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# A Brief Survey of the Gas Mixtures Used in Straw Tubes

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ABSTRACT

We have reviewed the gas mixtures which have been used in straw tubes. Based upon the present knowledge, the three main candidates for the gas to be used in straw-tube detectors are DME (dimethylether), $Ar/CO_2$ and $CF_4$. The advantages and disadvantages for these candidates are compared.

## DIMETHYLETHER (DME)

1. Spatial Resolution

   - The prototype test of MARK-3 vertex detector showed:[1]
     DME @1 atm yielded spatial resolution 35 $\mu$m.
     $Ar/C_2H_6$ @4 atm yielded spatial resolution 30 $\mu$m.
   - F. Villa[2] measured the spatial resolution of DME:
     Drift velocity = 0.36 $\mu$m/sec, $\sigma_\tau = 5.4$ ns $\Rightarrow \sigma_s = 16\mu$m @1 atm .
   - M. Basile *et al.*[3], see Fig. 1-2, for comparison is also shown the spatial resolution of $Ar/CO_2$ in Fig. 3.

2. General properties of DME [$(CH_3)_2O$]

| | |
|---|---|
| Molecular weight | 46.07 g |
| Density (25° C) | 1.918 g/l |
| Relative density (air=1) | 1.621 |
| Critical tempreture | 400°K |
| Vapor pressure at 20°C | 52 atm |
| Flammability limit in air | 3.4-18% (in volume) |
| Radiation length (25°C, 1 atm) | $4.5 \times 10^{-3}$ $X_0$/m |

3. Drift velocity

   See Fig. 4.

4. Chemical aggresivity tests

   - Adversely affects Mylar and Derlin (MARK-3).[1]
   - G. Bari *et al.*[4] have put several specimens in DME gas for a month, then weighing them and looking at the state of the surface. They

Fig. 2

Fig. 1

Fig. 3

Fig. 4. Drift velocity of DME

found the weight of all specimens had gone up at the end of the test. Signs of damage were found on the surface of Plexiglas, Stesalit and scintillator. Epoxy, Mylar, Teflon, G-10, PVC and carbon fibre seemed in good condition.

- M. Gibaly *et al.*[5] claim:

  Bad news —
  Teflon — to induce electron capture by poisoning the gas.
  Glass-bonded Mica endcaps — to produce flakes on the wire surface and caused quick damage.
  Macor — to produce wire damage.

  Good news —
  The materials found compatible with DME were:
  Stainless steel, Monel (gas tubing), Nylon 11 (gas tubing), brass, Derlin (chamber endcaps), Mylar with $SnO_2$ coating, Torr-seal epoxy and Kalrez O-ring.

5. Ageing effect

- G. Bari *et al.*[4] have done the ageing test using Kalrez (DuPont) O-rings(guarenteed resistant to ethers), using Cu tubing, H.V. wire isulated with Teflon and the best possible conditions of cleanliness. After collecting 1 C/cm, the chamber has had neither a change in the current drawn by the wire, nor in its gain. But deposits were found on the entire length of the wire(diameter has been increased from 20$\mu$m to 40$\mu$m).(?)

- M. Jibaly *et al.*[5] used Gold-plated wires with "dirty" DME, the operation of the chamber was stable up to 0.39 C/cm. "Pure" DME was better than "dirty" DME (see Table I to get the meaning of "dirty" and "pure"). Resistive wires exhibited quick damage and the wire current dropped down very fast. Ageing in DME chamber seems to be caused by Freon impurities. Nylon tubing looks safe, but Teflon is bad. Results are summarized in Table II.

Freon-11 ($CCl_3F$) in DME mostly contributed to wire damage. Using a Nanochem gas purifier drastically reduced the Freon content in DME.

- S. Majewski[6] claims that the ageing of DME is exellent, holds one of the world records of endurance.

