

Drift Velocity, Longitudinal and Transverse Diffusion in Hydrocarbons derived from Distributions of Single Electrons*

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Abstract

A time of flight method is described which allows the simultaneous measurement of drift velocity w and the ratios of the longitudinal and transverse diffusion coefficients to mobility (D_L/μ , D_T/μ) of electrons in gases. The accuracy achieved in this omnipurpose experiment is comparable with that of specialised techniques and is estimated to be $\pm 1\%$ for w and $\pm 5\%$ for the D/μ measurements. Results for methane, ethane, ethene, propane, propene and cyclopropane for values of E/N (the electric field strength divided by the number density) ranging from 0.02 to 15 Td are presented and discussed ($1 \text{ Td} = 10^{-21} \text{ V m}^2$).

1. Introduction

Cross sections for elastic and inelastic scattering of low energy electrons by molecules can be derived by different and rather complementary experimental techniques. The most detailed information is obtained in an angular resolved single scattering experiment using crossed beams of thermal molecules and electrons of a fixed energy. These experiments are indeed very powerful for the study of the energy and angular dependence of elastic as well as inelastic channels, but they are restricted to electron energies above 100 meV. Furthermore, complicated and delicate normalisation procedures have to be applied to obtain absolute cross sections from these data. Transport coefficients for low energy electron swarms measured as a function of the strength of an applied electric field offer an alternative approach to derive the desired cross sections. The energy range of this technique extends down to thermal energies given by the temperature of the gas. The drawback of the method is that the energy distribution of the electron swarm, as well as the resulting transport coefficients, are related to the fundamental scattering cross sections in a complicated way and a sophisticated kinetic theory has to be used to determine the microscopic properties from the measured data. The problem is even more complicated if the electron swarm is subject to boundary conditions which affect the observable quantities. Nevertheless, the method has been successfully used to derive elastic and inelastic cross sections for simple molecules (for example H_2 , N_2) which, when used with the appropriate numerical procedure to solve the transport equation, reproduce the measured transport

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coefficients to within the experimental uncertainties (Huxley and Crompton 1974 and references therein). The problem of disentangling the various cross sections for elastic scattering and rotational and vibrational excitation of the molecules makes it desirable to make use of the drift velocity and both longitudinal and transverse diffusion coefficients since these quantities depend in rather different ways on the microscopic behaviour of the electrons. In contrast to this, the existing cross section analyses are based on the drift velocity and the transverse diffusion coefficient alone, mainly due to the complete lack of experimental data on longitudinal diffusion.

Conventionally, the drift velocity and transverse diffusion coefficients are determined separately in dedicated experiments, the best of them achieving an absolute accuracy and reproducibility of about 1% (see Huxley and Crompton 1974 for a compilation). Unfortunately, these experimental procedures are delicate and time consuming and thus rather unwieldy for an overview of a variety of gases. In this paper we present a new technique which enables the complete set of low field transport parameters, i.e. drift velocity and both diffusion coefficients, to be measured in a single experiment with reasonable accuracy. The data obtained are an excellent base for the derivation of scattering cross sections, especially since the method used to measure the transport parameters is very direct and free of boundary corrections. The use of a proportional counter to detect single electrons restricts the technique to 'counting gases' and makes it ideal for the study of the hydrocarbons presented in this paper.

Data for scattering cross sections of hydrocarbons are of considerable interest now that supercomputers make quantum mechanical calculations for these gases feasible (Winstead *et al.* 1992; present issue p. 325). On the other hand, electron transport in hydrocarbons is of significant practical importance. The extensive use of those gases as counting gases for track detectors in high energy and nuclear physics makes it desirable to study the transport parameters of electron swarms in those gases as completely as possible. Whereas the design and the precision of drift chambers have been improved continuously within the last decade, the choice of the appropriate gas filling is still subject to experience or lucky chance, mainly due to the lack of precise data for the molecular gases involved. The powerful algorithms which have been developed in the last few years to solve the transport equations for all kinds of molecular gases (i.e. multi-term solutions of the Boltzmann transport equation) should enable detailed predictions of the behaviour of a gas mixture if the elastic and inelastic scattering cross sections of the constituent gases are known.

