THE DRIFT VELOCITY OF ELECTRONS IN OXYGEN AT 293 K

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Abstract

The drift velocity of electrons in oxygen at 293 K has been measured over the range $0{\cdot}8 \leqslant E/N \leqslant 12$ Td by the Bradbury–Nielsen time-of-flight method. The factors governing the range over which measurements can be made are discussed and it is shown that long drift tubes should be used for drift velocity measurements in oxygen at low values of E/N. A 50 cm drift tube is described. The error in the present results is estimated to be less than 1% for $1{\cdot}8 < E/N < 6$ Td, 2% for $E/N > 6$ Td and at 1·5 Td, 5% at 1 Td, and 10% at 0·8 Td. The present data are in good agreement with those of Fleming *et al.* (1972) and Nelson and Davis (1972) over the E/N range where the sets of data overlap.

I. INTRODUCTION

Electron transport coefficient data have been used in a number of analyses to obtain scattering cross sections, both elastic and inelastic, for electrons of low energy in a wide range of gases (Elford 1972). One of the coefficients used in these analyses is the drift velocity, but the particular published data for electrons in oxygen (Nielsen and Bradbury 1937; Doehring 1952; Herreng 1952; Chanin *et al.* 1962; Rees 1964 (cited after Fleming *et al.* 1972); Pack and Phelps 1966; Fleming *et al.* 1972; Nelson and Davis 1972) exhibit a large scatter, and until the recent work of Nelson and Davis were restricted to values of $E/N > 1$ Td† (where E is the electric field strength and N the gas number density). The scatter and limited E/N range are a direct consequence of negative ion formation. The aim of the present work has been to investigate the range of experimental parameters and operating conditions over which accurate data can be obtained using conventional drift tubes and to provide more accurate data, particularly at low values of E/N.

II. CHOICE OF EXPERIMENTAL PARAMETERS

The loss of electrons by attachment to form negative ions results in a variation of electron current with distance which is described by

$$I/I_0 = \exp\{-\alpha_a d\} = \exp\{-(\alpha_a/N)\,Nd\}, \tag{1}$$

where I is the electron current at a distance d from the source, I_0 the current at the source, and α_a the attachment coefficient. In order to achieve an adequate signal-to-noise ratio in the measurements it is necessary to choose the experimental conditions so that, at a given value of E/N, the product $\alpha_a d$ is as small as possible. When α_a/N is independent of N, as for example when the attachment process takes place through dissociation, $\alpha_a d$ becomes proportional to Nd and hence the requirement of a minimum

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† 1 townsend (Td) = 10^{-17} V cm^2.

value of $\alpha_a d$ implies a minimum value of Nd. However, at a given value of E/N the product Nd cannot be reduced without limit. Since errors due to diffusive effects are known to be proportional to $(Nd)^{-1}$ (Elford 1972), conditions leading to high signal-to-noise ratios also lead to large diffusive effects and vice versa. Above a minimum value of E/N either N or d can be adjusted to obtain the necessary compromise between an adequate signal-to-noise ratio and sufficiently small diffusive effects. We note that, in principle, a drift tube of any length can be used with a suitable choice of values of N, although in practice the length may be dictated by such factors as the need to reduce the possibility of electrical breakdown when measurements are made at large values of E/N, and the range of pressures that can be conveniently used.

