LETTERS TO THE EDITOR

PHYSICS

Propagation of a Gaseous Discharge in a Crossed Magnetic Field

THE application of a crossed magnetic field to an electron swarm moving under the influence of a uniform electric field enabled Townsend¹ to derive the high electron drift velocities, using a steady-state d.c. method without recourse to pulse techniques or oscilloscopes. From the measurement of the electron angular deflexion, θ^- , and making use of the expression, deduced by Townsend, $v_T = \frac{E}{B} \tan \theta^-$, in which E and B are the crossed electric and magnetic fields, respectively, the drift velocity, v_T , was obtained in an elementary way. In this communication the early treatment is extended to include the numerous practical cases in which Townsend's secondary ionization coefficient comes into play in the full development of a gaseous discharge.

The mode of charge movement together with the crossed electric and magnetic field directions are shown in Fig. 1. An electron, or bunch of electrons, starts off instantly at point 0. As the electrons move in the transverse ($\vec{e} \times \vec{B}$) direction, they are deflected in the perpendicular ($\vec{e} \times \vec{B}$) direction with velocity v_T . On reaching the point A (or A', A'' or A''', which corresponds to the end of the discharge region), sufficient positive ions have been produced which drift towards the cathode, in turn are deflected, though to a lesser extent on account of their mass, and strike the cathode surface to release a further burst of electrons. Thus, due to successive cycles, the discharge propagates in the perpendicular direction.

Analysis of Fig. 1 shows that the propagation velocity, v , is given by:

$$v = v_T^+ (\tan \theta^- + \tan \theta^+) \quad (1)$$

in which v_T^+ is the transverse positive ion velocity and θ^- and θ^+ are the angular deflexions of the respective particles. No specification has been made as to whether the motion is governed by a few individual collisions or by multiple processes, and an important aspect is that the propagation velocity in this régime is independent of the discharge-length.

It has been observed² that the emission of an electron from the cathode on positive ion bombardment may be delayed for a time τ_+ , called the site time, which may be comparable in duration with the ion transit time, τ_+ .

Fig. 1. Movement of electrons and ions of a Townsend discharge in a crossed electric and magnetic field

Taking this effect into account, the above expression becomes:

$$v = v_T^+ (\tan \theta^- + \tan \theta^+) \frac{\tau_+}{\tau_+ + \tau_-} \quad (2)$$

Thus the propagation velocity may vary over a wide range and is influenced by the properties of the gas and the nature of the electrodes.

In certain discharges, such as the column region, the regenerative process can be considered to take place continuously rather than in a stepped fashion, and a reconsideration of equation (1) shows that for this régime the propagation velocity is given by v_T^- or v_T^+ , depending on which ion component dominates the discharge. Thus, in general, the propagation velocity of a discharge will fall within the range:

$$v_T^- > v_T^+ (\tan \theta^- + \tan \theta^+) > v_T^+ \quad (3)$$

in which the limiting velocities can be associated with columnar processes and the middle range corresponds to the cathode fall condition. The large differences between electron and positive ion velocities would lead to charge separation, and as this continuous mode may only be active in columnar regions, the presence of space charges can no longer be neglected and the concept of ion coupling³ may have to be evoked.

It can be shown⁴ for an electron swarm in hydrogen with a mean energy, $\bar{\epsilon} = 3$ eV, that $v_T^- = 1.5 \times 10^5 \frac{E}{p}$ m/sec and $\tan \theta^- = 40 \frac{B}{p}$ for weak magnetic fields;

also $v_T^+ = \mu^+ \frac{E}{p}$ in which $\mu^+ = 96 \frac{\text{m cm}}{\text{sec volt}}$ mm mercury⁵,

yielding $v = 3.84 \times 10^3 \frac{E}{p} \frac{B}{p}$ m/sec. Thus, the electron

columnar velocity is $40 \times$ larger than the stepped velocity of the discharge, which could correspond to that of the cathode

fall. For $pd = 1,000$, $\left(\frac{E}{p}\right)_s = 20$ (ref. 6) and for $B = 0.1$ Wb/m² and $p = 1,000$ mm mercury, $v = 7.68$ m/sec in agreement as to order of magnitude with observed gas discharge propagation velocities⁷. In the numerical derivation, the positive ion angular deflexion, θ^+ , has been neglected. As no data are available for this quantity or v_T^+ , there is a need for these to be measured, particularly as it is claimed⁷⁻⁹ that θ^+ is the overriding quantity determining the propagation of an arc discharge. Useful information should also be gained from an investigation of the propagation velocity of a Townsend and glow discharge.

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