2. Apparatus and Experimental Procedure

(2a) Principle of the Measurement

The method presented here enables the transport parameters of electrons to be measured in a very direct and unbiased way. The drift velocity and longitudinal diffusion coefficient are determined from the arrival time distributions of single electrons at the end of a variable drift distance (Schmidt 1986). The electrons are produced at the focus of a pulsed UV laser via two photon ionisation directly in the gas far from the cathode. Thus no boundary corrections for the cathode have to be applied. After drifting a variable distance the electrons pass through

a pin hole in the anode and are detected in a proportional counter. The electric field in the drift region is therefore very well separated from the field inside the counter, distortions falling off exponentially on a scale given by the diameter of the aperture in the anode. Since the drift velocity as well as the diffusion coefficient are determined from a set of measurements using different drift lengths, field uncertainties and boundary effects near the anode cancel out as does the time resolution of the detector and the initial spread of the electron 'cloud'. The probability that an electron starting at a distance z passes the totally absorbing boundary between the drift region and the proportional counter in the time interval $(t, t+dt)$ is given by (Chandrasekhar 1943)

$$p(z, r) dt = \frac{z}{t} \frac{1}{\sqrt{4\pi D_L t}} \exp\left(-\frac{(z - wt)^2}{4D_L t}\right) dt, \quad (1)$$

where the drift velocity and longitudinal diffusion coefficient are denoted by w and D_L respectively. The maximum of this arrival time probability occurs at time t_m given by

$$t_m = \frac{z}{w} - 3 \frac{D_L}{w^2} + \frac{9}{2} \frac{D_L}{w^3 z} + \dots \quad (2)$$

It should be mentioned that, if the transport coefficients are derived from distributions at different drift distances, the (constant) first order correction term has no influence on the derived velocity. Higher order corrections are completely negligible due to the high gas pressures (200–1000 hPa) used in our experiment. The diffusional spread is small compared with the total drift time and the arrival time distribution is essentially Gaussian shaped.

The finite signal width of the proportional counter of about 20 ns does not permit the measurement of individual arrival times of electrons produced simultaneously within one laser pulse. A distortion of the drift time distribution resulting from the preferential detection of the first arriving electron can be avoided if the mean number of electrons per pulse entering the detector, n_{mean} , is kept small compared with unity. For n_{mean} less than 0.1 the systematic errors in the central value and width of the measured time distribution are well below 0.2%. As an additional bonus the space charge in the drift cell is kept negligibly small.

Since the UV light is focussed by a quartz lens into the drift cell, the region where electrons are produced is small in the two dimensions perpendicular to the laser beam. The waist of the beam is about 100 μm with the ionisation region being even smaller due to the quadratic dependence of the ionisation probability on the UV intensity. Since the aperture of the proportional counter is also small, the transverse distribution of the electrons arriving at the anode may be measured (Polenz and Schmidt 1988). According to similar arguments as given above, i.e. the negligible diffusion of the electrons during the typical spread of the arrival times, this distribution is also Gaussian and its variance increases linearly with the drift path. Thus the transverse diffusion coefficient of the electrons can be measured by scanning the laser spot over the aperture of the proportional counter while observing the counting rate normalised to constant

laser intensity. Again the initial spread as well as boundary effects cancel out if the distributions of different drift paths are compared. Since the transverse scan and the arrival time measurement can be done concurrently, the method enables the drift velocity and the longitudinal and transverse diffusion to be measured simultaneously from single drifting electrons.

