect pressure, potential, and current for a positively electrified point when extrapolated into this region, give values much smaller than those observed. No attempt has been made to develop a new relation for the variations in the region, for it will be seen later that these are further complicated by the size of the cathode.

II. EFFECT OF SIZE OF CATHODE ON THE CHARACTERISTIC CURVES.

Figs. 13 to 16 show the relation between current and potential when the distance between the anode and central part of the cathode was 4 cm. and air used as the dielectric. The characteristic curves shown are for pressures ranging from those less than to those greater than the critical pressure for this distance.

As noted previously, as soon as the cathode is completely covered with the luminosity and is functioning over the entire available area, there will be a rise in potential with increase of current. With the smaller cathode this condition will be attained for smaller values of current

than with the larger cathode. The numerals accompanying the various curves refer to the cases given in the accompanying table.

Fig. 13.

Fig. 14.

Fig. 15.

Fig. 16.

The area of the different plates is given. If a line be drawn from the midpoint of the cathode plate to the anode and another from the edge of the plate to the anode these lines will include the angle α .

Case.	α	Area of Cathode in Sq. Cm.
I.	54° 42'	85.0
II.	43° 54'	39.8
III.	33° 25'	19.0
IV.	12° 00'	5.9
V.	3° 36'	.2

III. EFFECT OF DIAPHRAGMS IN THE PATH OF THE DISCHARGE.

The full-sized cathode was used in this experiment. The anode was four centimeters from the plane of the cathode and placed symmetrically with reference to it. The outer zone of the cathode was surrounded by a ring of fiber. Over the top of this spacing ring a very thin diaphragm of mica was sealed. The part directly underneath the anode was pierced. Orifices of 5 mm., 2 mm. and 1 mm. diameter were used. By means of spacing rings of different heights these diaphragms were placed successively at distances of .5, 1, 2, 3, and 3.5 cm. above the cathode. Char-

Fig. 17.

acteristic curves were taken for three pressures in each case; fifteen cases in all, making forty-five characteristic curves. The differences obtained between any of these and the curves secured when no obstruction was present, was so slight that it may be asserted that the introduction of the diaphragms had no effect on the characteristic curve. Their introduction however increased the stability of the discharge. The appearance of the discharge is also modified. In addition to the luminosity over the cathode and at the anode there is a luminous patch in the aperture. The intensity of the luminous patch is much greater for the small openings. The characteristic curve for the 2 mm. opening is the lowest one in Figs. 17, 18 and 19, and differs very little from the corre-

sponding curves in Fig. 4, which shows the case when no diaphragm is interposed. It is well known that the potential gradient along a discharge of this character is not uniform but that the rate of change of

Fig. 18.

potential is greater near the electrodes, especially at the cathode. The diaphragms in all cases were interposed where the electric force is weak. It thus appears that the convergence of the stream lines for a short distance has little appreciable effect on the total potential fall.

Fig. 19.

IV. EFFECT OF A CONSTRICTION IN THE PATH.

The modification of the apparatus for this portion of the experiment consisted merely in piercing a diaphragm and inserting glass tubes of different lengths and bores. The constriction tubes were placed directly underneath the anode and symmetrical with reference to the cathode unless otherwise stated.

The tube was sealed into the mica diaphragm with waterglass and all the discharge passed through the tube. By means of spacing rings this was placed in turn at different elevations above the cathode. The lower end was placed 2 mm. above the cathode, again with the upper end of the tube 2 mm. below the anode and in the midposition. The effect of the introduction of the tube was considerable, but the location of the tube so far as elevation was concerned introduced no further variation, at least within the limits mentioned. The fiber spacing ring which with the mica diaphragm served to enclose the cathode was removed and a glass ring substituted. This permitted an unobstructed view of the entire phenomena occurring within the apparatus. The diameter of the constriction tubes employed ranged from 5 mm. to 1.85 mm. Figs. 17, 18 and 19 show the effect of introducing constrictions of different lengths. They indicate that the increase in potential necessary to maintain a given discharge through the constriction increased directly as the length of the constricted portion. The tube employed in securing the data shown by the curve was 2 mm. in diameter. The characteristic curves in each case are displaced upward with increasing length of tube, indicating that the increase in potential required to maintain a given current through the constriction over that for the unobstructed discharge is similar to the increase of a wire with length. If the increase in the apparent resistance is due to the crowding together of the stream-lines then confining these to increasing lengths will cause an increase in the resistance varying directly as the lengths of the constricted portions. In Fig. 17, where the pressure used was .5 mm., the curve for the discharge through the longest tube cuts across the one representing the one of less length. This is due, in my opinion, to the fact that in this region small variations of pressure produce relatively large changes in current density. A very slight error in reading the pressure would account for this.

Varying the area of the constricted portion produced smaller changes than variations of length. Variations of area in the ratio of 10 to 1 produced relatively small variation as compared with the effect of varying the lengths. Tubes whose diameters were smaller and others larger were varied in length and gave results in agreement with those represented for the 2 mm. tube. The larger tubes had the corresponding characteristic curves shifted upward less than the smaller tubes but the shift was not proportional to the inverse ratio of the areas.

In the case of tubes of small bore it is difficult to start a discharge through them. For the smallest tubes employed there is a very limited range of pressure and potential for which a discharge may be induced to

start. Once established, the pressure and potential could be changed through rather wide limits. The range of potentials at my disposal limited the experiments to tubes of about 1.5 mm. diameter if tubes longer than 1 cm. were to be employed, hence these observations were not extended to tubes of smaller bore.

A series of measurements was made with a tube of 2 mm. bore and 15 mm. length, the constriction being set out laterally. The constriction tube was first set out 1.5 cm. from the center of symmetry. The shift in the characteristic curves which resulted for this offset was inappreciable for the lower pressures, .5 mm. and 1 mm., but for the highest pressure, 2 mm., the curve was shifted upward, indicating an increase in the apparent resistance. When the same tube was set out 3 cm. from the line of symmetry the characteristic curves for the two larger pressures were shifted. Finally when the offset was 4.5 cm. all of the curves were displaced; the one corresponding to the highest pressure to a much greater extent than the others.

SUMMARY.

I. Characteristic curves for air, hydrogen and carbon dioxide in the region of the critical potentials have been obtained.

II. The strength of the current through a gas at low pressures is determined in part by the size of the cathode. Empirical formulæ for the discharge from a positively electrified point cannot be extrapolated from high pressure and potential regions to low pressure conditions.

III. Introducing a constriction into the path of a discharge has the effect of increasing the apparent resistance of the circuit. The increase in the apparent resistance varies directly with the length of the constricted portion.

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