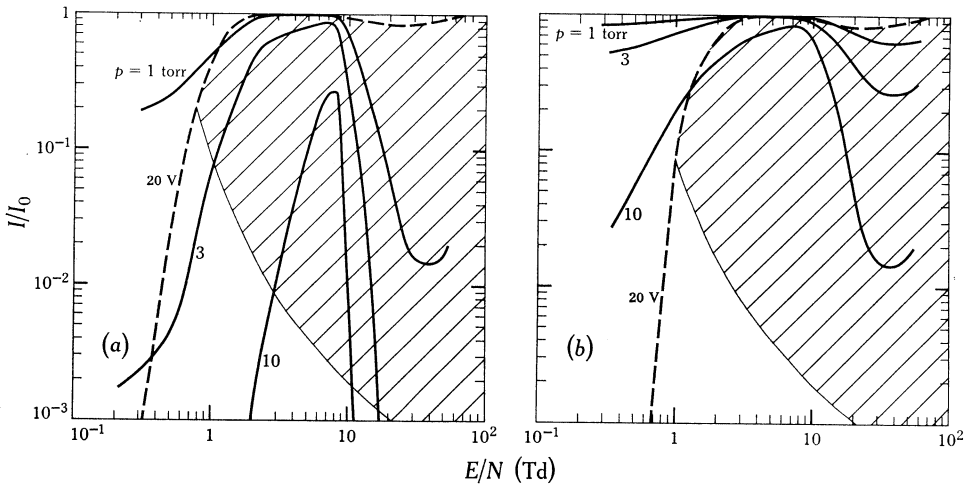

Fig. 1.—Attenuation I/I_0 of the initial electron current I_0 as a function of E/N at gas pressures of 1, 3, and 10 torr when I is the current after the electrons have travelled a distance d of (*a*) 50 cm and (*b*) 5 cm. The curves were calculated using data for the attachment coefficient from Grünberg (1969). The dashed curves indicate the experimental conditions when the potential difference across the drift chamber is 20 V. The shaded areas are the regions where experimental measurements can be made under the restrictions discussed in Section II.

In order to understand why measurement becomes difficult below a minimum value of E/N, we note that α_a/N may be expressed as $\alpha_a/N = (\nu_a/\mu N^2)(E/N)^{-1}$, where μ is the electron mobility and ν_a the collision frequency for attachment. As $E/N \to 0$ at a given value of N, the electron energy distribution function approaches the thermal Maxwellian form and hence both μ and ν_a approach constant values. Thus $\alpha_a/N \to$ const.$(E/N)^{-1}$ and consequently, as E/N is reduced, smaller values of Nd must be used to preserve the same signal-to-noise ratio. However, there is a consequent increase in the magnitude of the diffusive effects. The lowest value of E/N at which reliable measurements can be made is thus the one at which the maximum value of Nd that can be used while maintaining an adequate signal-to-noise ratio is equal to the minimum value of Nd that can be used without diffusive errors becoming excessively large.

In contrast to the case discussed above, the length of the drift tube becomes important when α_a/N is proportional to N at a given value of E/N, that is, when nondissociative attachment occurs. In this case I/I_0 is a function of $N^2 d$. Such a case

occurs in oxygen at values of $E/N \lesssim 2$ Td. The value of Nd necessary to achieve acceptably small diffusive errors at low values of E/N should then be obtained by using a large drift distance and a small value of N in order to obtain a small value of N^2d and thus optimize the signal-to-noise ratio. These considerations suggested the use of a very long drift tube for the present work, since the aim was to extend the range of reliable measurements of drift velocities in oxygen to lower values of E/N.

In order to determine the available range of values of E/N which was experimentally accessible with a very long drift tube, values of I/I_0 were calculated as a function of E/N for gas pressures p of 1, 3, and 10 torr and for a drift distance of 50 cm (Fig. 1(*a*)). A similar set of calculations was made for a drift distance of 5 cm as a comparison (Fig. 1(*b*)). The data used to calculate the curves in Figure 1 were taken from those of Grünberg (1969) and the attachment coefficients at low gas pressures were obtained by linear extrapolation of plots of α_a/p versus p for given values of E/N.

Before using the curves of Figure 1 to determine the usable E/N range it is necessary to specify two factors. The first is the maximum attenuation of the electron current that is consistent with accurate current measurement. In order to avoid space charge effects, the total initial electron current is normally kept below approximately 10^{-10} A. The action of the shutters of the drift tube reduces the current by a factor of between 10 and 100 and, since it is difficult to make accurate measurements at currents less than about 10^{-14} A by conventional electrometry, the maximum tolerable attenuation where initial currents of the order of 10^{-10} A are available (at values of $E/N \gtrsim 16$ Td) is estimated to be approximately 10^{-3}. At low values of E/N ($\lesssim 1$ Td) the maximum permissible attenuation is approximately 10^{-1} due to the lower drift velocities and hence smaller initial currents.

