THE DIFFUSION OF SLOW ELECTRONS IN DEUTERIUM

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Summary

The agitational energies and drift velocities of slow electrons diffusing in deuterium are measured as a function of the ratio Z/p of the electric field strength Z to the gas pressure p. The lateral spread of the diffusing electron stream is measured, which enables Townsend's energy coefficient to be calculated. Drift velocities are measured using a magnetic deflection method. On the basis of the kinetic theory of gases these measurements are used to calculate values for the mean free path L of the electrons at unit pressure, the mean proportion η of the energy lost by an electron in a collision with a deuterium molecule, and the collisional cross section A of the molecules in collisions with the electrons. The values obtained are compared with those of Crompton and Sutton (1952) for hydrogen.

I. Introduction

Measurements have been made by Crompton and Sutton (1952) of Townsend's energy coefficient k_T in hydrogen as a function of the ratio Z/p, where p is the pressure of the gas in which the electrons are drifting under the action of the constant and uniform electric field Z. Nielsen and Bradbury (1936), using an electrical shutter method, have measured the drift velocity W of slow electrons in hydrogen. If k_T and W are known it is possible to derive, on the basis of the kinetic theory of gases, formulae which enable calculations to be made of the mean free path L of the electrons at unit pressure, the mean proportion η of the energy lost by an electron in a collision with a gas molecule, and the collisional cross section A of the molecules for collisions with the electrons. It was thought that it would be of interest to have available experimental measurements of these quantities in deuterium. In both hydrogen and deuterium the measurements were made at 15 °C.

The electron temperatures were measured by the method described by Crompton and Sutton (1952), and the drift velocities by use of the deflection of the electron stream by a transverse magnetic field. The magnetic deflection method has the disadvantage that it does not enable an absolute determination of W to be made, the value obtained depending on the manner in which the agitational speeds of the electrons are distributed about their mean value. Two possible distributions are considered, that of Maxwell and that of Druyvesteyn.

In hydrogen, where measurements of drift velocities have been made both by the electrical shutter method and by the magnetic deflection method, by comparison of the two sets of results it is possible to say that Druyvesteyn's

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distribution is that which is appropriate over a large range of values of Z/p. No previous measurements are known to have been made of drift velocities in deuterium, but it may be assumed that, for values of Z/p greater than $0 \cdot 5$, the value of W corresponding to the distribution of Druyvesteyn is more nearly correct.

II. Apparatus

The diffusion apparatus used was the same as that described by Crompton and Sutton (1952). The deuterium was prepared by the method described by de Troyer, van Itterbeek, and van den Berg (1950). Heavy water was dropped slowly on to molten sodium in an evacuated vessel with the resultant evolution of deuterium. The heavy water used was stated to be $99 \cdot 75$ per cent. pure, and the deuterium evolved was left standing over liquid air for several hours before use in order to ensure the complete removal of all traces of heavy water vapour. In order to check the purity of the gas produced by this method, a sample of normal hydrogen was made using H_2O instead of D_2O. Values of k_1 were measured in the gas so obtained and compared with those measured when hydrogen was admitted through the walls of a heated palladium tube. Since the values were found to be identical, it was considered that the purity of the deuterium was adequate for experiments of this kind.

III. Results

A summary of the results for deuterium is given in Tables 1 and 2. The various physical quantities tabulated were calculated using the following formulae (Huxley and Zaazou 1949 ; Crompton and Sutton 1952) :

Townsend's energy coefficient $k_T = k_1$ (Maxwell)

$= 0 \cdot 875 k_1$ (Druyvesteyn)

Mean velocity of agitation of an electron $\overline{U} = 1 \cdot 06 \times 10^7 (k_1)^{\frac{1}{2}}$ cm sec^{-1} (Maxwell)

$= 1 \cdot 02 \times 10^7 (k_1)^{\frac{1}{2}}$ cm sec^{-1} (Druyvesteyn)

Mean free path at unit pressure $L = 7 \cdot 11 \times 10^{-9}\, W (k_1)^{\frac{1}{2}}/(Z/p)$ cm (Maxwell)

$= 7 \cdot 38 \times 10^{-9}\, W (k_1)^{\frac{1}{2}}/(Z/p)$ cm (Druyvesteyn)

Mean proportion of energy lost by an electron in a collision

$\eta = 1 \cdot 79 \times 10^{-14}\, W^2/k_1$ (Maxwell)

$= 2 \cdot 21 \times 10^{-14}\, W^2/k_1$ (Druyvesteyn)

Cross section of gas molecules for collision $A = \dfrac{1}{n_1 L}$, where

$$n_1 = \text{number of molecules/cm}^3 \text{ when } p = 1 \text{ mm}$$
$$= 3 \cdot 35 \times 10^{16} \text{ at } 15 \text{ °C.}$$

$$\frac{W}{K} = \frac{\text{Drift velocity}}{\text{Diffusion coefficient}} = 40 \cdot 3\ Z/k_1.$$

