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Electron Drift Velocities in Air

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Abstract

The drift velocities of electrons in dry CO_2-free air at 293 K have been measured over the range $0 \cdot 1 \leqslant E/N \leqslant 1$ Td for gas pressures between $0 \cdot 4$ and $1 \cdot 3$ kPa.

Introduction

In spite of the obvious importance of the transport properties of electrons in air for atmospheric physics, a relatively small amount of experimental data is available, particularly at low electron energies. The formation of O_2^- by the associative electron attachment process at low electron energies rapidly depletes the electron population and makes it increasingly difficult to measure electron drift velocities and diffusion coefficients by conventional techniques as the value of E/N (the ratio of the electric field strength to the number density) is reduced. The most recent measurement of the drift velocity v_{dr} for electrons in dry CO_2-free air (Rees 1973) extends down to $0 \cdot 4$ Td ($1 \text{ Td} \equiv 10^{-17}\ \text{V cm}^2$), with an estimate of v_{dr} at $0 \cdot 3$ Td. Milloy *et al.* (1975) measured v_{dr} for electrons in moist air and obtained an estimate for the zero-field mobility $N\mu_0$ ($\equiv \lim_{E\to 0} (v_{dr}/E)$) in dry air by adding small amounts of CO_2 ($\leqslant 5\%$).

Experimental Procedure

The present measurements were carried out using the drift tube described in the previous paper by Reid and Crompton (1980, present issue pp. 215–26) in which the electron density in the drift tube is sampled by applying a pulsed RF field in the detection region and measuring the resultant light output from the electron-initiated local discharges. The experimental equipment and techniques are described in detail by Reid and Crompton, the only difference being that in the present series of measurements the electron source was operated in a continuous mode, and only the Bradbury–Nielsen shutter was gated. The gas used was Matheson 'Ultra Zero Air', having a stated impurity level of less than 1 p.p.m. hydrocarbons and $0 \cdot 5$ p.p.m. CO_2. As in the oxygen measurements by Reid and Crompton, it was found necessary to flow the gas through the drift tube. The rate of flow was adjusted to change the gas in the tube once every 20–30 min. The temperature of the gas was assumed to be equal to the manifold temperature. The measurements were carried out at four different gas pressures. The upper limit to the pressure was set by the loss of electrons in the three-body attachment process.

The mean arrival times of the electron swarms were determined at two drift distances (30 and 50 cm) and the drift velocities were obtained by differencing. This procedure eliminates to the first order all errors due to end effects and diffusion. However, the effects of attachment on the drift velocity are not removed. Pack and Phelps (1966) give the following expression for the true drift velocity v_{dr} corrected for attachment:

$$v_{dr} \approx v'_{dr}\left(1-\frac{2D_{\|}/\mu}{E}\frac{\nu_a}{v_{dr}}\right) = v'_{dr}\left(1-\frac{2D_{\|}/\mu}{E/N}\frac{\nu_a}{N^2}\frac{N}{v_{dr}}\right), \qquad (1)$$

where v'_{dr} is the observed drift velocity, $D_{\|}$ the longitudinal diffusion coefficient, μ the mobility and ν_a the attachment frequency. In applying this correction, ν_a/N^2 was estimated from the graph (Fig. 12) of Goans and Christophorou (1974) and the values of the attachment coefficient (ν_a/v_{dr}) measured by Hessenauer (1967). The value of $D_{\|}/\mu$ was estimated from the measurements of $D_{\perp}/\mu$ by Rees and Jory (1964) for $E/N \geqslant 0{\cdot}7$ Td, assuming $D_{\|}/D_{\perp} = \frac{1}{2}$. This correction was less than 1% for $E/N \geqslant 0{\cdot}2$ Td, increasing to 1·6% at $E/N = 0{\cdot}1$ Td for a pressure $p = 1{\cdot}34$ kPa.

Table 1. Drift velocities of electrons in dry CO_2-free air at $T = 293$ K

E/N (Td)	v_{dr} (10^5 cm s^{-1}) at a pressure of $p = 0{\cdot}4133$	0·7231	1·033	1·343 kPa	Best estimate
1·00	6·395	6·349	6·324	6·325	6·35
0·80	5·649	5·593	5·644	5·631	5·63
0·60		4·792	4·738	4·767	4·77
0·50	4·338	4·346	4·358	4·318	4·34
0·40	3·865	3·879	3·880	3·868	3·87
0·35		3·663	3·663	3·643	3·66
0·30		3·466	3·468	3·442	3·46
0·25		3·278	3·228	3·270	3·26
0·20			3·037	3·074	3·06
0·17			2·857	2·933	2·90
0·14			2·888	2·811	2·85
0·12			2·759	2·663	2·71
0·10			2·529	2·561	2·55

Results

The values of the corrected drift velocities obtained in the above way are summarized in Table 1. The maximum scatter in the present results is less than ±1% for $E/N > 0{\cdot}2$ Td and ±2% for $E/N \leqslant 0{\cdot}2$ Td for all values of the pressure used. The main contributions to the systematic errors arise from the measurements of pressure, voltage, temperature and drift distance. The total error from these sources is estimated to be less than 1%. The attachment correction is assumed to be in error by less than a factor of 2. It is therefore considered that the present best estimates of v_{dr} are in error by less than ±3% for $E/N > 0{\cdot}2$ Td, increasing to ±5% at $E/N = 0{\cdot}1$ Td.

