Angular Distribution of Current from a Point in Hydrogen

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The angular distribution of current of electrons from a sharp point in hydrogen is measured for various currents and sizes of wire. Evidence is obtained for the critical effect of the potential drop in the ionization sheath.

IN previous articles on the corona discharge[1] from points, it has been supposed that the discharge takes place essentially forward from the point and grows backward to approach a hemispherical distribution for increasing current.

Recent measurements show this not to be the case at least in hydrogen, and the results seem to require a revision of some of the previously accepted ideas concerning the mechanisms of this form of discharge.

The tubes used in these measurements are illustrated in Fig. 1. In type 1, the collecting electrode was spherical with radius of one inch about the tip of the point except for a relatively narrow neck axial about the support for the point, as in Fig. 1. The sphere consisted of rings of equal thickness, insulated from each other with empire cloth to make possible the measurement of current to each ring insulated from the support for the point by a ground glass joint. Apiezon grease was used between surfaces and gave a vacuum tight system which was then rinsed with hydrogen and filled with hydrogen for a measurement.

In type 2 a modification was used in which all except a hemisphere was replaced with glass, down to *A* in Fig. 1. In type 3 all except nine collecting sectors are replaced with glass giving a little more than a hemisphere of collecting surface, down to *B* in Fig. 1. In all three forms, the wire tip was accurately centered and trimmed to come at the center of the spherical surface.

Since the rings all had the same thickness, the collecting surfaces of the sectors were all equal in area. The current to each ring would therefore be the same as the current to any other ring if the discharge current had uniform spherical density. A polar plot of the currents to the collecting sectors at radial directions midway between the angular extremities of the sectors represents correctly the current densities in those respective directions.

In Figs. 2 to 7 are shown some representative angular distributions of current in hydrogen at atmospheric pressure for several sizes of wire ends and tube types. It will be noted in Figs. 2 and 3 for the nearly complete sphere, at the lower currents, by far the greater part of the current moves sideways and a little backward when the glass is not obstructing such flow. The 0.0075-cm wire of Fig. 2 projects the discharge increasingly forward with increasing current, but the 0.0025-cm wire of Fig. 3 produces the largest increases in current to the

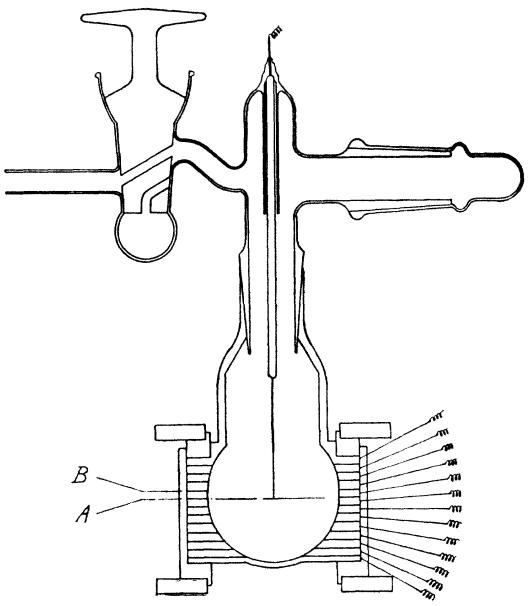

FIG. 1. Discharge tube.

[1] W. H. Otto and W. H. Bennett, J. Chem. Phys. **8**, 899 (1940); W. H. Bennett, Phys. Rev. **58**, 992 (1940). See also L. B. Loeb, *Fundamental Processes of Electrical Discharges in Gases* (Wiley, 1939), pp. 514–535.

