SHORT COMMUNICATION

ELECTRON DRIFT VELOCITIES IN AIR

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Abstract

The drift velocities of electrons have been measured in dry, carbon dioxide free, air at 293 K over the range $0\cdot 3 \leqslant E/N \leqslant 12$ Td for gas pressures between 10 and 50 torr. The results are compared with the data of Nielsen and Bradbury (1937) and Hessenauer (1967).

In spite of the interest of upper atmosphere physicists and others in the transport properties of electrons in air, and more particularly in their behaviour at low energies, there have been only two published measurements of electron drift velocities at low energies, those of Nielsen and Bradbury (1937) and Hessenauer (1967). Hake and Phelps (1967) compared the transport coefficients of electrons in air measured by Townsend and Tizard (1913), Nielsen and Bradbury (1937), Riemann (1944), Crompton *et al.* (1953), and Rees and Jory (1964) with coefficients deduced from the cross sections that they had shown to be compatible with measured transport coefficients for pure oxygen and nitrogen. They found the agreement for air to be significantly poorer than in the case of either oxygen or nitrogen on its own and concluded that a possible explanation was that the experimental data used in their analyses for one or more of the gases were in error. Their calculations were extended by Engelhardt (1966) in a study of time-dependent transport coefficients for electrons in dry air. Since Engelhardt's interest was primarily in the propagation of electromagnetic waves through air, he paid particular attention to the complex electronic conductivity of the gas. The cross sections adopted were generally those of Engelhardt *et al.* (1964) for nitrogen and of Hake and Phelps for oxygen, which, as already mentioned, are in conflict in some respects with experimental data for air. It is of interest therefore to re-examine transport data for both air and oxygen.

The drift tube and associated equipment used in the present investigation have been described previously by Crompton *et al.* (1968, 1970), and a general discussion of the experimental techniques and of the accuracy of the measurements has been given by Elford (1971). The gas samples used were dried and freed from carbon dioxide by storage, at reduced pressure, in a trap containing copper foil and cooled by liquid nitrogen for some hours before the gas was admitted to the drift tube. The gas pressures used were limited to 50 torr or less since at higher pressures it was difficult to detect the electron current above that of negative ions formed by electron attachment

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to the oxygen. The lower pressure limit of 10 torr was set primarily by the decreased ionization efficiency of the americium 241 source used to produce electrons in the tube (Crompton and McIntosh 1968).

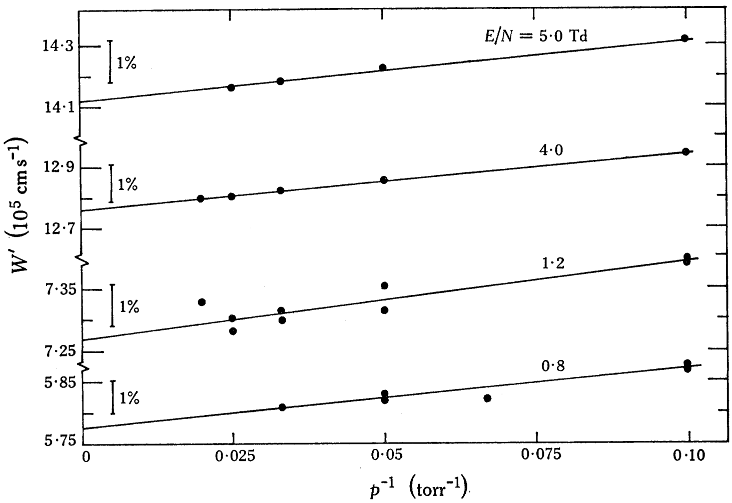

Fig. 1.—Typical variations of the experimental drift velocity W' with p^{-1} for electrons in air.

At the low pressures used in the investigation the experimental values of the drift velocity W' were significantly affected by diffusion effects. These effects have been considered by Lowke (1962), Huxley and Crompton (1973), and D. S. Burch (personal communication) but it is still difficult to calculate theoretically the magnitude of the diffusion effects for a given experimental situation. The correction to be

TABLE 1

ELECTRON DRIFT VELOCITIES IN DRY, CARBON DIOXIDE FREE, AIR AT 293 K

E/N (Td)	W (10^6 cm s^{-1})	E/N (Td)	W (10^6 cm s^{-1})
12·0	2·37(9)	2·0	0·952
10·0	2·10(3)	1·5	0·821
7·5	1·75(7)	1·2	0·729
6·0	1·55(0)	1·0	0·658
5·0	1·41(1)	0·8	0·578
4·0	1·27(6)	0·6	0·491
3·5	1·20(7)	0·5	0·450
3·0	1·13(6)	0·4	0·400
2·5	1·05(2)	0·3	(0·36)

applied to W' is generally small ($\sim 0\cdot2\%$) when gas pressures $\gtrsim 100$ torr are used, but at the low pressures employed in the present work correspondingly larger diffusion effects were observed. The analyses by the above authors have shown that W' is related to the true drift velocity W through an expression of the form