6. Gas purity

The purity of the gas used by G. Bari *et al.*[4]:

| Manufacturer | Purity(%) | Contaminant |
|---|---|---|
| Fluka | 99.2 | 0.8% Alkane, 0.001% methyl alcohol<br>0.016% $H_2O$, 0.002% alcohol, 0.003% Oil |
| Schweissen Technik | 99.8 | 0.2% Alkane, 0.0001% S |
| Matheson | 99.5 | 0.1% $CO_2$, 0.1% methyl formate,<br>0.3% alcohol |

7. Stability in gas discharge

B. Zhou *et al.*[7] claim DME has remarkable queching properties. There is no regeneration (in opposition, $Ar/C_2H_6$ (50:50) shows a significant amount of "after pulsing").

M. Jibaly *et al.*[8], DME is a very heavy quencher with the absorption edge at a longer wavelength than isobutane and methylal. See Fig. 5.

Fig. 5. DME transmission measurement

## Ar/$CO_2$ MIXTURE

Since MAC vertex detector[9] had got good results with Ar/$CO_2$, it looks rather encouraging people to use this mixture for their straw tubes.

1. Drift velocity and high gas pressure

   The drift velocity of different mixing proportion of Ar/$CO_2$ is shown in Fig. 6.
   MAC vertex detector is working at 4 atm. When the gas pressure goes higher, in order to mantain the gas gain unchanging, as indicated by, for example, Diethorn formula[10]:

$$\ln M = \frac{V \ln 2}{\ln(b/a)\Delta V} \ln[\frac{V}{KPa \ln(b/a)}],$$

   you have to increase the E-field as well. The trouble is electrostatic stability. The higher electric field may cause wire instability and spark. Also the gas leakage will take engineer painstaking effort to deal with.

Fig. 6

2. Diffusion

   Like DME, $CO_2$ is one of the so-called "cool" gas. The diffusion coefficients for several gases are shown in Fig. 7.

Fig.7. Diffusion coefficient and thermal limit

The diffusion coefficient follows the thermal limit very well up to $E \approx$ 900 V/cm. In our straw tubes the field $E$ will be much higher than 900 V/cm, the diffusion property will be certainly worse than the thermal limit. The compilation of the diffusion properties for DME, $CO_2$ and $Ar/CO_2$ is shown in Fig. 8.[11]

MAC vertex detector used $Ar/CO_2$ / $CH_4$(49.5/49.5/1) mixture at 4 atm, the spatial resolution was 45 $\mu$m.

Fig. 9 shows the spatial resolutions of $CO_2$ and DME under different gas pressures.[11]

3. Aging

MAC prototype test showed that the lifetime of straw tubes with $Ar/CO_2/CH_4$ (49.5/49.5/1) corresponding to an integrated charge $\sim 0.25$ C/cm, at this point disappearence of the aluminization on the cathode rended the straw difficult to opperate.

D. Pandoulas *et al.*[12] reported that having collected 1.0 C/cm with $Ar/CO_2$ (60/40), gas gain $\sim 2 \times 10^5$ and gold plated wire surface, the gas gain degradation

$$\frac{-1}{Q}\frac{dG}{G} \sim 4\%.$$

It is very good performance.

Fig. 8 Diffusion properties of DME, $CO_2$ and Ar/$CO_2$

Fig. 9 Gas pressure dependance of spatial resolution of $CO_2$ and DME

<u>$CF_4$</u>

1. Spatial resolution

Since $CF_4$ is a fast gas, we may suspect that its diffusion coefficient could be worse. In fact it is not the case. B. Schmidt and S. Polenz[13] has measured the longitudinal and transverse diffusion coefficients for $CF_4$ and Ar/$CF_4$ (80/20). The experimental results are shown in Fig. 10, we also show the results of Ar/$CH_4$ in Fig. 11 for comparison.

Fig. 10

Fig. 11

The longitudinal diffusion of $CF_4$ is around the thermal limit up to very high-$E$ field. Using these plots we can estimate the position resolution limit of $CF_4$.

