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Electron Swarm Transport through Low Pressure Noble Gases

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Abstract

The electron drift velocity, the longitudinal diffusion coefficient and the electron ionisation coefficient have been measured in helium, neon, argon and krypton using the integrated voltage transient technique. Whilst the present data agree substantially with previous determinations at those values of E/N at which they overlap, the current work represents a marked extension of the range of E/N covered for W_e and ND_L in most of the gases investigated.

1. Introduction

In two recent papers Purdie and Fletcher (1989, 1992) have demonstrated that the integrated voltage transient technique can be used to not only measure electron drift velocities at high gas pressure ($p > 100$ Torr, i.e. $>13{\cdot}3$ kPa) but, as long as the experimental data are fully analysed, to measure electron diffusion and ion transport data as well. Further it was found that, in nitrogen gas, information could be obtained on some of the operative ion chemistry. Following this work on nitrogen the method has been applied to the noble gases for which there exists a dearth of transport data above very low values of E/N, due to the early occurrence of ionisation and the inability of most experimental methods and the associated data analysis to handle ionisation. (Here E is the applied electric field and N is the gas number density.)

2. Experimental Apparatus

The experimental apparatus and the data analysis used were identical to those described by Purdie and Fletcher (1989, 1992). In general, research grade gas was used (99·9995% pure). At certain values of E/N in each gas, checks on the obtained data were made using spectroscopically pure gas (quoted as containing less than 10 parts per million impurity), to ensure that the data were not influenced by impurities.

Voltage transients were obtained in helium, neon, argon and krypton over the range $1 \geq E/N \geq 100$ Td, using a pressure range of $2 \geq p_0 \geq 50$ Torr. A typical transient in neon is shown in Fig. 1. The general curve is common to all the rare gases. The most notable difference between the rare gas transients and those in nitrogen (Purdie and Fletcher 1992) is the much larger ion contribution relative to the electron voltage. It is noticeable that the top of the transient continues

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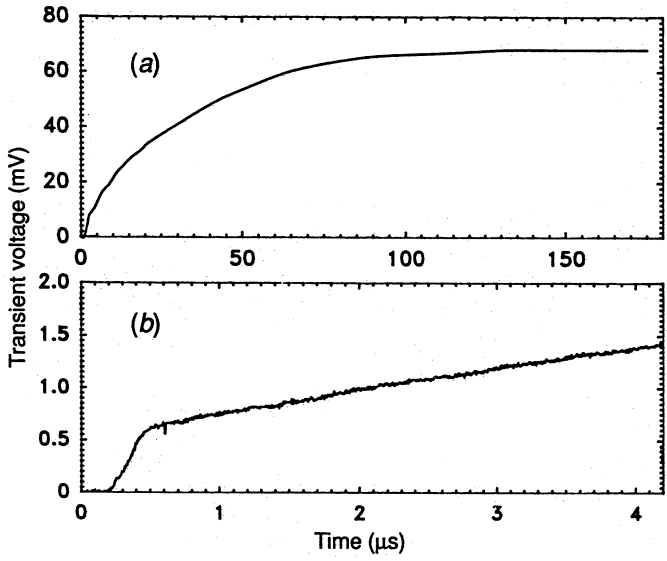

Fig. 1. A typical transient in the rare gases, shown for neon gas with $E/N = 58{\cdot}6$ Td: (*a*) 40 ns/point; (*b*) 5 ns/point.

to increase very slightly even after a first inspection of the curve indicates that saturation has been achieved. This necessitates the greatest care in ensuring that the transient is saturated well before the integration time of the electronic measuring circuit. An integration time of 10 ms was found to be sufficient for all the rare gases used in the present work. Further, display of the transient on a conventional oscilloscope could not amplify the transient sufficiently to observe the continuing rise of the voltage signal at long times. A transient digitiser had to be used. In the present work a LeCroy TR8828 module was used, incorporated in a LeCroy 1434A CAMAC crate controlled by a LeCroy model 6010 which provided continuous on-line averaging. Each transient was the average of at least 50 pulses.

3. Results

(a) Electron Drift Velocity

The electron drift velocity W_e in the noble gases has been extensively studied at low E/N. At values of E/N above about 20 Td, however, there are few published data. The present technique yields measurements of W_e with a lower experimental error than any of the other transport parameters (±2% rising to ±5% at the extremes of the E/N range). These data are presented in Fig. 2. The helium data are compared with the photon flux results of Amies *et al.* (1985) and with the measurements of Anderson (1964) who used a Hall effect technique in the positive column of a 0·05–50 mA glow discharge. To within the combined experimental error, good agreement is observed between the results from the three quite disparate methods. Anderson's results are also compared with the present data for neon. For argon the data of Herreng (1943), Caren (1963) and Brambridge (1964) are also included for comparison. Little previous experimental work has been published for neon and krypton at values of E/N

