DIMETHYLETHER: A LOW VELOCITY, LOW DIFFUSION DRIFT CHAMBER GAS*

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1. Introduction

There are two main motivations to look for a low electron mobility gas: the first is that a low drift velocity relaxes the need to measure drift times with nanosecond (or even subnanosecond) precision; the second is that (in an ideal drift geometry), the capability of resolving two closely spaced tracks depends upon the ratio of electron mobility to ion mobility μ_e/μ_i. Since μ_i is rather constant, the way to separate two tracks is to slow down the electrons.

A low drift velocity can be obtained at low electric field, but the gain in dual track separation and precision is offset by a large diffusion.

Many other properties are required besides low mobility and low drifting electron temperature: the gas should have a large ($> 10^3$) stable gain; it must be chemically stable and not toxic; it should not attack materials commonly used to fabricate drift chambers, etc. With these requirements in mind, we have tried a few promising (on paper) gases, either pure or in admixture with Argon. Water, for instance, has an extremely low mobility (v_d about 0.05 cm/μsec at 3 KV/cm field), and almost thermal diffusion up to 8 KV/cm (Ref. 1); its toxicity, chemical stability, and cost are acceptable; but the gain is not measurable, and the temperature at which the chamber must run is uncomfortable. One of the gases examined, dimethylether [$(CH_3)_2O$], has shown interesting characteristics.

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2. Rationale of the Search

Drift velocity and diffusion are related to the cross sections for various processes involved in electron-molecule interactions in a very complicated manner.

Under the assumption that the electron energy distribution is Maxwellian, and that the collision cross section does not vary rapidly with energy, one can write an approximate relation (Ref. 2) for v_d (drift velocity) and k (mean energy of electron/mean energy of gas molecule) as:

$$v_d = A \lambda^{1/4} \sigma^{-1/2}$$

$$k = B \lambda^{-1/2} \sigma^{-1}$$

where A, B are functions of pressure, temperature, and electric field, λ is the fractional energy loss (mass electron/mass of molecule, for elastic collisions), σ the collision cross section. Since both k and v_d should be small, one needs a gas with a large cross section, and large inelasticity: in other words, a gas that appears "viscous" to the electrons. Gases with a large electric dipole moment have large cross sections; the inelasticity is given by the presence of a rich vibrational and rotational spectrum.

3. Gain and Drift Velocity Measurements

A small drift chamber has been used to measure gain and drift velocity of different gases (Fig. 1). The chamber is designed to have a uniform drift field for a distance of 3 cm. The collimated electrons from three ^{106}Ru sources traverse the gas and trigger a scintillation counter. Drift velocity as a function of E is measured by the difference of time of flight between source 2 and source 3.

For substances having low vapour pressure at room temperature, we have used a single proportional tube that can be heated up to 200^oC: two polar molecules, m-Xylene and o-Xylene $[(C_6H_4)(CH_3)_2]$, showed reasonable gain for a short period of time (a few hours). After this time, it was necessary to clean the anode wire by flushing the tube with Argon and letting the wire draw current. As mentioned before, water does not have a value of α (first Townsend coefficient) sufficiently large; and there are conflicting reports about its electron capture cross section.

The first gas tried was NH_3. Pure Ammonia has low drift velocity and low diffusion (Ref. 1), but no discrenible gain up to an electric field 2.7 times greater than the field needed with $Ar|CO_2|CH_4$ (90:9:1) mixture. In admixture with Argon (up to 35% in volume) there is gain, but the gas is so poorly quenched as to be useless.

A brief test on 3-Methylbutene-1, (C_4H_{10}) also gave very little (if any) gain, either pure or in admixture with Argon.

The next gas tried was dimethylether (DME). In admixture with Argon, it behaves like any other Argon-hydrocarbon mixture, perhaps not as well quenched as Argon|Ethane or Argon|Propane (1:1). In the drift cell of Fig. 1, $Ar|CO_2|CH_4$ (90:9:1) requires 1600 V on the anode wire to reach about 100% efficiency: for pure DME this voltage is 2700 V, with a plateau 600 V wide.

The measured drift velocity of DME is shown in Fig. 2, together with the velocity in $Ar|CO_2|CH_4$ mixture; the typical times of arrival spectra for the three sources are in Figs. 3 and 4.