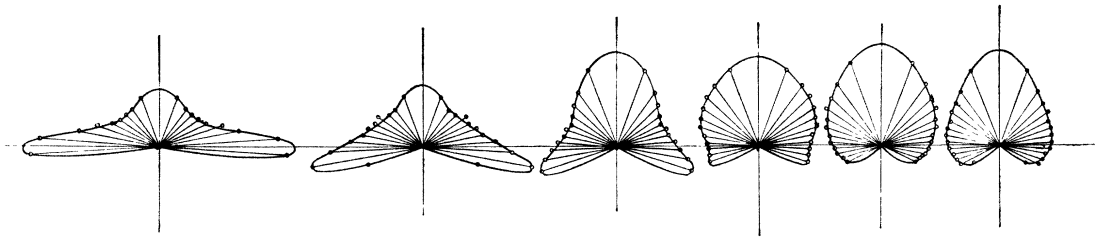

FIG. 2. Distributions from 0.0075-cm wire end in tube of type 1. Currents were, from left to right, in ma, 0.02, 0.05, 0.1, 0.2, 0.5, 1.0.

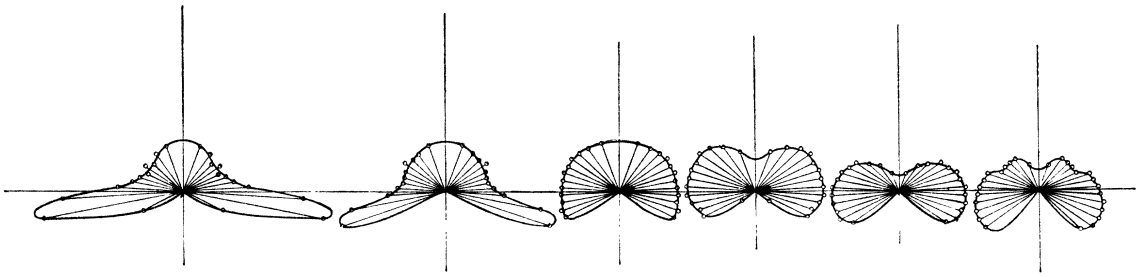

FIG. 3. Distributions from 0.0025-cm wire end in tube of type 1. Currents were, from left to right, in ma, 0.02, 0.05, 0.1, 0.2, 0.5, 1.0.

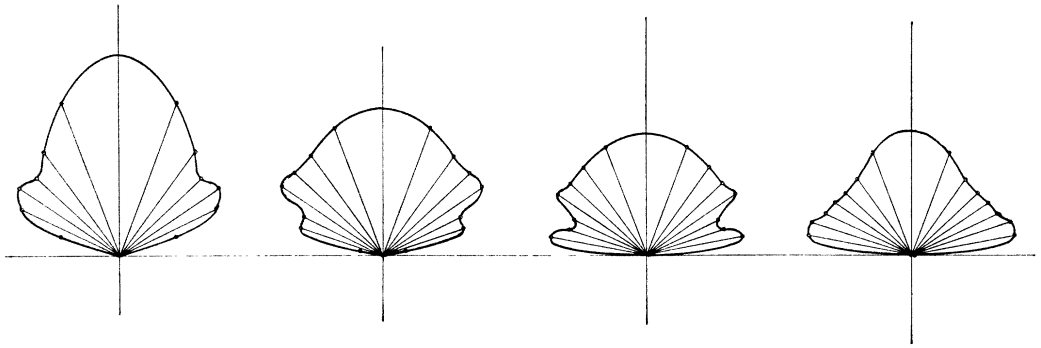

FIG. 4. Distributions from 0.0075-cm wire end in tube of type 2. Currents were, from left to right, in ma, 0.1, 0.2, 0.5, 1.0.