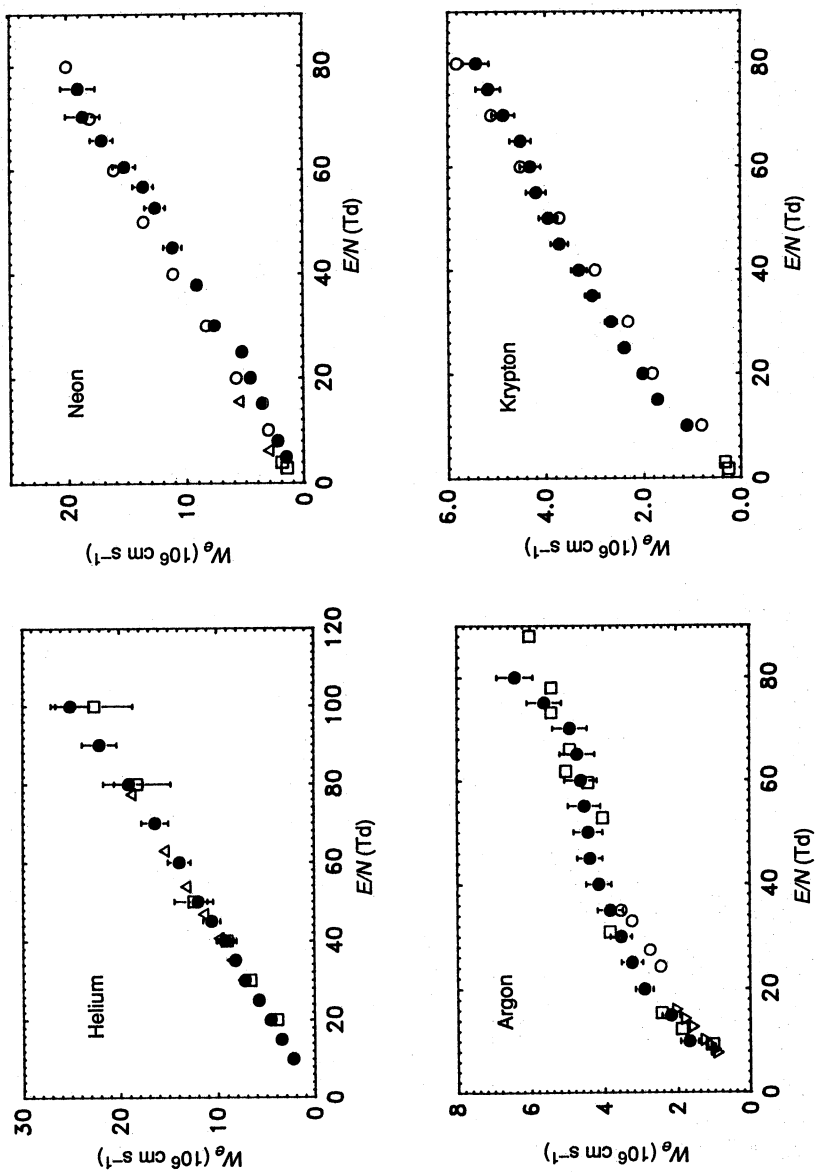

Fig. 2. Electron drift velocity W_e as a function of E/N in the rare gases. All graphs: ●—present results. Helium: □—Amies *et al.* (1985), △—Anderson (1964). Neon: □—Nielson (1936), △—Anderson (1964), ○—Sakai *et al.* (1991). Argon: □—Brambridge (1964), ○—Caren (1963), ▽—Herring (1943). Krypton: □—Pack *et al.* (1962), ○—Sakai *et al.* (1991).

