SHORT COMMUNICATIONS

THE DIFFUSION OF ELECTRONS IN A GAS AT LOW TEMPERATURES*

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Introduction

In the absence of an electric field, the state of motion of electrons moving freely among molecules of a gas is one in which the mean energy of agitation Q of an electron is the same as that, Q_0, of a molecule of the gas. It is known, however, that in the presence of an applied uniform electric field Z the steady state of motion is one in which Q exceeds Q_0, and, for a constant gas temperature, Q is a function of Z/n where n is the number of gas molecules in unit volume. Usually the measurements are made at room temperature, generally taken as 288 °K, and it is convenient to replace Z/n by Z/p where p is the pressure of the gas in millimetres of mercury. It is of interest, however (Crompton, Huxley, and Sutton 1953), to investigate how the dependence of Q upon Z/n is influenced by the temperature of the gas itself, that is to say, by Q_0. If the dependence of Q upon both Z/n and Q_0 be expressed by some formula $Q = f(Z/n, Q_0)$, then all that is known with certainty about the function f is that when $Z/n = 0$, $Q = Q_0$. In view of the absence of any theoretical guidance concerning the dependence of Q upon both Z/n and Q_0, it was decided to investigate the matter experimentally in two simple diatomic gases, nitrogen and hydrogen.

Apparatus

The diffusion chamber, of length h cm, was the same as that used by Crompton and Sutton (1952), as were the electrometers and current measuring devices. The chamber was mounted near the bottom of a glass envelope which stood in a cylinder containing either dry ice or liquid air.

The envelope was made considerably longer than that used previously as it was necessary to keep the electrometer terminals at the top as nearly as possible at room temperature in order to avoid deterioration of the electrostatic insulation by the condensation of water vapour. In addition, heater wires were wrapped around the envelope near the top. The leads from the diffusion chamber to the top of the envelope were made of 50 gauge copper wire to reduce the thermal conduction.

The temperature in the diffusion chamber was measured with a copper-constantan thermocouple made of 45 gauge wire, the cold junction being soldered to the earthed ring surrounding the collecting electrode. The hot junction

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was at room temperature and the thermo-e.m.f. was measured with a galvanometer and scale. The thermocouple was then calibrated over the useful range of temperatures by using a pentane in nitrogen thermometer as standard. It was assumed that the temperature of the gas in which the electrons were diffusing was the same as that of the lower electrode.

Both the nitrogen and the hydrogen were introduced into the apparatus according to the procedure described by Crompton and Sutton (1952).

Results

The ratio Q/Q_0 is denoted by k_T, but the quantity measured in the diffusion experiments is k_1 where $k_1 = Ak_T$, the factor A being a constant determined by the manner in which the speeds of agitation of the electrons are distributed about their mean value. As described in papers by Huxley and Zaazou (1949) and Crompton and Sutton (1952), the measurement of the ratio of the current falling on the inner circular electrode to that falling on the whole electrode enables k_1 to be determined. Good agreement was obtained between values of k_1 measured at different pressures, but at constant temperature, for the same value of the ratio Z/p.

If k_1 is measured at a temperature T, then

$$Q = \left. \begin{array}{c} C_M \\ C_D \end{array} \right\} k_1\, T/288 \text{ ergs,}$$

where $C_M = 6 \cdot 0 \times 10^{-14}$ and $C_D = 5 \cdot 3 \times 10^{-14}$ are constants appropriate to the distributions of Maxwell and Druyvesteyn respectively.

