# Townsend's First Ionization Coefficient in Nitrogen*

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Measurements of Townsend's first ionization coefficient, $\alpha$, have been made in nitrogen for values of $E/p$ from 24 to 82. The ionization coefficient $\alpha$ is the mean number of ionizations per cm in the field direction produced by electron collision. $E$ is the electric field strength measured in volts per cm and $p$ is the pressure in mm of mercury. Sodium azide was used as a nitrogen source in an effort to obtain pure nitrogen. Data were also taken in tank nitrogen and mass spectrographic analyses of gas from both sources were made. No impurities were detectable in the sodium-azide-produced gas, while the tank nitrogen was found to contain some contamination even after a purification process. Results at low values of $E/p$ differ considerably from previously reported data, while at high values the results agree very well with data obtained by Bowls. Values of $\alpha/p$ in tank nitrogen were found to be considerably lower at low $E/p$ than those found in gas produced from sodium azide, although at high values the difference was small. The effect of wall potential on $\alpha/p$ was investigated and was found to be unimportant over a range from 45% to 100% of anode potential.

## INTRODUCTION

MEASUREMENTS of Townsend's first ionization coefficient in nitrogen have been made several times by previous investigators.[1–6] The ionization coefficient, $\alpha$, is the mean number of ionizations per cm in the field direction produced by electron collision. That previous results differ substantially is not surprising, for the gases used in these experiments were of doubtful purity and except for references 5 and 6 mercury vapor was nearly always present to influence the results. Seemingly the most reliable data were obtained at high values of $E/p$ (electric field in volts per cm/pressure in mm of mercury) where the influence of contaminants does not appear to be as great as at low values of $E/p$. The measurements which are herein reported were made in an effort to obtain data in pure, mercury free nitrogen over an extended range of values of $E/p$.

It was thought that some of the previous differences in measured values of $\alpha/p$ could have been due to the varying influence of the walls of the discharge chamber. Experiments were therefore conducted to determine the effect of the wall potential on the measured values of $\alpha/p$.

TABLE I. Values of $\alpha/p$ in nitrogen. Sodium-azide-produced gas at 10.6, 23.1, 47.2, and 90.3 mm pressure.

| $E/p$ | $\alpha/p$ |
|---|---|
| 24 | 0.00239 |
| 26 | 0.00285 |
| 28 | 0.00595 |
| 30 | 0.00855 |
| 32 | 0.0118 |
| 34 | 0.0155 |
| 36 | 0.0199 |
| 38 | 0.0248 |
| 40 | 0.0298 |
| 42 | 0.0356 |
| 44 | 0.0420 |
| 46 | 0.0488 |
| 48 | 0.0562 |
| 50 | 0.0655 |
| 52 | 0.0750 |
| 54 | 0.0860 |
| 56 | 0.0990 |
| 58 | 0.111 |
| 60 | 0.124 |
| 62 | 0.139 |
| 64 | 0.158 |
| 66 | 0.171 |
| 68 | 0.191 |
| 70 | 0.209 |
| 72 | 0.227 |
| 74 | 0.246 |
| 76 | 0.268 |
| 78 | 0.285 |
| 80 | 0.302 |
| 82 | 0.318 |

## APPARATUS AND PROCEDURE

The discharge tube used in this work has been described in a previous paper,[7] and with only minor variations the experimental procedures were the same as reported therein. The negative power supply was replaced by a well-regulated 5000-v positive supply and the Dolezalek electrometer by an electronic instrument.

## GAS SOURCES

Nitrogen gas was obtained from the decomposition of sodium axide, passed slowly through finely divided hot copper and a liquid nitrogen trap, and then admitted into the discharge chamber. One sample of gas was stored for eight hours in thermal contact with liquid nitrogen before it was used, but the results did not differ from those taken in gas not so stored. As a check on the purity of the nitrogen, a mass spectrographic analysis of the gas was made in the University

