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Electron drift velocity in hydrogen, nitrogen, oxygen, carbon monoxide, carbon dioxide and air at moderate *E/N*

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Abstract. The drift velocity of electrons in hydrogen, nitrogen, oxygen, carbon monoxide, carbon dioxide, and air free from water vapour and carbon dioxide, at ambient temperatures (293–296 K) has been measured by the modified Bradbury–Nielsen time-of-flight method over the range of the reduced electric field E/N: $0.05 \leqslant E/N \leqslant 250$ Td, $0.1 \leqslant E/N \leqslant 250$ Td, $1.0 \leqslant E/N \leqslant 275$ Td, $0.1 \leqslant E/N \leqslant 150$ Td, $0.6 \leqslant E/N \leqslant 250$ Td and $0.05 \leqslant E/N \leqslant 400$ Td respectively. The present results are compared with those obtained by other investigators.

1. Introduction

It is well known that knowledge of electron transport coefficients in gases is necessary to determine the appropriate cross-sections for elastic and inelastic processes in the collisions of low energy electrons with the molecules of the medium. The drift velocity is one of these transport coefficients. The traditional methods of measuring transport coefficients are based on the analysis of the spatial and temporal distribution of the electron swarm, diffusing through a gas in a homogeneous electric field in the space between cathode and anode. This can lead to significant experimental errors due to boundary effects. Attempts to minimise these effects are fully justified and useful (Breare and von Engel 1964, Blevin *et al* 1976a). The quantitative estimation of the errors caused by the boundary effects resulting from large density gradients near the electrode surfaces (Lowke *et al* 1977, Braglia and Lowke 1979) is very difficult under actual experimental conditions. Comparison of the consistent experimental data obtained by a traditional measurement method with those obtained by the method substantially minimising the boundary effects could facilitate the estimation of these effects, particularly at elevated values of reduced electric field.

From the earlier analyses of drift velocity measurements it follows that the Bradbury–Nielsen time-of-flight method gives, under the appropriate experimental conditions, highly precise results (Crompton *et al* 1967). The measurements carried out using the system suggested by Blevin and Hasan (1967) have shown that this method makes it possible to obtain advantageous data over a relatively wide range of E/N values at a slight reduction of the measurement accuracy.

The aim of this work has been to obtain consistent drift velocity data, within the method applied and the experimental errors, for pure molecular gases: hydrogen,

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nitrogen, oxygen, carbon monoxide, carbon dioxide and dry air at moderate *E/N* values using the Blevin and Hasan (1967) technique.

2. Experimental method

In the experiment of Blevin and Hasan (1967) the usual Bradbury–Nielsen type of coplanar grid system was replaced by a double grid system (figure 1) with the electrical shutters operated by an AC voltage applied between the adjacent grids. In the present version of the experimental system the grid separation was about 0.5% of the drift

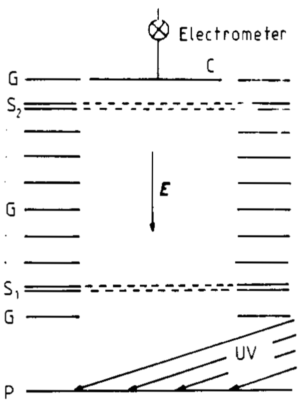

Figure 1. Schematic diagram of apparatus used in the present experiment. Key: P, photocathode; G, guard rings; S, electrical shutters; C, collector.

distance (which was 10.97 cm). For the measurements a HF power generator controlled by a digital timer was used, with an amplitude of 0–21 V over the applied range of frequency from 20 kHz to 20 MHz. The DC voltage applied to the electrodes of the drift tube changed from 20 to 500 V and was known to an accuracy of 0.01 V in the range 20–120 V and to an accuracy of 0.1 V above 120 V. The source of electrons was a goldleaf photocathode illuminated by UV radiation. The rate of increase in pressure for the system isolated from a liquid nitrogen cooling trap was less than 10^{-8} Torr litre s^{-1}. The measurements of the gas pressure were made with three mercury-filled McLeod gauges, connected with the liquid nitrogen or the solid carbon dioxide cooling traps, which covered the range of pressure 0.097–39.76 Torr. All measurements were carried out at room temperature, i.e. 294.5 ± 1.5 K, and temperature variation was controlled with an accuracy of 0.5 K. For the measurements spectrally pure molecular gases (purity higher than 99.99%) and dry air (H_2O < 10 PPM and CO_2 < 1 PPM) have been used.

