Week 13, Lecture 3 – Radiation Detectors – 1

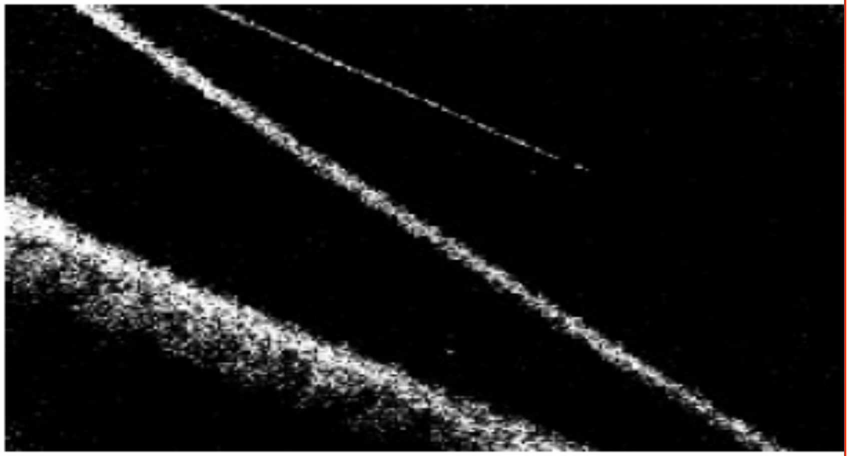
Radiation Detectors

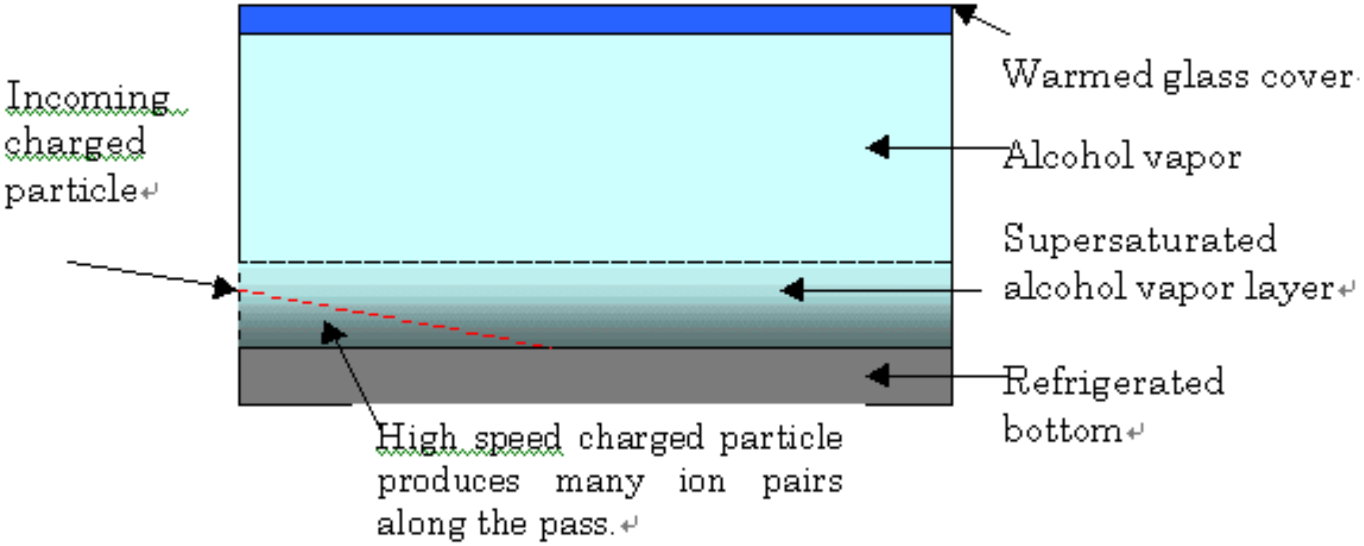
- Overview
- Gas-filled Devices
-- Ion Chambers
-- Geiger Counters
-Solid state Devices
--Semiconductor devices
--Scintillators

- Homeland security detectors

Problem set #9 due Monday

Radiation Detector – Cloud Chamber





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/

General Features of Radiation Detectors

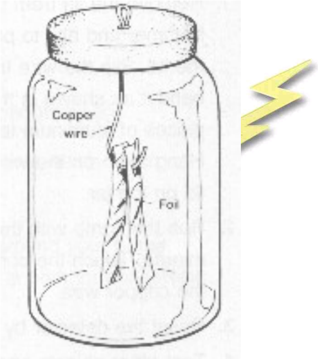
MICHIGAN STATE UNIVERSITY

Primary Ionization is created by the interaction of the radiation in the bulk material of the 'detector' – Then what?

