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The Townsend Ionization Coefficients for Ni and Al Cathodes in an Atmosphere of Hydrogen

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Measurements of the first and second Townsend coefficients for ionization by collision have been carried out for surfaces of Ni and Al in an atmosphere of hydrogen. The Al surface was evaporated in an atmosphere of argon and is estimated to be a few hundred molecular layers thick. The values found for the α- and γ-coefficients are compared with the results previously reported for a Pt surface in hydrogen. The values of α/p, in pure hydrogen, plotted as a function of X/p show a decreasing characteristic between values of X/p from 900 to 1400. The curves of values of γ plotted as a function of X/p show a characteristic photoemission peak at an X/p of 131, and a gradual rise at the higher values of X/p. Sparking potential curves are calculated from the γ-values and are compared with the experimentally determined curves.

INTRODUCTION

MEASUREMENTS of the Townsend ionization coefficients for Pt and NaH surfaces in an atmosphere of hydrogen have been previously reported.[1] These measurements have been extended to surfaces of Ni and Al. An improved ionization chamber has been constructed with which it was possible to extend the measurements of α/p to an X/p of 1700 volts/cm per mm Hg.

A diagram of the ionization chamber is shown in Fig. 1. The chamber is of glass 18 cm in diameter and 45 cm in length. Fitted inside the glass wall of the chamber is a grounded wire gauze which is not shown in the diagram. The electrodes are of Ni. The rod supporting the upper electrode is threaded and this electrode can thus be raised or lowered by turning the armature with an exterior electromagnet. The electrodes are 6 cm in diameter and the distance between them may be varied from zero to 6 cm. A quartz window is attached to a side arm by a graded seal. Light from a quartz mercury lamp passed through a quartz lens and the window and then fell upon a spot near the center of the cathode. This radiation gave the photoelectric current i_0 at the surface of the cathode. From 2 to 10 cm² of the cathode surface was illuminated, the larger area being used in the case of the Ni cathode. The data taken with the larger area of illumination showed some irregularities when the plate separation was greater than 2 cm. This was taken to indicate that in these cases there was some field distortion at the greater values of the plate separation.

The Al surface was evaporated directly upon the Ni surface of the cathode. This evaporation was carried out in an atmosphere of argon at a pressure of 0.8 mm of mercury. The side arm, shown sealed off in Fig. 1, was extended to 32 cm in length and carried a support for a filament and a soft iron armature. By means of an external

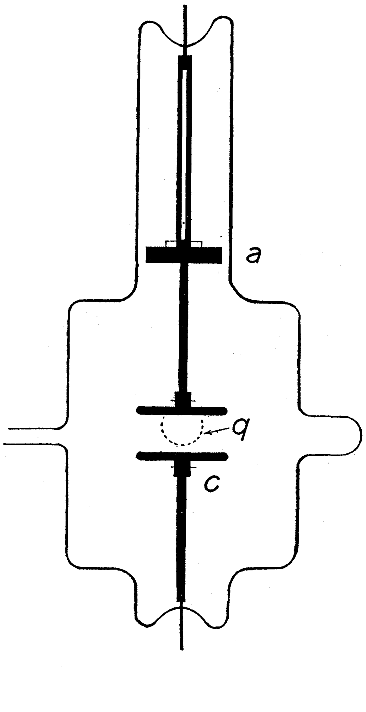

FIG. 1. The ionization chamber. a is a soft iron armature, c the cathode and q a quartz window.

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[1] Donald H. Hale, Phys. Rev. 55, 815 (1939).