The second factor in the choice of experimental parameters is the minimum acceptable value of Nd ($= V/(E/N)$, where V is the potential difference across the drift chamber). At a given value of E/N this amounts to the specification of a minimum value of V. In order to avoid large diffusive errors as well as errors from the effects of contact potential differences and surface charges, the minimum value of V was arbitrarily chosen to be 20 V. The dashed curves in Figures 1(*a*) and 1(*b*) show values of I/I_0 versus E/N corresponding to $V = 20$ V calculated from equation (1), which may be written in the form

$$I/I_0 = \exp\{-(\alpha_a/N)\, V/(E/N)\}. \tag{2}$$

If attachment in oxygen were dissociative at all values of E/N, the form of equation (2) shows that the attenuation would be independent of the drift length for a given value of V, that is, the dashed curves in the two figures would coincide. However, at low values of E/N where the attachment is predominantly nondissociative the dependence of I/I_0 is more usefully expressed as

$$I/I_0 = \exp\{-(\alpha_a/N^2)(V^2/(E/N)^2)/d\} \tag{3}$$

and it can be seen that, for a given V and E/N, the attenuation is greater in the shorter tube. This fact is confirmed by a comparison of Figures 1(*a*) and 1(*b*). The reason for the majority of the available electron drift velocity data lying in the E/N range above 1 Td can be seen from an inspection of the two figures. As a result of the variations

of α_a/N with both N and E/N it is only in this E/N range that the loss of electron current due to attachment does not present a major experimental difficulty.

Since measurements were arbitrarily restricted to $V \geqslant 20$ V and $I/I_0 \geqslant 10^{-3}$ (or 10^{-1} at the lowest values of E/N), the range of parameters is restricted to that shown by the shaded areas in Figures (1*a*) and 1(*b*). The lowest value of E/N at which measurements can be made is approximately 0·7 Td for a 50 cm drift tube and 1·0 for a 5 cm drift tube, the gas pressure being approximately 2 torr in the first case and 10 torr in the second. In practice, a correction for diffusive effects is made empirically and this requires that measurements be carried out over a range of gas pressures with V remaining greater than 20 V. This raises the lower E/N limit to about 0·8 Td for the 50 cm tube and 2 Td for the 5 cm tube.

Since an insignificant decrease in the lower E/N limit is obtained by using a drift tube longer than 50 cm and, furthermore, the construction problems become severe at lengths much greater than this, 50 cm was chosen as the length of the drift tube for the present work. The construction and operation of the tube are described in the following section.

III. Experimental Details

The drift tube used is shown schematically in Figure 2(*a*). The electric field was produced and maintained uniform by a "thick" guard ring system of the type described by Crompton *et al.* (1965). The guard rings, when placed at potentials appropriate to their position in the electrode system, produce an electric field of high uniformity except in the close vicinity of the internal surfaces of the guard rings, where the effects of field distortion are unimportant because the electron number density here is generally very low. The guard rings were located in position by glass rods and were separated by Pyrex glass spacers, but no clamping was used since the weight of the individual rings was considered sufficient to hold the structure rigid. There were 29 major guard rings with the dimensions

internal diameter	100 mm,	thickness (internal)	16·16 mm,
external diameter	150 mm,	spacing between rings	0·5 mm.

All electrodes were copper.

The electrode system was mounted on a brass base plate containing the electrical feed-throughs and was enclosed by a glass bell jar which was sealed to the base plate by W40 vacuum wax. The electron drift velocity was measured by the Bradbury–Nielsen time-of-flight technique which has been described in detail previously (Elford 1972). The upper grid was supported on a steatite annular ring and mounted between two guard rings with an internal diameter of 26 mm. The wires forming the lower grid were held between two soda-glass annular rings in the manner described by Crompton *et al.* (1967). The diameter of the apertures of the lower shutter guard electrodes was 88 mm. In each case the wires were sealed to their respective supports by Pyroceram 95 frit (Corning Glass Co.). The wires in both grids were 0·08 mm diameter nichrome spaced 0·4 mm apart. Before insertion in the tube, both grids were coated with gold by vacuum deposition to reduce contact potential differences. The distance between the mid-planes of the grids was $499{\cdot}95 \pm 0{\cdot}10$ mm.

A precision voltage divider established the potential of each guard ring to within $\pm 0{\cdot}1\%$ of the potential appropriate to its position in the electrode system.

The potential difference across the drift chamber was measured with an error of less than $\pm 0{\cdot}02\%$ by a Fluke type 891AR differential voltmeter.