3. Results and discussion

For all gases studied in this work, except oxygen for $E/N \leqslant 2.5$ Td, the experimental error has been estimated as ±1.5% for $E/N \leqslant 50$ Td, and ±3% for the values above 50 Td. In the case of oxygen the error for $E/N \leqslant 2.5$ Td has been taken to be ±5%, for $2.5 < E/N \leqslant 50$ Td as ±2%, and for $E/N > 50$ Td as ±3%. The percentage differences

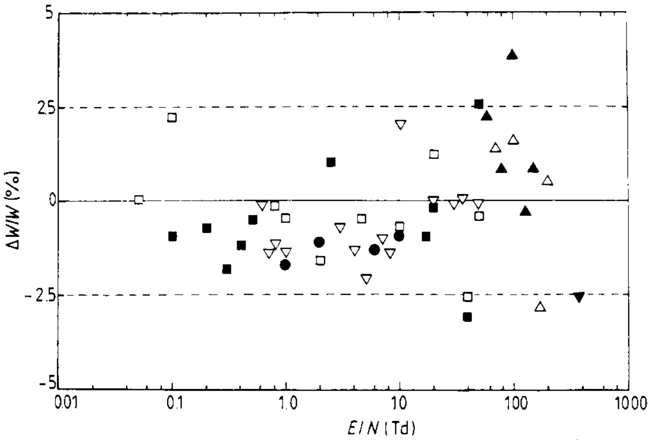

Figure 2. Percentage difference between the present results and those of other investigators for hydrogen, nitrogen, and carbon dioxide. Hydrogen: ■ (Lowke 1963); ● (Robertson 1971); ▲ (Blevin and Hasan 1967); ▼ (Saelee 1976). Nitrogen: □ (Lowke 1963); △ (Blevin and Hasan 1967). Carbon dioxide: ▽ (Elford and Haddad 1980).

between the present results and those of other investigators for hydrogen, nitrogen and carbon dioxide (whose estimated experimental errors did not exceed ±4% over the *E/N* range up to about 250 Td) are shown in figure 2. These differences, except for a few individual points, lie within the limits of error of the present experiments, while for all experimental points they lie within the limits of combined errors of the experiments which are compared.

Table 1 contains the results of the drift velocity measurements for $E/N \geqslant 50$ Td obtained in the present experiment.

3.1. Hydrogen

The comparison between our results and those of Lowke (1963), Robertson (1971), Blevin and Hasan (1967) and Saelee (1976) is shown in figure 2. The majority of our

Table 1. Drift velocity of electrons in hydrogen, nitrogen, oxygen, carbon monoxide, carbon dioxide and air free from water vapour and carbon dioxide at 293–296 K.

	Drift velocity W (10^4 m s^{-1})					
E/N (Td)	Hydrogen	Nitrogen	Oxygen	Carbon monoxide	Carbon dioxide	Air
50	5.861	6.065	9.476	4.534	10.96	8.725
75	9.244	8.533	12.11	—	—	11.82
100	13.35	10.68	14.93	8.360	12.53	13.24
125	17.27	—	16.81	—	13.32	14.12
150	21.48	15.10	19.39	12.91	14.01	16.32
175	25.42	18.15	23.24	—	15.55	18.99
200	30.45	21.31	25.93	—	17.37	21.52
250	40.09	27.60	30.08	—	21.01	25.71
300	—	—	—	—	—	31.65
400	—	—	—	—	—	39.60