TABLE 1

SUMMARY OF RESULTS FOR DEUTERIUM AT 15 °C ASSUMING MAXWELL'S DISTRIBUTION

Z/p	$W_M \times 10^{-5}$	$k_1 = k_{TM}$	$L_M \times 10^2$	$\bar{U}_M \times 10^{-7}$	$\eta_M \times 10^4$	$(\eta k_T)_M \times 10^3$	$A_M \times 10^{16}$	W/K ($p=1$ mm)
0·1	2·8	2·1 (7)	2·93	1·56	6·46	1·40	10·2	1·86
0·2	4·0	3·3 (6)	2·58	1·94	8·53	2·86	11·5	2·40
0·3	4·7	4·5 (3)	2·37	2·25	8·76	3·96	12·6	2·66
0·4	5·4	5·7 (5)	2·31	2·54	9·07	5·22	12·9	2·80
0·5	5·8	6·7 (9)	2·14	2·76	8·90	6·04	13·9	2·97
0·6	6·1	7·7 (0)	2·02	2·94	8·66	6·67	14·8	3·14
0·7	6·6	8·6 (4)	1·99	3·12	9·04	7·81	15·0	3·27
0·8	7·0	9·5 (0)	1·93	3·26	9·24	8·77	15·5	3·39
0·9	7·5	10·3	1·90	3·39	9·76	10·0	15·7	3·52
1·0	7·9	11·0	1·85	3·52	10·2	11·2	16·1	3·67
1·2	8·6	12·5	1·81	3·75	10·6	13·3	16·5	3·88
1·5	9·5	14·4	1·72	4·03	11·2	16·1	17·3	4·18
1·8	10·6	16·3	1·69	4·28	12·3	20·0	17·7	4·46
2·0	10·9	17·5	1·63	4·44	12·3	21·6	18·3	4·61
3·0	14·1	23·0	1·60	5·07	15·5	35·6	18·7	5·25
4·0	16·2	27·7	1·53	5·56	16·9	45·5	19·5	5·83
5·0	18·5	32·2	1·51	6·00	19·0	61·2	19·8	6·26
10·0		56·4						

TABLE 2

SUMMARY OF RESULTS FOR DEUTERIUM AT 15 °C ASSUMING DRUYVESTEYN'S DISTRIBUTION

Z/p	$W_D \times 10^{-5}$	k_{TD}	$L_D \times 10^2$	$\bar{U}_D \times 10^{-7}$	$\eta_D \times 10^4$	$(\eta k_T)_D \times 10^3$	$A_D \times 10^{16}$
0·1	3·1	1·90	3·36	1·50	9·82	1·86	8·89
0·2	4·4	2·94	2·96	1·87	12·9	3·79	10·1
0·3	5·2	3·97	2·72	2·16	13·2	5·24	11·0
0·4	6·0	5·04	2·65	2·45	13·8	6·96	11·3
0·5	6·4	5·95	2·46	2·66	13·4	7·97	12·2
0·6	6·8	6·75	2·32	2·83	13·2	8·91	12·9
0·7	7·4	7·56	2·29	3·00	13·8	10·4	13·0
0·8	7·8	8·32	2·22	3·14	14·2	11·8	13·5
0·9	8·3	9·02	2·18	3·26	14·8	13·3	13·7
1·0	8·8	9·64	2·15	3·38	15·5	15·0	13·9
1·2	9·5	10·9	2·07	3·61	16·1	17·6	14·4
1·5	10·5	12·6	1·97	3·88	16·9	21·3	15·2
1·8	11·7	14·3	1·94	4·13	18·6	26·6	15·4
2·0	12·1	15·3	1·87	4·27	18·6	28·5	15·9
3·0	15·6	20·2	1·84	4·88	23·4	47·4	16·2
4·0	17·9	24·3	1·76	5·37	25·6	62·2	16·9
5·0	20·5	28·2	1·73	5·77	28·8	81·3	17·2
10·0		49·4					

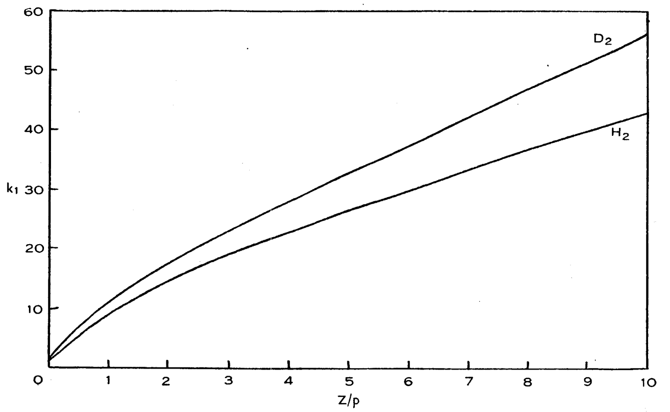

Fig. 1.—Values of k_1 in deuterium compared with those in hydrogen.