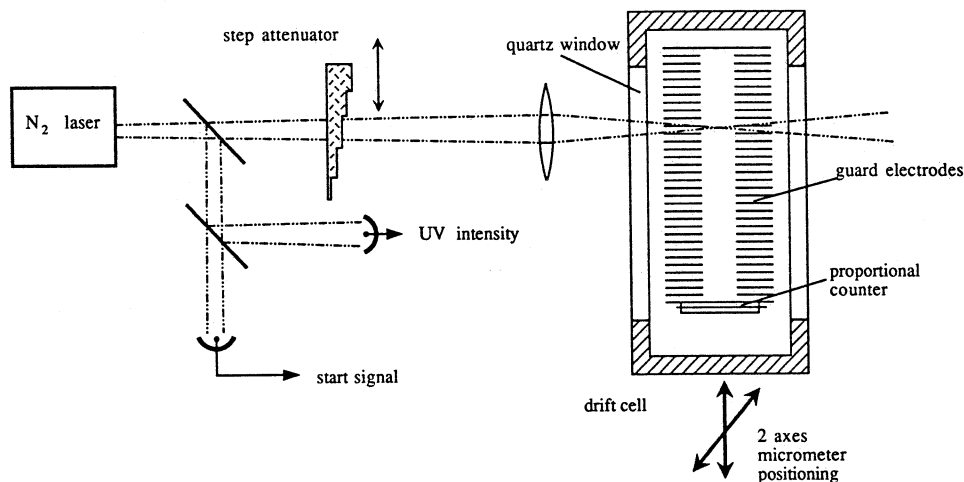


Fig. 1. Schematic view of the experimental set-up. The gas system is shown in Fig. 4.

(2b) The Apparatus

A schematic view of the experimental set-up is given in Fig. 1. The drift cell consists of a stainless steel housing with two quartz windows for the laser beam. Inside this cell the drift field is maintained by a set of guard electrodes connected to a resistor chain, the brass electrodes being separated by a ceramic insulator. The maximum drift distance is 10 cm. The aperture of the proportional counter is a 0.1 mm pin hole in a 50 μm gold foil acting as the anode of the drift region and cathode of the proportional counter. This counter consists of a gold plated tungsten wire 7 μm in diameter mounted in a rectangular brass tube 1 cm in width. For the gases investigated here the counter has a very high efficiency (>95%) for detecting single electrons and a fast pulse rise time (<2 ns).

The electrons are produced by a UV pulse from an N_2 laser (Type LN1000 from PRA); the pulse width is 0.8 ns and the average energy is 1 mJ per pulse. The laser runs with a repetition rate of 20 Hz. The ionisation occurs via two photon absorption at traces of impurities in the gas. For a typical energy density of about 0.1 J mm⁻² at 334 nm in the focus of the laser, extremely low concentrations of 10⁻¹⁰ to 10⁻¹¹ of aromatic hydrocarbons are sufficient to produce one photoelectron per pulse. These concentrations are difficult to avoid but fortunately have no significant influence on the measured transport coefficients. As mentioned above, in order to comply with the necessary condition of an ionisation probability of about 0.1 per pulse, the UV intensity is adjusted using a system of absorbing parallel glass plates brought into the beam. The energy of the individual laser shots is measured by a photodiode, mainly to correct for fluctuations in the laser intensity during the measurement of the

transverse diffusion. A second (fast) photodiode produces the start signal for the drift time measurement. The entire drift cell can be moved in two dimensions by a precision gear thus providing for the variable drift distance and to scan the laser focus transverse to the drift direction. The position of the cell is measured by electric gauges to an accuracy of $20\text{ }\mu\text{m}$.

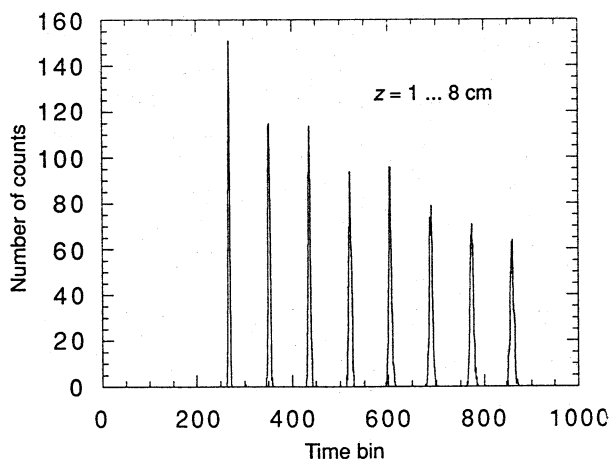


Fig. 2. Typical arrival time spectra for drift paths from 1 to 8 cm. The time offset is arbitrary.

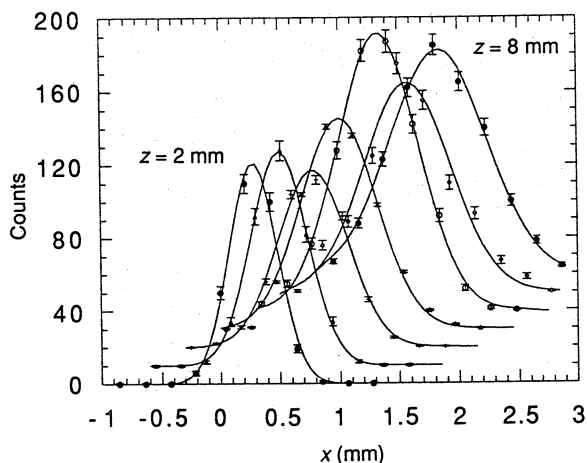


Fig. 3. Transverse distributions for drift paths from 2 to 8 cm. The data are shifted in both dimensions for better visibility.