* Supported by a grant from the Research Corporation.
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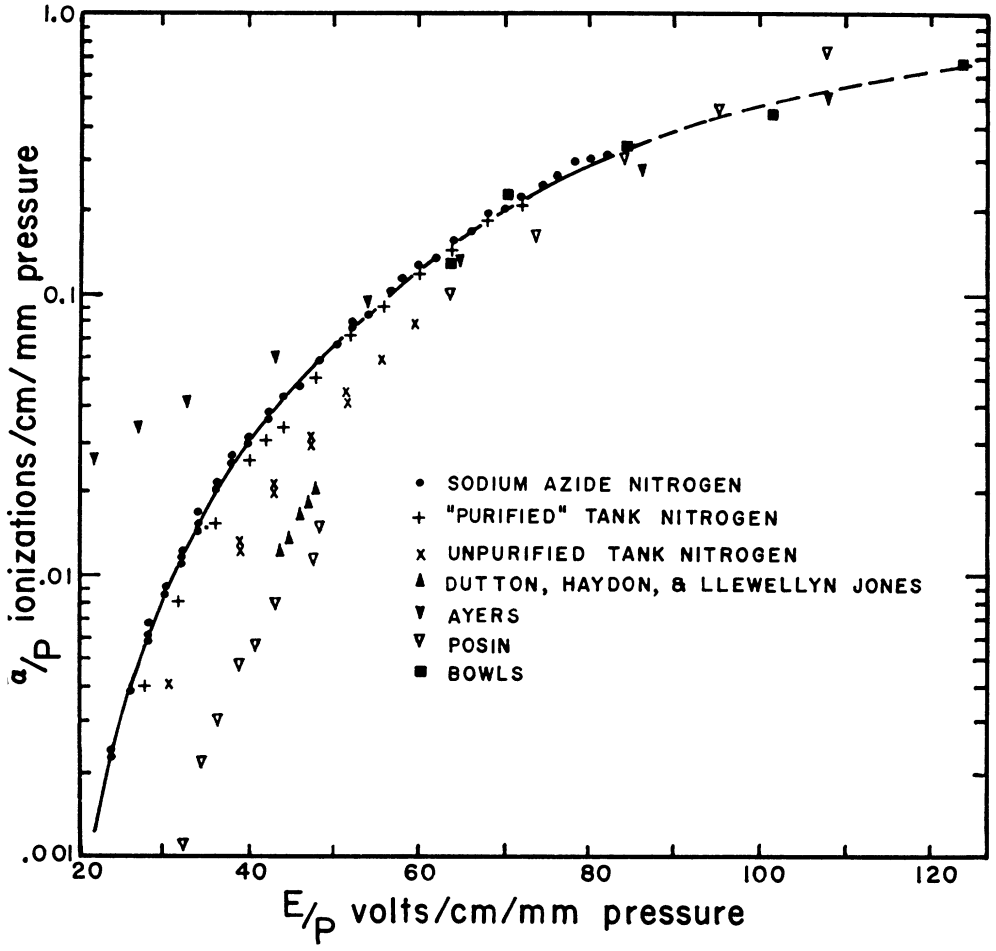


FIG. 1. Variation of ionization coefficient with $E/p$ for nitrogen. All data are reduced to 0°C.

of Washington mass spectrograph. No impurities above background (0.01%) were found by this instrument.

Tank nitrogen was also used as a source of gas and some samples were purified by the above process. Mass spectrographic analysis showed the "purified" tank nitrogen to contain 0.06% oxygen and 0.04% argon with no other impurities greater than 0.01%. The tank nitrogen not purified as above and taken directly from the tank is about 99.9% pure.

Pressures were measured with a mercury manometer and reduced to 0°C. At all times a liquid nitrogen trap was used to protect against mercury contamination.

## DATA

Semilogarithmic plots of current *versus* electrode separation yield straight lines as required by Townsend's equation:

$$i=i_0e^{\alpha d}.$$

The photoelectric current density, $i_0$, was kept at approximately $5\times10^{-12}$ amp/sq cm. Data were obtained for several pressures over a range of $E/p$ from 24 to 82.

## RESULTS AND DISCUSSION

The results in nitrogen are given in Fig. 1 and in Table I. It is to be noted that at low values of $E/p$ the present values of $\alpha/p$ are considerably higher than most previous values, while the agreement with Bowls'[4] results at high $E/p$ is quite good. Bowls' results are given for mercury-free gas, while those of Ayers,[1] Masch,[2] and Posin[3] are definitely mercury-contaminated. To avoid confusion, Masch's data are not plotted. The gas used by Dutton, Haydon, and Jones[5] was from a tank and only the water vapor was removed. The experiments of DeBitetto and Fisher,[6] which give results that agree with Dutton, Haydon, and Jones, are not given in sufficient detail in their abstract to discuss.

