

Zero-field Mobility for Electrons in Dry and Humid Air

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Abstract

The zero-field mobility of electrons in dry and humid air at 294 K has been studied with drift tube techniques. For air containing 1.5% water vapour (50% relative humidity) the zero-field mobility was found to be $8.4 \pm 0.2 \times 10^5 \text{ cm s}^{-1} \text{ Td}^{-1}$. The zero-field mobility of electrons in dry air ($4.7 \pm 0.2 \times 10^6 \text{ cm s}^{-1} \text{ Td}^{-1}$) was deduced from measurements in which small quantities of CO_2 were added to reduce the electron energy. It is estimated that the momentum transfer cross section for electron-oxygen collisions, at near thermal energies, is at least four times smaller than it is for electron-nitrogen collisions.

Measurements of the transport properties of low energy electrons in air are hampered by the rapid formation of negative oxygen ions by nondissociative attachment. The attachment coefficient for this process is a decreasing function of E/N (Grünberg 1969), where E is the electric field strength and N is the gas number density, and for this reason all previous transport coefficient measurements in both pure oxygen and air have been limited to relatively large E/N values (Crompton and Elford 1973; Rees 1973). Since knowledge of the motion of electrons in dry and humid air is of obvious practical importance, the work reported here was carried out to obtain more reliable data at low energies. In the case of humid air, which has not previously been investigated, the zero-field mobility was established from measurements at relatively high E/N values because inelastic collisions with water molecules had a large thermalizing effect on the electrons. The technique used to investigate the motion of electrons in dry air was similar in principle. Small quantities of a gas with a large total inelastic cross section and an accurately known elastic cross section were added to the air to reduce the mean electron energy at a given E/N . In this way the motion of low energy electrons could be studied from measurements at relatively high E/N values. The disadvantage of this technique is that all gases with suitably large inelastic cross sections also have large elastic cross sections, with the result that the addition of small quantities of gas can dramatically decrease the zero-field mobility and reduce the sensitivity of the results to changes in the cross sections for the major constituents of air. This reduction of the zero-field mobility also causes an increase in the attachment coefficient and a corresponding decrease in the available E/N range, but this was not a major disadvantage.

The Bradbury-Nielsen time of flight method was used to measure the electron drift velocities. The experimental tube was that used by Crompton *et al.* (1970), the only modification being the use of an electron source of the type described by Crompton and Elford (1973; see also Elford and Milloy 1974). The experimental

technique has been fully described by Huxley and Crompton (1974). The air used was dried and the CO_2 initially present in the sample was removed by storage in a trap cooled by liquid oxygen.

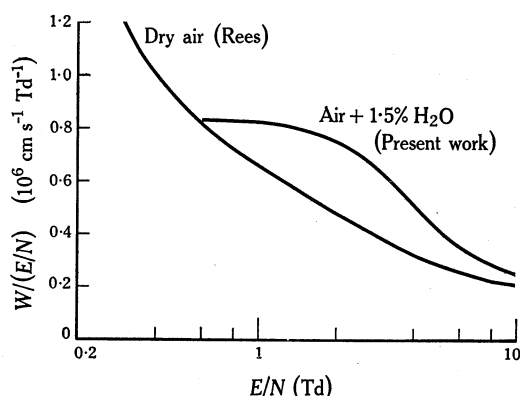


Fig. 1. Mobility $W/(E/N)$ of electrons in air at 294 K as a function of E/N . The results of Rees (1973) for dry CO_2 -free air are compared with the results of the present work for CO_2 -free air containing 1.5% water vapour.

The mobility, $K = W/(E/N)$, of electrons in a sample of air containing 1.5% water vapour (approximately 50% relative humidity) is plotted as a function of E/N in Fig. 1. It was deduced from preliminary measurements of the ratio D/K (where D is the lateral diffusion coefficient) that at the lower end of the E/N scale in Fig. 1 the electrons are approximately in thermal equilibrium with the gas molecules. This is in direct contrast to the results for dry CO_2 -free air (Rees 1973; also shown in Fig. 1) which emphasize the difficulty of studying the motion of near-thermal electrons in air. The mobility of electrons in various air-water mixtures over the E/N range 0.7–2.0 Td is given in Table 1.