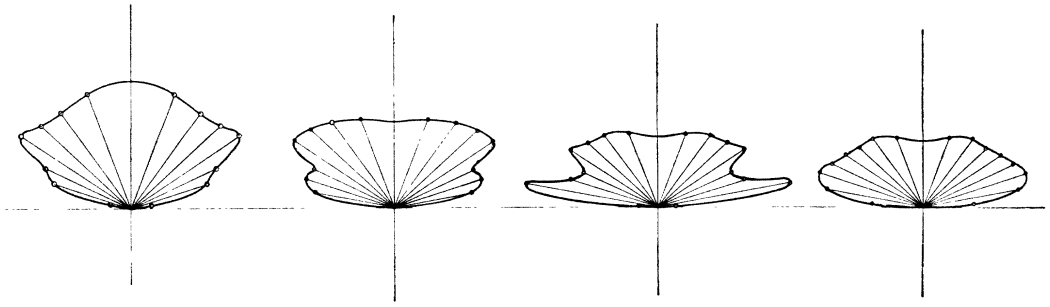

FIG. 5. Distributions from 0.0025-cm wire end in tube of type 2. Currents were, from left to right, in ma, 0.1, 0.2, 0.5, 1.0.

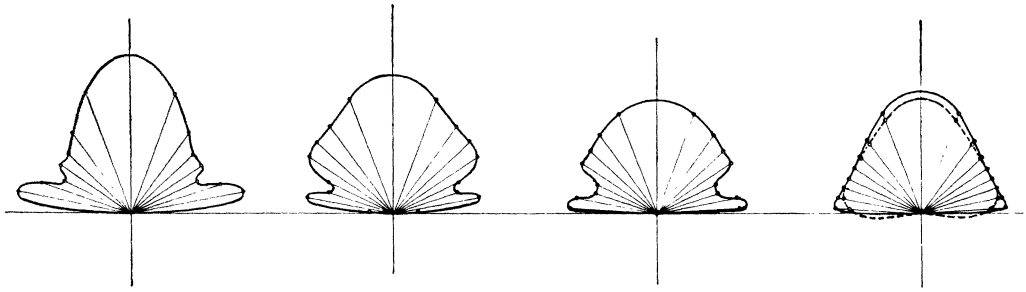

FIG. 6. Distributions from 0.0075-cm wire end in tube of type 3. Currents were, from left to right, in ma, 0.1, 0.2, 0.5 , 1.0

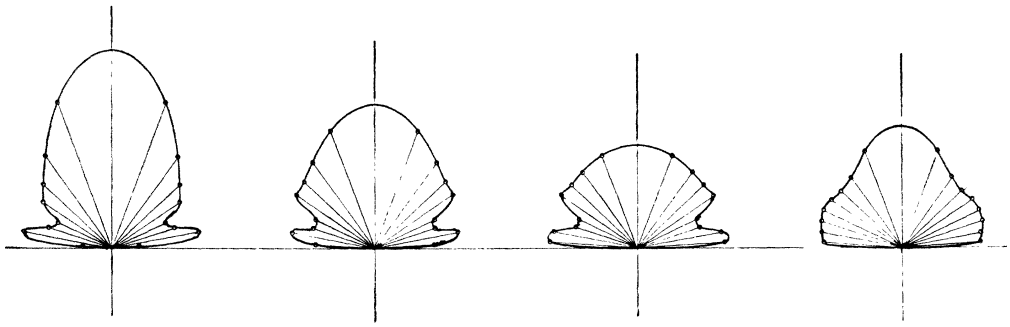

FIG. 7. Distributions from 0.0050-cm wire end in tube of type 3. Currents were, from left to right, in ma, 0.1, 0.2, 0.5, 1.0.

side and back. The increase of current from the 0.0025-cm wire from 0.5 ma to 1.0 ma is accompanied by a growth of the visible glow on the tip back along the wire for about one millimeter which probably explains the excessively large backward current from this wire at 1 ma.

The change to a hemispherical collecting electrode in Figs. 4 and 5 turns the collecting current forward without changing the relative form of the discharge distribution.

In Fig. 6, an extra ring is added and brings the discharge a little more nearly to a uniform hemispherical distribution. The dotted line shows a check run after the tube had been completely disassembled and cleaned, and a new wire end put in.

In Fig. 7, the distribution is similar to that for 0.0075-cm wire in Fig. 6, showing that there is a change in the character of the discharge between 0.0050-cm wire and 0.0025-cm wire to result in an excessive sidewise current from the smaller wire.

