DEVELOPMENT OF A DUAL-POLARITY ION DRIFT CHAMBER &
STUDY OF ION TRANSPORT PROPERTIES IN NE-CF4 MIXTURES


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Introduction and motivation

**Ion Mobility Spectroscopy**

Technique that aims at identifying ionized molecules in a gas based on their mobility in a carrier buffer gas.

**Gaseous Radiation Detectors**

+HV

**Time projection Chamber**

- Powerful tool in high energy and nuclear physics.
- Future Linear Collider TPC (LCTPC)

**Negative Ion Time Projection Chamber**

Rare event physics searches
- Neutrinoless beta decay (0νββ)
- Dark matter (WIMPs)

Astrophysics
- Polarimetry

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Theoretical Background

Drift velocity

\[ v_d = KE \]

E - Electric Field
K - Ion Mobility

Reduced Mobility

\[ K_0 = \frac{KN}{N_0} \]

N - Gas number density
\( N_0 \) - Loschmidt Number

Langevin Limit

\[ K_0 = 13.88 \left( \frac{1}{\alpha \mu} \right)^{\frac{1}{2}} \]

\( \mu \) - ion-neutral reduced mass
\( \alpha \) - neutral polarizability

Blanc’s Law

\[ \frac{1}{K_{0_{\text{mix}}}} = \frac{f_1}{K_{0g1}} + \frac{f_2}{K_{0g2}} \]

\( f_1, f_2 \) - molar fraction of gas 1, 2
\( K_{0g1}, K_{0g2} \) - ion mobility in the gas 1 and gas 2
Experimental system and techniques

- Xenon UV flash lamp: 10Hz, <500ns
- Frisch Grid

Charge Pre-amplifier
Digital Oscilloscope

P.N.B. Neves et al. 2009

GEM

CsI
After the signal and the background were recorded...

- Subtract the background to the signal
- Identify possible peaks
- Fit Gaussian curves to the spectrum obtained

peaks centroids

average drift time of the ion’s distribution ($t_{drift}$)

$$v_d = \frac{x_{drift}}{t_{drift}} \quad K = \frac{v_d}{E}$$

**Argon**

$p = 7.039$ Torr

$E/N = 30$ Td

UV Flash signal

$K_{01} = 1.57 \text{ cm}^2\text{V}^{-1}\text{s}^{-1} (\text{Ar}^+ ?)$

$K_{02} = 1.92 \text{ cm}^2\text{V}^{-1}\text{s}^{-1} (\text{Ar}_2^+ ?)$

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(A review on) Ion mobility in pure Ne and CF4

**Ion mobility in pure Ne**
- One peak (below 8 Td) - Ne$_2^+$
- Two peaks present (between 8 and 12 Td)
- One peak (above 12 Td) - Ne$^+$

**Appearance Energies**
- Ne$^+$ 21.56 eV

**Reactions:**
- Ne$^+$ + 2Ne $\rightarrow$ Ne$_2^+$ + Ne
- Ne$^+$ + Ne $\rightarrow$ Ne + Ne$^+$
- $K_{01}$ $\sim$ 4.4 cm$^2$V$^{-1}$s$^{-1}$ Ne$^+$
- $K_{02}$ $\sim$ 6.2 cm$^2$V$^{-1}$s$^{-1}$ Ne$_2^+$

**Ion mobility in pure CF4**
- One peak present

**Appearance Energies**
- CF$_3^+$ 15.0 eV
- CF$_2^+$ 19.0 eV
- CF$^+$ 22.3 eV
- F$^+$ 23.1 eV

**Reactions:**
- CF$_3^+$ + 2CF$_4$ $\rightarrow$ CF$_3^+$ . (CF$_4$) + CF$_4$

**Possibility of Cluster Formation**
- (Pressure dependent)
- $K_{01}$ $\sim$ 1.10 cm$^2$V$^{-1}$s$^{-1}$ CF$_3^+$

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P.N.B. Neves et al. 2011

M.A.G. Santos et al. 2018

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Ion mobility in Ne-CF4

Ions move slower with the presence of CF4.

Behaviour well described by Blanc’s law and Langevin theory.

- Cross section.
- Presence of CF4 in mixtures with Ne leads to the same ion as in pure CF4.

Only one peak for 15 Td

Increasing pressure may lead to the formation of cluster (about 10% slower than CF3+).

(Charge Transfer Reaction)

\[
\text{Ne}^+ + \text{CF}_4 \rightarrow \text{CF}_3^+ + \text{Ne} + \text{F}
\]

Data for 15 Td

Data for 20 Td

Prevents the formation of Ne⁺.

