Basis for Liquid Xe TPC LIQ course
Fundamental Processes

Amplification Gap

Beam

Ionizations

→ Liberation of Electrons

$P_I(N; \bar{N})$

Normal incidence
(no angle effect)

No $\delta$-ray

Drift and Diffusion

$P_D(x_i; \sigma_d) = \frac{1}{\sqrt{2\pi}\sigma_d} \exp \left( -\frac{x_i^2}{2\sigma_d^2} \right)$

$\sigma_d = C_d\sqrt{z}$

Amplification and further Diffusion

$P_G(G/\bar{G}; \theta) = \frac{(\theta + 1)^{\theta + 1}}{\Gamma(\theta + 1)} \left( \frac{G}{\bar{G}} \right)^\theta \exp \left( -(\theta + 1) \left( \frac{G}{\bar{G}} \right) \right)$

Pad Response

Coordinate
Reconstruction of incident angle in Compton scattering

\[
\cos \theta = 1 + \frac{m_0 c^2}{E_1 + E_2} - \frac{m_0 c^2}{E_2}
\]

\[
\cos \varphi = \frac{E_1}{\sqrt{E_1^2 + 2m_0 c^2 E_1}} + \frac{m_0 c E_1}{(E_1 + E_2)\sqrt{E_1^2 + 2m_0 c^2 E_1}}
\]
Table 1.5: Physical properties of noble liquids (adapted from Ref. (98)).

<table>
<thead>
<tr>
<th>Property</th>
<th>LAr</th>
<th>LKr</th>
<th>LXe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic Number Z</td>
<td>18</td>
<td>36</td>
<td>54</td>
</tr>
<tr>
<td>Atomic Weight A</td>
<td>39.95</td>
<td>83.8</td>
<td>131.3</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>1.39</td>
<td>2.45</td>
<td>3.06</td>
</tr>
<tr>
<td>Melting Point $T_m$ (K)</td>
<td>83.8</td>
<td>115.8</td>
<td>161.4</td>
</tr>
<tr>
<td>Boiling Point $T_b$ (K)</td>
<td>87.3</td>
<td>119.8</td>
<td>165.1</td>
</tr>
<tr>
<td>Critical Temperature $T_c$ (K)</td>
<td>150.7</td>
<td>209.5</td>
<td>289.7</td>
</tr>
<tr>
<td>Critical Pressure $P_c$ (atm)</td>
<td>48.3</td>
<td>54.3</td>
<td>57.64</td>
</tr>
<tr>
<td>Critical Density (g/cc)</td>
<td>0.54</td>
<td>0.91</td>
<td>1.10</td>
</tr>
<tr>
<td>Volume Ratio ($\rho_l/\rho_g$)</td>
<td>784</td>
<td>641</td>
<td>519</td>
</tr>
<tr>
<td>Fano Factor</td>
<td>0.107</td>
<td>0.057</td>
<td>0.041</td>
</tr>
<tr>
<td>Drift Velocity (mm/µsec) @ 1(5) kV/cm</td>
<td>1.8(3.0)</td>
<td>2.4(4.0)</td>
<td>2.2(2.7)</td>
</tr>
<tr>
<td>Mobility (cm V$^{-1}$s$^{-1}$)</td>
<td>525</td>
<td>1800</td>
<td>2000</td>
</tr>
<tr>
<td>Radiation Length (cm)</td>
<td>14.3</td>
<td>4.76</td>
<td>2.77</td>
</tr>
<tr>
<td>(dE/dx) (MeV/cm)</td>
<td>2.11</td>
<td>3.45</td>
<td>3.89</td>
</tr>
<tr>
<td>Liquid Heat Capacity (cal/g-mole/K)</td>
<td>10.05</td>
<td>10.7</td>
<td>10.65</td>
</tr>
<tr>
<td>W-value (eV) (ionization)</td>
<td>23.3</td>
<td>18.6</td>
<td>15.6</td>
</tr>
<tr>
<td>W-value (eV) (scintillation)</td>
<td>19.5</td>
<td>15.5</td>
<td>14.7</td>
</tr>
<tr>
<td>Wavelength of Scintillation Light (nm)</td>
<td>130</td>
<td>150</td>
<td>175</td>
</tr>
<tr>
<td>Decay const.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fast (ns)</td>
<td>6.5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>slow (ns)</td>
<td>1100</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td>Refractive index @ 170 nm</td>
<td>–</td>
<td>1.41</td>
<td>1.60</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>1.51</td>
<td>1.66</td>
<td>1.95</td>
</tr>
</tbody>
</table>
**diffusion:**

widening pulse shape

\[ \sigma^2 = 2Dt = 2DL/v \]

\[ C_D^2 = D/v \]

Example:

\[ t = 104 \mu \text{sec} \]

\[ D = 50 \text{cm}^2/\text{sec} \]

\[ C_D = 145 \mu \text{m}/\text{SQRT(cm)} \]

\[ \sigma = 1 \text{mm} \]

note: 170 \mu \text{m}/\text{SQRT(cm)}

**spatial resolution**

\[ \sigma_x = \sqrt{\sigma_x(0)^2 + C_D^2/N_{\text{eff}}z} \]