The gas temperature was measured by two calibrated copper–constantan thermocouples situated as shown in Figure 2(*a*). The temperature difference between the thermocouples was less than 0·2 K in all measurements and the temperature used to calculate the gas number density was taken as the mean value. The change in mean gas temperature with time was less than 0·2 K per hour, owing to the large thermal capacity of the electrode system and the control of the air temperature of the laboratory.

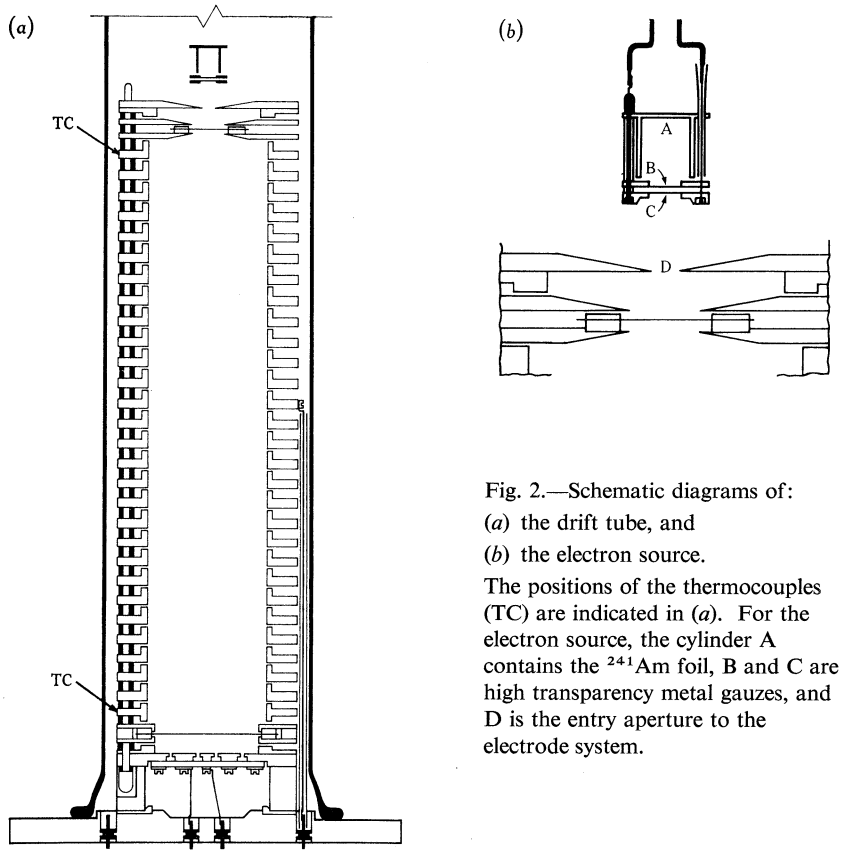

Fig. 2.—Schematic diagrams of:
(*a*) the drift tube, and
(*b*) the electron source.
The positions of the thermocouples (TC) are indicated in (*a*). For the electron source, the cylinder A contains the ^{241}Am foil, B and C are high transparency metal gauzes, and D is the entry aperture to the electrode system.

The oxygen used was Matheson Research Grade, and the gas inlet and vacuum systems were identical with those described by Elford (1972). The pressures were measured by a quartz spiral gauge (Texas Instruments Inc. Model No. 141B) which was calibrated using the double dead-weight tester described by Gascoigne (1972). The error in the measurement of all pressures is estimated to be less than $\pm 0{\cdot}1\%$.

The electron currents ranged from 10^{-11} to less than 10^{-14} A. At the lowest currents the frequency of the signal applied to the shutters at which the transmitted current was a maximum was obtained by plotting the electron current as a function of frequency. Each current measurement was made by the rate of charge method using a period of 100 s. In order to carry out this measurement procedure it is necessary to

achieve a high degree of stability in the electron emission from the source. In a number of previous electron drift velocity measurements (e.g. Crompton *et al.* 1970) high stability was achieved by using a ^{241}Am foil, the electrons being obtained by α-particle ionization of the gas. This type of source, however, has a limited useful pressure range and at the values required in the present work the available current is too small to be usable. In order to increase the electron current, the source shown in Figure 2(*b*) was used. Electrons produced in the cylinder A, which contains the americium foil rolled into a cylinder, are extracted and transmitted through a high transparency copper gauze B into a region where E/N is sufficiently high for ionization and hence current amplification to occur. The electrons then pass through a second high transparency gauze C into a region where E/N may be varied in order to control the electron current and thence through the aperture D in the uppermost electrode of