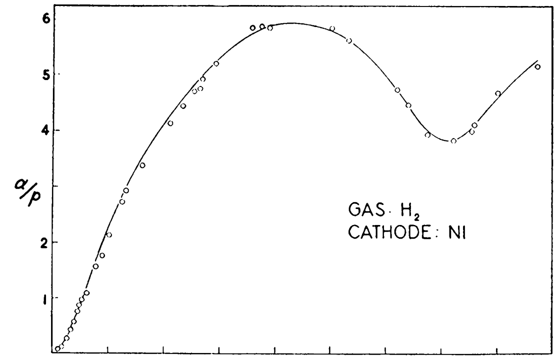

FIG. 2. The values of α/p plotted as a function of X/p.

electromagnet the filament could be moved to a position about 1.5 cm above the cathode and after the evaporation was complete the filament and its supports retracted into the side arm. The filament consisted of three 20-mil tungsten wires loosely twisted together. To this filament were fastened several small pieces of aluminum plate 0.4 mm thick and about 0.25 cm^2 in area. The metal was analytical grade and contained 0.32 percent of iron and 0.45 percent of SiO_2 as impurities. The filament was first heated while retracted into the side arm until the sheets melted. This treatment removed the surface contamination which was deposited on the walls of the side arm.

Tank hydrogen was used. The gas was purified by passing it through a purifying train in the conventional manner and then through two liquid-air traps and a fine leak before it entered the chamber. The photoelectric current was kept at a minimum at all times in order that the measurements might not be falsified by space charge effects.

The ionization chamber was built into an oven and was baked out at a temperature of 425°C for 16 hours each time air was admitted. A discharge in hydrogen was run for one hour after each baking and before any data were taken. The reason for this treatment of the cathodes was that in the presence of hydrogen neither the clean Ni surface nor the freshly evaporated Al surface was stable photoelectrically but the photoemission changed continually with time and in these measurements it was essential to have a stabilized surface. Thus these surfaces were carefully formed probably as hydrogen coated surfaces of some stability. In each case this treatment increased the photoelectric sensitivity of the surface. In the case of Al the treatment also apparently shifted the photoelectric threshold towards the long wave-length side of the spectrum as it was found that this surface was sensitive to visible light after the discharge had been run. It was therefore necessary in all measurements on the Al surface to have the ionization chamber covered by a light-tight box. The Al surface was not baked after it was deposited upon the surface of the Ni cathode.

In this type of measurement it is necessary that a fairly steady source of ultraviolet radiation be used as a source of the photoelectric current i_0. It was found that a lamp designed by Mr. E. H. Guyon of this laboratory was quite satisfactory when used with a stabilizer of the iron wire-hydrogen type.[2]

All data given in this paper are reduced to a temperature of 22°C.

EXPERIMENTAL RESULTS

The Al and Ni surfaces gave the characteristic curves, as shown by Bowls,[3] when $(1/p)\ \ln\ (i/i_0)$ was plotted as a function of the plate separation x. The exact amount of Al evaporated in forming the Al cathode could not be determined but it was estimated that the surface was a few hundred molecular layers thick. The values of α/p plotted as a function of X/p are shown in Fig. 2. Here α is the first Townsend ionization

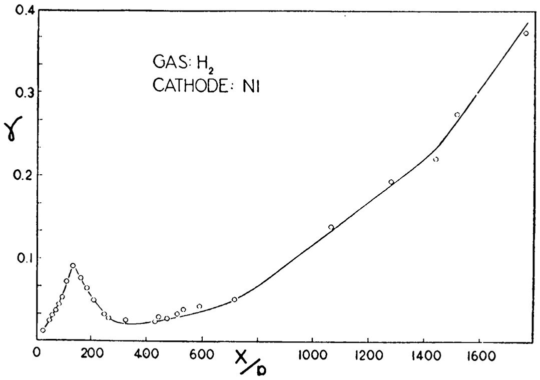

FIG. 3. The values of γ plotted as a function of X/p for the Ni cathode.

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[2] Francis A. Jenkins and Harvey E. White, *Fundamentals of Physical Optics* (McGraw-Hill Book Company, 1937), p. 248.

[3] W. E. Bowls, Phys. Rev. **53**, 293 (1938).

coefficient and represents the number of electrons produced by each electron in 1 cm of path in the direction of the electric field. X is the field strength in volts/cm and p is the pressure in mm Hg. The Al cathode gave values of α/p which lay along this curve within experimental error. The values of α/p found for the Pt surface[1] also agree with those shown in Fig. 2. In the case of the Pt surface the measurements were reliable only to an X/p of about 900. With the new ionization chamber reliable measurements of α/p could be extended to an X/p of 1700. This curve shows a falling characteristic between values of X/p of 900 to 1400. Above an X/p of 1400 the curve starts a second sharp rise.