The time interval between the pulses from the photodiode and the proportional counter are fed into a time to pulse height converter (TAC) and the resulting pulse height is digitised by means of a 10 bit resolution analog to digital converter (ADC). The system has been calibrated using an ORTEC 431 time calibrator and nonlinearities up to t^3 have been corrected. The accuracy achieved is better than 10^{-4} for a range of times up to $80\text{ }\mu\text{s}$. A typical set of arrival time spectra for eight drift distances from $z = 1$ to 8 cm is given in Fig. 2. Mean value $t_m(z)$ and

the width $\sigma_t(z)$ of the individual distributions are deduced using the maximum likelihood method: Using equation (1) the arrival time distribution having the maximal probability to produce the measured time histogram is determined using standard optimisation algorithms. The linear increase of t_m and σ_t^2 with the drift distance z furnishes the drift velocity w and the ratio of the longitudinal diffusion coefficient to mobility D_L/μ respectively. To determine the transverse diffusion coefficient we measured the counting rate of electrons normalised to constant laser intensity as a function of the displacement x of the laser focus perpendicular to the drift direction z . A sample of distributions obtained in this way for seven drift paths is given in Fig. 3. The linear increase of $\sigma_x^2(z)$ with the drift distance is used to deduce the ratio of the transverse diffusion coefficient to mobility D_T/μ .

(2c) Gas Handling and Purity

All gases used were of the highest commercially available purity. No further purification was carried out. A schematic sketch of the gas system is given in Fig. 4. The gas under investigation has been stored at the desired pressure in

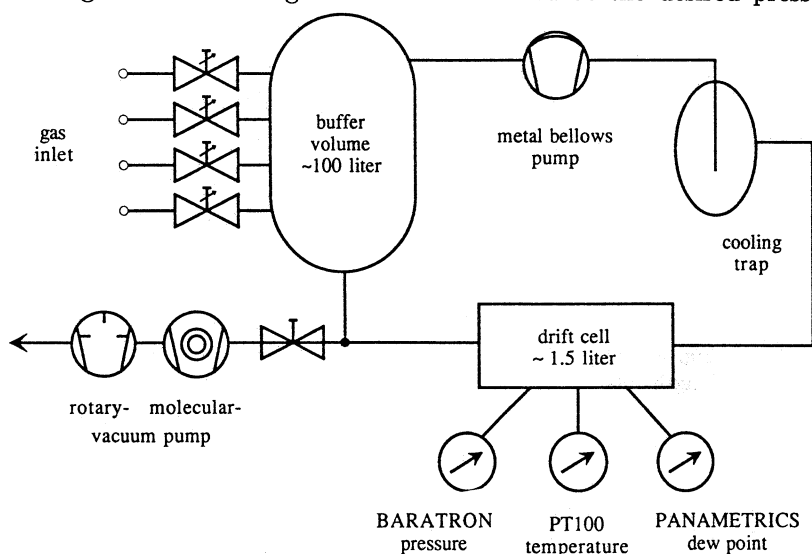


Fig. 4. Schematic view of the gas system.

Table 1. Purity and upper limits for various impurities in parts per million for the gases investigated as given by the supplier

	Methane	Ethane	Propane	Cyclopropane	Ethene	Propene
Purity (%)	99.9995	99.95	99.95	99.90	99.95	99.92
O ₂	0.5	10	10		15	
N ₂	2	40	40		50	20
H ₂	0.1					
CO ₂	0.1	10	10			
Other hydrocarbons	0.1	400	400		400	100
H ₂ O ^A	1	1	15	30	1	6

^A Water vapour contamination was measured during the experiment.

a reservoir of 50 litres volume and circulated continually through the drift cell by means of a metal bellows pump. The most critical impurity is water vapour, due to both its very high elastic and inelastic cross sections and its abundance in standard vacuum systems. To keep the water content as low as possible the gas was passed through a cooling trap before entering the drift cell, the temperature of the cooling trap being adjusted according to the vapour pressure of the gas under investigation. Thus water as well as other impurities having similar or lower vapour pressures have been kept at the ppm level. In addition the water content of the gas has been measured using a dew point sector connected directly to the drift cell. The limits of various impurities (as given by the gas supplier Messer Griesheim GmbH, Düsseldorf, Germany), together with the measured water content of the gases investigated, are summarised in Table 1.

