

The Townsend Coefficients for Ionization by Collision in Pure and Contaminated Hydrogen as a Function of the Cathode Material

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The Townsend coefficients for ionization by collision were measured for pure mercury-free hydrogen and for hydrogen contaminated with sodium and NaH vapor. Cathodes of platinum and sodium and NaH-coated platinum were used. The values of α/p at values of X/p below 300 are found to be smaller for pure hydrogen than for hydrogen contaminated with mercury vapor. The values of α/p for hydrogen contaminated with sodium and NaH are as much as twice as great as those for pure hydrogen at the lower values of X/p . The curve of α/p plotted as a function of X/p , for this case, shows a sharp peak at an X/p of 350. This peak indicated the presence of some substance which is ionized by the excitation of hydrogen. The curves of β/α and γ for the platinum cathode plotted as functions of X/p show peaks at the lower values of X/p which are analogous to those shown by Bowsls. The curves for the NaH cathode show a narrow but remarkably high peak at an X/p of 10. There are also several lower peaks but no general rise for the NaH cathode.

These peaks indicate relatively large photoemission effects ($\Theta\eta g/\alpha$) at the cathodes at the lower values of X/p . In the case of the platinum cathode at the higher values of X/p the curves show a general rise caused by electron emission due to the bombardment of the cathode by positive ions. The values of β/α and γ for the sodium surfaces are much smaller than in the case of platinum for the higher values of X/p indicating that these surfaces are relatively poor emitters under positive ion bombardment. In the course of the work it was possible, in most cases, to measure a sparking potential at the conclusion of the experimental work at each value of X/p . These data for the sparking potentials give curves which agree fairly well with the experimental curves as derived by Ehrenkranz. From the values found for the γ -coefficient, the sparking potentials were calculated and these potentials gave sparking potential curves which are in rough agreement with the experimentally derived curves of Ehrenkranz.

INTRODUCTION

CONSIDERABLE work has been done in the past to determine the values of the Townsend α - and β -coefficients for ionization by collision in pure hydrogen. However, a study of the experimental procedures used in these researches shows that certainly mercury vapor was present as a contamination in the ionization chambers. Penning¹ has shown that a trace of mercury vapor will greatly alter the value of the α -coefficient in the inert gases. Bowsls² has shown that a small amount of mercury vapor, present as a contamination in otherwise pure nitrogen, will change the value of α by as much as seventeen percent. It was found early in this work that traces of mercury would alter the value of α for otherwise pure hydrogen by as much as fifty percent at certain values of X/p .

Recent work has also shown that the second Townsend coefficient represents a cathode mechanism³ and therefore in the presence of mercury vapor the value found for this coefficient would not be that for an uncontaminated surface.

It was the purpose of this investigation to determine the first and second ionization coefficients for hydrogen gas with the modern techniques to secure pure gas and to exclude mercury vapor from the ionization chamber. The second coefficient β has been determined for both platinum and NaH surfaces. Two NaH surfaces were used. The apparatus and experimental procedure used in this work were essentially that described by Bowsls.² In all cases the illumination of the cathode was reduced to the lowest intensity which would give a measurable photoelectric current i_0 in order that space charge effects⁴ might be reduced to a minimum. In most cases the photoelectric current was less than 5×10^{-15} ampere per cm^2 of illuminated surface on the cathode.

Tank hydrogen was used. It was purified by passing through a purifying train and two liquid-air traps. It was found early in the work that at the higher pressures of the gas in the ionization chamber mercury was at times admitted. This mercury contamination was evident as in these cases the value found for α/p lay upon the curve

¹ F. M. Penning, *Phil. Mag.* **11**, 979 (1931).

² W. E. Bowsls, *Phys. Rev.* **53**, 293 (1938).

³ L. B. Loeb, *Rev. Mod. Phys.* **8**, 267 (1936).

⁴ Varney, White, Loeb and Posin, *Phys. Rev.* **48**, 818 (1935).

