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Section A

Consistent measurements comparing the drift features of noble gas mixtures

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Abstract

We present a consistent set of measurements of electron drift velocities and Lorentz deflection angles for all noble gases with methane and ethane as quenchers in magnetic fields up to 0.8 T. Empirical descriptions are also presented. Details on the World Wide Web allow for guided design and optimization of future detectors. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

A systematic knowledge of electron drift properties in many gas mixtures at varied electric and magnetic fields is essential for the design of future particle detectors. Though measurements, calculations and interpretations of the drift velocities of electrons through many gas mixtures are available in the literature (Refs. [1–5]), no systematic study allowing precise interpolation of features has been done. The purpose of this publication is to give a consistent set of data for an accurate relative comparison allowing detailed understanding of the principal features. Empirical fits of the data provide a more compact form to communicate the results and give physical insight.

2. Apparatus and measurement procedure

The experimental setup has been described in Ref. [6]. A voltage difference between the cathode plate and the anode mesh creates a variable driving electric field (E) up to 1.3 kV/cm (Fig. 1). A 337 nm N_2 laser beam provides ionization along tracks precisely known from the positioning of a mirror by a micrometer. Electrons drift under the influence of the electric and magnetic fields to the amplification gap, where signal wires measure arrival times and induction pads behind these wires measure deflection. Differential measurements between the positions allow high accuracy. Knowing Δx and measuring Δt determines $v_{\parallel} = \Delta x/\Delta t$, the velocity component parallel to E. The entire chamber is situated in the MIT cyclotron magnet which provides a uniform magnetic field (B) which is perpendicular to the E field and the wires.

Helium, neon, argon, krypton, and xenon were mixed with 10–50% of quenching hydrocarbons,

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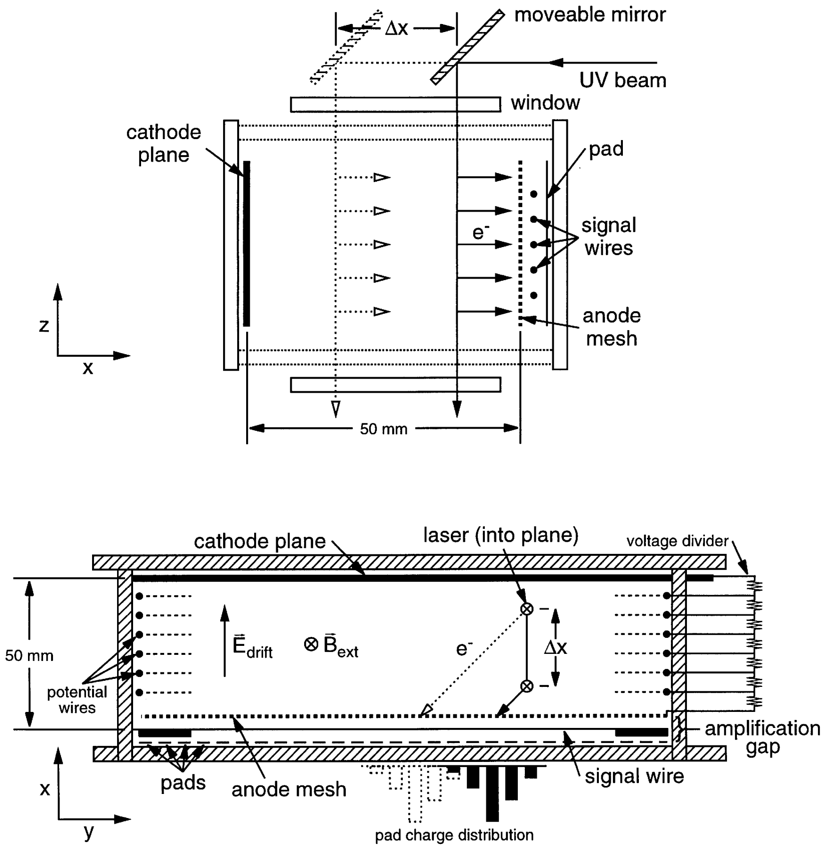


Fig. 1. Schematic representation of test chamber used in drift velocity and Lorentz angle measurement. The side view shows the UV laser beam displacement while the top view shows the center of gravity measurement of the magnetic deflection.

here methane and, for comparison, ethane. Drift time and the "center of gravity" of the pad's charge distribution is averaged over 100 laser shots for each of the 24 electric field settings, four magnetic field settings, and at least two position settings of the laser beam for each of the 25 gas mixtures with two quenchers resulting in a total of $(24 \cdot 4 \cdot 2 \cdot 25 \cdot 2) = 9600$ measurements.

