Aust. J. Phys., 1980, **33**, 215–26

The Drift Velocity of Low Energy Electrons in Oxygen at 293 K

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Abstract

A new drift tube technique incorporating electron density sampling to locate the drifting electron swarms has been used to measure electron drift velocities in the range 0·14–1·4 Td. The data were obtained at several pressures from 0·2 to 0·5 kPa. The estimated accuracy ranges from 2% at 1·4 Td to 5% at 0·14 Td.

1. Introduction

Cross sections for elastic and inelastic collisions between molecules and low energy ($\lesssim$1 eV) electrons have been determined by analysing measurements of the transport coefficients for electron swarms in many gases (see e.g. Gilardini 1972; Huxley and Crompton 1974). However, the technique as applied to oxygen (Hake and Phelps 1967) has had limited success because the available transport data have been less extensive and, at least for low energy swarms, less accurate. The difficulty in making reliable measurements in oxygen is a direct result of electron attachment which, at the pressures necessary for such measurements (Crompton and Elford 1973), causes rapid depletion of the electron swarm. As a consequence, in experiments to measure electron drift velocities, few free electrons remain after the swarm has traversed the drift distance, and those remaining must be detected against a background of negative ions. In the case of lateral diffusion experiments of the Townsend–Huxley type, the composition of a mixed stream of electrons and ions has to be analysed to determine electron characteristic energies and attachment rates (Huxley and Crompton 1974). In both cases these factors have limited the range of experimental parameters that could be used in previous experiments, and the range of E/N (ratio of electric field strength to gas number density) that could be investigated.

Previous drift tube measurements of electron drift velocities in oxygen have been summarized by Crompton and Elford (1973). These authors used a long (50 cm) drift tube and low gas number densities to extend the range of E/N beyond that previously accessible to such techniques, but nevertheless their data were limited to $E/N > 0{\cdot}8$ Td (1 Td $\equiv 10^{-17}$ V cm^2). A novel technique was devised by Nelson and Davis (1972) in which the effect of the terminating boundaries was reduced by introducing the electron swarm into the drift region and also extracting it with an electric field whose strength was larger than that of the field applied during the intervening time interval. This technique (the 'drift–dwell–drift' technique) enabled

measurements to be made down to $E/N = 0$, but experimental difficulties limited the measurements to a single pressure. Consequently it was not possible to verify the data by the normal procedure of comparing the results obtained for a given E/N over a range of gas number densities.

In order to extend the range of measurements accessible in a conventional drift tube experiment, the method of detecting the arrival of the electron groups by charge-sensitive devices has been replaced in our experiments by a pulsed RF technique similar to that used by Cavalleri (1969) for the measurement of electron diffusion coefficients. This detection technique responds only to electrons and can thus be used to detect them in the presence of a background of negative ions. Moreover it is capable of very high sensitivity since individual electrons can be detected. A salient feature of the method is that the detector is triggered to operate only at appropriate times, whereas in most other methods (see e.g. Huxley and Crompton 1974) the arrival of the electrons initiates the response of an already active system. The sequence of events in the present experiment was to generate a series of electron groups at regular intervals at a known position S_1 (see Fig. 1), and to detect their arrival in the sampling region SR by generating a short-duration RF field in SR at a series of time delays corresponding approximately to the transit time. To first order the transit time then corresponds to the delay at which the maximum response (light signal) from SR is recorded.

The drift tube incorporating this method of detection and the associated experimental techniques are described in Section 2. The new experimental results are presented in Section 3 and discussed in relation to earlier data in Section 4.

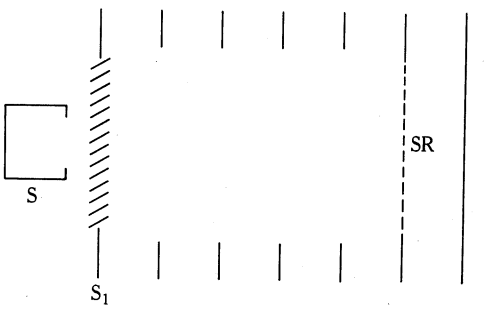

Fig. 1. Schematic diagram of the drift tube incorporating electron density sampling: S, electron source; S_1, electrical shutter; SR, sampling region.