data points agree within our experimental errors with the results of the references given. Our remaining results lie within the limits of the combined errors of our experiment and those of the references. The additional point measured for E/N = 367.2 Td confirms the good agreement between our results and those of Saelee (1976). Except for the results for E/N = 55 Td, our results agree fairly well with the data of Jaeger and Otto (1962) and with the results of Frommhold (1960), for $E/N \leqslant 120$ Td. Larger discrepancies with the data of Frommhold (1960) are found over the E/N range $120 \leqslant E/N \leqslant 250$ Td, where all our data points lie between 6 and 17% higher. Good agreement was found with the results of Blevin *et al* (1976b), obtained from observations of the photon flux produced in a Townsend discharge, but our data are lower than those obtained by Blevin *et al* (1978) using the Monte Carlo simulation technique and the difference between both sets of data increases to about 10% at 200 Td.

3.2. Nitrogen

Throughout the whole range of E/N values good agreement (within the combined errors of each two sets of experimental data) has been observed with the results of Lowke (1963) and of Blevin and Hasan (1967) (figure 2). However, the discrepancies with the results of the latter work for both sets of data over the E/N range $140 \leqslant E/N \leqslant 170$ Td, increase from 3 to 6%. A better agreement was found, over the same range of E/N, with the results of Tholl (1964). For the remaining values from the common E/N range our results agree with those of Tholl (1964) within the experimental error of our work. For $E/N \leqslant 120$ Td our measured results are in very good agreement with the data of Prasad and Smeaton (1967). Over the E/N range $150 \leqslant E/N \leqslant 250$ Td our data points are found to be higher than the corresponding results of Wagner (1964), and the discrepancies increase monotonically from about 1% for 150 Td to about 15% for 250 Td. From

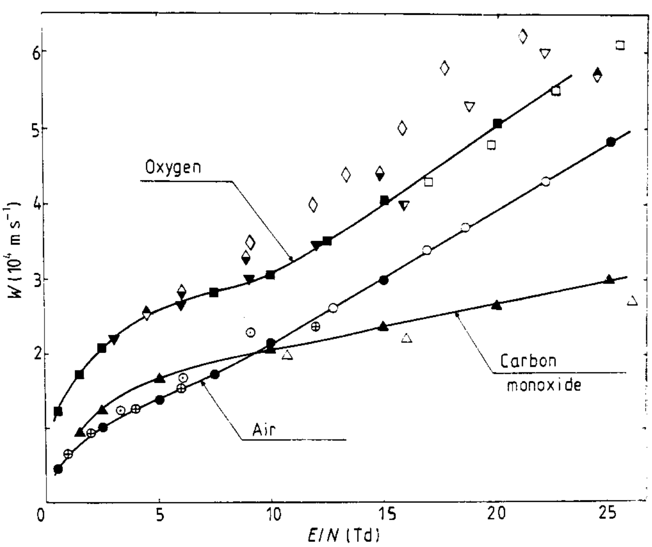

Figure 3. Drift velocities in oxygen, carbon monoxide and air below 27.5 Td. Oxygen: ▼ (Crompton and Elford 1973); ◇ (Doehring 1952); ⧫ (Fleming *et al* 1972); □ (Herreng 1952); ▼ (Naidu and Prasad 1970); ▽ (Nielsen and Bradbury 1937); ⧫ (Pack and Phelps 1966); ■ (present results). Carbon monoxide: △ (Pack and Phelps 1962); ▲ (present results). Air: ⊙ (Hessenauer 1967); ○ (Heylen 1962); ⊕ (Rees 1973); ● (present results).

comparison with the results of Fletcher and Reid (1980) it is seen that the agreement between both sets of data is good for $E/N < 200$ Td, while for $E/N \geqslant 200$ Td our results are found to be higher by about 7% at 200 Td and about 10% at 250 Td. Some discrepancies have been noted in relation to the theoretical data of Pitchford and Phelps (1982). It is seen that the agreement is quite good at 100 Td for their Monte Carlo simulation value, while for the remaining three E/N values (40, 70 and 200 Td) the discrepancies exceed the experimental errors of the present experiment independent of the drift velocity and calculation technique applied, and the maximum difference reaches about 12% at 200 Td. Good agreement was observed with the results of Monte Carlo simulations by Braglia *et al* (1982) for 100 Td and Novak and Frechette (1983) for 200 Td. For 40 and 100 Td discrepancies were found between our results and those presented in both quoted works which exceeded our experimental errors.