According to definition of the diffusion coefficient we have

$$\sigma_x = \sqrt{\frac{2Dx}{W}},$$

in which $D$ is the diffusion coefficient, $W$ is the drift velocity, and $x$ is the drift length.

The parameter $\varepsilon$ used in the plots is defined as

$$\varepsilon = eE\frac{D}{W},$$

in which $W = \mu E$, $\mu$ is the electron's mobility. It follows

$$\sigma_x = \sqrt{\frac{2 \times \varepsilon \times x}{eE}}.$$

If $E/N = 2$ V/(cm·Torr),$x = 2.6$ mm, from Fig. 10 we have $\varepsilon_L \approx 0.026$ eV, it yields

$$\sigma \approx 30\mu\text{m}.$$

2. Primary ionization cluster density

When very fine straw tubes are to be used, you may concern how fine the tube could be if the efficiency still maintains at $\sim 100\%$? It depends on the primary ionization density. The density goes higher, the tube could be thiner.

J. Fischer *et al.*[14] gave the numbers as following

| Gas | Electron per molecule | Average primary cluster/cm | Minimum gas thickness for 6 clusters* |
|---|---|---|---|
| $CH_4$ | 10 | 12 | 5 mm |
| $C_2H_2$ | 14 | 17 | 3.5 |
| Ar+10% $CH_4$ | $\approx 17$ | 20,16 | 3,3.6 |
| $C_2H_6$ | 18 | 21 | 2.8 |
| $CO_2$ | 22 | 26 | 2.3 |
| $C_3H_8$ | 26 | 30 | 2.0 |
| i-$C_4H_{10}$ | 34 | 40 | 1.5 |
| $CF_4$(alone) | 42 | 50 | e attachment losses |
| $CF_4$(in gas mixture) | 42 | 41 | 1.4 |

| | | | |
|---|---|---|---|
| $C(CH_3)_4$ | 42 | 50 | 1.2 |

* Efficiency for single cluster detection $\eta \approx 1 - e^N$, when $N \geq 6$, $\eta \geq 99.8\%$.

On the other hand the high density of the primary ionization cluster will reduce the fluctuation of the primary cluster's distribution along the track, it will help to improve the spatial resolution too.

3. Drift velocity

   One of the fastest gases. See Fig. 12.[15]

4. Stability in gas discharge

   $CF_4$ alone is not sufficiently self-quenching as a counter gas. A reasonably dense additive is neopentane ($C(CH_3)_4$) at small concentration ($10 \sim 20\%$) or isobutane.

   $CF_4$ attached electrons mainly via dissociative attachment processes occurring at electron energies above $\approx 4.5$ eV with cross-section maxima at 6 to 7.5 eV.

   The energy resolution of $Fe^{55}$ source with $CF_4$ gas mixtures is as good as P-10:

| Gas mixture | Pulse height resolution |
|---|---|
| 100% $CF_4$ | $\approx 75\%$ |
| 80% $CF_4$ + 20%isobutane or 80% $CF_4$ + 20% $C(CH_3)_4$ | $\approx 22\%$ |
| 90% Ar + 10% $CH_4$ | $\approx 20\%$ |

5. Ageing effect

   Excellent! R. Openshaw *et al.*[16] pointed out the $CF_4$/ isobutane chamber has shown effectively zero pulse height degradation to accumulated charges exceeding 5 C/cm. Their results are shown in Fig. 13. It would seem that in the $CF_4$/isobutane (80/20) mixture polymerization does not occur under typical MWPC conditions. This is likely due to $CF_4$ being able to combine with polymer precursors forming stable volatile species.

6. Conclusion

   $CF_4$/isobutane (80/20)

   - negligible ageing up to 1.2 C/cm[17] or 5.0 C/cm.[16]
   - Fast gas (12 cm/$\mu$sec).
   - Small longitudinal diffusion.
   - High linear ionization density.

   Very attractive candidate for BCD and SSC tracking devices.

Fig. 12 Drift velocity of $CF_4$ mixture

Fig. 13

Table I

Table II

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