Radiation Detectors
- Overview
- Gas-filled Devices
  -- Ion Chambers
  -- Geiger Counters
-Solid state Devices
  --Semiconductor devices
  --Scintillators

- Homeland security detectors

Problem set #9 due Monday
Radiation Detector – Cloud Chamber

Contrails from high flying jets are the result of condensation of water vapor into droplets...

[Diagram]

Incoming charged particle

Warmed glass cover

Alcohol vapor

Supersaturated alcohol vapor layer

Refrigerated bottom

High speed charged particle produces many ion pairs along the pass.

http://www.cloudchambers.com/
Primary Ionization is created by the interaction of the radiation in the bulk material of the ‘detector’ – Then what?

<table>
<thead>
<tr>
<th>Rate</th>
<th>Technique</th>
<th>Device</th>
<th>Energy Proportionality?</th>
<th>Temporal Information?</th>
<th>Position Information?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>View Ions</td>
<td>Cloud/Bubble Chamber, Film</td>
<td>Small range</td>
<td>Little or None</td>
<td>Very good</td>
</tr>
<tr>
<td>Low</td>
<td>Collect ions</td>
<td>Ion Chamber</td>
<td>Can be Excellent (0.001)</td>
<td>Generally Poor</td>
<td>Average (mm)</td>
</tr>
<tr>
<td></td>
<td>Multiply &amp; Collect ions</td>
<td>Proportional counter</td>
<td>Very good</td>
<td>Average (μs)</td>
<td>Good (10’s μm)</td>
</tr>
<tr>
<td>Medium</td>
<td>Convert into photons</td>
<td>Scintillation counter</td>
<td>Acceptable (0.05)</td>
<td>Good (0.1 ns)</td>
<td>Varies</td>
</tr>
<tr>
<td></td>
<td>Create discharge</td>
<td>Geiger-Mueller Ctr. Spark chamber</td>
<td>No</td>
<td>Good to excellent</td>
<td>None Excellent (μm)</td>
</tr>
<tr>
<td>High</td>
<td>Collect current</td>
<td>Ion Chamber</td>
<td>Radiation Field</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Ion Chambers – the electroscope

Electroscope: an early device used to study static electricity continues to be used for personal dosimeters. Put a (known) charge on the central electrode, leaves separate, watch the leaves move back together as the charge is neutralized (lost) by collecting gaseous ions.

Create ionization in gas-filled volume: \( t_{\text{creation}} = \text{size/c} \sim 3\text{cm} / 3 \times 10^{10} \text{ cm/s} = 10 \text{ ps} \)

Amount of ionization: \( Q \sim (\Delta E / 34 \text{ eV}) 2q_e \)

Some properties of oxygen at 25°C, 1 bar

\( v_{\text{RMS}} = 480 \text{ m/s} \) , \( \lambda_{\text{MFP}} = 70 \text{ nm} \)
Collision rate: \( Z = v_{\text{RMS}} / \lambda_{\text{MFP}} = 7 \times 10^9 /\text{s} \)

No electric field – ions diffuse \( \sigma^2_x = 2Dt \)
Diffusion coefficient: \( D = \lambda_{\text{MFP}} v_{\text{avg}} / 3 \)

\( \sigma^2_x = 2 (\lambda_{\text{MFP}} v_{\text{avg}} / 3) \ast t \rightarrow \sigma^2_x \sim 2.2 \times 10^{-5} (\text{m}^2/\text{s}) \ast t \)

Ok for dose measurement, not so good for pulses!

http://www.nbc-med.org/SiteContent/MedRef/OnlineRef/FieldManuals/amedp6/PART_I/annexa.htm
Ion Chamber: the individual pulses are summed in a system that has a long time-
constant. 

\[ I = r \left( \frac{\Delta E}{w} \right) 2q_e = r Q \]

where \( I \) is the observed current,
\( r \) is the rate of the incident radiation,
\( \Delta E \) is the energy deposited in the sensitive volume \( \sim 10\text{'s keV} \)
\( w \) is the “effective work function” for bulk material \( \sim \text{few tens of eV} \)