TABLE 1

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The best-estimate values have been corrected for diffusive effects and attachment by the procedure described in Section IV

E/p_{273}	E/N	Drift velocity W (10^6 cm s^{-1})				
(V cm^{-1} torr^{-1})	(Td)	p_{273} = 1·44	2·16	3·61	7·22 torr	Best estimate
0·30	0·849	1·121	1·079	1·067		0·99(4)
0·35	0·990	1·220	1·188	1·178		1·12(8)
0·43	1·216	1·366	1·351	1·337		1·30(8)
0·54	1·527	1·555	1·547	1·534	1·526	1·50(9)
0·64	1·81	1·713	1·706	1·692	1·694	1·67(5)
0·86	2·43	2·008	1·997	1·995	1·992	1·98
1·07	3·03	2·226	2·221	2·216	2·214	2·21
1·61	4·55	2·552	2·543	2·540		2·53
2·14	6·05	2·709	2·693			2·66
3·21	9·08	3·038	3·029			3·01
4·28	12·1	3·482				3·46

the electrode system. The electrons traverse a region 1 cm in length in which the value of E/N is the same as that in the drift chamber itself, in order to ensure that the electron swarm has reached an equilibrium state. The drift velocity was measured as a function of the potential difference between C and D with the value of E/N in the drift chamber held constant. This check was repeated at a number of values of E/N and showed that the measured drift velocity was independent of the potential difference between C and D, thus indicating that the electron swarm had reached an equilibrium state before entering the drift chamber. Adequate stability in the electron current was achieved by using highly stabilized power supplies to provide the potentials to the electron source.

In all cases the frequencies at which the first two maxima occurred were measured and checks were made to ensure that the frequency of the second was twice that of the first. This condition was found to hold to within $\pm 0{\cdot}2\%$ in all measurements.

Under certain experimental conditions it was necessary to use widely divergent electron swarms and in such cases it was thought that the distorted field region near the guard rings might affect the measured drift velocity. In order to check that the drift velocity measurements were not significantly in error from this cause, a series of

measurements of the drift velocity of electrons in hydrogen was made using first the inner collector (14 mm diam.) and secondly the outer collector (16 mm inner diam., 59 mm outer diam.). Even when 80% of the current arriving at the collector fell outside the outer collector, the drift velocities measured using each of the collectors agreed to within 0·1%. The test was carried out using hydrogen rather than oxygen in order to have sufficient electron current available for accurate measurement when only the inner collector was used.

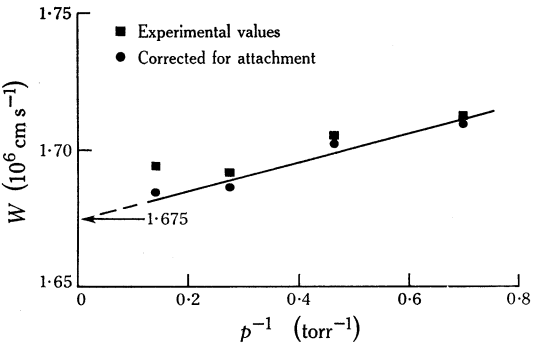

Fig. 3.—Variation of the measured drift velocity W with p^{-1} at $E/N = 1{\cdot}81$ Td. The experimental results have been corrected for attachment by the method described in Section IV and the value of W then found by linear extrapolation.