\( N_{\text{eff}} = \text{no. of electrons} \)

if \( N_{\text{eff}} = 1000 \) and \( z = 24 \text{cm} \),

\( C_D^2/N_{\text{eff}}z = (20 \mu \text{m})^2 \)

with pad–analog readout

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Fig. 1. Diffusion coefficients of electrons in liquid xenon and argon versus the density-normalized electric field. The full circles represent the authors' results and the open circles the results obtained by Derenzo [LBL, Group A Physics Note No. 786 (1974) unpublished]. T. Doke, NIM 196 (1982), 87
Transverse diffusion coefficient to electric field
Fig. 1. Density-normalized electron mobility $N\mu(E/N)$ as a function of $E/N$. Present calculation in comparison with measurements by refs. 1, 5 and 6.

$$\mu N = 1.5 \times 10^{22} \text{ (V cm sec)}^{-1} \text{ at Td}=1$$

$$N = 2.5 \times 10^{19} \text{ cm}^{-3} \text{ for Xe gas, 1 atm}$$

$$\mu = 602 \text{ V}^{-1} \text{ cm}^2 \text{ sec}^{-1} \text{ at Td}=1$$

Fig. 2. Electron transverse characteristic energy $\varepsilon_T(E/N)$ and mean electron energy $\langle \varepsilon \rangle(E/N)$ as a function of $E/N$. Present calculation in comparison with measurements by ref. 8 and calculations. 6, 9

$$\langle \varepsilon \rangle = 7 \text{ eV at Td}=1$$

$$\varepsilon = eD/\mu \text{ in eV}$$

$$D = \mu/e \langle \varepsilon \rangle = 602 \times 7 = 4,215 \text{ cm}^2\text{sec}^{-1} \text{ at Td}=1$$
Figure: Electron cross section in Xe: $q_m$=momentum transfer, $q_i$=ionization, $q_{em}$=excitation to meta stable levels, $q_e$=other excitations than $q_{em}$
Measurement of attenuation length of drifting electrons in liquid xenon

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Received 4 January 1993 and in revised form 10 March 1993

To realize a long attenuation length of drifting electrons in liquid xenon, a purification system which consists of Oxisorb, molecular sieves and a Zr–V–Fe alloy getter has been constructed. A dual type gridded ionization chamber is used for the measurement of the attenuation length. An attenuation length longer than 2 m is achieved in the purified liquid xenon.

attenuation length > 2m!, -11% at 24cm drift
α source of 5.31, 5.49MeV ($^{210}$Po, $^{241}$Am)

Parallel plate chamber with 3.5mm gap, no grid

Collected charge ($Q/Q_0$%) vs. electric field for $^{210}$Po in liquid xenon (□) and $^{241}$Am in liquid xenon (○) and liquid argon (△)

E. Aprile et al., NIM A307 (1991)119-125
Parallel plate chamber with 3.5mm gap, no grid

Q/Qo=4 (2.4) % at E=2 (0.5) kV/cm

Energy resolution in FWHM =5.1% at E=2kV/cm
FIG. 2. Variation of relative luminescence intensity $L$ and collected charge $Q$ in liquid argon, krypton, and xenon vs applied-electric-field strength for 0.976- and 1.05-MeV electrons.

"Typically 83(80)% of this charge escapes immediate recombination at the operating field of 1(0.5)kV/cm."

A. Curioni, Dr. Thesis, Columbia univ. 2004

Parallel plate chamber with 5mm gap
Drift velocity in Xe gas for drift in 10mm

![Graph showing drift velocity vs. TPC HV]

- 0.14 MPa
- 0.29 MPa

2013年 3月 20日 水曜日
Drift velocity in Xe gas for drift in 10mm

![Graph showing drift velocity vs. TPC HV in kV/cm for different pressures.]

- 0.14MPa
- 0.29MPa
Drift velocity in Xe gas for drift in 10mm
Fig. 5. Electric field dependence of the electron drift velocity in liquid xenon at $T = 195 \text{ K}$. The solid line is the fit of $v_d = \mu_0 E$, giving $\mu_0 = (4230 \pm 400) \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$. Other lines are from refs. [23,24].

Ref ) E.Aprile et al., NIM A300 (1991) 343-350
Drift velocity in liquid and solid Xe

from L.S. Miller, S. Howe, W.E. Spear, Phys. Rev. 166 (1968), 871
希ガス

$V_d \times 10^5 \text{ cm/s}$

$E_d/N \times 10^{-17} \text{ Vcm}^2$

Herium
Neon
Argon
Krypton
Xenon
Signals in Xe Gas at 1.4 atm, Aug.-Sept, 2011

Drift velocity in mm/μsec

Pulse heights

8/6 8/8 8/9 8/12 8/15 8/16 8/19 8/23 8/24 8/26 8/29 9/1

8/31 13:30 - 9/1 purification

Scintillation (PMT1, α1)

Charge (α1)

Charge (α2)

Scintillation (PMT1, α2)
Estimation of the grid transparency

assumption of no dependence of medium?

0.76 measured efficiency of gamma (661 keV, $^{137}$Cs)

0.57

Performance of grid transparency

Xe gas at 1.4 atm
TPC : 5cm drift
-2.5KV

Pad channels:
5,6,8,9,10,12
Large squares for the sum

note : grid of 50 mesh with 100um diameter SUS wires and 410um spacing, so aperture of 57%
Pre-amp (A250) NIM 16ch
post amp CAEN/N568B 16ch
( shaping amplifier)

Trigger: pmt1xpmt2, test pulse, cosmic
HV power supplies
- positive (brown) : PMTs
- negative cathode, PMT3(cosmic)

DAQ : CAMAC
FADC 500MHz  2ch/module
8bits/3.3V, 8k words/ch
FADC 20MHz   16ch/4modules
8bits/2V, 1k words/ch
ADC 2249W    12ch, 11bit integrated ADC
0.25pC/count, 800nsec gate