2. Experimental Apparatus and Method

Drift Tube

The drift tube is shown in Fig. 2. The guard electrodes (5–26), which were pressed from copper sheet, are separated by accurately ground cylindrical glass spacers. The 20 mCi ($1\ \text{Ci} \equiv 3{\cdot}7 \times 10^{10}$ Bq) americium ionization source is similar in principle to the one described by Crompton and Elford (1973) but is modified to give an enhanced level of ionization at the low pressures used in the present experiments. A nickel foil supports the americium coating to form a source with an active area of 30 mm by 25 mm. The foil is located between grooves cut in electrodes 1 and 2 thus forming a cylindrical surface with the coating on the inner surface. Electrodes 3 and 4 carry Micromesh (Buckbee Mears Co.) gauzes which

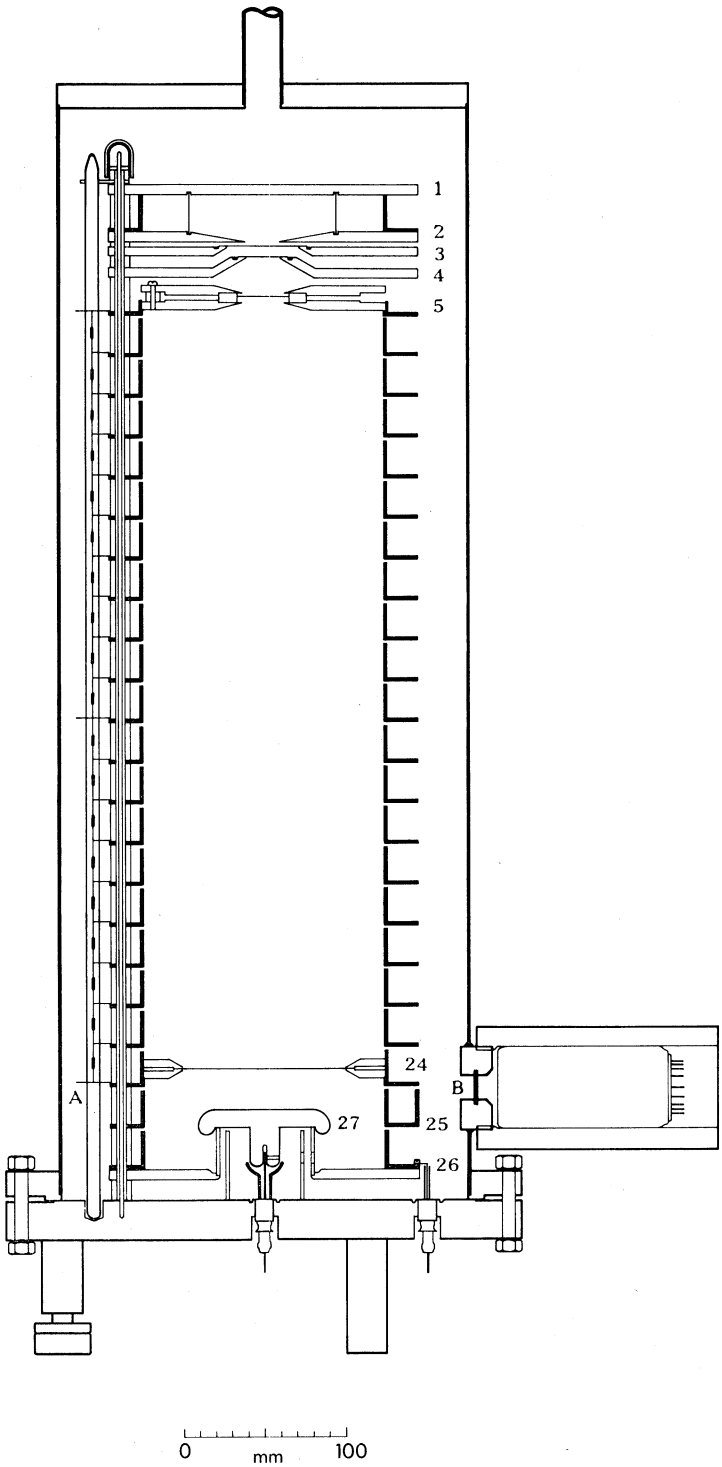

Fig. 2. Sectional drawing of the drift tube. Electrical connections are made via the ceramic feedthroughs (Ceramaseal Inc.) in the base of the stainless steel vacuum envelope: A, voltage divider chain; B, quartz window.