IV. Results

The electron drift velocities measured in oxygen at 293 K are given in Table 1 as a function of both E/N and gas pressure. Two known sources of error in these data are the effects of diffusion, which have already been discussed in Section II, and errors due to the effect of attachment on the electron pulse as it passes through the second shutter. This second source of error was first discussed by Pack and Phelps (1966) and has been shown by J. J. Lowke (personal communication) to give rise to a correction factor Δ which, in the case of the Bradbury–Nielsen method, is given by

$$\Delta = 2\left(\frac{D_L/\mu}{E/p}\right)\frac{\alpha_a}{p}.$$

The measured drift velocity W' may therefore be written as

$$W' = W\left\{1+\left(\frac{D_L/\mu}{E/p}\right)\frac{C}{pd}+2\left(\frac{D_L/\mu}{E/p}\right)\frac{\alpha_a}{p}\right\}, \tag{4}$$

where W is the true electron drift velocity and D_L the longitudinal diffusion coefficient. In Lowke's (1962) analysis the constant C was calculated to be 3, but in practice its value is found to vary considerably although the hyperbolic dependence of W' on p remains unchanged.

The correction procedure adopted in the present work was as follows. Firstly the data were corrected by the factor Δ to account for the effect of attachment, the values used in making the correction being those of Grünberg (1969) for α_a and Lowke and Parker (1969) for D_L/μ. The corrected data were then plotted as a function of p^{-1} and the value of W was found by linear extrapolation (Fig. 3). Although there is some doubt concerning the numerical factor 2 in the attachment correction Δ, it is not possible to avoid assuming the validity of this factor at values of E/p where α_a/p is independent of p, since Δ also becomes independent of p. However, it should be noted

that even if the numerical factor in Δ is doubled the change in the value of W obtained by extrapolation is much less than the stated error limits. At low values of E/p, α_a/p is proportional to p and Δ increases linearly with pressure, that is, W' increases as p^{-1} decreases. The correction for attachment should therefore reduce the W' data points so that they become collinear on a plot of W' versus p^{-1}. For all values of $E/N > 1{\cdot}2$ Td no corrected datum point lay more than $\pm 0{\cdot}2\%$ from the line of best fit. This tends to support the numerical factor of 2 in Δ, but because of the small magnitude of the correction no reliable estimate of this factor can be obtained from the experimental data; nor, of course, is a better estimate necessary. At values of $E/N < 1{\cdot}2$ Td the corrected points did not lie on a straight line to within the estimated experimental scatter and in fact to produce a linear relation required a numerical factor in the attachment correction of greater than 20. Such a factor appears very unlikely and the correction procedure for these values of E/N must be regarded with caution. The reason for the nonlinearity after the attachment correction with a numerical factor of 2 had been applied is not known. The procedure used in these cases was to draw the line of best fit to the corrected points and to increase the error bars to take into account the uncertainty in the correction procedure. The values listed as "best estimate" in Table 1 are the values of W estimated by the graphical procedure described above. The absolute errors of the best-estimate values are considered to be 1% for $1{\cdot}8 < E/N < 6$ Td, 2% for $E/N > 6$ Td and at 1·5 Td, 5% at 1 Td, and 10% at 0·8 Td.

V. Discussion

Before making a comparison between the present best-estimate results and other sets of data reported in the literature, it is first necessary to note that two sets of data, namely those of Brose (1925) and Healey and Kirkpatrick (1939, cited after Healey and Reed 1941) are not in fact true drift velocity measurements although they have been included even in recent comparisons of work (e.g. Nelson and Davis 1972). The data of Brose, which were published as electron drift velocities, were obtained by the Townsend magnetic deflection method and are therefore *magnetic drift velocities* W_M. The values of W_M differ from W by a factor which depends on the energy dependence of the momentum transfer cross section and the electron velocity distribution function, and in certain circumstances this factor may be very large (Jory 1965). The data of Healey and Kirkpatrick appear only in the book by Healey and Reed (1941) and were obtained presumably by the method of Bailey (1930) using longitudinal magnetic fields. The values obtained by this method are also subject to a factor depending on the momentum transfer cross section and electron velocity distribution function and are therefore not direct measurements of the drift velocity. Two other sets of data will be omitted from comparison with the present results: those of Bradbury (1933) and Goodwin (1951). The former set of data were taken using the inaccurate method of Bradbury (1932) and exhibit an experimental scatter of more than 10% about the curve of best fit, while Goodwin's data were obtained by the Bradbury–Nielsen method and appear only in Figure 1 of the paper by Chanin *et al.* (1962), where they are erroneously attributed to Crompton. The data obtained by Goodwin are omitted because no experimental details are available.