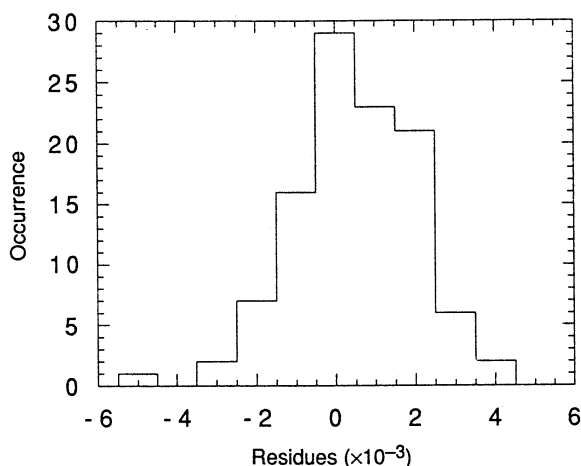


Fig. 5. Observed deviations from a linear drift time to drift length relation for an arbitrarily chosen set of measurements.

(2d) Accuracy of the Transport Parameters

Naturally, the drift velocity can be determined with much higher accuracy than the diffusion coefficients in a swarm experiment. In Fig. 5 we show the distribution of the residues, i.e. the relative deviations from a linear drift time versus drift distance relation, for an arbitrary set of measurements. This demonstrates the uniformity of the electric field in the drift region, as well as the absence of nonlinear distortions caused by diffusion or space charge effects. Thus the 'drift velocity under given conditions' can be determined with an uncertainty of $\leq 0.1\%$. However, the systematic uncertainties in the experimental parameters (gas density, temperature and purity etc.) restrict the reliability of the drift velocity obtained to about 1%. Various tests of reproducibility support the validity of this number.

On the other hand, the accuracy of the diffusion coefficients is limited mainly by statistical errors. A χ^2 analysis of the linear z dependence of the measured σ^2 follows the expected distribution, showing that the quoted statistical errors of the individual variances are reasonable and no hidden systematic deviations

are to be expected. For a practicable time of measurement of about 1 hour (longitudinal only) or 6 hours (including transverse scan) for eight drift distances at fixed E/N , a 5% accuracy for the diffusion coefficients is obtained.

3. Results and Comparison with Other Experiments

The experimental results for the drift velocity and the longitudinal and transverse diffusion are summarised in Tables 2–4. All measurements have been

Table 2. Drift velocity in $\text{cm } \mu\text{s}^{-1}$ at $297 \pm 3 \text{ K}$

E/N (Td)	Methane	Ethane	Propane	Ethene	Cyclopropane	Propene
0.020					0.063	
0.025					0.079	
0.030				0.097	0.094	
0.035				0.113	0.110	
0.040	0.130			0.130	0.125	
0.050	0.158			0.163	0.156	
0.060	0.198			0.189	0.187	
0.070	0.238			0.222	0.218	
0.080	0.270	0.289		0.257	0.248	
0.10	0.337	0.366		0.328	0.309	
0.12	0.409	0.445		0.393	0.369	
0.14	0.485	0.526	0.228	0.455	0.429	
0.16	0.566	0.609	0.262	0.515	0.487	
0.18	0.656	0.693	0.297	0.584	0.544	
0.20	0.745	0.777	0.332	0.651	0.601	0.106
0.25	0.964	0.988	0.421	0.807	0.738	0.132
0.30	1.20	1.19	0.514	0.931	0.871	0.158
0.35	1.44	1.41	0.610	1.08	1.00	0.184
0.40	1.70	1.62	0.705	1.22	1.12	0.211
0.50	2.24	2.00	0.894	1.49	1.36	0.264
0.60	2.84	2.36	1.08	1.73	1.59	0.319
0.70	3.44	2.68	1.26	1.96	1.79	0.374
0.80	4.10	2.98	1.44	2.17	1.97	0.429
1.00	5.22	3.47	1.78	2.55	2.29	0.540
1.20	6.37	3.83	2.09	2.88	2.56	0.652
1.40	7.33	4.11	2.36	3.18	2.78	0.765
1.60	8.13	4.33	2.61	3.46	2.97	0.883
1.80	8.76	4.50	2.82	3.69	3.13	1.00
2.00	9.27	4.64	3.00	3.89	3.27	1.13
2.50	10.09	4.89	3.40	4.28	3.52	1.44
3.00	10.44	5.06	3.67	4.57	3.67	1.73
3.50	10.50	5.18	3.88	4.77	3.78	2.03
4.00	10.46	5.27	4.05	4.91	3.84	2.33
4.50	10.31	5.33	4.17	5.01	3.89	2.62
5.00	10.06	5.38	4.28	5.07	3.91	2.88
6.00	9.47	5.44	4.45	5.13	3.92	3.36
7.00	8.90	5.47	4.59	5.12	3.91	3.76
8.00	8.36	5.48			3.89	
10.0	7.52					
12.0	6.93					
14.0	6.45					