The results in "purified" tank nitrogen are interesting in that these values of $\alpha/p$ are consistently lower than those in gas produced from sodium azide, while the values of $\alpha/p$ in unpurified tank gas are far lower still. Evidently the presence of impurities lowers appreciably the measured values of $\alpha/p$ in nitrogen.

The differing results obtained by different investigators are in all likelihood due primarily to contamination of the gas used. It was found in this experiment

that power supply drift could also be responsible for a dispersion of results. Since the experimental electrodes act as a parallel plate capacitor, even a very slight voltage drift results in a displacement current in the circuit. This current easily could be of the order of magnitude of the current being measured. Consequently, it was necessary to insure a high degree of stability in the voltage source. The power supply used possessed sufficient stability so that the displacement current was always below $10^{-13}$ amp. This was less than one percent of the currents measured.

It has been suggested that in experiments of this kind the wall potential may influence the measured values of $\alpha/p$. In this experiment the wall potential was varied in 5% steps from 45% to 100% of the anode potential and no effects on the values of $\alpha/p$ were found.

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# Moving Striations in Direct Current Glow Discharges*

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A theoretical examination of the ion balance equations for a plasma, such as the positive column of a direct current glow discharge might be, shows that a uniform plasma is not always possible. When ionization proceeds by a two-stage process involving accumulated metastable excited atoms, as may be the case in the noble gases, small perturbations of the ion concentrations from their equilibrium values may not remain small. Under such conditions, a spatially uniform steady plasma cannot exist. A general stability criterion is developed which may be used whenever accurate expressions are known for the ion and metastable production and loss rate terms. Application of the stability criterion is made using several approximations.

The instability of a spatially uniform plasma suggests that the ion concentrations may vary along the direction of current flow. The ion balance equations are re-examined for wave-like solutions. Two approximate solutions showing some agreement with experimental observations on moving striations are obtained. The first solution, ignoring variations in the metastable concentration, yields ion and electron concentration waves traveling in the direction of the current flow with velocity probably considerably greater than the positive ion drift velocity. The amplitude of the positive ion wave is much greater than that associated with the electrons.

The second approximate solution ignores diffusion and represents a concentration wave dependent solely upon production and loss processes. It can travel in either direction, depending upon conditions in the plasma. General expressions for velocity, frequency, and wave number are given, but these cannot be evaluated numerically without better expressions for some of the quantities involved.

## I. INTRODUCTION

MANY studies have been made of direct current glow discharges in the noble gases.[1] The characteristic appearance of such discharges is well known. Commonly displayed features include the cathode glow, Crookes dark space, negative glow, Faraday dark space, and a uniformly glowing positive column or plasma.

The behavior of the positive column, despite its uniform appearance, is far from simple. As Donahue and Dieke[2–4] have demonstrated, moving striations are almost always present. When the positive column is observed by means of a phototube and cathode-ray oscilloscope, as was done by Donahue and Dieke, the light intensity from any small region of the positive column is seen to fluctuate rapidly. Often the fluctuation is periodic, though not usually sinusoidal. Figure 1, taken from reference 3 or from Fig. 5 of reference 2, shows typical periodic fluctuations in the light intensity at several points in the positive column of an argon discharge at 12 mm pressure and 19.20 ma current. The tube diameter was about 13 mm, and the Faraday dark space extends to about 2.0 cm from the cathode. All the points in Fig. 1 are in the positive column, beyond the cathode region.

Points to be noted are (1) that the maximum amplitude varies little, and not in any systematic manner, and (2) that the light intensity actually becomes zero (or at least very small) during part of the cycle. The largest peak, labeled $P$, may be followed from one point in the tube to another. It is seen to appear at progressively later times as the phototube is moved toward the cathode. This peak is identified as a positive striation, since it moves in the direction of current flow (from anode to cathode). A second, smaller peak, labeled $N$, is observed to appear almost at the same time whenever it may be identified. It actually does appear slightly earlier as the cathode is approached,

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