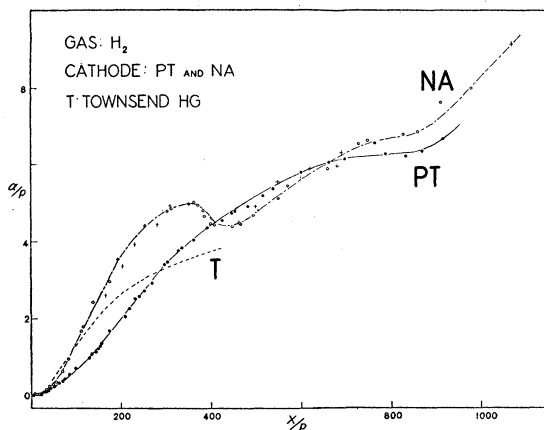


FIG. 1. Values of α/p as a function of X/p . Two sodium surfaces were used and are shown as circles and crosses.

given by Townsend. The contamination was avoided by adding a fine leak and a spiral-type liquid-air trap. The chamber was pumped out at the close of each day's work. In no case was the gas used after it had stood overnight in the ionization chamber.

The tube was baked out at 375°C for periods of 16 to 20 hours each time air was admitted. Every time mercury contamination was suspected the chamber was given a thorough cleaning before more data were taken. The plate surfaces were subject to heavy discharges, in an atmosphere of hydrogen, except in the case of the second NaH surface.

All pressures given in this paper were reduced to 22°C.

EXPERIMENTAL RESULTS

The data for hydrogen gave the characteristic curves when $(1/p) \log i/i_0$ was plotted as a function of d , the plate separation.⁵ The values of α/p plotted as a function of X/p are shown in Fig. 1. Two sodium cathodes were used in this work. In the first case a thin layer of sodium was distilled on the platinum cathode after which a discharge was run for thirty minutes in an atmosphere of hydrogen. This gave a surface of NaH. The second sodium surface was heavier and no discharge was set up at any time during the measurements with this surface. It was hoped

⁵ For the terminology and the method of reduction of data the reader is referred to Bowl's paper (reference 2) and Loeb's treatment of this field (reference 3).

that with the second cathode it would be possible to get data for a sodium surface but the first few runs showed a constant change of the photosensitivity of the surface with time and this was taken to indicate that a NaH surface was being formed. After the potential had been applied to the chamber for some twelve hours the photoemission became steady. In all the curves shown the data derived with the first sodium surface are shown as circles and those taken with the second surface are indicated by crosses.

The data for the second coefficient was computed in two ways. (1) The Townsend⁶ equation

$$i = i_0 \frac{(\alpha - \beta)e^{(\alpha - \beta)d}}{\alpha - \beta e^{(\alpha - \beta)d}} \quad (1)$$

was assumed. This equation gave the quantity β . (2) The modified Townsend equation, which was independently derived by Thomson,⁷

$$i = i_0 \frac{e^{\alpha d}}{1 - \gamma(e^{\alpha d} - 1)} \quad (2)$$

was used to compute the quantity γ . This latter equation involves a cathode secondary emission process. Loeb³ has shown that the mechanism assumed by Townsend, leading to Eq. (1), does not occur under the conditions met with in this work. He also has shown that if β is small compared with α , then β can be interpreted either in

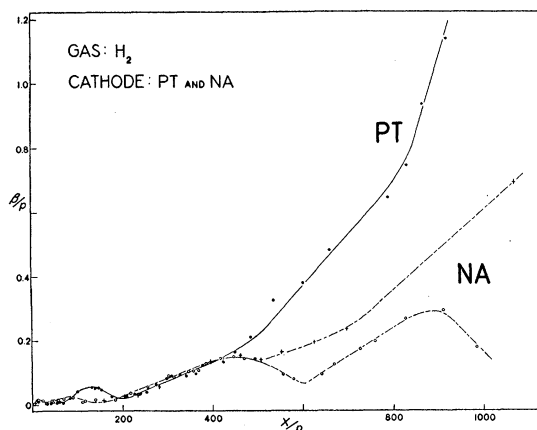


FIG. 2. Values of β/p as a function of X/p .

⁶ J. S. Townsend, *Electricity in Gases* (Oxford University Press, 1914), p. 314.

