The Process of Ionization in Active Nitrogen

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Average energy and concentration of electrons along the axis of a nitrogen afterglow tube have been measured by means of a movable Langmuir probe. Electrons with energies of more than 20 volts have been found throughout the afterglow. The experimental curves of potential and electron density distribution could be explained by solving the diffusion equation. It is shown that a part of the ions in the afterglow is produced by the collision of fast electrons with N_2 molecules.

According to Mitra's theory,[1] active nitrogen consists of positive ions of nitrogen molecules in the $N_2^+(X')$ state. Because of the absorption of a layer of nitrogen molecules or atoms, the walls of the containing vessel are so conditioned that they have a very high reflection coefficient for electrons and ions. The long-life of the nitrogen afterglow is ascribed to the slow process of three-body recombination in the volume of the gas. It is as follows,

$$N_2^+(X')+e+N_2\rightarrow N_2(B)+N_2(A),$$

which explains the emission of the characteristic spectrum of the Lewis-Rayleigh afterglow and some features of the Kaplan afterglow, as recently reported.[2] The source of ionization in the afterglow is, however, still not clear. The experiments of Rayleigh[3] show that the ionization is not produced either by the bombardment of any metallic surfaces by the active nitrogen particles or by the photoelectric emission in the volume of the gas. The present note is a report of some experiments to show that the ionization in the afterglow is produced in the gas partly by the collision of fast electrons with N_2 molecules, and is derived partly from the main discharge into the observation vessel through ambipolar diffusion.

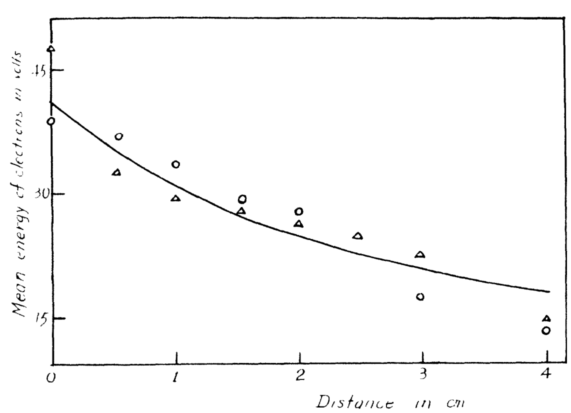

FIG. 1. Mean energy of electrons along afterglow tube. Voltage across discharge tube, 635 volts. Discharge current, 2.7 ma. Gas pressure, 0.48 mm Hg.

[1] S. K. Mitra, *Active Nitrogen—A New Theory* (Indian Association for the Cultivation of Science, Calcutta, 1945).
[2] S. K. Mitra, Phys. Rev. **74**, 1637 (1948).
[3] Lord Rayleigh, Proc. Roy. Soc. **A180**, 123 (1942).

In a cylindrical discharge tube with plane parallel disk electrodes, a side tube of the same diameter as the latter was fixed perpendicularly onto the main tube near the cathode. When a d.c. potential of about 600 volts was applied across the tube with a gas pressure of pure nitrogen of 0.5 mm Hg, the glowing gas was observed to extend a considerable distance into the side afterglow tube.

By means of a movable cylindrical probe mounted along the axis of the afterglow tube, the mean kinetic energy of electrons has been measured from the center of the main tube to 4 cm in the afterglow tube. The result is shown in Fig. 1. One notices that the electrons with energies of more than 20 volts have penetrated far into the afterglow tube. These electrons are able to produce ionization and even simultaneous excitation of N_2 molecules for the emission of the first negative bands.

The potential distribution and the concentration of electrons measured along the afterglow tube are represented in Figs. 2 and 3. These results could be explained by assuming that both the positive ions and electrons are diffused into the afterglow tube from the main discharge. Within the afterglow tube the potential was found to be decreasing linearly. Since electrons diffuse much faster than ions because of their smaller mass, a decreasing potential might be created along the tube axis. If the constant electric field is E, the potential V

