STRIATED DISCHARGE IN HYDROGEN

By Arthur Bramley

Abstract

Potential distribution, electron concentration and mean electron energy at eleven points were determined for a discharge through a tube 15 cm long at pressures of .625, .20, .09 and .02 mm, using Langmuir's probe method. The total potential difference was 270-300 volts. The potential dropped to a minimum within 2 mm of the cathode, of 125, 60 and 20 volts for pressures .20, .09 and .02 respectively, giving a reverse gradient in a region 1 to 2 cm long through which the current must have been carried by diffusion of positive ions and electrons. The gradient was also reversed at the anode edge of a striation for pressures of .20 and .09 mm—the lower pressure .02 mm gave a uniform positive column. The electron concentration reached a maximum 1 to 2 cm in front of the cathode; the values, in general, are lower the higher the pressure. The mean electron energy decreases sharply at the cathode to a minimum of 1 to 2 volts, then rises gradually to about 10 volts at the beginning of the positive column; it also reaches 10 volts at a striation. Such electrons have sufficient energy to cause the ionization which is associated with the luminosity in the positive column. The anode drop within 2 mm was only 5 to 15 volts, the potential distribution depending on the position of the nearest striation.

ALTHOUGH a large amount of work has been done on the striated discharge in monatomic gases, very little has been done recently on the discharge in diatomic gases at low pressures, where the presence of various kinds of ions renders the interpretation of the results obtained more difficult.

The method employed in this investigation is the one suggested by Langmuir. If a wire is introduced into the discharge and maintained at a negative potential with regard to the surrounding space, a positive space charge arises which limits the positive ion current reaching the wire. As the potential of the wire is raised, electrons reach the wire against the potential of the field until the resultant current becomes zero. Finally, when the wire exceeds the potential of the space, positive ions are prevented from reaching the wire, so that it becomes surrounded with a negative space charge. Therefore when the potential of the wire becomes equal to that of the space surrounding it, a change in the law governing the current to the wire must take place.

If there is a Maxwellian distribution of velocity the current reaching the wire can be expressed in the following form

$$I = N_0 e \sqrt{(e\bar{v}/3\pi m)}\,\epsilon^{-3(v_s - v)/2\bar{v}} \qquad (1)$$

where I is the current to the exploring electrode, N_0 the concentration of the electrons, m and e the mass and charge of an electron, $\bar{v}$ the average velocity of the electron, expressed in equivalent volts, v the potential of the wire and v_0 the potential of the space. From this equation it follows that

$$\log I = -(3/2)\ (v_0 - v)/\bar{v} + \text{const.}$$

so that if $\log I$ is plotted against v a straight line ought to be obtained, whenever there is a Maxwellian distribution of velocities. The slope of this curve ($\tan\theta$) enables us to find the average velocity of the electrons at once, for $\tan\theta = 3/2\bar{v}$. The potential of the space will be the potential at which the graph of $\log I$ plotted against v begins to deviate from a straight line.

When $v_0 - v = 0$ the equation simplifies to the form

$$I = N_0 e\ \sqrt{(e\bar{v}/2\pi m)}$$

so that, knowing $\bar{v}$ from the slope of the curve, we can compute the concentration of the electrons.

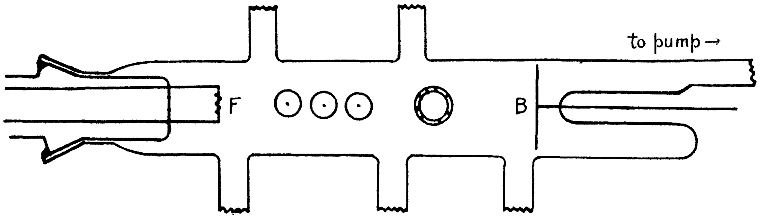

Fig. 1. Discharge tube with exploring electrodes inserted through side tubes.

A diagram of the apparatus used in this experiment is given in Fig. 1. The filament F, which serves as a hot cathode to maintain the discharge at low voltages, and the anode B were fixed with respect to the main tube of 3.8 cm diameter. The exploring electrodes, of which there were eleven placed at different positions in the path of the discharge, were each of 4 mil (.1 mm) tungsten wire covered with glass to within a few millimeters of the end which was placed as near the axis of the discharge as possible. The object of using the eleven fixed electrodes in preference to a moving cathode-anode system and a single electrode was to enable a series of readings of the current to be taken without altering conditions in the discharge.