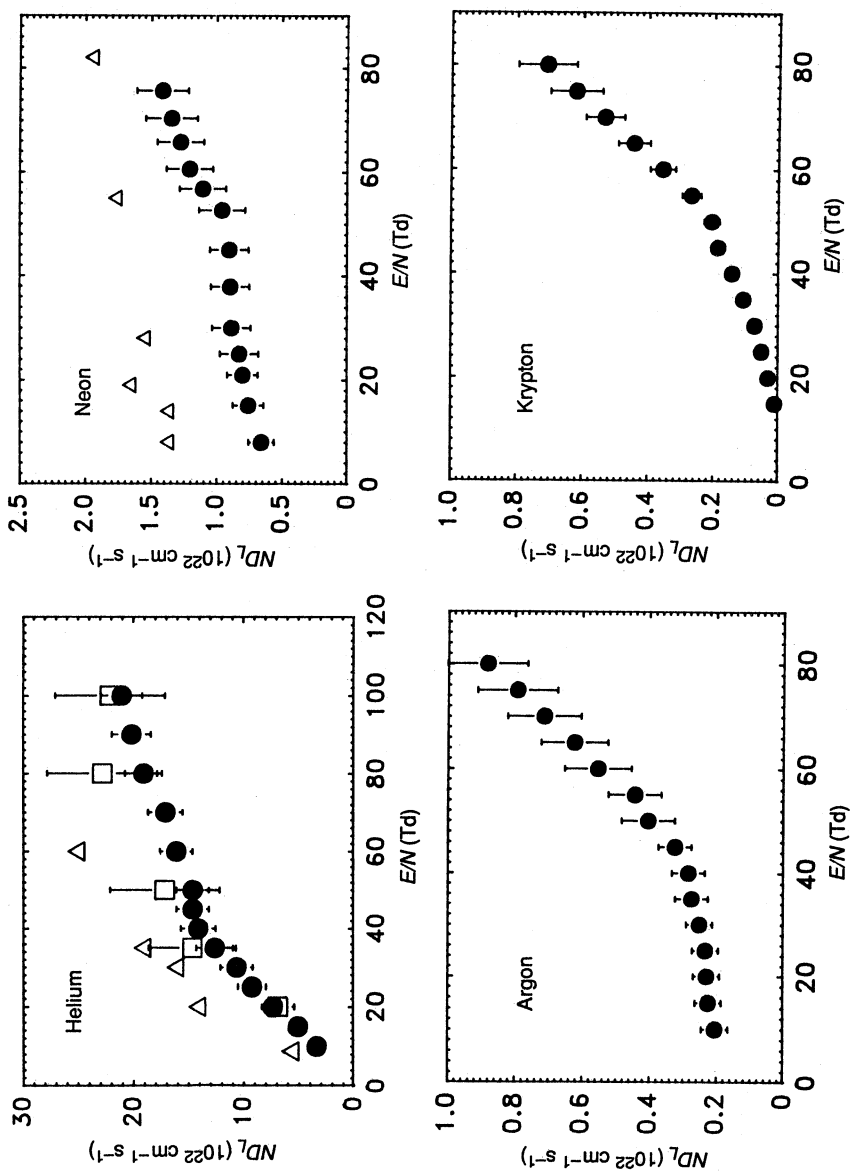

Fig. 3. Electron longitudinal diffusion coefficient ND_L in the rare gases as a function of E/N. All graphs: ●—present data. Helium: □—Amies *et al.* (1985), △—Kucukarpaci *et al.* (1981). Neon: △—Kucukarpaci *et al.* (1981).