In previous work in this field, the electronic energy Q is represented as a function of the ratio Z/p where p is the pressure of the gas at 15 °C. It is, however, not the physical pressure p that is significant but the concentration n of the gas molecules per cubic centimetre, of which p is a measure provided the temperature remains constant. Since at 15 °C the concentration of the molecules of a gas exerting a pressure of 1 mm of mercury is $n = 3 \cdot 35 \times 10^{16}$ cm^{-3}, the parameter Z/p is in effect the same as $(Z/n) \times 3 \cdot 35 \times 10^{16}$. When experiments are performed at other temperatures, the pressures p corresponding to the same n differ, and thus in Figures 1 and 2, in order to simplify comparison with other work in this field, the electronic energy Q is represented as a function of $(Z/n) \times 3 \cdot 35 \times 10^{16}$, which reduces to Z/p at 15 °C. When this is done it is found that, over a large range of values of Z/n, Q is a function of Z/n only and independent of the thermal energies Q_0 of the gas molecules.

In Figures 1 and 2 the curves drawn show the results obtained by Crompton and Sutton (1952), while the points plotted represent the mean energy of agitation of the electrons at -190 °C in nitrogen and -192 °C in hydrogen. Measurements of electron energies made at dry ice temperatures gave essentially the same results.

Conclusions

Since as $Z \rightarrow 0$ the mean energy of agitation Q of an electron approaches Q_0, it follows that the curve of Q as a function of Z/n for a particular temperature T must cut the axis $Z/n = 0$ at a point corresponding to the thermal energy of

agitation of the gas molecules at that temperature.   When a field Z is applied the electrons acquire energy from the field and a value of Z/n is very soon reached at which Q depends only upon Z/n and is independent of the temperature T.
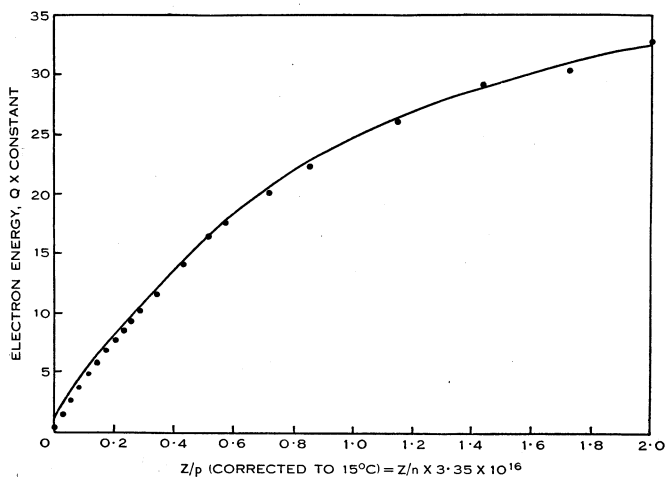

Fig. 1.—Electron energies in nitrogen.

Thus for a constant electric field and fixed molecular concentration the electron energy is independent of the energy of the gas molecules; consequently the motion of the molecules can have very little effect on the diffusion of electrons
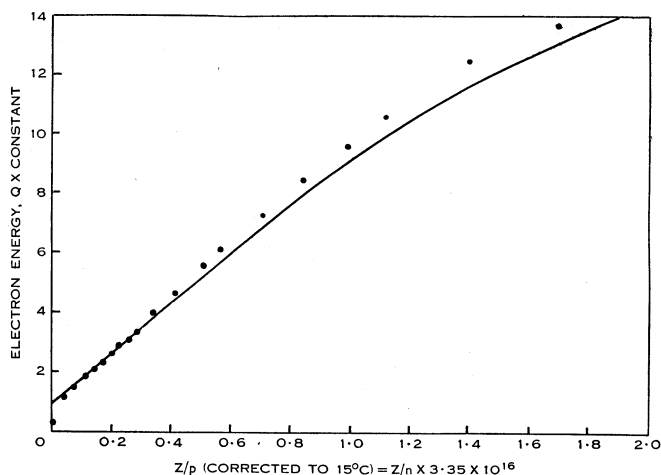

Fig. 2.—Electron energies in hydrogen.

through the gas, and to a first approximation they may be considered to be at rest.

In hydrogen the two sets of results begin to diverge slightly for larger values of Z/n, but it is impossible to say whether or not this is of significance.

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