are used to establish a region of high electric field and thus further enhance the level of ionization. A Bradbury–Nielsen type electrical shutter, which may be used to form the electron groups, is situated above electrode 5, and the drift space is terminated by the detection region defined by the grid attached to electrode 24 and electrode 27 which is 25 mm below it and to which the RF pulses are applied. A uniform electric field is established throughout the space between electrodes 5 and 26 by applying to the electrodes appropriate potentials derived from a glass encapsulated voltage divider chain (A in Fig. 2). A photomultiplier tube (EMI type 9789B) is mounted in the side tube adjacent to a quartz window (B) and views a relatively narrow portion of the sampling region whose solid angle is defined by the apertures between the vertical sections of electrode 25 and the base of 24. Metal, glass and ceramic only were used in the construction of the apparatus and its associated vacuum system; gold and indium wire were used for the baseplate and window vacuum seals respectively. The drift tube was baked to 50°C for 70 h prior to the experimental runs.

Although it was intended to form the electron groups by the Bradbury–Nielsen shutter it was found that, under some experimental conditions, the electron stream could not be adequately gated by the shutter since high energy electrons were still transmitted when the shutter was 'closed'. These electrons received their energy from the amplification region to which electric fields of up to 2000 $V\,cm^{-1}$ had to be applied to obtain adequate electron current. In the majority of the experiments reported here this problem was avoided by using an alternative method for producing electron groups. Electrons were released into the drift region by momentarily changing the extraction potential difference between the source cylinder and the first multiplication grid from $+30$ to -30 V. In this mode the Bradbury–Nielsen grid was held 'open' by connecting both sets of wires to electrode 5. Subsequently the difficulty was largely overcome by increasing the grid separation in the amplification region from 1 mm to 6 mm, thus enabling the same amplification to be achieved with smaller electric fields and consequently lower average electron energies. Even with this modification, however, there was some transmission by the shutter when 'closed' and the best signal to noise ratio was obtained by keeping the source reverse-biased except for a short time interval which included the shutter open time.

Electrons arriving at the detection region were detected in the following way (see e.g. Cavalleri 1969). At a time corresponding approximately to the arrival of an electron group an intense RF field is established between electrode 27 and the grid attached to electrode 24. The RF field is initiated when a thyratron discharges a small capacitor, charged to several kilovolts, through the primary of an air-cored transformer whose secondary winding connects electrodes 24 and 27 (see Fig. 3 below). The oscillating circuit has a time constant of approximately $0{\cdot}5\ \mu s$ and a resonant frequency of about 20 MHz. The grid and the divider chain are coupled to ground with capacitors so that the field in the sampling region follows the voltage applied to the pulsing electrode. In the quiescent mode the potential of electrode 27 is held at the appropriate value to maintain a uniform field in the drift space by connecting the secondary winding of the transformer to the appropriate point on an extension of the divider chain external to the tube.

If there are any free electrons in the sampling region when the RF pulse is applied, they gain sufficient energy from the field to initiate local electron

avalanches. The light output accompanying the formation of the avalanches, which is taken to be proportional to the number of initiatory electrons, is viewed by the photomultiplier.

The present method of detection has several advantages over other methods of detecting the arrival of the electron groups. In the first place it discriminates between electrons and negative ions since the ions are too massive to acquire sufficient energy from the RF field to excite or ionize the oxygen molecules. (This was confirmed by triggering the RF pulse at time delays long enough to ensure that no free electrons remained in the drift tube. The absence of any response also showed that detachment was not a significant process.) Secondly, while the method shares with particle detectors the ability to detect a single electron, it does not require a separately pumped vacuum chamber since the detector is situated in the drift tube envelope and operates at the same pressure. The high sensitivity of the detector, resulting from its inherent sensitivity and its large active area, and its location *in situ*, enabled measurements to be made over a range of pressures even in the difficult circumstances presented by oxygen at low E/N (for a discussion see Crompton and Elford 1973). A disadvantage of the method is that energetic metastable species produced in the sampling process release electrons at subsequent times, presumably via a surface reaction. Consequently there is an upper limit to the repetition rate of the experiment if there are to be no spurious electrons present at the time of arrival of a group. The rate that could be used varied from 1·2 to 2·5 Hz, depending on the pressure and hence the diffusion rate of the metastables.