⁷ J. J. Thomson and G. P. Thompson, *Conduction of Electricity through Gases* (Cambridge University Press, second edition), Vol. II, p. 518.

terms of γ or in terms of a photoelectric mechanism. Thus to an approximation one sets $\beta/\alpha = \gamma = \Theta\eta g/\alpha$ where Θ , η and g are constants which determine the photoemission from the cathode surface. The derivations of β and γ (Eqs. (1) and (2)) are rigorous while that for $\eta\Theta g$ is only approximate. In this case α is not much greater than β and the β value found cannot accurately be substituted for either $\Theta\eta g$ or for γ . However for purposes of comparison β and γ were computed, from Eqs. (1) and (2).

The values of β/p , β/α and γ are plotted as functions of X/p in Figs. 2, 3 and 4. A comparison of Figs. 3 and 4 shows that β/α and γ are not essentially different except in the absolute values at the peaks. The β/p curve of Fig. 2 shows the same general characteristics as Bowls' curve for mercury-free surfaces of platinum and NaH in nitrogen. In this work, with somewhat better resolving power, the curves show a more complex structure. The γ curve, for the platinum surface, shows a prominent peak at an X/p of 125. This curve eventually starts a rapid rise at values of X/p greater than about 600. When the NaH cathode was used the values of γ showed an exceptionally high peak at an X/p of 10, followed by lower peaks at values of X/p of 50, 450 and 825. The general rise which is found for the platinum cathode does not appear in this case. The highest value of γ occurs at an X/p of 10. In the case of the second sodium surface, which was a heavy layer of sodium with some NaH present, the γ curve shows a gradual rise at the higher values of X/p .

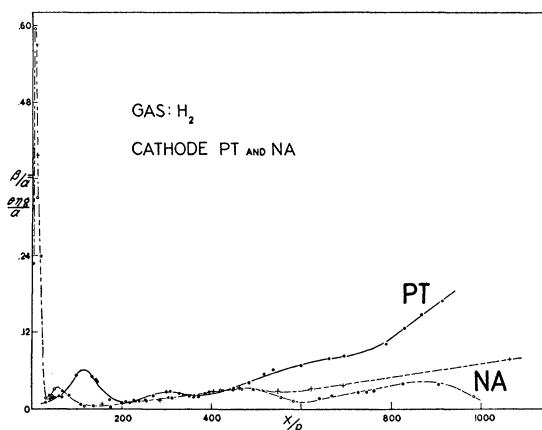


FIG. 3. The values of β/α as a function of X/p .

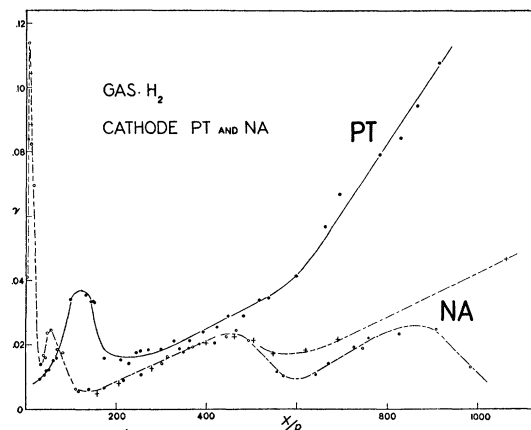


FIG. 4. Values of γ as a function of X/p .

Florence Ehrenkranz⁸ has experimentally determined the sparking potentials for platinum and NaH cathodes in mercury-free hydrogen. Fig. 5 shows the Ehrenkranz curve for the NaH cathode and also a curve calculated from the α and γ values as given in this paper and the method of calculation outlined in Loeb's article.³ The agreement is quite good, within 5 to 7 percent, over the short range of values of $p\delta$ for which it was possible to calculate V_s from the experimentally determined γ values of this work. All of the γ values used in the calculations lay below an X/p of 500. The sparking potential curve was also calculated for the platinum cathode and gave about the same sort of agreement. The deviation near the minimum of Fig. 5 could be caused by a difference in the conditioning of the two NaH surfaces. In the Ehrenkranz experiments the cathode was subject to larger currents and repeated heavy discharges. The sparking potentials were also experimentally observed in this work and for both cathodes gave curves of V_s plotted against $p\delta$ which lie from 5 to 8 percent above the curves of Ehrenkranz.