The present results are shown in Figures 4(*a*) and 4(*b*) together with other available measurements. In order to facilitate the comparisons all data are shown as

values of μN. In general, the present results lie below those of most previous authors. Since both diffusive effects and the effect of attachment increase the drift velocity, it is possible that the cause of the discrepancy lies in the lack of correction for these effects in the previous work. A detailed comparison with each of the other sets of data is given below.

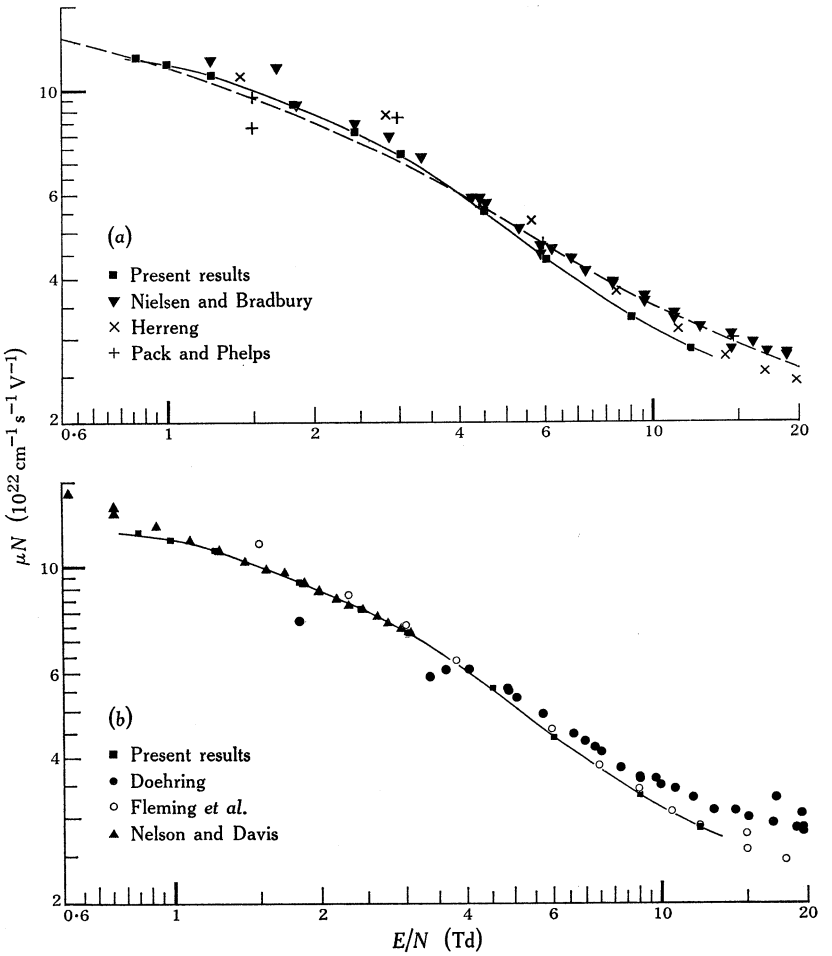

Fig. 4.—Comparisons of the present results with previous experimental data for the variation of μN for electrons in oxygen at 293 K. The dashed curve in (*a*) shows the values predicted by Hake and Phelps (1967).

Nielsen and Bradbury (1937)

The data of Nielsen and Bradbury (Fig. 4(*a*)) cover the E/N range 1–17 Td. For $1 \leqslant E/N \leqslant 6$ Td their values are systematically 5% higher than the present work. The discrepancy increases with E/N until at 11 Td the earlier data are approximately 10% higher. A gas temperature of 293 K was assumed in order to convert the E/p values of these authors to values of E/N.

Herreng (1952)

The data of Herreng (Fig. 4(*a*)) were obtained by an oscillographic technique in which the electrons were produced by a flash of X-rays. His values show a distinctly different behaviour from the other sets of data in Figure 4. Although Herreng estimates an error of less than 3%, at $E/N = 3$ Td his data are approximately 15% higher than three other sets of data, all of which agree to within $\pm 5\%$. For $3 \leqslant E/N \leqslant 6$ Td his data are therefore almost certainly too high. At higher values of E/N, Herreng's data approach the present results and would appear to merge smoothly with them at values of E/N greater than 12 Td.