performed at room temperature (297 ± 3 K) and at pressures within the range 200–900 hPa. The uncertainty (including systematic uncertainties) in the data is 1% for w and 5% for D_L and D_T according to arguments given above; no pressure dependences have been observed within these limits. Since the values at fixed E/N presented in these tables are derived as averages and interpolation of the actually measured data they are to some extent correlated and should not be treated as independent measurements. The diffusion is given as the diffusion coefficient to mobility ratio for the sake of E/N scaling.

Table 3. Longitudinal diffusion coefficient to mobility ratio in eV at 297 ± 3 K

E/N (Td)	Methane	Ethane	Propane	Ethene	Cyclopropane	Propene
0.0200					0.0267	
0.0250					0.0267	
0.0300					0.0266	
0.0350	0.0347			0.0268	0.0266	
0.0400	0.0350			0.0268	0.0266	
0.0500	0.0355			0.0269	0.0266	
0.0600	0.0359			0.0269	0.0266	
0.0700	0.0362			0.0269	0.0265	
0.0800	0.0365	0.0317		0.0270	0.0265	
0.100	0.0371	0.0333		0.0271	0.0267	
0.120	0.0383	0.0348		0.0272	0.0269	
0.140	0.0398	0.0362		0.0272	0.0272	
0.160	0.0415	0.0376	0.0276	0.0273	0.0274	
0.180	0.0433	0.0390	0.0282	0.0274	0.0276	
0.200	0.0453	0.0403	0.0288	0.0275	0.0277	0.0244
0.250	0.0496	0.0430	0.0306	0.0280	0.0276	0.0242
0.300	0.0537	0.0443	0.0327	0.0284	0.0279	0.0241
0.350	0.0578	0.0449	0.0349	0.0288	0.0286	0.0241
0.400	0.0615	0.0452	0.0371	0.0292	0.0293	0.0242
0.500	0.0706	0.0454	0.0410	0.0293	0.0295	0.0248
0.600	0.0776	0.0454	0.0441	0.0295	0.0297	0.0256
0.700	0.0834	0.0456	0.0460	0.0300	0.0297	0.0264
0.800	0.0882	0.0460	0.0468	0.0306	0.0296	0.0272
1.00	0.0921	0.0467	0.0476	0.0317	0.0295	0.0287
1.20	0.0950	0.0469	0.0481	0.0325	0.0300	0.0301
1.40	0.0940	0.0472	0.0484	0.0332	0.0304	0.0315
1.60	0.0912	0.0481	0.0487	0.0340	0.0311	0.0330
1.80	0.0884	0.0496	0.0491	0.0345	0.0319	0.0346
2.00	0.0860	0.0516	0.0494	0.0349	0.0327	0.0363
2.50	0.0823	0.0582	0.0491	0.0361	0.0346	0.0409
3.00	0.0829	0.0644	0.0503	0.0376	0.0362	0.0459
3.50	0.0872	0.0695	0.0507	0.0393	0.0374	0.0508
4.00	0.0927	0.0731	0.0500	0.0410	0.0387	0.0545
4.50	0.0982	0.0772	0.0499	0.0428	0.0403	0.0559
5.00	0.103	0.0812	0.0508	0.0447	0.0422	0.0564
6.00	0.109	0.0862	0.0553	0.0485	0.0472	0.0585
7.00	0.115	0.0910		0.0523	0.0535	0.0677
8.00	0.126	0.0955			0.0598	
10.0	0.156	0.104				
12.0	0.165					
14.0	0.168					