The present results are compared in Fig. 1 with previously published data for the same range of E/N. The data of Rees (1973) are, in general, 3–4% higher than the present best estimates. Rees quotes an error of ±1% for $E/N > 0{\cdot}6$ Td, while for $E/N = 0{\cdot}4$ and 0·5 Td the error is estimated to be ±2%. Thus, the present results agree with those of Rees to within the combined error limits. Furthermore, Rees's data are not corrected for attachment. Application of the formula (1) above to his data at 0·8 Td (Fig. 1 of Rees 1973) gives a 0·8% reduction of the drift velocity, thus improving the agreement between the two sets of data.

The results of Nielsen and Bradbury (1937) are up to 10% larger than the present results. Rees (1973) points out that their data could well be 4–5% too high, owing to their neglect of diffusion errors, which would make Nielsen and Bradbury's data agree with the present set to within the combined error limits.

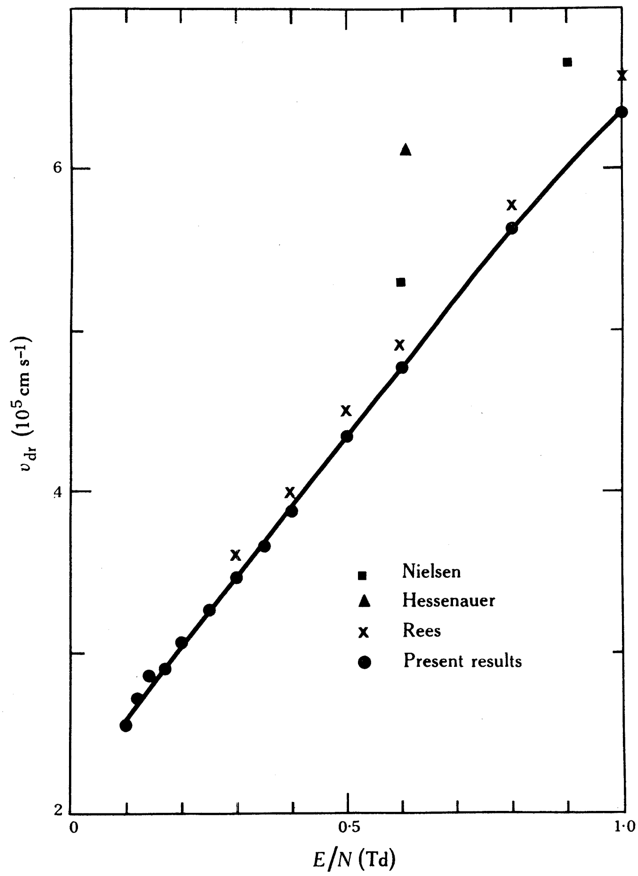

Fig. 1. Comparison of the present results for the drift velocity of electrons in dry CO_2-free air measured between *E*/*N* values of 0·1 and 1 Td with previous data from Nielsen and Bradbury (1937), Hessenauer (1967) and Rees (1973).

The value of v_{dr} at 0·6 Td given by Hessenauer (1967) is 20% greater than ours, and the difference is significantly larger than the combined errors.

The observed drift velocity was found to be very sensitive to the presence of a condensable impurity in the gas, presumably H_2O, which caused the measured drift velocity to increase. The water vapour is thought to be produced by a surface reaction between oxygen and hydrogen molecules outgassing from the stainless steel envelope. This high sensitivity of v_{dr} to water vapour and other molecular impurities must be taken into account when applying the present data. As demonstrated by the measurements of Milloy *et al.* (1975), the true drift velocity in atmospheric air may be either higher or lower than the values in dry CO_2-free air, depending upon the concentration of H_2O or CO_2 and the value of E/N.

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References

Goans, R. E., and Christophorou, L. G. (1974). *J. Chem. Phys.* **60**, 1036.
Hessenauer, H. (1967). *Z. Phys.* **204**, 142.
Milloy, H. B., Reid, I. D., and Crompton, R. W. (1975). *Aust. J. Phys.* **28**, 231.
Nielsen, R. A., and Bradbury, N. E. (1937). *Phys. Rev.* **51**, 69.
Pack, J. L., and Phelps, A. V. (1966). *J. Chem. Phys.* **44**, 1870.
Rees, J. A. (1973). *Aust. J. Phys.* **26**, 427.
Rees, J. A., and Jory, R. L. (1964). *Aust. J. Phys.* **17**, 307.
Reid, I. D., and Crompton, R. W. (1980). *Aust. J. Phys.* **33**, 215.

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