$$W' = W\left(1+\frac{C(D_L/\mu)}{V}\right), \tag{1}$$

where D_L is an apparent or equivalent diffusion coefficient in the direction of the electric field, $\mu = W/E$ is the mobility, and V is the total d.c. voltage applied between the two electrical shutters of the drift tube. It is difficult to calculate theoretically the coefficient C and at present it is preferable to treat C as unknown. This does not preclude the determination of W since equation (1) can be written as

$$W' = W\left(1+\frac{C(D_L/\mu)}{(E/N)Nh}\right) \quad \text{or} \quad W' = W\left(1+\frac{C(D_L/\mu)}{(E/p)ph}\right), \tag{2}$$

where p is the gas pressure and h is the distance between the electrical shutters (10·00 cm in the present work). Hence, a plot of W' against p^{-1} allows W to be determined

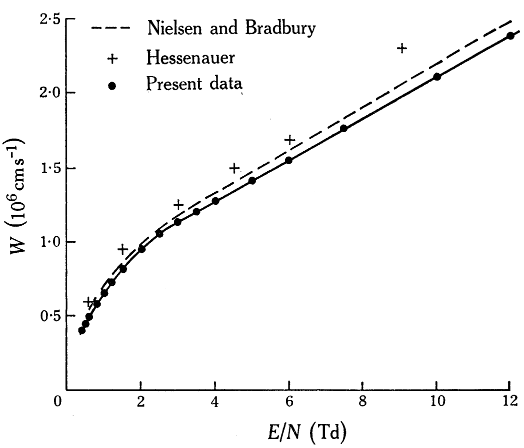

Fig. 2.—Comparison of the present data for the true drift velocity W against E/N with the data of Nielsen and Bradbury (1937) and Hessenauer (1967).

from the intercept at $p^{-1} = 0$. Figure 1 shows the experimental data for $E/N = 0{\cdot}8$, 1·2, 4·0, and 5·0 Td* plotted in this way; the plots for $E/N = 0{\cdot}8$ and 1·2 Td show the worst scatter obtained from measurements taken at four and five gas pressures respectively while the other two plots are the corresponding ones showing least scatter. It can be seen that the variation in W' over the range of pressures studied was less than 2%, the values of W' for $p \geqslant 20$ torr being already within 1% of the extrapolated value which was taken to be the true drift velocity W.

The values of W obtained in this way are summarized in Table 1. For $0{\cdot}6 \leqslant E/N \leqslant 7{\cdot}5$ Td the values of W are subject to an error due to the extrapolation procedure which is estimated to be less than $\pm 0{\cdot}5$%, while for $E/N = 0{\cdot}4$, 0·5, 10, and 12 Td the error from this source could be as large as ± 1%. To this error should be added systematic errors of up to 0·6% incurred in the measurements of gas pressure (0·1%), temperature (0·1%), potential difference between the shutters

* 1 townsend (Td) = 10^{-17} V cm^2.

(0·05%), and drift distance (0·3%) (see Elford 1971). The first group of measurements is therefore subject to an overall error slightly in excess of $\pm 1\%$, while the error limit for the second group is $\pm 2\%$. The value of W given in the table for $E/N = 0\cdot 3$ Td was a single reading at $p = 15$ torr and should be treated as an estimate only.

The present data are compared in Figure 2 with previously published data for the same range of E/N. It can be seen that the present results lie up to 5% below those of Nielsen and Bradbury (1937) and from 10% to 16% below those of Hessenauer (1967), who states an error of $\pm 8\%$ for values of $E/N > 3$ Td. The difference between the present data and those of Hessenauer is therefore significant. In the case of Nielsen and Bradbury, the discrepancy is rather larger than that found when comparing their data for other diatomic gases with reliable recent data (e.g. Lowke 1963), and it is suggested that the discrepancy arises from the neglect of diffusion effects similar to those observed in the present work. The electrical shutters in Nielsen and Bradbury's drift tube were 6 cm apart instead of the present 10 cm so that the effects would have been approximately twice as large for given E/N and p conditions. However, the range of pressures used for air is not specifically given in their paper (the range for air, oxygen, nitrous oxide, and ammonia is given as between 2 and 10 torr) but was probably limited to $\lesssim 10$ torr for the same reasons as in the present work. Under these conditions their measured values of W could well have been 4% to 5% too high, the variation with pressure being say $\pm 2\%$ over the range studied.

Comparison of the present values of W with those calculated from analyses of swarm data for oxygen and nitrogen (see e.g. Hake and Phelps 1967) has not been attempted here. Although the necessary data for nitrogen are largely available, the situation for oxygen is somewhat less satisfactory. Drift velocity data for low values of E/N have recently been reported by Nelson and Davis (1972) but the corresponding values of D_T/μ (where D_T is the transverse diffusion coefficient) are not yet well established. The data of Rees (1965) are likely to be too low by $\sim 5\%$ because of the effects of anisotropic diffusion on the analysis of the experimental data (Lowke 1971; Huxley 1972).

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