If in the calculations of the sparking potential curve one uses those values of γ which lie in the region of the narrow peak at the lower values of X/p the resulting values for V_s do not lie on the Ehrenkranz curve. As an example the calculated V_s for the γ value at X/p equals 20.4 is shown in Fig. 5. The value of γ at X/p equals 8.65 gives even worse agreement while the γ value at X/p equals 5.85 gives about the same agreement as

⁸ Florence Ehrenkranz, Phys. Rev. 55, 219 (1939).

the point shown. Thus it appears that on either side of this narrow peak the γ values will yield sparking potentials which agree with those experimentally determined.

The fact that these low values of V_s have not been generally observed is not strange. For in general, in sparking potential measurements the conditions have been such that at values of $p\delta$, in which the anomalous behavior is observed in this work, the range of X/p values used in the experiments did not coincide with the X/p of a prominent peak. However sparking potential measurements have at times yielded abnormally low values of V_s . It may be that these low values were, in some cases, caused by use of a $p\delta$ value which had an X/p value in the region of a peak. In general such values of X/p would require large values of $p\delta$.

DISCUSSION OF THE EXPERIMENTAL RESULTS

The values found for α/p as a function of X/p in pure hydrogen at the higher pressures are not seriously different from those of Ayres.⁹ At the lower pressures and higher values of X/p , where the percentage of mercury contamination becomes appreciable, the Ayres and Townsend curves rise to nearly twice the values of α/p observed here. However values of α/p which lie upon the Townsend curve were found in this work when the gas was admitted too rapidly and thus carried mercury from the gauges to the ionization chamber. The low values of α/p in the absence of mercury are in agreement with Bowls¹² work and thus are not surprising.

The α/p curve obtained when sodium was distilled into the chamber is interesting. In agreement with the observations of Ehrenkranz and Bowls sodium in the presence of hydrogen and nitrogen yields some volatile compound of low ionizing potential which is present at a pressure of at least 10^{-3} mm. In nitrogen this raised α/p some 25 percent at the highest values of X/p studied. In this work it increased α/p by as much as 100 percent at the lower values of X/p . Above an X/p of 350 the values of α/p show a decrease until they are approximately the same as those for the normal curve. There appears to be no doubt as to the interpretation. There is some substance in the presence of

⁹ T. L. R. Ayres, *Phil. Mag.* 45, 353 (1923).

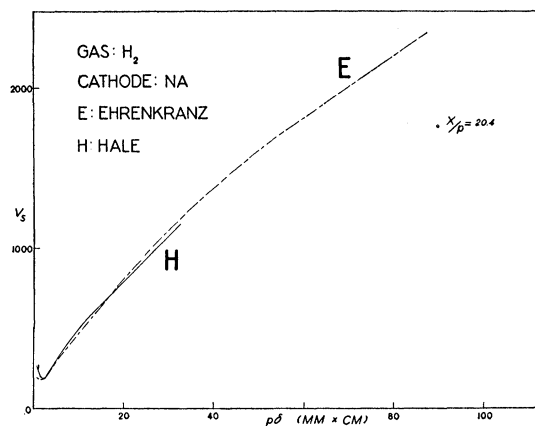


FIG. 5. The sparking potentials V_s in volts as a function of $p\delta$.

sodium which is very effectively ionized at low values of X/p in hydrogen and which shows a decreasing efficiency of ionization at the higher X/p and thus electron energies. This can only be caused by an ionization by excited states in hydrogen of some easily ionized sodium compound present in traces only. That such actions occur is indicated by the peaks in the values of γ at low values of X/p .

