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Temperature Dependence of the Diffusion Coefficient for Thermal Electrons in Carbon Dioxide over the Range 296–468 K

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Abstract

Values of μN for thermal electrons in carbon dioxide have been derived from measurements of the diffusion coefficient over the temperature range 296-468 K. The present values of $\mu N_{\rm th}$ are in agreement with those reported by Haddad and Elford.

Introduction

Recent measurements of electron drift velocities in carbon dioxide at temperatures ranging from 193 to 573 K (Elford and Haddad 1980) have shown that the thermal value of μN (where μ is the electron mobility and N the gas number density), i.e. $\mu N_{\rm th}$, decreases with increasing temperature T. This variation is in the opposite sense to that predicted when the momentum transfer cross section $\sigma_{\rm m}$ of Bulos and Phelps (1976) is used to calculate the mobility, using the relation

$$\mu N_{\rm th} = -\left(\frac{2}{m}\right)^{\frac{1}{2}} \frac{e}{3} \int_0^\infty \frac{\varepsilon}{\sigma_{\rm m}} \frac{\mathrm{d}f_{\rm M}(\varepsilon)}{\mathrm{d}\varepsilon} \,\mathrm{d}\varepsilon\,. \tag{1}$$

Here $f_{\rm M}(\varepsilon)$ is the Maxwellian energy distribution function corresponding to the given gas temperature and e and m are the electronic charge and mass respectively.

It has been suggested by Haddad and Elford (1979) that this difference between the calculated and experimental behaviour of $\mu N_{\rm th}$ with T may be due to the contribution made to the total momentum transfer cross section by collisions with carbon dioxide molecules in the first vibrationally excited state. This explanation relies heavily on one value of $\mu N_{\rm th}$ obtained by Elford and Haddad (1980) from an extrapolation to E/N = 0 of drift velocity data taken at 573 K, although there is some additional supporting evidence from the data taken by Pack *et al.* (1962) at 413 K. It is clearly desirable to have additional experimental evidence for the variation of $\mu N_{\rm th}$ with gas temperature, preferably by an alternative experimental method.

An alternative way of obtaining $\mu N_{\rm th}$ is by measuring the diffusion coefficient for thermal electrons and calculating $\mu N_{\rm th}$ from the Einstein (or Nernst-Townsend) relation

$$\mu N_{\rm th} = N D_{\rm th} \, e/kT,\tag{2}$$

where D_{th} is the diffusion coefficient for thermal electrons and k is Boltzmann's constant. This procedure was adopted in the present work.

Experimental Details

The method used to measure the diffusion coefficient was that devised by Cavalleri (1969) and later developed by Gibson *et al.* (1973). Experimental details of the construction of the all-glass cell, the light-tight enclosure and the temperature control system will be described by Hegerberg and Crompton (1980) and will not be discussed further here.

Table 1.	Values	of	ND_{th}	and	μN_{th}	as	a	function	of	gas
			temp	erati	ire T					

Т (К)	$\frac{ND_{th}}{(10^{20}\mathrm{cm^{-1}s^{-1}})}$	$\frac{\mu N_{\rm th}{}^{\rm A}}{(10^{22}{\rm cm}^{-1}{\rm s}^{-1}{\rm V}^{-1})}$
296	$4 \cdot 51 \pm 0 \cdot 08$	1.77 ± 0.03
411	6.06 ± 0.14	$1 \cdot 71 \pm 0 \cdot 04$
468	$7 \cdot 12 \pm 0 \cdot 16$	1.765 ± 0.04

^A The values of $\mu N_{\rm th}$ were derived from $ND_{\rm th}$ using relation (2).



Fig. 1. Values of $\mu N_{\rm th}$ as a function of gas temperature *T*. The curve denoted BP was obtained using relation (1) and the momentum transfer cross section of Bulos and Phelps (1976). The points shown are: circles, Elford and Haddad (1980); triangles, Pack *et al.* (1962); squares, present work.

Special care had to be taken to ensure that significant levels of impurities were not introduced by outgassing of the cell, the associated ballast volume, tubulation, and isolation valves. These components were therefore outgassed at approximately 200°C for two weeks before measurements with carbon dioxide commenced. The carbon dioxide, of Matheson Research Grade, was further purified by freezing in a liquid nitrogen trap and pumping off the residual permanent gases. The trap was then warmed to room temperature and the process repeated a number of times. This purification procedure was found to be necessary to avoid the values of the measured time constant increasing over the initial period of the data accumulation. The impurity was shown to be introduced with the carbon dioxide gas sample and to be largely removed by the action of the RF sampling discharges. The behaviour of the time constant over the initial measurement period suggested that the change was due to electron attachment. The most likely impurity is therefore oxygen but the mechanism by which the oxygen is removed by the sampling discharge is open to speculation.

Results

The present data for ND_{th} and the derived μN_{th} values are shown in Table 1 as a function of temperature. Tests showed that there was no dependence on the gas pressure to within the experimental scatter over the range used of 0.8-2.5 kPa, indicating that the data are not affected by attachment. Diagnostic tests similar to those described by Gibson *et al.* (1973) were made to check that the results were not significantly affected by space charge effects.

The error in the ND_{th} values is considered to be <3%. The major sources of error are the uncertainty in the cell constant (0.5%) and the statistical scatter (r.m.s. error 2%).

Discussion

The present μN_{th} values are shown in Fig. 1 together with the values derived by Elford and Haddad (1980) and Pack *et al.* (1962) from their respective sets of drift velocity data. It can be seen that these three sets of data agree to within the estimated errors (assuming a $\pm 2\%$ error for the values of Pack *et al.*), thus confirming the variation of μN_{th} with T derived by Elford and Haddad.

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