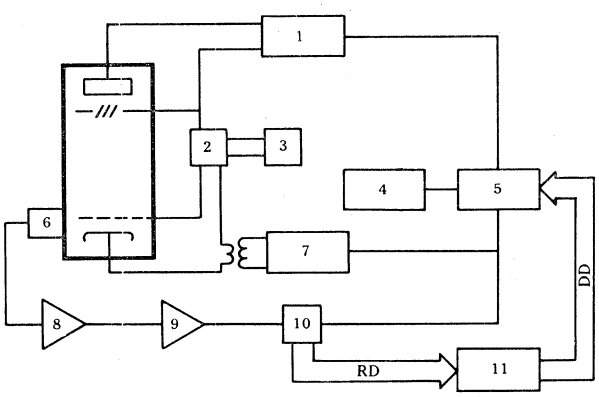

Fig. 3. Block diagram of the automatic control and data collection system: 1, source and shutter control; 2, voltage divider; 3, field power supply; 4, clock for repetition rate; 5, digital delay generator; 6, photomultiplier tube; 7, thyratron circuit; 8, preamplifier; 9, amplifier; 10, analogue to digital converter; 11, minicomputer PDP/8e; RD, response data (12 bits); DD, delay data (24 bits).

Control and Data Acquisition

Experimental conditions were frequently encountered when very few electrons survived the drift distance. Indeed it was common for there to be at most one or two electrons present when the sampling pulse was applied. Therefore a large number of samples had to be taken to obtain satisfactory statistics. For example, under certain conditions as many as 4000 samples were taken at each of 21 sample times

for a single transit-time measurement. This dictated the use of the automatic control and data collection system shown schematically in Fig. 3.

A minicomputer (DEC PDP/8e) sends delay instructions to a programmable digital delay generator (DDG) (BNC model 7020) and receives response information from an analogue to digital converter (ADC) (Canberra Industries model 8040). A local clock controls the repetition rate of the experiment. At each clock pulse the computer is interrupted and sends an appropriate delay instruction to the DDG. The DDG triggers the source (or shutter) pulse and sends a delayed trigger pulse to the sampling pulse generator. The light signal resulting from electron avalanches in the sampling region is amplified, digitized by the ADC, and stored cumulatively in a memory location assigned to that particular delay time. The computer then updates the delay instruction and repeats the cycle. The delay range to be covered is swept through cyclically thus minimizing errors due to drifts.

Procedure

A table of average responses is obtained for delay times in a range containing the transit time and extending to delays where the response is about 50–60 % of the peak value. The time of maximum response t_m is then found by fitting a third-degree polynomial to this portion of the response curve and differentiating to find the maximum.

Two factors result in the length of the drift space being poorly defined compared with that of a conventional drift tube, notwithstanding its magnitude (50 cm). Firstly, most of the experiments were performed using the pulsed source rather than the Bradbury–Nielsen grid so that the position from which the electron groups originate is less well defined. Secondly, light is collected by the photomultiplier from a zone in the detection region which is also not well defined despite the use of the collimating apertures. To avoid these uncertainties a differencing technique was used to determine the drift velocity. After a full set of results was recorded with a nominal drift distance of d_1, the drift space was shortened to d_2 and the set was repeated under identical conditions. The apparent drift velocity v'_{dr} for a given set of experimental parameters is then given by

$$v'_{dr} = (d_1 - d_2)/(t_m^{(1)} - t_m^{(2)}), \tag{1}$$

where $t_m^{(1)}$ and $t_m^{(2)}$ are the times of maximum response obtained with the two drift distances. Typical response peaks and the polynomials fitted to them are shown in Fig. 4.

Although the use of the differencing method eliminates errors due to the finite width of the initial pulse and end effects, and (to first order) those due to diffusion, the effect of attachment on v_{dr} is not removed. When the spatial density distribution of the travelling group is modified by both diffusion and attachment it can be shown that the time t_m for maximum response of the detector is related to d/v_{dr} by (Pack and Phelps 1966)

$$t_m \approx (d/v_{dr})(1 - C\beta - 2\beta v_a\, d/v_{dr}),$$

it being assumed that the attachment collision frequency v_a is the same throughout the group.* In this relation d is the drift distance, C is a constant and β is the ratio

* Errors due to this assumption (see e.g. Tagashira *et al.* 1977) have not been calculated but are expected to be small.