3. Drift velocity and Lorentz angle measurements

It is for this reason that we will present and discuss only some examples in this paper. The complete set of results can be obtained on the World Wide Web page from MIT at http://cyclotron.mit.edu/drift/drift.html.

Fig. 2 gives an overview of noble gas mixtures with methane. Helium and xenon are "slow" gases relative to neon and argon. Deflection angles are particularly large for the commonly used gas argon. The drift velocity generally increases with methane content, which is not surprising since methane itself is a "fast" gas at low E (Fig. 3). Methane's cross-section is similar to argon's cross-section in that it also has a "Ramsauer" minimum (Ref. [7]) at electron energies of 0.2 eV which allows for fast drifting at corresponding E.

For increasing B, the drift velocity component along E is seen to diminish in all gases. One might expect the rms deflection, α, to grow proportionally to the magnetic force $q(v \times B)$ relative to the electric force qE, i.e. $\tan \alpha = v \times B/E$. The $1/E$ dependence is clearly visible in the data of Fig. 2 and Fig. 3 at

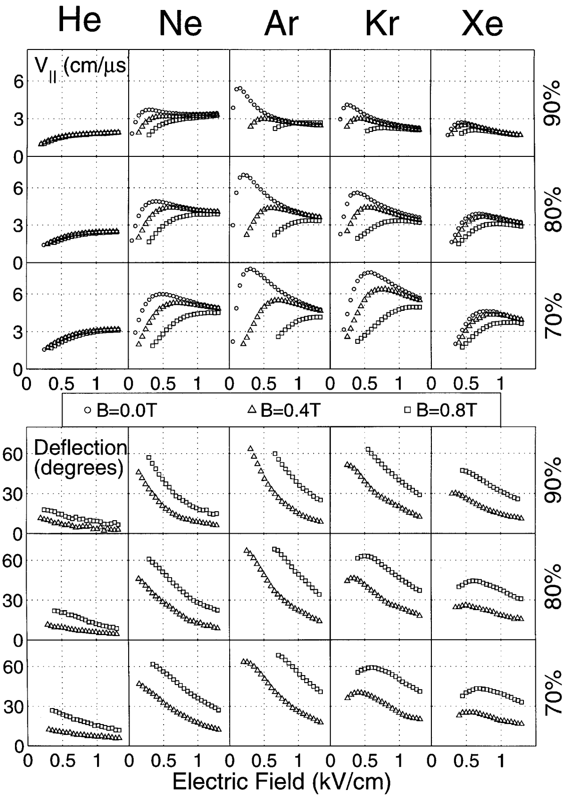


Fig. 2. An overview of the drift velocity and deflection angle measurements for noble gases with methane additions from 10% to 30%.

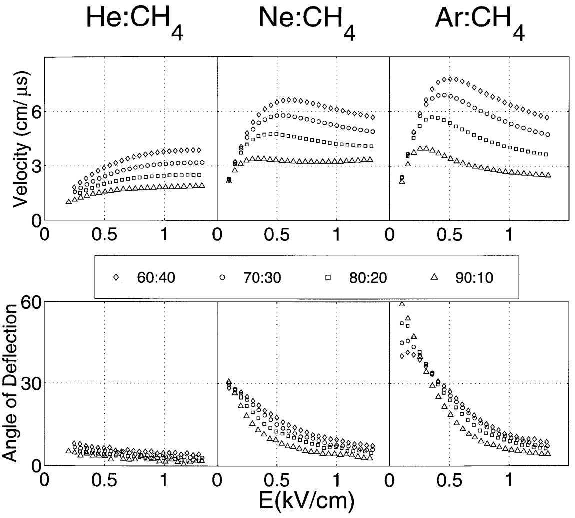


Fig. 3. Increasing drift velocity with additional methane content (from 10% to 40%) for He-, Ne- and Ar-based mixtures.

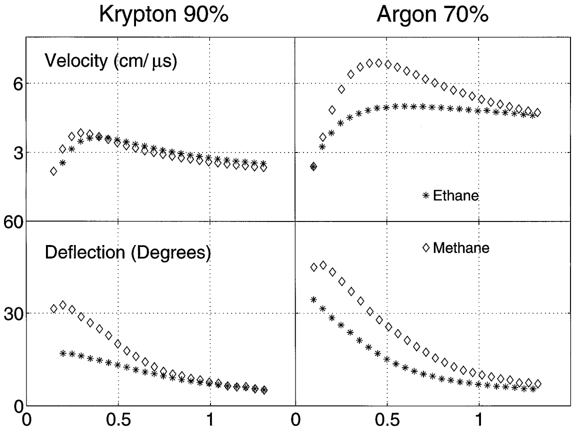


Fig. 4. A comparison between methane and ethane quenchers in Kr- and Ar-based gases.

large E field strengths. For low E, the situation is not as simple, thus direct measurements must be carried out.