As mentioned previously,[1] a tube conditions itself with the passage of current. Microscopic examination of a conditioned wire end shows that some of the material is etched away, usually leaving a conical end which is sharper than a freshly cut wire end. There are two conditioning processes which take place. The sharpening of the wire end goes on quite rapidly while the most of the electron-attaching impurities are removed from the gas. This usually takes 2 to 30 minutes in hydrogen at 1 ma, but the tube will decondition with standing unless the discharge is continued for another 30 minutes to 2 hours. It is believed that this continued passage of current is needed for elimination as permanently precipitated material of the last traces of the electron attaching impurities.

TABLE I. Variation of tube voltage with type of tube.

Tube type	Wire size	Current 0.1 ma	0.2 ma	0.5 ma	1.0 ma	Distribution
1	0.0075	1640	1760	2450	3330	Fig. 2
2	0.0075	1490	1680	2440	3360	Fig. 4
3	0.0075	1510	1650	2340	3220 3310	Fig. 6
1	0.0025	1360	1560	2160	3060	Fig. 3
2	0.0025	1350	1590	2300	3050	Fig. 5

The variation in sharpness results in a small variation in the voltage required for a given current as shown in Table I, and any difference in voltage required for the current due to changing the character of collecting surface is less than this random variation between wire ends.

DISCUSSION

In a previous article[2] it was reported from point-to-plane measurements that there is an ionization sheath potential drop which remains approximately constant while the distance to the collector is varied by large amounts.

The observations being reported here show that for the finest points, the charge in front of the tip of the point reduces the field intensity more in those parts of the ionization sheath nearer that space charge in a manner to reduce the ionization current in the forward direction and thus favor the lateral current. This effect is most noticeable at the smallest values of current so it is evident that a very small reduction of field intensity produces a large percentage reduction in ionization current. At the largest values of current, the current is essentially a space charge limited current arising at the hemispherical cap over the tip, and as such the percentage change of field intensity at the tip does not vary so much with angle at the tip.

The heavier wires have dull enough ends to prevent this effect from pushing the discharge back because the field attenuates less rapidly with distance from the tip and there is a less accumulation of charge near the tip.

[2] W. H. Bennett, reference 1, pp. 995, 996.

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The Electrical Conductivity of Titanium Dioxide

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Experiments on titanium dioxide show that it is an electronic semi-conductor in which the the current carriers are actually free electrons, as contrasted with the hole conduction of the other type of semi-conductor. It is found that the variation with oxygen pressure is that which would be expected if the titanium dioxide decomposes in the following manner: $TiO_2 \rightarrow Ti^+ + O_2 + e^-$. The deviation of the curves at low pressures is probably due to the presence of small impurities in the samples used. It is found that the variation of conductivity with temperature is represented by the formula $\sigma = Ae^{-\epsilon/kT}$. The activation energy ϵ is about 1.7 electron volts. Transport measurements show that the ionic conductivity is less than that which can be measured in these experiments. Measurements of the Hall effect, although not very quantitative, show that the mean free path for the conduction electrons is very small.

INTRODUCTION

The Electrical Conductivity of Titanium Dioxide

RECENTLY much interest has been shown in the mechanism of electrical conduction in solid materials known as semi-conductors. These substances are characterized by the fact that they possess a room temperature resistivity lying between approximately 10^3 and 10^8 ohm-cm, which decreases with increasing temperature. They differ from metals in that their resistance is much higher and that their temperature coefficient of resistance is of the opposite sign. The current in semi-conductors is usually carried by electrons, although ions may carry a large part or all of the current. Substances in which the conduction is principally by ions are spoken of as ionic semi-conductors. Their resistance in general is slightly lower than that of the electronic semi-conductors.

There are three well-known means of distinguishing between electronic and ionic conductivity. These are: Hall effect measurements,