For example: 0.01 MeV deposited in an air-filled ion chamber
\( w = 34 \text{ eV/IP for fast electrons in air} \)
whereas the ionization potentials for \( \text{O}_2 = 12.1 \text{ eV}, \text{N}_2 = 15.6 \text{ eV} \)

\[ N_{IP} = \frac{\Delta E}{w} = 10^4 \text{ eV} / (34 \text{ eV/IP}) \]
\[ N_{IP} = 3 \times 10^2 \quad \rightarrow \quad \sigma_{N_{IP}} / N_{IP} = \sqrt{N_{IP} / N_{IP}} = 6 \times 10^{-2} \]

for a statistical distribution

\[ I = r \left( \frac{\Delta E}{w} \right) 2q_e \]
\[ I = r \left( 3 \times 10^2 \text{ IP} \right) 2 \times 1.602 \times 10^{-19} \text{ coul/IP} \]
\[ I = r \left( 1 \times 10^{-16} \right) \text{ coul} \]
Gas-Filled Detectors – Multiply Ions?

Consider the drift motion of an ion in a simple ion chamber. The ions will have a thermal velocity plus a component along the field lines. Then after traveling for a mean-free-path they will undergo a collision that will randomize their velocity and they start over. What if the energy gain in one step is greater than the FIP of the buffer gas?

\[ \Delta KE \sim q_e \varepsilon \Delta x \quad \text{where} \quad \Delta x \sim \lambda_{MFP} \quad \rightarrow \quad q_e \varepsilon \sim \frac{\Delta KE}{\lambda_{MFP}} \]

\[ \lambda_{MFP} = \frac{1}{\sqrt{2 \pi d^2 \rho_n}} \quad \text{(for molecules)} \]

\[ \lambda_{MFP} (\text{air}) = 6.6 \text{ mm/ Pa} \quad \text{or} \quad \sim 7 \times 10^{-8} \text{ m at 1 atm} \]

\[ q_e \varepsilon \sim \frac{FIP}{7 \times 10^{-8} m} \sim 200 \text{ MV/m} \]

This value is too large for a nominal detector and so no multiplication of/by molecular ions. However, a few MV/m = keV/mm is achievable.

Recall that the electrons will have much lower mass and can reach higher velocities for the same electric field – electrons can be multiplied or even “avalanched.”
Proportional counters are gas filled and generally use wire anodes (recent devices use thin lines on printed circuit boards).

Typical Case: wire radius, $a = 80 \, \mu m$ @ $2 \, kV$ & chamber radius $2 \, cm$
Gas-Filled Detectors – Multiply Electrons

The multiplication of the electrons in a radiation detector can increase the signal even though $\frac{1}{2}$ of the original charge (the positive ions) is ignored. The multiplication follows a relatively simple pattern shown below and has three distinct regions.

Similar to Fig. 18.7 in text
Gas-filled detectors – Geiger Counter

Increase field in Proportional counter so that the avalanche spreads along the entire length of the wire ... this will produce the largest signal but a sheath of cations will terminate the applied field.
Rutherford & Geiger, 1908

Recombination at the wall leads to “after pulse”
\[
\text{He}^+ + e^- \text{(wall)} \rightarrow \text{He}^* \rightarrow \text{He} + h\nu \text{ (UV)} \\
\text{He}^+ + M \rightarrow \text{He} + M^+ \\
M^+ + e^- \text{(wall)} \rightarrow M^* \rightarrow M + h\nu \text{ (IR)}
\]
GM tubes are sealed ... “M” gets burned up over time.

Hans Geiger (1882-1945) was a German physicist who introduced the first reliable detector for alpha particles and other ionizing radiation. His basic design is still used, although more advanced detectors also exist. His first particle counter was used in experiments that identified alpha particles as being the same as the nucleus of a Helium atom. He accepted his first teaching position in 1925 at the University of Kiel, where he worked with Walther Müller to improve the sensitivity and performance of his particle counter.