Comparing methane and ethane contaminations, we generally see lower drift velocities for ethane, as shown in Fig. 4. In addition, ethane produces lower α than methane, even if the velocities are roughly equal. For example, this can be seen if one compares Kr : CH$_4$ (90 : 10%) with Kr : C$_2$H$_6$(90 : 10%) at $E = 0.3$ kV/cm (Fig. 4). Gases with large deflection allow less accurate coordinate reconstruction. For low-deflection gases, accurate reconstruction in inhomogeneous and even non-orthogonal E, B fields is possible (Ref. [8]).

More precise values for these, as well as other mixtures, are best obtained from http://cyclotron.mit.edu/drift/drift.html. Because all measurements are made with the same apparatus, relative comparisons are accurate to the 1% level.

4. Empirical description

In order to reduce the wealth of information and gain insight into regularities of the results, we give empirically fitted functions describing the measured behavior of $v_{||}$ and α as a function of E and B. The number of parameters is adjusted in order to obtain a χ^2 per degree of freedom less than

1.5. We use

$$v_{\parallel} = u_1(1 - \mathrm{e}^{-E'/E_1}) + u_2 E' \mathrm{e}^{-(E' - \varepsilon_2)E_2} + wE', \qquad (1)$$

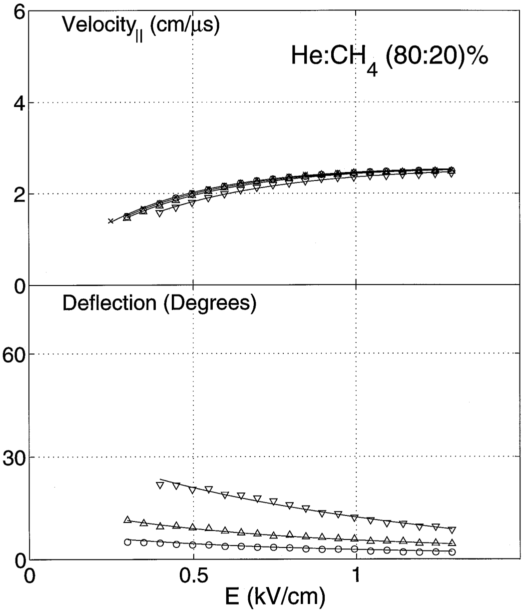
where E' is the adjusted electric field, $E - \varepsilon$. The first term goes to the limiting value u_1 for $E' \gg E_1$, corresponding to an electron drifting through a medium of constant cross-section or, in other words, constant viscosity. The second term accounts for an increase in drift velocity produced by Ramsauer minima in the gases' cross-sections. The last term is simply a linear correction in E'.

The magnetic deflection angle is described by the Lorentz force with an additional corrective expansion in E.

$$\sin\alpha = \frac{v_{\parallel} B}{E} + p_1 + p_2 E + p_3 E^2, \qquad (2)$$

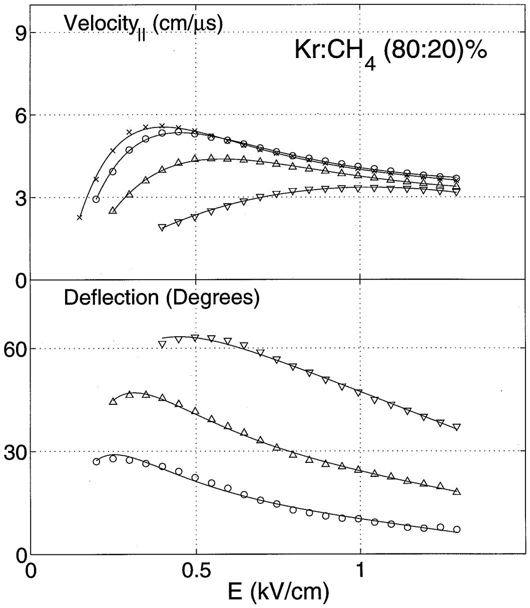
where $v_{\parallel}$ is just $v \cos\alpha$, the projection of the total drift velocity in the direction of E.

Helium's nearly constant cross-section requires only the first term of the velocity fit for an adequate description (Fig. 5; note that the legend and salient parameters are included in the table below the graphs). Gases with pronounced Ramsauer minima, such as argon and krypton, require the second term to account for the peak in the drift velocity (Fig. 6). Because these simple empirical fits do not model rapid changes at low E, their validity is strictly limited to the range indicated by the solid line.