3.3. Oxygen

For the lowest E/N values measured in this work we found agreement with the results of Reid and Crompton (1980) within the combined errors of both sets of the experimental data. Below 12 Td our results agree well with the data of Crompton and Elford (1973). We also found a fair agreement with the results of Fleming *et al* (1972) over the common E/N range and with the data by Herreng (1952) for $E/N \leqslant 25$ Td. The discrepancies observed with the data of other investigators for $E/N \leqslant 27.5$ Td are shown in figure 3. For $20 \leqslant E/N \leqslant 100$ Td results of this work agree well with those of Naidu and Prasad (1970), but for $E/N \geqslant 100$ Td our data points are situated about 5% lower than the results of Naidu and Prasad (1970). There were larger discrepancies with the results of Frommhold (1964) over the E/N range $100 \leqslant E/N \leqslant 275$ Td but the difference between both data sets decreases from about 20% at 100 Td to about 3% at 275 Td. The two experimental points at 200 and 250 Td measured by Schlumbohm (1965) lie about 5% higher than ours.

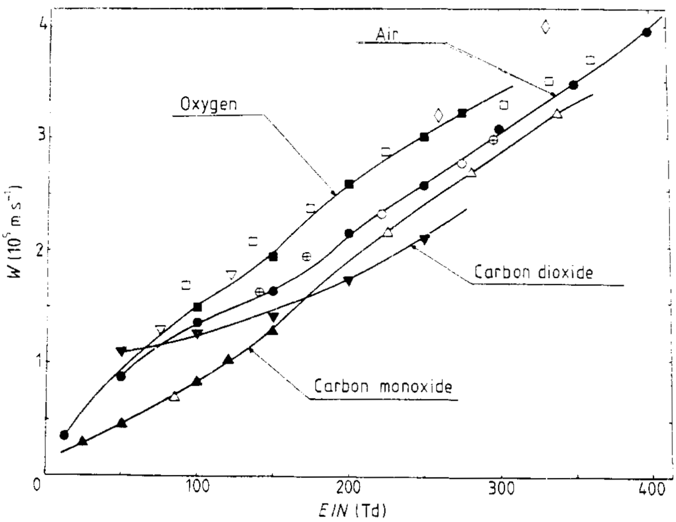

Figure 4. Drift velocities in oxygen, carbon monoxide, carbon dioxide and air at moderate E/N. Oxygen: □ (Frommhold 1964); ▽ (Naidu and Prasad 1970); ◇ (Schlumbohm 1965); ■ (present results). Carbon monoxide: △ (Saelee 1976); ▲ (present results). Carbon dioxide: ▼ (present results). Air: ○ (Frommhold 1974); ⊕ (Ryżko 1965); ● (present results).

3.4. Carbon monoxide

The agreement between the present results and those measured by Pack *et al* (1962) is good for $E/N \leqslant 0.8$ Td, but over the E/N range of $0.8 \leqslant E/N \leqslant 3$ Td our results are lower by rather more than 10%. Above 10 Td the results of this work are higher than the data of Pack *et al* (1962) and the difference between both sets of data increases up to 7% at 25 Td (figure 3). Good agreement with the data calculated by Lowke and Parker (1969) is observed over the common E/N range. Above 50 Td our results agree well with the data of Saelee (1976).