According to Ref. 1, k, the Townsend energy coefficient (mean electron energy/mean energy of gas molecule) is smaller in DME than in CO_2; the values of k for CO_2 and DME are in Fig. 5. Since spatial diffusion in a drift field E is proportional to $\sqrt{k/E}$, DME should allow high precision measurements. From the value of k, we calculate the values of σ for 1 cm drift (Fig. 6) and compare DME, CO_2, and $Ar|CO_2$ (90:10, from Ref. 3). At this point it is important to notice that the diffusion properties of a gas at high values of electric fields are affecting the overall measurement precision, i.e., the contribution of diffusion in the high electric field close to the anode wire can be as large as the diffusion in the first part of "low field" drift (see Appendix).

4. Spatial Accuracy

Preliminary measurements of the spatial accuracy obtainable with DME were made by using the cell of Fig. 7. The drift region is separated from the sense wires by a fine (25 microns square opening, 60% transparent) mesh held at a fixed potential. In this manner drift velocity and gain can be controlled independently. The field wires are held at -100 V; the sense wires are at ground through the input impedance (50 Ω) of

an Avantek GPD 201 amplifier. The delays between a trigger counter and the output of three sense wires (t_1, t_2, t_3) was used to generate an analog signal τ proportional to

$$\tau \propto \frac{t_1 + t_3}{2} - t_2 \; .$$

The distribution of τ (Fig. 8) is related to the intrinsic spatial accuracy. If one assumes that the timing error is equal for each wire, the spatial accuracy σ is given by

$$\sigma = \sqrt{2/3} \, \sigma_\tau \cdot v_{drift}$$

σ_τ being the variance of the distribution of τ. In this measurement, velocity was 0.36 cm/μsec, $\sigma_\tau = 5.4$ ns, giving a value of σ of 16 μ.

Some physical properties of DME are in Table I.

5. Conclusions

The use of DME in a drift chamber promises excellent spatial accuracy (perhaps as high as 5-10 microns at 4 atm pressure); in presence of a magnetic field, the Lorentz angle is negligibly small; Coulomb scattering is less than in Argon mixtures. However, the fact that the drift velocity is not saturated requires a very accurate monitoring of the gas density and of the electric field.

Table I

Dimethylether $(CH_3)_2O$

Molecular Weight :	46.07 *gr*
Density (25°*C*, 14 *cm*) :	1.918 *gr/liter*
Relative Density (*air* = 1) :	1.621
Critical Temperature :	400° *K*
Critical Pressure :	52 *atm*
Vapor Pressure at 20°*C* :	5.24 *atm*
Flammability Limits in Air :	3.4 − 18% (*in volume*)
Radiation Length (25°*C*, 1 *atm*) :	4.5 × 10^{-3} X_0/*meter*

Appendix

The spatial diffusion after a drift x in a field E is given by (c is a constant):

$$\sigma = c \sqrt{x\, k(E)/E}$$

$k(E)$ is unity for thermal electrons at low fields, but increases rapidly when E increases, as in the case of the field near a sense wire. For CO_2, one of the best gases with respect to diffusion, k goes from 3 at $E/P = 3$ to 12 for $E/P = 6$ [E/P in volt/(cm torr)].

The field near a sense wire can be approximated as:

$$E(r) = V/r \ , \ \ E_0 R \simeq V$$

E_0 being the "uniform" field, R the distance of the sense wire to the nearest neighbor. The diffusion in the "near field" will be

$$\sigma^2 = c^2 \int_{r_0}^{R} [k(E)/E]\, dr$$

r_0 being the sense wire radius. $k(E)$ can be written as (from an eyeball fit to experimental data from Ref. 1)

$$k(E) \simeq 1 + \gamma E^2 \ .$$

Then

$$\sigma^2_{near\,field} = c^2 \left[\frac{R}{2E_0} + \gamma E_0 R \, \ell n \, \frac{R}{r_0} \right].$$

In a typical drift cell, $x/R {\sim} 4$ (x being the extent of the "uniform" field region), so that the previous quantity has to be compared with

$$\sigma^2_{cell} = 4c^2 R \left[\frac{1 + \gamma E_0^2}{E_0} \right].$$

for $\gamma E_0^2 > 1.6$, $\sigma^2_{near\,field}$ is larger than σ^2_{cell}.