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DP-IDC: Working principle and design proposal

**Dual Polarity – Ion Drift Chamber**

Allows to:

- study the transport properties of negative ions in gases, in addition to the study of positive ions;
- vary the drift distance.
DP-IDC: Components, preliminary tests and system proposal

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DP-IDC: Assembly
DP-IDC: First results

1. One peak clearly visible in both spectra, as expected. A long tail and two smaller peaks are also visible.

2. Measured mobility about 40% lower than in previous work.

- No noticeable signal for:
  - $V_{GEM} = 25$ V & $E/N < 30$ Td
  - $V_{GEM} = 35$ V & $E/N < 20$ Td

- High and unstable electrical noise (6-10 mV).

- Lamp pulse 200 time wider than expected.

Solutions:
- reducing the length of the cables between the pre-amplifier and the collection feedthrough by
- insuring a stable and single ground across the detector.

*Test gases chosen both by their availability and their known mobility lower than the upper limit of the mobility possible to be measured.

**Tests will follow in the next couple of months to solve these issues.
DP-IDC: Limitations

**Electric field**

- Variations on the mobility of about 23% in half biased mode and of 2% in full biased modes;
- Can lead to lose of signal in half biased mode due to diffusion.

**Residual gas**

Due to outgassing, to the gas non-purity and minimum residual vacuum.
In the present installation:
- Conductance < 0.012 l/s → Residual vacuum > $4.89 \times 10^{-3}$ Torr

**Lamp induced**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of the pulses</td>
<td>0.1 s</td>
<td>Max. Mob. 0.012 cm²V⁻¹s⁻¹</td>
</tr>
<tr>
<td>Expected pulse duration</td>
<td>0.5 µs</td>
<td>Theor. Min. Mob. 2481 cm²V⁻¹s⁻¹</td>
</tr>
<tr>
<td>Experimental pulse duration</td>
<td>0.1 ms</td>
<td>Exp. Min. Mob. 12.4 cm²V⁻¹s⁻¹</td>
</tr>
</tbody>
</table>

**Teflon spacers**

Mean thermal expansion of Teflon and thermal expansion coefficients at a given temperature vary a lot in the range of thermal temperatures leading to variations of the order of 0.1 mm in the drift distance.
*Also, explains why the first double grid prototype failed.*
## Conclusions

### On the ion mobility

- The ion mobility in various mixtures of interest.
- The mobility values are consistent with the theoretical ones given by Blanc’s law using Langevin’s theory, following CF3+ ions.
- At **higher pressures**, the distribution of the final ions may differ, however these accurate ion mobility measurements have been consistently in accordance with the ones obtained at higher pressures (**Kalkan et al. 2015**).

### On the DP-IDC

- The DP-IDC was designed, constructed, preliminarily tested and assembled **successfully**;
- First tested revealed **poor accuracy but good precision**;
- Still some **problems should be addressed**, specially in what concerns the uniformity of the electric field.

### Future work

- Pursuit the investigation on the mobility of ions in different gas mixtures of interest for TPCs and NITPCs:
  - Ne-iC4H10
  - Xe-iC4H10
  - SF6
  - CS2
  - O2
  - N2O
  - CH3NO2
  - SF6-CH4
  - SF6-C2H6
  - CS2-CH4
  - CS2-C2H6
  - Xe-SF6
  - Xe-CS2
  - CO2-CH3NO2
  - Ne-CO2-CH3NO2
Thank you!

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### GEM Voltage

- Maximum energy gained by electrons.
- Primary ions possible to be formed.

\[
\text{Rg (pure)} \\
\text{Rg + e } \rightarrow \text{Rg}^+ + 2e
\]

### Possible Reactions

Ions formed through reactions of the primary ions with neutral atoms or molecules from the medium.

### Select Most Probable Ions

- Identification the possible ions present.

### Reaction Time

Used to calculate the mobility of an ion in a gas mixture.

\[
\tau = \frac{1}{kN}
\]

- Identification the possible ions present.

### Universal decay law

Used to calculate the variation of the concentration of a specific ion in a mixture.

\[
\frac{[\text{Rg}^+]}{[\text{Rg}^+]_0} = e^{-\frac{t}{\tau}} \\
\frac{[\text{X}^+]}{[\text{X}^+]_0} = 1 - \frac{[\text{Rg}^+]}{[\text{Rg}^+]_0}
\]

- Identification the possible ions present.

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Langevin Limit

To determine the mobility of an ion within a gas (not the parent).

\[ K_p = 13.88 \left( \frac{1}{\alpha \mu} \right)^{\frac{1}{2}} \]

- \( m \) – reduced mass
- \( \alpha \) – neutral polarizability

Experimental Ion Mobility Values

Mobility of an ion within his parent gas (if known).

Theoretical Mobility Values

Blanc’s Law

Used to calculate the mobility of an ion in a gas mixture.

\[ \frac{1}{K_{0\text{mix}}} = \frac{f_1}{K_{0g1}} + \frac{f_2}{K_{0g2}} \]

- \( f_1, f_2 \) – molar fraction of gas 1 and 2