For *methane* the drift velocity and transverse diffusion have been measured over a similar range of E/N values with high accuracy by Haddad (1985) using Bradbury-Nielsen and Townsend-Huxley drift tubes respectively. Thus a comparison with his data could be useful for checking the consistency of these well known and established experimental techniques with the method presented in this paper. As shown in Fig. 6, the drift velocities of both experiments are in excellent agreement, as the deviation never exceeds the combined errors of both experiments. Also shown in Fig. 6 are the deviations from the results of three other experiments published more recently. Hunter *et al.* (1986) as well as Floriano *et al.* (1986) used a pulsed Townsend experiment, whereas the data of Al-Amin *et al.* (1985) were derived using a time of flight technique. The results of Hunter *et al.* exhibit small but nevertheless systematic deviations in the range $\pm 5\%$ partially outside the combined experimental uncertainties. The substantial deviations of the results obtained by Al-Amin *et al.* and Floriano *et al.*

Table 4. Transverse diffusion coefficient to mobility ratio in eV at 297 ± 3 K

E/N (Td)	Methane	Ethane	Propane	Ethene	Cyclopropane	Propene
0.0500		0.0295		0.0321	0.0259	
0.0600	0.0289	0.0295		0.0321	0.0260	
0.0700	0.0292	0.0295		0.0321	0.0260	
0.0800	0.0295	0.0295		0.0321	0.0261	
0.100	0.0301	0.0295		0.0321	0.0263	
0.120	0.0307	0.0296	0.0316	0.0321	0.0265	
0.140	0.0313	0.0298	0.0319	0.0321	0.0268	
0.160	0.0319	0.0301	0.0321	0.0321	0.0272	
0.180	0.0325	0.0305	0.0325	0.0321	0.0276	
0.200	0.0331	0.0311	0.0328	0.0322	0.0280	0.0269
0.250	0.0346	0.0333	0.0336	0.0324	0.0290	0.0269
0.300	0.0363	0.0363	0.0346	0.0330	0.0301	0.0269
0.350	0.0381	0.0394	0.0356	0.0339	0.0313	0.0270
0.400	0.0399	0.0425	0.0369	0.0349	0.0326	0.0270
0.500	0.0436	0.0483	0.0400	0.0370	0.0353	0.0271
0.600	0.0479	0.0539	0.0434	0.0387	0.0381	0.0273
0.700	0.0522	0.0593	0.0464	0.0400	0.0408	0.0278
0.800	0.0566	0.0647	0.0489	0.0410	0.0433	0.0285
1.00	0.0671	0.0753	0.0547	0.0428	0.0472	0.0300
1.20	0.0770	0.0859	0.0629	0.0449	0.0501	0.0308
1.40	0.0883	0.0962	0.0709	0.0474	0.0529	0.0311
1.60	0.101	0.106	0.0758	0.0504	0.0556	0.0316
1.80	0.113	0.115	0.0785	0.0536	0.0585	0.0323
2.00	0.125	0.122	0.0818	0.0569	0.0614	0.0332
2.50	0.158	0.136	0.102	0.0656	0.0687	0.0370
3.00	0.196	0.145	0.133	0.0746	0.0762	0.0417
3.50	0.240	0.156	0.179	0.0837	0.0840	0.0466
4.00	0.287	0.167	0.228	0.0929		0.0515
4.50	0.334	0.181		0.102		0.0564
5.00	0.380	0.196		0.111		0.0612
6.00	0.479	0.227		0.129		0.0707
7.00	0.585	0.263		0.149		0.0803
8.00	0.690	0.305		0.168		