The values of the second coefficient γ were computed from the equation of Townsend[4] which was also derived by Thomson,[5]

$$i=i_0\frac{e^{\alpha x}}{1-\gamma(e^{\alpha x}-1)}. \qquad (1)$$

This equation assumes a secondary emission process at the cathode. Loeb[6] has shown that under the conditions obtaining in the ionization chamber in this work it is likely that Eq. (1) properly describes the mechanism. This may be either a secondary emission of electrons at the cathode due to positive ion bombardment or a photoelectric mechanism. The values of the second coefficient plotted as a function of X/p are shown in Figs. 3 and 4. These curves show the same general characteristics. It is quite probable that the values of γ for the Ni surface are somewhat less accurate than those for Al. In the case of Ni the larger area of the cathode was illuminated and there were indications that at plate separations above 2 cm there was a small field distortion. Such a distortion would tend to lower the measured values of γ but these values are of the right order of magnitude. This error would not alter the form of the curve. There is a pronounced peak at the lower values of X/p and at the higher values of X/p both curves show a general rise. The maxima, at the lower values of X/p, occur, within experimental error, at an X/p of 131. The maximum in the similar peak as shown by the Pt surface in hydrogen was at an X/p of 120 which is nearly the same. The maximum value of γ, at an X/p of 131, for the Al surface is greater than for the Ni surface. However, this may be due to the field distortion which is suspected in the case of the Ni surface. The ratio of the value of γ for Al to that for Ni, at an X/p of 131, is 1.25.

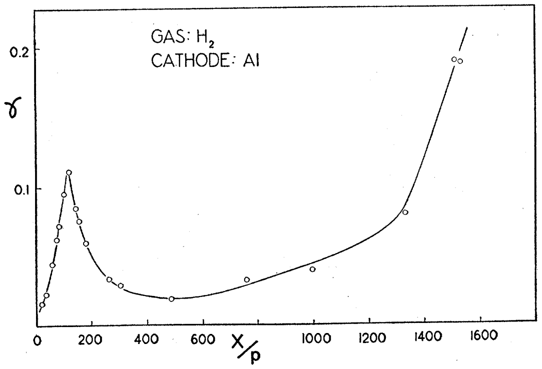

FIG. 4. The values of γ plotted as a function of X/p for the Al cathode.

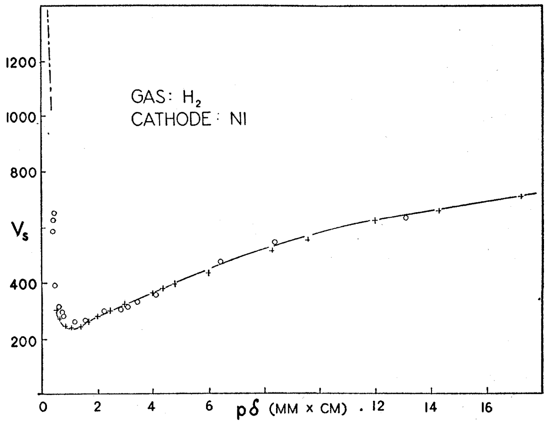

FIG. 5. The sparking potential curve for the Ni cathode. The crosses are experimentally determined points. The circles are values of the sparking potential calculated from the γ values determined in this work.

In the range of values of X/p from 300 to 1400 the value of γ for the Al surface is smaller and the rise with increasing values of X/p is more gradual than is the case for the Ni cathode. However, above an X/p of 1400 the Al surface gives γ values which increase more rapidly than is the case for the Ni cathode. This again may be due to field distortion as such distortion in falsifying α would have more effect on the value of γ at the lower values of X/p.

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[4] J. S. Townsend, *Electricity in Gases* (Oxford University Press, 1914), p. 314.

[5] J. J. Thomson and G. P. Thomson, *Conduction of Electricity through Gases* (Cambridge University Press, third edition, 1933), Vol. II, p. 518.