Table 1. Mobility of electrons in moist air at 294 K

H_2O (%)	Mobility $W/(E/N)$ ($10^5 \text{ cm s}^{-1} \text{ Td}^{-1}$)				
	$E/N = 0.7$	0.8	1.0	1.5	2.0 Td
0.30	14.3	13.4	11.7	8.60	6.75
0.45	13.7	13.2	11.9	9.01	7.13
0.60	13.1	12.7	11.7	9.32	7.50
0.75	12.0	11.8	11.2	9.41	7.80
0.90	11.1	10.9	10.5	9.29	8.00
1.0	10.5	10.4	10.1	9.11	8.00
1.2	9.56	9.45	9.25	8.66	7.85
1.5	8.40	8.43	8.27	7.83	7.45

It is evident from the data in Fig. 1 and Table 1 that the addition of small quantities of water vapour has a dramatic effect on the zero-field mobility, and for this reason it was not possible to use air-water mixtures to estimate the zero-field mobility for electrons in dry air. The addition of small quantities of CO_2 to air is more favourable, since the elastic cross section is considerably smaller than that for water and yet the inelastic collisions greatly reduce the electron energy. The quantity of CO_2 added to the air is, however, still a compromise between adequate thermalization of the electrons and loss of sensitivity due to the large CO_2 elastic cross section.

The best compromise was obtained by adding to the air about 5% CO₂. The results for two mixtures (A and B) in this regime are plotted in Fig. 2. It can be seen that at the lower end of the E/N range the mobility in the 5% mixture (B) is approaching a constant value. The zero-field mobility was estimated in each case by assuming that the form of the mobility versus E/N curve was, at low E/N values, the same for an air-CO₂ as for a N₂-CO₂ mixture, the curves for which are also plotted in Fig. 2 (C and D). The justification for this procedure is that, in the region of overlap and below, the electron temperature in both the air-CO₂ and N₂-CO₂ mixtures does not greatly exceed the gas temperature and therefore cannot be greatly different for the two mixtures at a given value of E/N . The difference between the two mobility curves is thus due primarily to the difference between the effective momentum transfer cross sections and not to the difference between the energy distribution functions at a given E/N , and the curves are therefore expected to be parallel to first order. Additional justification for this procedure is afforded by the self-consistency of the data obtained from the analysis described below. The zero-field mobilities estimated in this way were $2.19 \times 10^6 \text{ cm s}^{-1} \text{ Td}^{-1}$ for electrons in a CO₂(3.2%)-air mixture and $1.81 \times 10^6 \text{ cm s}^{-1} \text{ Td}^{-1}$ for electrons in a CO₂(5.0%)-air mixture. Extrapolations of 29% and 23% were involved.

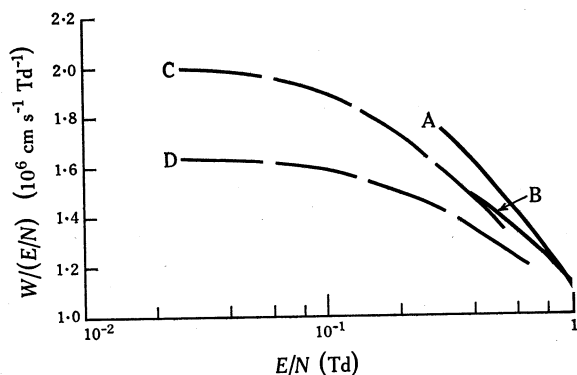


Fig. 2. Mobility $W/(E/N)$ of electrons in various mixtures of CO₂ in air and nitrogen plotted as a function of E/N :

- A, CO₂(3.2%)-air
- B, CO₂(5.0%)-air
- C, CO₂(3.2%)-N₂
- D, CO₂(5.0%)-N₂

From the data for the CO₂-air mixtures it is possible to estimate the zero-field mobility for electrons in dry air using the momentum transfer cross sections for N₂ (Engelhardt *et al.* 1964) and CO₂ (Hake and Phelps 1967) and regarding the O₂ cross section as an adjustable parameter. Although the oxygen cross section has not been accurately determined at thermal energies, the work of Hake and Phelps suggests that the assumption of energy independence is adequate for this calculation. In this way the zero-field mobility of electrons in dry air was calculated to be 4.6×10^6 and $4.8 \times 10^6 \text{ cm s}^{-1} \text{ Td}^{-1}$ from the data for the 3.2% and 5.0% mixtures respectively. The largest source of error in these determinations is probably the extrapolation of the experimental data to zero E/N but the consistency of the results obtained is, in retrospect, a good justification of the extrapolation procedure. We conclude that the zero-field mobility of electrons in dry air is $4.7 \pm 0.2 \times 10^6 \text{ cm s}^{-1} \text{ Td}^{-1}$.

It is estimated from this work that the oxygen momentum transfer cross section, at near thermal energies, is at least a factor of four smaller than the momentum transfer cross section for electrons in nitrogen. This value is approximately 40% lower than the available microwave results (Phelps 1972) but, in view of the errors

involved in both determinations, the agreement is satisfactory. No theoretical estimates of either the oxygen or nitrogen momentum transfer cross sections are available.

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