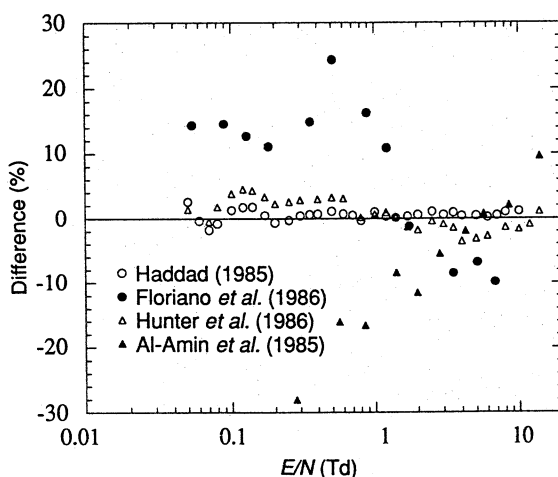


Fig. 6. Difference between the measured drift velocities in methane from various experiments and the results of this work. (Positive values indicate a higher drift velocity measured in the reference quoted.)

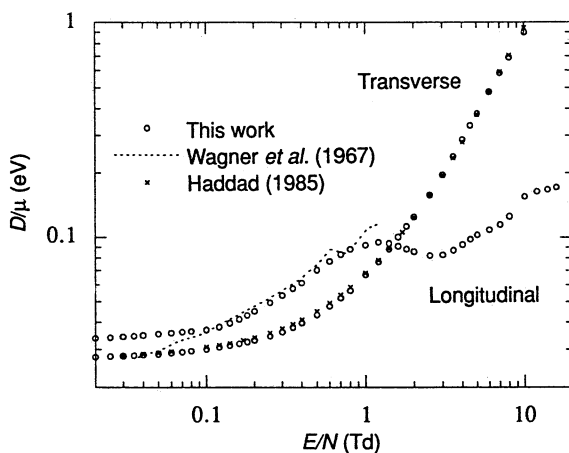


Fig. 7. Transverse and longitudinal characteristic energy in methane as measured in this experiment and compared with previous results.

exceed, especially in the range of low E/N , the quoted uncertainties of these experiments by almost a factor of 10 and are presumably due to systematic effects or impurities in the gas.

The transverse and longitudinal diffusion coefficients in methane as measured in this experiment are given in Fig. 7 and compared with the little available experimental data for this range of E/N . Again the agreement with the transverse data of Haddad is very good and does not exceed the experimental uncertainties. The deviation of about 4% in the region of $E/N = 0.3$ Td is insignificant to within the quoted accuracy of our experiment, but might be subject to further

investigation. The data for the longitudinal diffusion coefficient obtained in the pioneering experiment of Wagner *et al.* (1967) are consistent with our results in the range of field from 0.1 to 1 Td.

For the heavier hydrocarbons in this range of E/N values only drift velocity data have been available so far. Besides methane, as mentioned above, Floriano *et al.* (1986) have published results on *ethane*, *propane* and *isobutane*. Whereas their drift velocity values for *propane* agree with our result to within $\pm 5\%$, their data for *ethane* and *isobutane* exhibit behaviour similar to methane, the drift velocities being up to 15% higher for low reduced fields. The data of McCorkle *et al.* (1978) for *ethane* and *propane* are consistent with our results within their quoted error of $\pm 5\%$. In contrast to the situation found in methane, the vintage measurement of longitudinal diffusion in *ethene* by Wagner and co-workers (1967) exhibits systematic deviations of up to $\pm 30\%$.

4. Conclusions

The experimental method described in this paper enables the drift velocity and both longitudinal and transverse diffusion of electrons to be measured in counting gases over a wide range of E/N with good accuracy. The good agreement of the experimental results for methane with the data obtained by Haddad using 'conventional' drift tubes indicates that there are no significant systematic errors in this new technique. The transport parameters for the light hydrocarbons presented here are an excellent basis for determining the elastic and inelastic cross sections of these gases. A detailed analysis for methane, based on the experimental data shown above and using a multi-term solution of the Boltzmann equation (Ness and Robson 1986), has been published recently (Schmidt 1991). It turned out to be impossible to describe the drift velocity and both transverse and longitudinal diffusion with a unique set of cross sections when *isotropic* scattering was assumed. The necessary inclusion of two higher order partial cross sections for elastic scattering in the vicinity of the Ramsauer minimum influences the ratio of transverse to longitudinal diffusion by about 18%, and enables the complete set of transport coefficients in the range of field up to 20 Td to be reproduced within the experimental uncertainties. Similar analyses for the heavier hydrocarbons are under way and will be presented in a forthcoming publication.

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