$(D_{\|}/\mu)/V$, with $D_{\|}$ the longitudinal diffusion coefficient, $\mu = v_{dr}/E$ the electron mobility and $V = Ed$. It then follows that the drift velocity v_{dr} is related to v'_{dr} by

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

In the energy range in which the experiments were conducted, attachment is a three-body process proceeding via a vibrationally excited negative molecular ion which is subsequently stabilized by collision with a neutral molecule. Thus v_a/N^2 is assumed constant for a given E/N. In applying the correction given by equation (2), v_a/N^2 was estimated from the data published by Chanin *et al.* (1962). The values of $D_{\|}$ were those of D. R. Nelson (personal communication), and v'_{dr} was assumed to be an adequate approximation for v_{dr} since the correction was at most 6%.

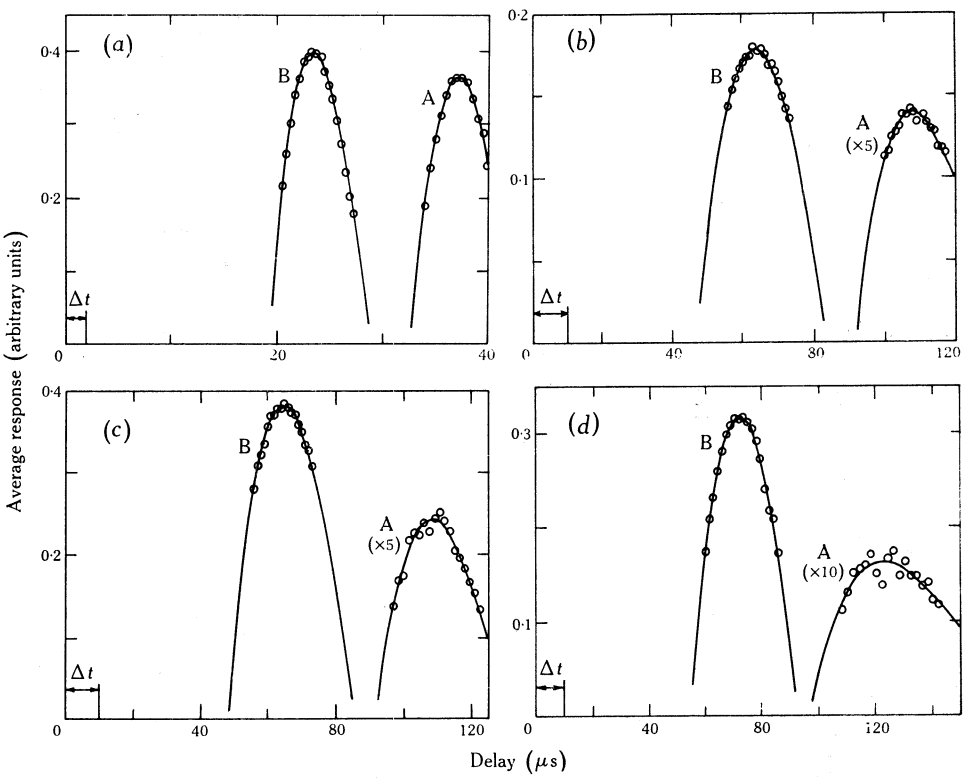

Fig. 4. Examples of the responses recorded under various experimental conditions: (curve A) with the original drift distance of 50 cm and (curve B) after the distance had been shortened to 30 cm;

(*a*) $E/N = 1{\cdot}4$ Td, $p = 0{\cdot}53$ kPa; (*b*) $E/N = 0{\cdot}20$ Td, $p = 0{\cdot}33$ kPa;
(*c*) $E/N = 0{\cdot}20$ Td, $p = 0{\cdot}41$ kPa; (*d*) $E/N = 0{\cdot}14$ Td, $p = 0{\cdot}41$ kPa.

In each case the duration of the source pulse is indicated by Δt.

In the early experiments a significant increase of the drift velocity was observed over the duration of an experimental run, typically 12 h. The time dependence was attributed to the accumulation of a molecular impurity which provided an additional energy loss mechanism thus lowering the average energy of the swarm and raising

the drift velocity. The effect was particularly evident at low values of E/N where the energy distribution of the electrons was such that there was insignificant energy loss due to vibrational excitation of O_2.