		$V_{\parallel}=U_1(1-e^{-(E-\varepsilon)/E_1})+U_2(E-\varepsilon)e^{-(E-\varepsilon+\varepsilon_2)^*E_2}+W(E-\varepsilon)$								$\sin(\alpha)=V_{\parallel}B/(10^*E)+P_1+P_2{}^*E+P_3{}^*E^2$			
B(T)		U_1	E_1	U_2	E_2	W	ε	ε_2	χ^2/dof	P_1	P_2	P_3	χ^2/dof
0.0	×	2.6	0.33	0	0	0	0	0	0.73	0	0	0	–
0.2	○	2.6	0.34	0	0	0	0	0	0.48	0	0	0	0.44
0.4	△	2.6	0.35	0	0	0	0	0	0.69	0	0	0	0.19
0.8	▽	2.6	0.41	0	0	0	0	0	0.88	0.11	−0.082	0	1.01

Fig. 5. He : CH$_4$ (80 : 20)%. An empirical fit overlaying data with the formula and parameters given below.



		$V_{\parallel}=U_1(1-e^{-(E-\varepsilon)/E_1})+U_2(E-\varepsilon)e^{-(E-\varepsilon+\varepsilon_2)^*E_2}+W(E-\varepsilon)$								$\sin(\alpha)=V_{\parallel}B/(10^*E)+P_1+P_2{}^*E+P_3{}^*E^2$			
B(T)		U_1	E_1	U_2	E_2	W	ε	ε_2	χ^2/dof	P_1	P_2	P_3	χ^2/dof
0.0	×	4.7	0.4	27	4.7	−0.88	0.1	−0.11	1.37	0	0	0	–
0.2	○	3.5	0.23	34	4.4	0	0.12	0	0.64	0.17	−0.0054	−0.065	2.06
0.4	△	5.2	2	27	2.9	0	0.14	0	0.63	0.3	0.079	−0.11	0.61
0.8	▽	1.1	1	11	0.61	−3.2	0.13	0	1.85	0.47	0.17	−0.18	1.04

Fig. 6. For Kr : CH$_4$ (80 : 20)%, more parameters are needed for a good description.

We plan to add to the data and fits on WWW[1] the predictions of the latest version of the program Magboltz [4], which was made available to us after the completion of this paper.

5. Attempt for unified description

Further data reduction is possible with the realization that low B fields primarily change electrons'

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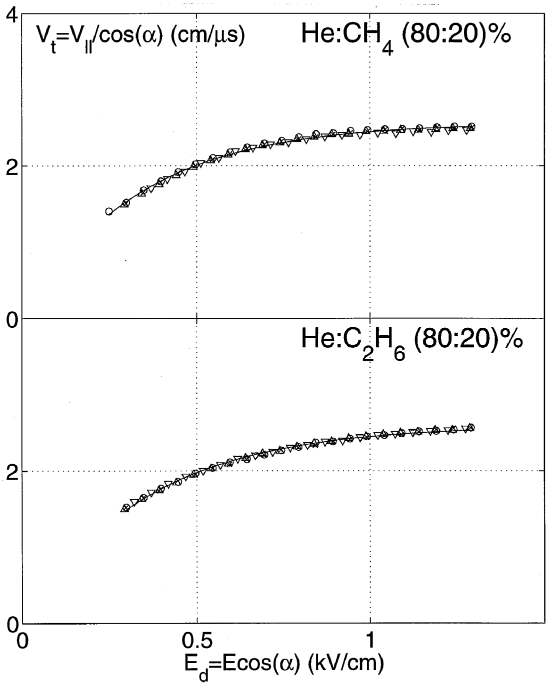
[1] http://cyclotron.mit.edu/drift/drift.html.



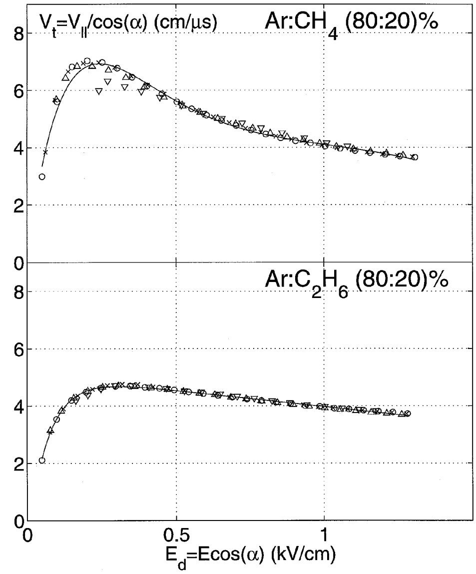
B(T)	Universal Fit Information
0.0 × 0.2 ○ 0.4 △ 0.8 ▽	$V_t=U_1(1-e^{-(E_d-\varepsilon)/E_1})+U_2(E_d-\varepsilon)e^{-(E_d-\varepsilon+\varepsilon_2)^{*}E_2}+W(E_d-\varepsilon)$ 1st: $U_1=2.6$ $E_1=0.33$ $U_2=0$ $E_2=0$ $W=0$ $\varepsilon=0$ $\varepsilon_2=0$ 2nd: $U_1=2.6$ $E_1=0.35$ $U_2=0$ $E_2=0$ $W=0$ $\varepsilon=0$ $\varepsilon_2=0$