Doehring (1952)

The data of Doehring (Fig. 4(*b*)) cover the E/N range 1·8–30 Td but there are only three points below $E/N = 4$ Td. These points are significantly lower than all other sets of data and are therefore probably in error. At values of $E/N > 4$ Td his data are in good agreement with those of Nielsen and Bradbury.

Chanin et al. *(1962)*

The data of Chanin *et al.* are limited to the E/N range 0·6–3 Td and show a large scatter (of the order of $\pm 5\%$) from the curve of best fit. For this reason their data are not shown in Figure 4. Over the common E/N range, their data agree, to within the scatter, with the present results. A gas temperature of 300 K was assumed in order to convert the E/p values of these authors to values of E/N.

Pack and Phelps (1966)

The E/N range covered by the data of Pack and Phelps (Fig. 4(*a*)) is approximately 1·5–15 Td. For values of $E/N \gtrsim 4$ Td, their data are in good agreement with those of Nielsen and Bradbury (1937), and hence in significant disagreement with the present results. At values of $E/N \lesssim 4$ Td, their data show considerable scatter, making it difficult to draw comparisons.

Fleming et al. *(1972)*

Fleming *et al.* used the Bradbury–Nielsen method in conjunction with oxygen–hydrogen mixtures. The hydrogen reduces the population of O^- ions by associative detachment (Moruzzi and Phelps 1966) and thus considerably facilitates measurement when the electron loss mechanism is dissociative attachment resulting in the formation of O^- ions. As a consequence of this, the data of Fleming *et al.* (Fig. 4(*b*)) were limited to E/N values greater than 1·5 Td, the highest value being 21 Td. Although three gas pressures 5, 10, and 15 torr were used, no dependence of the measured drift velocity on the gas pressure was observed. With the exception of the point at $E/N = 1{\cdot}5$ Td, their data lie within 3% of the present results over the whole common E/N range. This difference is less than the sum of the estimated experimental error of the two sets of measurements. The data of Rees (1964) are discussed by Fleming *et al.* and shown to agree with their data, and hence with the present data, to within $\pm 1\%$ up to $E/N = 12$ Td. At values of E/N in the range 12–18 Td, the data of Rees lie up to 3% below those of Fleming *et al.* and within 2% of the present results. This

difference is within the combined limits of experimental error. For the sake of clarity the data points of Rees have not been included in Figure 4.

Nelson and Davis (1972)

Two methods of measuring electron drift velocities were used by Nelson and Davis: for values of $E/N > 0{\cdot}5$ Td a time-of-flight technique was employed which involved the measurement of the electron arrival time spectrum (Wagner *et al.* 1967), while for values $<0{\cdot}5$ Td the drift velocity was determined by a modification of the drift–dwell–drift method described by Nelson and Davis (1969). In the E/N range in which a comparison can be made with the present data only the time-of-flight technique was used (Fig. 4(*b*)). There is excellent agreement (to within $\pm 2\%$) for values of E/N between $1{\cdot}2$ and 3 Td but for smaller E/N values the difference increases to 8% at $0{\cdot}85$ Td, although this difference is within the error limits at this value of E/N. As only one pressure (4 torr) was used in their measurements, the dependence on pressure observed in the present work could not have been detected. No corrections were made for the effect of attachment on the drift velocity.

The most encouraging development in measurements of electron drift velocities in oxygen is that, over at least part of the accessible E/N range (1–10 Td), the three most recent sets of measurements agree to within their respective experimental errors. However, it is apparent from the present work that it is essential to take data as a function of gas pressure as well as E/N if significant errors due to diffusive effects and attachment are to be detected.

When the present data are compared with the predicted μN values of Hake and Phelps (1967), significant differences are found (Fig. 4(*a*)). The Hake and Phelps values are in good agreement in the vicinity of $E/N = 4$ Td but are lower by approximately 5% at $E/N = 1$ Td and higher by about 10% at $E/N = 12$ Td. These results suggest that the cross sections, and in particular the momentum transfer cross section, as determined by Hake and Phelps from their analysis of the then available electron transport data, require some modification.

VI. Acknowledgments

The experimental tube was constructed by Mr. J. Gascoigne and Mr. F. Johnson, and their assistance and that of Mr. H. B. Milloy is gratefully acknowledged.

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