Table 1. Differences in transit times for a 20 cm change in drift length
Most of the results shown for the difference Δt_m in time of maximum response at each pressure p were obtained by pulsing the source; those printed in italics were obtained by operating the Bradbury–Nielsen grid

E/N (Td)	Pulse width (μs)	Δt_m (μs)	Pulse width (μs)	Δt_m (μs)
	$p = 0{\cdot}2000$ kPa		$p = 0{\cdot}3306$ kPa	
0·20			10·0	44·45±0·75
0·25			7·0	39·35±1·5
0·30	6·0	35·3 ±0·5	5·0	36·45±0·7
			7·0	36·15±0·5
0·35	6·0	32·55±0·7	5·0	32·85±0·6
0·40	6·0	31·0 ±0·6	5·0	30·45±0·4
0·50	6·0	26·45±0·65	5·0	26·8 ±0·35
0·60	3·0	23·85±0·4	5·0	23·65±0·35
0·80	3·0	19·85±0·35	5·0	19·7 ±0·4
1·00	3·0	17·1 ±0·3	4·0	17·2 ±0·25
1·20	3·0	15·4 ±0·3	3·0	15·55±0·2
1·40	3·0	14·05±0·2	*3·0*	*13·9 ±0·25*
	$p = 0{\cdot}4133$ kPa		$p = 0{\cdot}5333$ kPa	
0·14	10·0	50·4 ±1·0		
0·17	*10·0*	*48·5 ±3·2*		
0·20	10·0	43·75±0·3		
	10·0	*43·15±0·75*		
0·25	6·0	40·05±0·55	10·0	40·1 ±0·7
	6·0	*38·75±0·8*	*10·0*	*40·0 ±2·1*
	10·0	39·9 ±0·95		
0·30	4·0	36·8 ±0·7	10·0	35·85±0·7
0·35	*6·0*	*33·1 ±0·85*	10·0	33·1 ±0·35
0·40	4·0	30·85±0·35	8·0	30·5 ±0·45
0·50	*6·0*	*27·8 ±0·35*	4·0	27·0 ±0·15
0·60	4·0	24·25±0·4	4·0	23·55±0·2
0·80	3·0	19·7 ±0·2	4·0	19·9 ±0·2
1·00	3·0	17·1 ±0·3	2·0	17·05±0·25
1·20	2·0	15·25±0·35	2·0	15·35±0·15
1·40	2·0	14·1 ±0·2	2·0	13·85±0·1

The impurity was found to be condensable with a liquid nitrogen trap. The major constituent is thought to be H_2O formed by the reaction of an excited oxygen species generated in the source with hydrogen from the stainless steel of the envelope. The mechanism is probably a surface reaction since the rate of outgassing from the envelope was much smaller than that needed to create the observed amount of impurities. A flowing gas system was installed to overcome this problem. Liquid nitrogen traps were used on both the inlet and outlet lines to provide further purification or prevent contamination. The flow rate was adjusted so that the gas in the 45 l. envelope was replaced every 20–40 min. After each series of experiments

Table 2*a*. Uncorrected drift velocities for electrons in oxygen
See Table 1 for an explanation of the values in italics

E/N (Td)	v'_{dr} (10^6 cm s^{-1}) at p (kPa) of: 0·2000	0·3306	0·4133	0·5333
0·14			0·397	
0·17			*0·412*	
0·20		0·450	0·457	
			0·463	
0·25		0·508	0·499	0·499
			0·516	*0·500*
			0·501	
0·30	0·567	0·549	0·544	0·558
		0·553		
0·35	0·614	0·609	*0·604*	0·604
0·40	0·645	0·657	0·648	0·656
0·50	0·756	0·746	*0·719*	0·741
0·60	0·839	0·846	0·825	0·849
0·80	1·008	1·015	1·015	1·005
1·00	1·170	1·163	1·170	1·173
1·20	1·299	1·286	1·311	1·303
1·40	1·423	*1·436*	1·418	1·444

Table 2*b*. Final corrected drift velocities for electrons in oxygen
See Table 1 for an explanation of the values in italics