[6] L. B. Loeb, Rev. Mod. Phys. **8**, 267 (1936).

The sparking potentials for both surfaces in hydrogen were experimentally determined. These data are shown in Fig. 5 for the Ni cathode. The crosses are the experimentally determined sparking potentials. The dotted line at the lower values of $p\delta$ is taken from data published by Quinn.[7] The circles in this figure are calculated break down potentials which are found by use of the values of γ shown in Fig. 4. The agreement is good except at the minimum values of the sparking potential. The data for the Al surface gave about the same sort of agreement.

Discussion

The α/p curve shows the same values for the Pt, Ni and Al cathodes as it should since this coefficient is a function of the gas between the electrodes. Above an X/p of 900 the values of α/p show a decline and then rise again starting at an X/p of 1400. The decline is analogous to the results of Huxford[8] for argon-filled tubes. This behavior may logically be ascribed to a decrease in the cross section for ionization by electron impact at the higher energies as shown by the Compton-van Voorhis curves. The effect observed at the higher values of X/p is not, in any case, to be confused with the decline observed in hydrogen contaminated with a volatile sodium compound[1] which is caused by a secondary ionization of the volatile compound by hydrogen photons. The subsequent rise, as shown by the curve of Fig. 2, above an X/p of 1400 is unexplained. If as conjectured the decline is a reflection of the decline of probability of ionization with increasing electron energies, one must assume that the subsequent rise in α/p is caused by the failure of the electrons to gain their terminal energy in the gap at the pressures used and thus the increase in α/p is due to the fact that below the maximum terminal energy their chance to ionize is greater. The pressures of 0.1 mm used in determining the values of α/p in the range of values of X/p from 900 to 1400 make this explanation plausible. However, at the rise in the curve the pressures were reduced by less than 10 percent below those near the minimum. Hence it is possible that the entire decline may be caused by failure of the electrons to achieve their terminal energy and that the hump corresponding to the Compton-van Voorhis curve may occur at much higher values of X/p.

It is seen that, except for minor differences due in part to experimental errors, the values of γ for the Ni and Al surfaces are nearly the same. There is for all three surfaces a definite photoelectric peak. These peaks occur at the same value of X/p for the Ni and Al surfaces and at nearly this value of X/p for Pt. However, it is to be remembered that a discharge was run in hydrogen, in the case of the Ni and Al surfaces before any data were taken. It must also be remembered that Pt is notoriously sensitive to absorption of hydrogen as shown by Langmuir in 1918.[9] The values found for γ for Pt surfaces in nitrogen[3] and for NaH surfaces in hydrogen[1] are not alike nor do they resemble the values found for the Pt, Ni and Al surfaces in hydrogen. This indicates the probability that for secondary emission by positive hydrogen ion bombardment surfaces of Pt, Ni and Al in hydrogen are essentially the same.

In a measure the similarity of these curves for Pt, Ni and Al cathodes in hydrogen for γ as a function of X/p is disappointing as it was hoped to find that different surfaces had markedly different properties. Since, however, Ni and Pt are noted catalysts for hydrogenation reactions, this result might have been expected. The behavior of Al is interesting in that it indicates its affinity for hydrogen. Further less reactive metals should be deposited by the Beeck[10] process and the γ values determined for such cathodes. It is unfortunate that hydrogen, one of the few gases free from metastables, should be so chemically active with metals. This fact must lead one to seek another nonreactive vehicular gas free from metastables in which to test the intrinsic properties of surfaces for secondary electron libration in the Townsend gap.

The calculated values of spark breakdown at low values of $p\delta$ agree satisfactorily with the experimentally determined values.

It is a pleasure to acknowledge that Professor L. B. Loeb has contributed much to this paper by many helpful discussions of the interpretation of the experimental results.

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[7] Robert B. Quinn, Phys. Rev. **55**, 482 (1939).

[8] W. S. Huxford, Phys. Rev. **55**, 754 (1939).

[9] I. Langmuir, J. Am. Chem. Soc. **40**, 1361 (1918).

[10] Otto Beeck, A. Wheeler and A. E. Smith, Phys. Rev. **55**, 601(A) (1939).