References

1. T. L. Cottrell *et al.*, Trans. Faraday Soc. *61*, 1585 (1965).

2. L. G. H. Huxley *et al.*, Proc. Roy. Soc. A *128*, 2661 (1949).

3. G. Baranko, SLC Note *45*.

Figure Captions

1. Drift chamber used for velocity measurements.

2. Drift velocity of $Ar|CO_2|CH_4$ (90:9:1) and DME.

3. Arrival time spectrum from chamber of Fig. 1 for $Ar|CO_2|CH_4$.

4. As in Fig. 3, for DME.

5. k, Townsend energy coefficient for CO_2 and DME.

6. Diffusion for 1 cm drift in $Ar|CO_2$ (90:10), DME and CO_2.

7. Schematic of the chamber used for accuracy measurements.

8. Distribution of $[(t_1 + t_3)/2] - t_3$ obtained from the cell of Fig. 7. The Gaussian is a fit to the data.

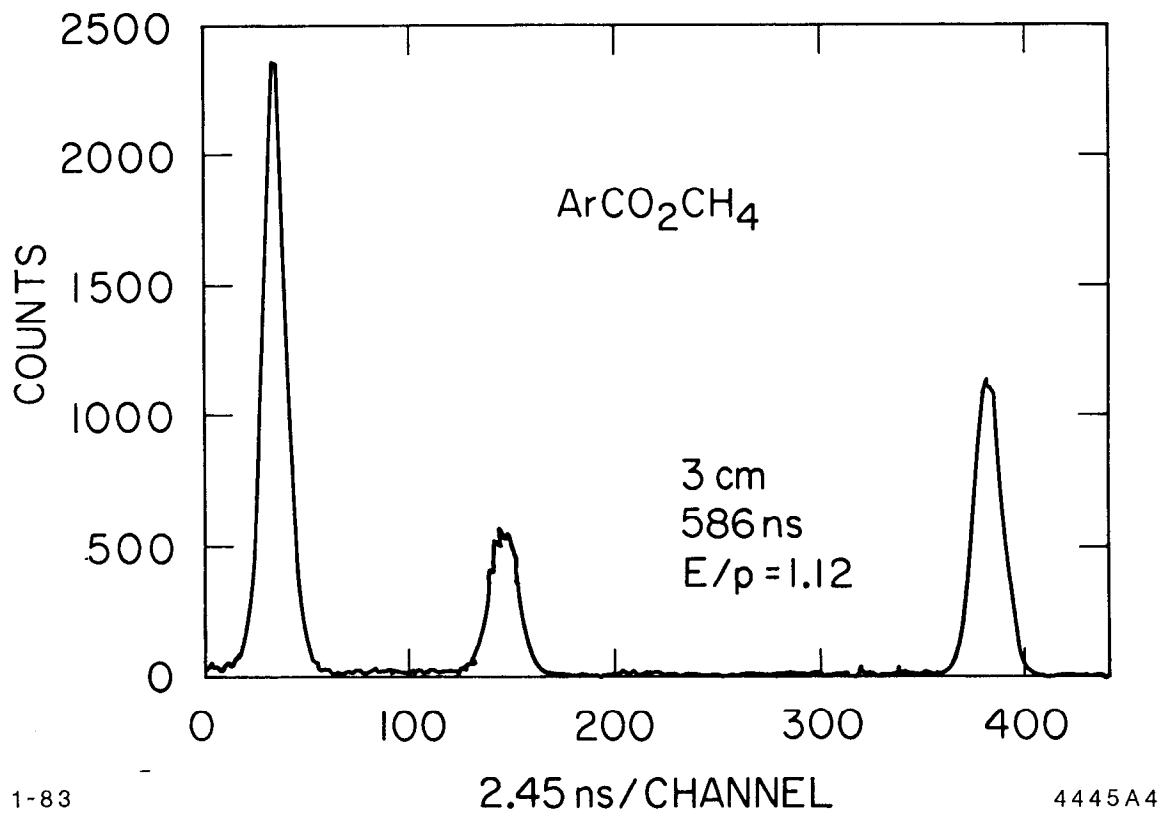Collimated ^{106}Ru Sources

Source 3   2   1

Cu Strips
for Grading
Drift Field

Sense
Wire

|←——— 3 cm ———→|←— 1.5 cm —→|←— 1.5 cm —→|

Drift Direction ——→

Scintillation Counter

1—83
4445A1

Fig. 1

Fig. 2

Fig. 3

Fig. 4

4445A7

Fig. 5

Fig. 6

Uniform $\vec{E}$

Field Wire
30 μ

Sense Wire
7 μ

2 mm

2.5 cm

Mesh

1−83

4445A2

Fig. 7

TIME   (2.18 ns / BINS)

Fig. 8