Fig. 7. An “universal” fit of He : CH_4 (80 : 20)% giving all velocities for different magnetic fields with one curve. Fit function and parameters are also given below.

direction rather than their velocity. Hence plotting the total drift velocity, v, versus the “effective” field component, $E\cos\alpha$, should result in curves independent of B. These “universal” curves can describe the behavior for a given mixture very well, as shown in Ref. [9]. For example, helium-based mixtures (Fig. 7) are very predictable, as are argon mixtures with ethane (Fig. 8). However, argon with methane shows deviations at 0.8 T. A further example with xenon (Fig. 9) corroborates the accuracy of the fits up to 0.8 T with ethane and 0.4 T with methane.

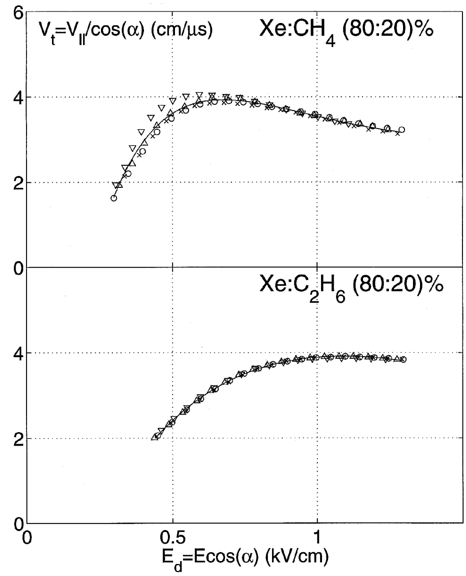
The information for all other gases can be obtained.[1]

Using these fit functions, data sets, which typically contain over 160 points, can be described by at most 16 parameters – an order of magnitude reduction!



B(T)	Universal Fit Information
0.0 × 0.2 ○ 0.4 △ 0.8 ▽	$V_t=U_1(1-e^{-(E_d-\varepsilon)/E_1})+U_2(E_d-\varepsilon)e^{-(E_d-\varepsilon+\varepsilon_2)^{*}E_2}+W(E_d-\varepsilon)$ 1st: $U_1=19$ $E_1=-2.1$ $U_2=78$ $E_2=5$ $W=15$ $\varepsilon=0$ $\varepsilon_2=0$ 2nd: $U_1=5.1$ $E_1=0.071$ $U_2=0$ $E_2=0$ $W=-1.1$ $\varepsilon=0.009$ $\varepsilon_2=0$

Fig. 8. For Ar : CH_4 (80 : 20)%, velocities are lower than expected at $B = 0.8$ T.



B(T)	Universal Fit Information
0.0 × 0.2 ○ 0.4 △ 0.8 ▽	$V_t=U_1(1-e^{-(E_d-\varepsilon)/E_1})+U_2(E_d-\varepsilon)e^{-(E_d-\varepsilon+\varepsilon_2)^{*}E_2}+W(E_d-\varepsilon)$ 1st: $U_1=1e+02$ $E_1=-25$ $U_2=24$ $E_2=2.7$ $W=5.8$ $\varepsilon=0.22$ $\varepsilon_2=0$ 2nd: $U_1=7.8$ $E_1=0.5$ $U_2=0$ $E_2=0$ $W=-2.9$ $\varepsilon=0.24$ $\varepsilon_2=0$

Fig. 9. For Xe : CH_4 (80 : 20)%, velocities are higher than expected at $B = 0.8$ T.

6. Summary

The paper draws attention to a large set of systematic drift gas measurements on the WWW, part of which are presented. This information allows guided optimization for new designs. Whereas we consider the data more important in their comparitive systematics, we also give an empirical formula to describe them. Finally, we give a universal description allowing analytic predictions of the velocities for various E and B. The accuracy depends on the gas, but the procedure gives understanding of the gas drift features and allows interpolation to different B fields.

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