E/N (Td)	v_{dr} (10^6 cm s^{-1}) at p (kPa) of: 0·2000	0·3306	0·4133	0·5333	Mean value
0·14			0·374		0·374
0·17			*0·390*		0·390
0·20		0·434	0·437		0·438
			0·443		
0·25		0·494	0·482	0·477	0·486
			0·498	*0·478*	
			0·484		
0·30	0·560	0·537	0·530	0·535	0·541
		0·541			
0·35	0·608	0·599	*0·592*	0·593	0·598
0·40	0·640	0·648	0·637	0·638	0·641
0·50	0·752	0·739	*0·710*	0·736	0·734
0·60	0·835	0·840	0·818	0·831	0·831
0·80	1·005	1·010	1·009	1·004	1·007
1·00	1·168	1·159	1·165	1·163	1·164
1·20	1·297	1·283	1·307	1·295	1·296
1·40	1·421	*1·436*	1·415	1·424	1·424

the traps were warmed and the system was pumped by an ion pump to a pressure of $\sim 10^{-5}$ Pa. In this way the effect of impurities was reduced to an insignificant level. The gas used was Matheson Research Grade oxygen.

The temperature of the gas was taken to be that of the tube envelope which was situated in a temperature controlled room. The temperature was normally 293 ± 1 K and varied by less than 0·2 K during the course of an experiment.

3. Results

At least three values of t_m were obtained consecutively with each set of experimental conditions to check for time dependence in the results. In some cases as many as nine separate experiments were conducted. Table 1 lists the differences Δt_m in time of maximum response for a 20 cm change in drift length, together with the combined scatter and the duration of the initial pulse to either the source cylinder or the Bradbury–Nielsen grid. Most of the results were taken by pulsing the source; those shown in italics were taken by gating the Bradbury–Nielsen grid after the source had been modified.

Table 2*a* lists the apparent drift velocities v'_{dr} calculated from the data in Table 1, while Table 2*b* gives the corrected drift velocities and the mean values. With few exceptions the scatter in the present results is less than $\pm 2\%$ from the mean values for all values of pressure and E/N. The main contributions to systematic errors arise from the measurements of pressure, voltage, temperature and drift distance. The most significant of these, the drift distance, has an uncertainty of $0{\cdot}25\%$. In view of the excellent agreement with the data of Crompton and Elford (1973) above $1{\cdot}0$ Td, it appears that the systematic errors are less than 1%. It is considered therefore that the uncertainty in the present values of v_{dr} is $\pm 2\%$ at $1{\cdot}4$ Td, rising to $\pm 5\%$ at $0{\cdot}14$ Td.

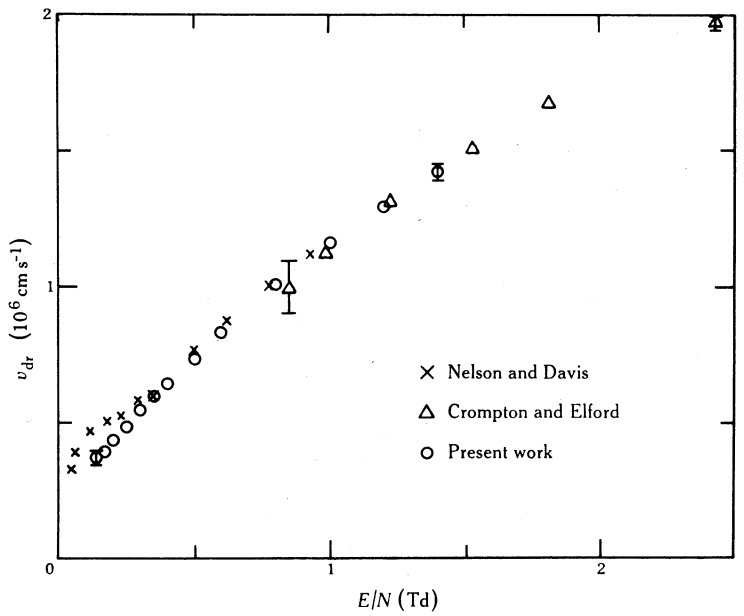

Fig. 5. Comparison of the present results for the drift velocity of electrons in oxygen with the experimental data of Nelson and Davis (1972) and Crompton and Elford (1973).