Fig. 2 gives a few typical $\log I$ vs potential curves for different conditions in the tube. Curves 1 and 2 represent the type obtained near the cathode where we have relatively high speed electrons together with slow ones. In this type of curve, we find first a linear part with small slope which represents large energy since the energy varies inversely as the slope, curving upwards as the slow speed electrons reach the electrode against the space charge sheath; this second part which becomes also a straight line with much greater slope than the first changes into a parabolic curve when the potential of the space is reached. Curve 3 gives the form of curve obtained in the positive column; the breaks in this curve at 12 volts apart which are found above the potential of the field have received as yet no adequate explanation. The breaks in the curves fall about 16 and 12 volts apart on the average and may represent the ionization of the hydrogen molecule and atom respectively. Curve 4 is typical of the curves obtained at high pressure (p = .625 mm) where the mean free path is so small that different conditions from those obtained at the other pressures seem to be present.

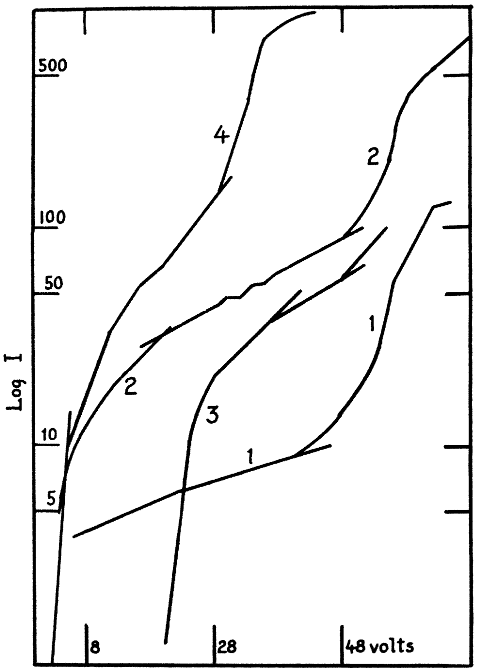

Fig. 2. Typical log I vs potential curves for exploring electrodes.

In Fig. 3 the distribution of potential, the log of the concentration of the electrons and the mean energy of the electrons for the different points in the discharge from cathode to anode where the exploring electrodes are situated are given for pressures of .625, .20, .09 and .02 mm. Below .015 mm no discharge would pass through the gas although the potential across the tube was increased from 270 to 750 volts. At .02 mm it was