3.5. Carbon dioxide

Below 50 Td very good agreement (except for one point within about 1.5%) was observed with the experimental results of Elford and Haddad (1980) (figure 2). Over the E/N range $115 \leqslant E/N \leqslant 160$ Td our data points lie lower by about 15% than those measured by Frommhold (1960) and Schlumbohm (1965). Better agreement is seen with the result of Lowke and Parker (1969) at about 180 Td, where the difference is 7%.

3.6. Air

For $E/N \leqslant 12$ Td the results of this experiment agree very well with those of Rees (1973), whereas the difference between our results and the results of Hessenauer (1967) increases up to about 18% at 9 Td. Our present results for $E/N \leqslant 50$ Td are in good agreement with the theoretical data of Heylen (1962). Some discrepancies are observed above 50 Td within the limits 5 to 7%, and all our data points, except for one point at about 100 Td, lie higher than those of Heylen (1962). Over the common E/N range (up to about 300 Td) the present results agree well with the experimental data of Ryżko (1965).

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References

Blevin H A, Fletcher J and Hunter S R 1976b *J. Phys. D: Appl. Phys.* **9** 1671
—— 1978 *Aust. J. Phys.* **31** 299
Blevin H A, Fletcher J and Marzec L M 1976a *J. Phys. D: Appl. Phys.* **9** 465
Blevin H A and Hasan M Z 1967 *Aust. J. Phys.* **20** 735
Braglia G L and Lowke J J 1979 *J. Phys. D: Appl. Phys.* **12** 1831
Braglia G L, Romano L and Diligenti M 1982 *Phys. Rev.* A **26** 3689
Breare J M and von Engel A 1964 *Proc. R. Soc.* A **282** 390
Crompton R W and Elford M T 1973 *Aust. J. Phys.* **26** 771
Crompton R W, Elford M T and Jory R L 1967 *Aust. J. Phys.* **20** 369
Doehring A 1952 *Z. Naturf.* **7a** 253
Elford M T and Haddad G N 1980 *Aust. J. Phys.* **33** 517
Fleming J A, Gray D R and Rees J A 1972 *J. Phys. D: Appl. Phys.* **5** 291

Fletcher J and Reid I D 1980 *J. Phys. D: Appl. Phys.* **14** 1685
Frommhold L 1960 *Z. Phys.* **160** 554
—— 1964 *Fortschr. Phys.* **12** 597
Herreng P 1952 *Cah. Phys.* **38** 7
Hessenauer H 1967 *Z. Phys.* **204** 142
Heylen A E D 1962 *Proc. Phys. Soc.* **79** 284
Jaeger H and Otto 1962 *Z. Phys.* **169** 517
Lowke J J 1963 *Aust. J. Phys.* **16** 115
Lowke J J and Parker J H 1969 *Phys. Rev.* **181** 302
Lowke J J, Parker J H and Hall C A 1977 *Phys. Rev.* A **15** 1237
Naidu M S and Prasad A N 1970 *J. Phys. D: Appl. Phys.* **3** 957
Nielsen R A and Bradbury N E 1937 *Phys. Rev.* **51** 69
Novak J P and Frechette M 1983 *J. Appl. Phys.* in press
Pack J L and Phelps A V 1966 *J. Chem. Phys.* **44** 1970
Pack J L, Voshall R E and Phelps A V 1962 *Phys. Rev.* **127** 2084
Pitchford L C and Phelps A V 1982 *Phys. Rev.* A **25** 540
Prasad A N and Smeaton G P 1967 *Br. J. Appl. Phys.* **18** 371
Rees J A 1973 *Aust. J. Phys.* **26** 427
Reid I D and Crompton R W 1980 *Aust. J. Phys.* **33** 215
Robertson A G 1971 *Aust. J. Phys.* **24** 445
Ryżko H 1965 *Proc. Phys. Soc.* **85** 1283
Saelee H T 1976 *PhD Thesis* University of Liverpool
Schlumbohm H 1965 *Z. Phys.* **182** 317
Tholl H 1964 *Z. Phys.* **178** 183
Wagner K H 1964 *Z. Phys.* **178** 64