The present results are compared with those of Nelson and Davis (1972) and Crompton and Elford (1973) in Fig. 5. All three sets of data are in good agreement over their common ranges of E/N down to $0{\cdot}35$ Td. Below this value of E/N the present results fall significantly below those of Nelson and Davis. It should be noted that Nelson and Davis used a conventional time-of-flight technique down to

0·5 Td, the drift–dwell–drift method being used only below this value. The reason for the discrepancy between the two sets of data is not known, although evidence in favour of the present set is the invariance of the results with pressure that has been demonstrated for $E/N \geqslant 0{\cdot}25$ Td. For $E/N \geqslant 0{\cdot}30$ Td the results were taken at four pressures covering a range of more than 2·5:1. No systematic variation of the results with pressure is evident (Table 2*b*). At the two lowest values of E/N (0·14 and 0·17 Td) it was not possible to take results at more than one pressure and the error estimate has therefore been arbitrarily increased at the lower end of the E/N range. Nevertheless it should be noted that all the data are derived by the differencing technique which is expected to remove the majority of the errors arising from pressure-dependent diffusive effects.

The new data agree to within the combined error bars with the data of Crompton and Elford (1973). However, the apparent trend of the latter data towards a mobility for thermal electrons much lower than that of Nelson and Davis (1972) (see Fig. 4 of Crompton and Elford 1973, and Table 14.3.7 of Huxley and Crompton 1974) is not supported by the present data. Our new data do not extend to values of E/N low enough to reach the regime of constant mobility, and hence it is not possible to infer a thermal mobility value to compare with that of Nelson and Davis.

4. Discussion and Conclusions

The aim of the work described in this paper was to measure electron drift velocities in oxygen below $E/N = 1$ Td with the same accuracy as that already achieved for other atomic and molecular gases and, in fact, for oxygen above 1 Td. The need for such data is illustrated by the large differences that are found below 0·1 eV between the momentum transfer cross section derived from DC swarm measurements (Hake and Phelps 1967) and from microwave conductivity data (van Lint *et al.* 1960; Fehsenfeld 1963; Mentzoni 1965; Veatch *et al.* 1966; for a discussion see Hake and Phelps 1967), and the lack of definitive experimental data for rotational excitation cross sections, the only source of which is likely to be the results of swarm experiments.

Hake and Phelps (1967) adjusted the momentum transfer cross section below 0·1 eV so as to be consistent with the thermal mobility of electrons in O_2 as deduced by Pack and Phelps (1966) from their mobility measurements in O_2–CO_2 mixtures. No data for pure O_2 were available at sufficiently low E/N to establish the cross sections below 0·1 eV from these data alone. More recently A. V. Phelps (personal communication) has repeated the calculations using modified momentum transfer and rotational excitation cross sections in order to fit the later low E/N drift velocity and thermal mobility data of Nelson and Davis (1972). The momentum transfer cross section that he finds to be consistent with the data is very much lower at thermal energies than the cross section of Hake and Phelps and is more consistent with the majority of the microwave data.

A reliable determination of the momentum transfer cross section below 0·1 eV requires accurate data for either (i) thermal mobilities over a wide range of temperature or (ii) drift velocity data over a range of E/N for $E/N \lesssim 1{\cdot}0$ Td coupled with either experimental diffusion coefficient data or accurate theoretical rotational excitation cross sections. A third possibility is pairing of the drift data with

corresponding data for the attachment collision frequency (Phelps, personal communication). The work described here was undertaken to complement measurements of the diffusion coefficient D by the Cavalleri (1969) density sampling technique which, when applied to an attaching gas, enables simultaneous determination of D and the attachment collision frequency. The results from this part of our program are not yet available. For this reason, and because no definitive statement can so far be made about the validity of theoretically derived rotational excitation cross sections, there appear to be no suitable experimental or theoretical data with which to combine the new drift data to yield a cross section at low energies that would be any more reliable than existing estimates. However, the new data, when coupled with earlier data, establish the drift velocity in O_2 to within $\pm 2\%$ in the range $0{\cdot}4 \leqslant E/N \leqslant 10$ Td, and to within 5% down to $0{\cdot}14$ Td, thus enabling the cross section to be determined in this important energy region when the complementary data become available.

Acknowledgments

The authors would like to thank J. Gascoigne, F. R. Johnson and K. B. Roberts for their assistance in the construction of the drift tube, and N. Esau and J. Kennedy for their help with the design and construction of the peripheral and interface units. They also wish to thank other members of the Ion Diffusion Unit, particularly M. T. Elford and T. O. Rhymes, for valuable discussions throughout this work. One of us (I.D.R.) acknowledges receipt of a Commonwealth Postgraduate Research award for part of this work.

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Manuscript received 19 July 1979, accepted 20 September 1979