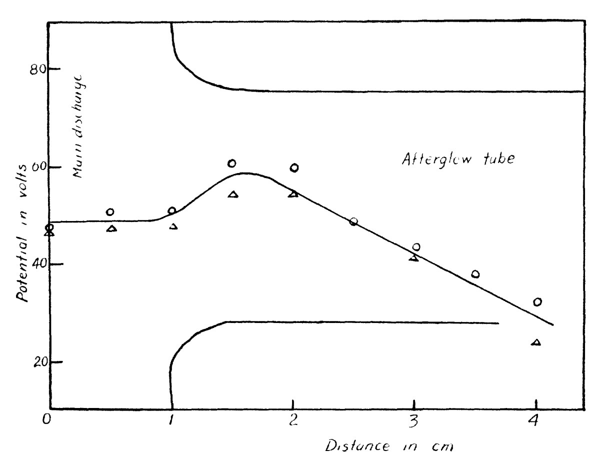

FIG. 2. Potential distribution along afterglow tube.

at any position z along the tube axis can be expressed as $V=V_0-Ez$, where V_0 is the value of V at $z=0$.

The distribution of electrons along the tube in Fig. 3 could be obtained by considering the solution of the following diffusion equation for the electron concentration n,

$$D_a \operatorname{div} \operatorname{grad} n + qn = 0.$$

In this equation q is the number of electrons produced per sec. per unit volume due to ionization by collision of each fast electron in the volume of the gas. D_a, the coefficient of ambipolar diffusion, is given by

$$D_a = (D_+b_- + D_-b_+)/(b_+ + b_-),$$

where D_-, b_- are the diffusion coefficient and mobility of electrons, respectively, and D_+, b_+ those for positive ions. If cylindrical coordinates are used, the equation can be solved subject to the condition that in the steady state the diffusion current along the axis of the tube is equal to that due to drift. The result obtained is given as

$$n = n_0 J_0([(b_-E/D_-)^2 + (q/D_a)]^{\frac{1}{2}} r) \exp(-b_-Ez/D_-),$$

where J_0 is the Bessel function of order zero and n_0 is the value of n when $z=0$ and $r=0$. A plot of $\log n$ *versus* z using values from the curve in Fig. 3 gave a fair straight line, the slope of which, after division by E (from Fig. 2), gives $b_-/D_- = 0.041$ volt^{-1}; but $b_-/D_- = e/kT_e$, where T_e is the electron temperature and e and k have their usual significance. Since the slope of $\log n$ *versus* z plot is constant, T_e must be independent of z in the afterglow tube, which is nearly so from experiment as shown in Fig. 1. If now, from Fig. 1, the value of 25 volts is taken as the mean energy of electrons in the tube, we have $b_-/D_- = e/kT_e = 0.059$ volt^{-1}, which is approximately checked with the value obtained in the other way.

The electron distribution along a radius of the afterglow tube was not measured. However, an estimate of the value of q could be made by taking measured values in the main tube. From Fig. 3 we have $n/n_0 = 0.24$ at $r=1$ cm, the radius of the tube, and then

$$[(b_-E/D_-)^2 + q/D_a]^{\frac{1}{2}} = 1.9.$$

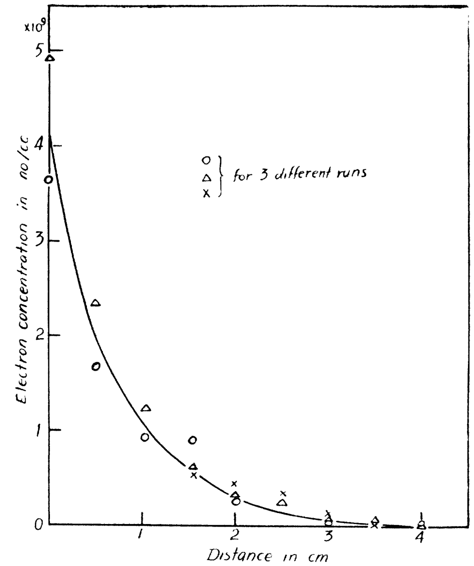

FIG. 3. Variation of electron concentration along afterglow tube.

If the existing experimental value[4] $b_+ = 9.7 \times 10^2$ cm/sec./volt/cm is used, one gets $q = 3.85 \times 10^4$ electrons produced per sec. per cc by each electron in the volume of the gas. These are probably mostly slow electrons, and they may play an important role in the process of the three-body collision, as the coefficient of recombination for fast electrons is very small according to Thomson's theory of collision.[5]

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[4] A. v. Engel and M. Steenbeck, *Elektrische Gasentladungen* (Verlag. Julius Springer, Berlin, 1934), Vol. 1, p. 182.
[5] J. J. Thomson, Phil. Mag. **47**, 337 (1924).