This appears to be the first evidence for a pronounced action of this kind. The results of Penning and Kruithoff¹⁰ in the proper admixture of argon and neon have yielded similar but not as pronounced peaks for α/p . It will be observed that there is an indication in Fig. 1 of a second such rise in the α/p curve above values of X/p of 1000. However these points are near the limit of the present ionization chamber and the precision of the measurements is not good. The only other case reported to date for a decline in the values of α/p with increasing values of X/p is that of Huxford and Engstrom¹¹ who used argon. Their curve shows a decline in the α/p value above values of X/p of 700. Here the decline is caused by the decrease in probability of ionization at the higher values of X/p .

As regards the values of γ it seems that the peaks which appear at the low values of X/p in both hydrogen and hydrogen contaminated with sodium are characteristic photoelectric emission peaks. These are conditioned by the excitation of

¹⁰ F. M. Penning and A. A. Kruithoff, *Physica* 3, 515 (1936); 4, 430 (1937).

¹¹ W. S. Huxford and R. W. Engstrom report these results in a letter to Professor Loeb.

certain lines in hydrogen as the average electron energy passes through peaks in the excitation curves. These excitation or photon yields have their effect on γ modified by absorption in the gas and by photoelectric peculiarities of the cathode surface. Note for example the difference in the locations of the peaks for the platinum and the NaH surfaces. In agreement with this it should be noted that the peaks in the γ curve for the NaH cathode disappear at those values of X/p where α/p has its maximum point. Here hydrogen is being excited but the sodium compound removes some photons by ionization. At the higher values of X/p the platinum surface in hydrogen, as is known from the results of Curtis,¹² is a good secondary electron emitter under proton bombardment. NaH on the other hand is a sensitive photoelectric emitter but appears to be relatively insensitive to secondary electron emission on bombardment by ions of sodium and protons.

¹²L. F. Curtis, Phys. Rev. **31**, 1010, 1127 (1928).

These results illustrate the different types of mechanisms producing the second Townsend coefficient. They clearly show the two types of secondary processes and the conditions under which they occur. They illustrate the fact that a good photoemitter may not be a good emitter under positive ion bombardment. This fact was also observed by the Farnsworth group in studies of the Cs-Ag-O surfaces under *electron* bombardment. These results also show why, with mercury contamination, the values of γ are low. The mercury vapor causes most of the peaks in the γ -curves to disappear. The radiation is destroyed by absorption by the mercury and its ionization while the mercury ions are known to be inefficient in producing secondary emission by ion bombardment of the cathodes.

In conclusion the writer wishes to express his thanks to Professor L. B. Loeb who suggested this problem and who has given generously of his time in discussions of the experimental results.

The Resonance Scattering of Protons by Lithium

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The scattering of protons by a thick target of lithium has been studied in the energy region 272–586 kev at an angle of 156°, with a ball counter. The number of counts per microcoulomb at 458 kev is 2.08 times its value at 408 kev, and at 487 kev it has dropped to 1.48 times the value at 408 kev. The energy at which the maximum slope of the thick target curve occurs is within five kev of the energy for the lithium gamma-ray resonance maximum. The fact that the scattering from a beryllium crystal increased smoothly with proton energy throughout the region, showed that the resonance effect is not a peculiarity of the counter. This scattering anomaly indicates: (1) that the gamma-radiation obtained when Li⁷ is bombarded with 440-kev protons arises from a virtual level of Be⁸; (2) that the Be⁸ state is odd; and (3) that there are no odd excited states of the alpha-particle below approximately 13 Mev.

INTRODUCTION

IN 1934 Lauritsen and his collaborators¹ observed gamma-radiation produced when lithium was bombarded by protons. Hafstad and Tuve² showed later that the reaction occurs as a

sharp resonance at 440-kev proton energy, and later work by them, with Heydenburg³ showed the resonance half-width to be about 11 kev.

The process of this gamma-ray emission was not known.⁴ Crane and Lauritsen assumed that

¹Crane, Delsasso, Fowler and Lauritsen, Phys. Rev. **46**, 531 (1934).

²L. R. Hafstad and M. A. Tuve, Phys. Rev. **47**, 506 (1935).

³Hafstad, Heydenburg and Tuve, Phys. Rev. **50**, 504 (1936).

⁴This problem is discussed by Breit in the paper by Hafstad, Heydenburg and Tuve, reference 3, pp. 510–514.