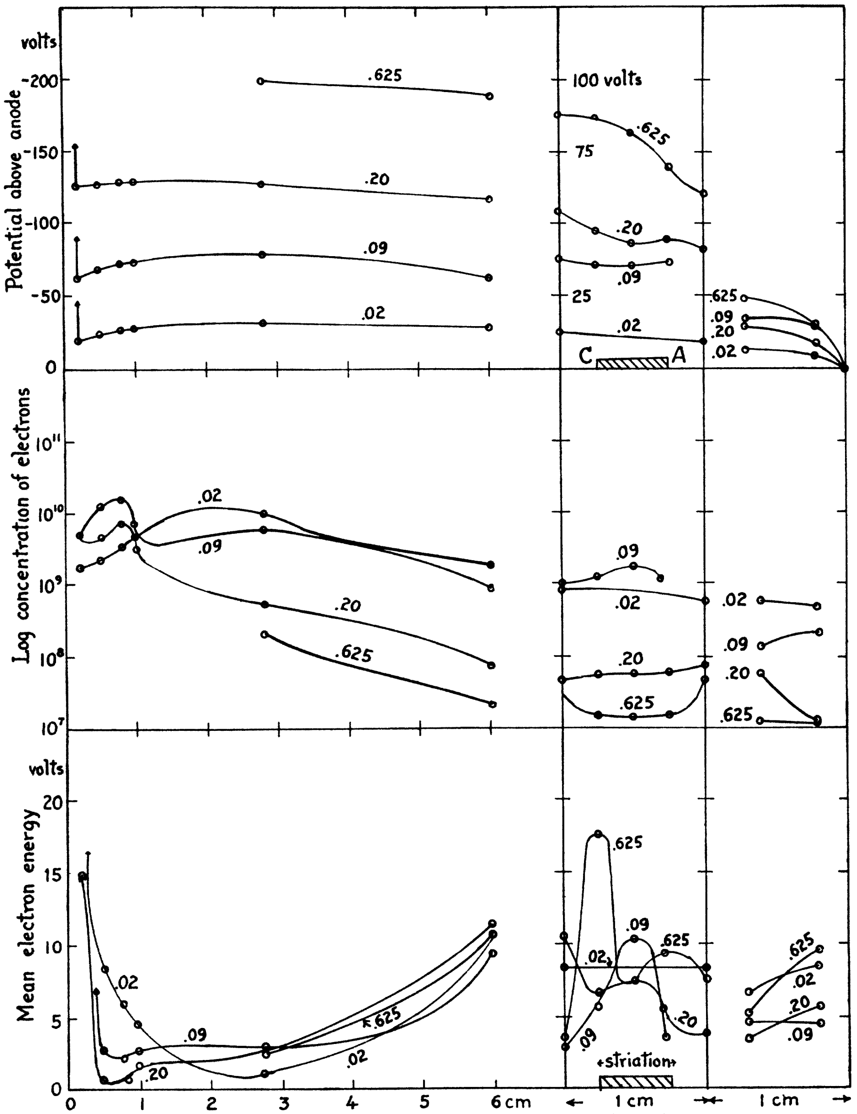

Fig. 3. Potential, logarithm of concentration of electrons, and mean electron energy at different parts of the discharge within 6 cm of the cathode (left), in a striation (middle) and within 1 cm of the anode (right) where the eleven fixed exploring electrodes were situated, for pressures of .02, .09, .20 and .625 mm. For the lowest pressure there were no striations, merely a uniform positive column. In the positive column the indicated position of the striation is only approximate; the maximum mean electron energy occurs near the cathode edge in each case.

found impossible to maintain a striated discharge in the gas through the same potential range. The explanation of this is probably connected, as we shall see, with the condition of the discharge in the neighborhood of the cathode.

We shall first consider the conditions near the cathode and in the region of the Faraday dark space. As the pressure of the gas in the tube is diminished the cathode fall becomes a greater fraction of the total potential applied to the tube until a pressure is finally reached such that the electric intensity is reversed in the Faraday dark space. In this case there is a group of higher speed electrons proceeding from the cathode together with the group of slow electrons which have a large concentration in this region. The higher speed electrons evidently cause continual ionization which results in the large concentration of low speed electrons, the current in the tube being carried by diffusion of positive ions toward the cathode. At high pressures the concentration of electrons is much smaller and the current is due to the electric field; in this case the first term of the equation

$$F = N_0 eE - kT\, dN_0/dx$$

predominates while at low pressures (since both N and E are very small as compared with dN/dx and kT—see Fig. 3), the last term (which is due to diffusion) governs the conditions in the discharge. In this equation F is the force on the ions, E the electric field and kT is two-thirds the kinetic energy of the ions.[1] If the pressure is lowered still further, the intensity of ionization must become smaller until a point is reached where the concentration of positive ions is not sufficient to maintain the discharge.

From the concentration and average velocity of high speed electrons for the pressure of .02 mm, a calculation of the total emission from the filament (using Eq. 1) gave results in approximate agreement with the total current in the tube. The total emission calculated was 50 milli-amp. while the total current in the tube as calculated from the measured concentrations was 35 milli-amp. In the calculation the higher speed electrons were assumed to move radially from the cathode without taking into account (1) the possibility of collisions before reaching the electrode, (2) ionization in the region of the space charge sheath surrounding the electrode, and (3) loss due to collisions with the walls of the tube, since the mean free path was nearly four times the radius of the tube.

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[1] A thorough discussion of the effects of the electric field intensity and diffusion on the type of discharge has been given by K. T. Compton, Louis A. Turner and W. H. McCurdy, Phys. Rev. **24**, pp. 597-615 (Dec. 1924).

As we move down the tube, the average energy of the electron increases until, as we approach the head of the positive column, the energy becomes nearly equal the ionization potential of hydrogen. In the positive column, the fall in potential over a striation decreased from 30 volts to about 11 volts as the pressure decreased from .625 mm to .09 mm; at the same time, however, the average velocity of the electrons within the striation did not decrease appreciably. Throughout this range of pressure a group of electrons, with average velocity over 10 equivalent volts, was found in the striation toward the cathode side. These electrons must cause the ionization which results in the luminous striated discharge since accumulative ionization has not been found in hydrogen. When the pressure was still further lowered to .02 mm the positive column was uniform and the average energy of the electrons was constant at about 8.4 volts throughout this region.

At the anode the fall of potential within 2 mm never exceeded 15 volts and seemed to be determined by the position of the last striation relative to the anode. In the case of the uniform column (.02 mm) the fall of potential was only about 5 volts.

In the positive column, the character of the discharge at high pressures is determined by the conductivity due to the large electric gradient while at low pressures since the electric field is very small and even negative in some places, the diffusion of the electrons and ions plays a more fundamental rôle than the electric field.

In conclusion, I wish to express my gratitude to Professor K. T. Compton for suggesting the problem and for his helpful suggestions during the course of the investigation.

Palmer Physical Laboratory,
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