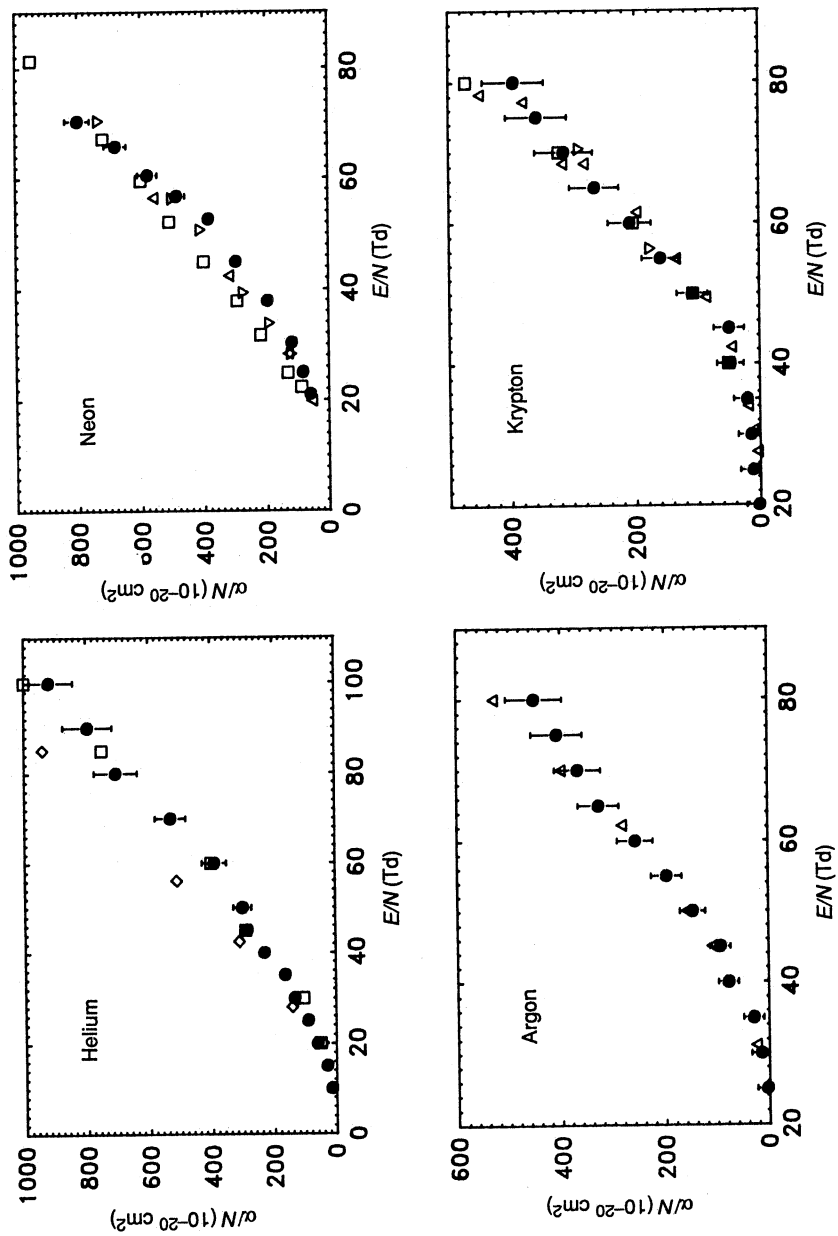

Fig. 4. Electron ionisation coefficient as a function of E/N. All graphs: ●—present data. Helium: ◇—Chanin and Rock (1964), □—Davies *et al.* (1962). Neon: △—Chanin and Rork (1963), □—Dutton *et al.* (1969), ▽—Bhattacharya (1979). Argon: △—Burgmans and Sweets (1983). Krypton: △—Heylen (1971), ▽—Bhattacharya (1979), □—Burgmans and Merks-Eppingbroek (1984).

greater than about 10 Td (i.e. 10^{-16} V cm^2). The present experimental data are thus compared with the recent theoretical values of the diffusion-modified drift velocity ($v_d = W_e - \alpha_D$) of Sakai *et al.* (1991). Reasonable agreement is observed although such good agreement would not be expected at higher E/N as the α_D term becomes more important.

(b) Electron Longitudinal Diffusion Coefficient

There is, within the literature, a dearth of data on the longitudinal diffusion coefficient D_L in the rare gases at these higher values of E/N. Fig. 3 shows the present values of ND_L as a function of E/N in all the gases studied. The errors in the measurement of ND_L are probably of the order of ±10%. In helium a comparison is possible with the previous data of Amies *et al.* (1985), who used the photon flux technique. The published data of Kucukarpaci *et al.* (1981) who used a pulsed Townsend method are included in the helium and neon graphs. These latter data lie above the present results. Whilst great care has been taken in the present work only to obtain data over that range of Nd above the critical value (Purdie and Fletcher 1992), Kucukarpaci *et al.* did not give the pressure range of their measurements. Since measurements in helium over a range of pressures have shown that at low values of Nd, both W_e and ND_L are higher than the equilibrium (Nd independent) values, it is possible that the work of Kucukarpaci *et al.* was taken in this region. The absence of any previous determinations of the longitudinal diffusion coefficient is clearly demonstrated in argon and krypton for which no previous experimental measurements appear in the literature.

(c) Ionisation Coefficient

In the present technique the primary ionisation coefficient α can be measured in two ways: from the fitting of the overall transient similar to the other transport parameters and from the ratio R of the total transient voltage after all the charged species have traversed the gap V_T to the electron component of the transient V_e. The part of the transient most markedly affected by α/N is the initial part of the curve — the first few tens of nanoseconds. Hence any error in detecting the starting channel, which would introduce timing uncertainties of the order of ±10 ns, could lead to severe errors at the higher energy end, perhaps as high as 20–30%. Hence, in the present work the ratio method was used to determine α/N. This method has been well documented by Hunter *et al.* (1986), who showed that, for a non-attaching gas,

$$R = \frac{\alpha d}{1 - \exp(-\alpha d)} .$$

The results of these determinations are given in Fig. 4 and compared with previous results. In all the gases investigated the present data agree to within experimental error with most of the previous published results. In helium the values of Davies *et al.* (1962) agree well with the present data, whilst the results of Chanin and Rork (1964) lie above both these determinations. The present neon data appear to lie marginally below the previous values of Chanin and Rork (1963), Dutton *et al.* (1969) and Bhattacharya (1979), but when the combined

errors are included a substantial overlap is observed. Results for both argon and krypton agree well with the published values of Burgmans and Sweets (1983) in the former case, and Heylen (1971), Burgmans and Merks-Eppingbroek (1984) and Bhattacharya (1979) in the latter.

4. Conclusion

The transport parameters of electrons plus the ionisation coefficient have been measured in all of the rare gases, except xenon, using the integrated voltage transient method. A full mathematical analysis has been applied to the raw data to allow for both image terms and diffusion effects. The present data cover a much wider range of E/N than previously achieved in a controlled Townsend discharge and give the first experimental results for the longitudinal diffusion coefficient in argon and krypton.

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