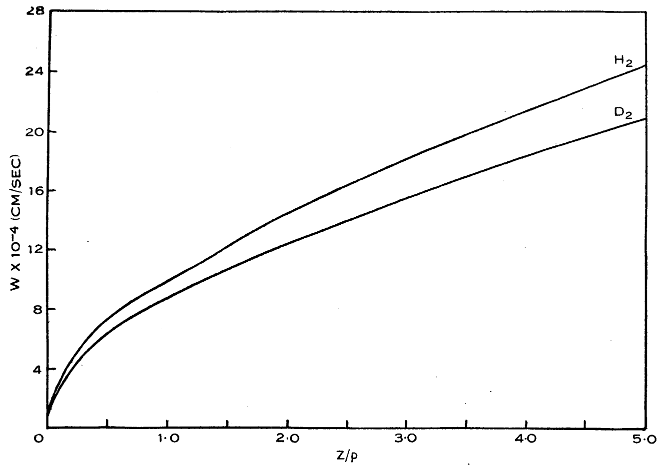

Fig. 2.—Values of W_D in deuterium compared with the values of W obtained by Nielsen and Bradbury in hydrogen.

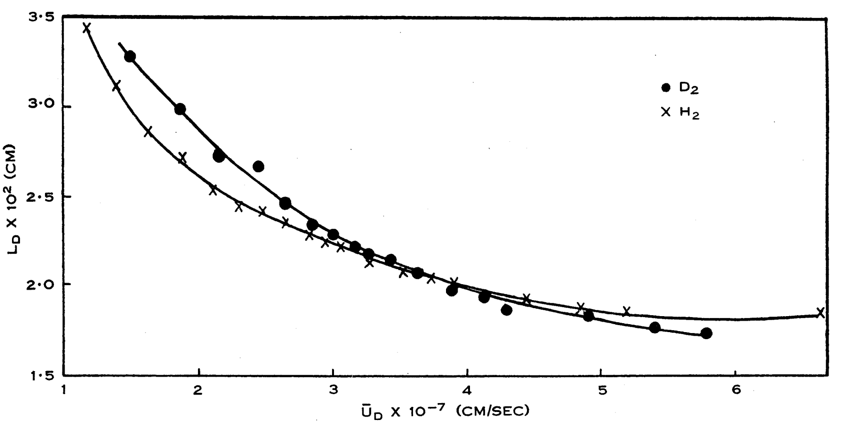

Fig. 3.—Mean free paths.

The results are shown also in the form of graphs (Figs. 1–5), together with the results of Crompton and Sutton for hydrogen, in order to facilitate comparison between the values for the two gases.

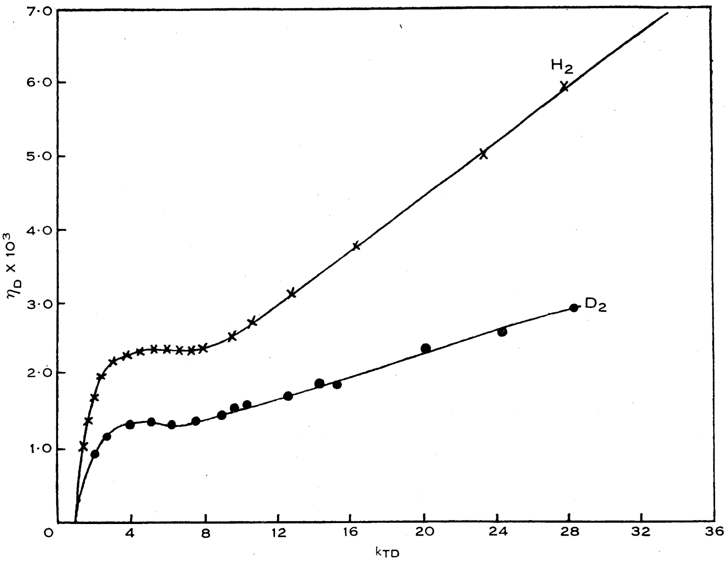

Fig. 4.—The mean proportion η of energy lost by an electron in a collision.

It can be seen that the mean free paths and hence the cross-sectional areas of the molecules of deuterium and hydrogen are almost identical for the same value of $\overline{U}$, which indicates that, as one would expect, these quantities are determined by the outer electronic structure of the molecule and by the nuclear

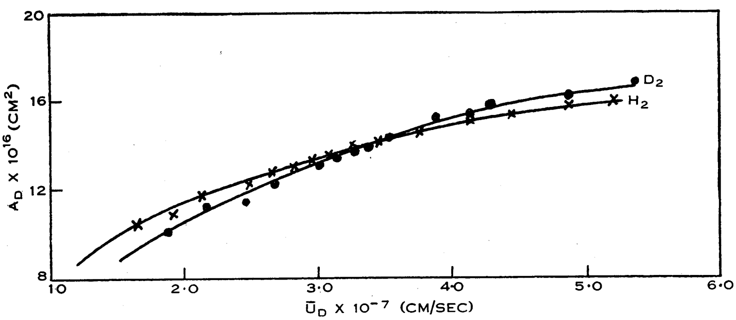

Fig. 5.—The collisional cross section A of deuterium molecules.

charges rather than by the masses of the individual nuclei. The mean proportion of the energy lost per collision is less for electrons in deuterium than for those in hydrogen.

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