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

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: $t_{creation}$ = size/c ~ 3cm / 3×10^{10} cm/s =10 ps

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

Some properties of oxygen at 25°C, 1 bar

$v_{RMS} = 480$ m/s , $\lambda_{MFP} = 70$ nm

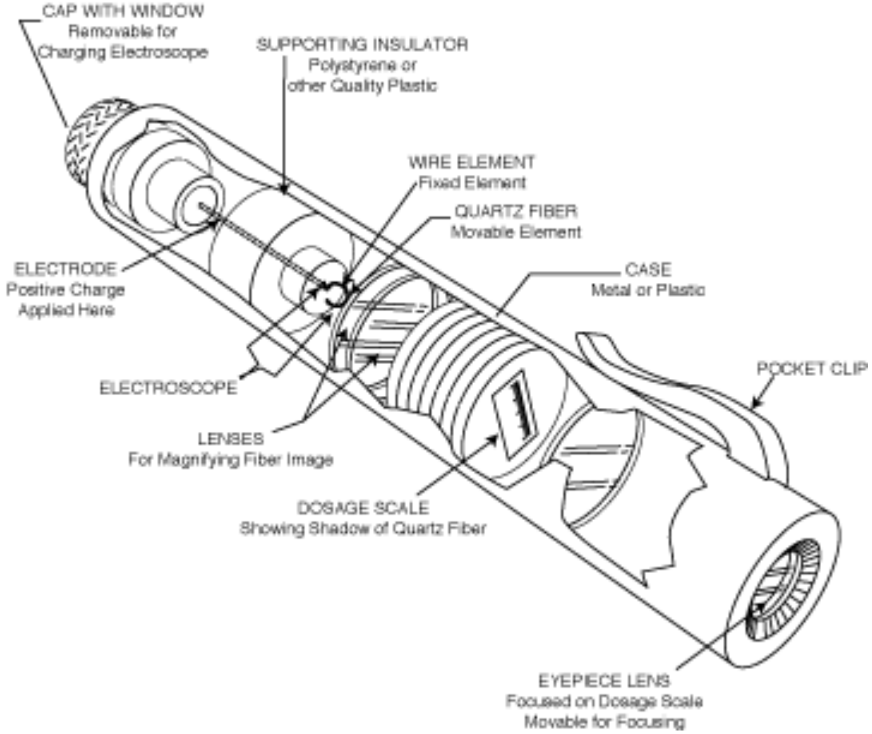
Collision rate: $Z = v_{RMS} / \lambda_{MFP} = 7 \times 10^9$ /s

No electric field – ions diffuse $\sigma^2_x = 2Dt$

Diffusion coefficient: $D = \lambda_{MFP}\, v_{avg}/3$

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

Ok for dose measurement, not so good for pulses!

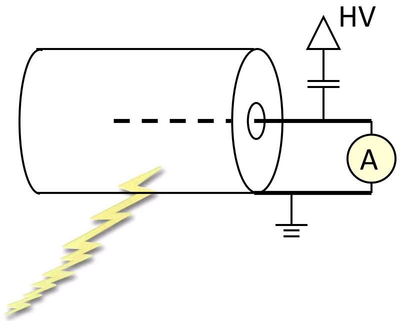


http://www.nbc-med.org/SiteContent/MedRef/OnlineRef/FieldManuals/amedp6/PART_I/annexa.htm

Gas-Filled Detectors – Collect Charge

Ion Chamber: the individual pulses are summed in a system that has a long time-constant. $I = r\ (\Delta E\ /\ w)\ 2q_e = r\ Q$

where I is the observed current,
r is the rate of the incident radiation,
ΔE is the energy deposited in the sensitive volume ~ 10's keV
w is the "effective work function" for bulk material ~ few tens of eV



Related to Fig. 18.1 in text

For example: 0.01 MeV deposited in an air-filled ion chamber
w = 34 eV/IP for *fast electrons in air*
whereas the ionization potentials for O_2 =12.1 eV , N_2 =15.6 eV

Values from NIST

$$N_{IP} = \Delta E / w = 10^4 eV / (34 ev / IP)$$

$$N_{IP} = 3x10^2 \quad \rightarrow \quad \sigma_{N_{IP}} / N_{IP} = \sqrt{N_{IP}} / N_{IP} = 6x10^{-2}$$

for a statistical distribution

$$I = r\ (\Delta E / w) 2q_e$$

$$I = r\left(3x10^2 IP\right) 2x\, 1.602x10^{-19} coul / IP$$

$$I = r\ (1x10^{-16})\ coul$$

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?

$$\Delta KE \sim q_e\, \varepsilon\, \Delta x \quad where \quad \Delta x \sim \lambda_{MFP} \qquad \rightarrow \quad q_e\, \varepsilon \sim \frac{\Delta KE}{\lambda_{MFP}}$$

$$\lambda_{MFP} = \frac{1}{\sqrt{2}\, \pi d^2 \rho_n}$$ (for molecules)

$$\lambda_{MFP}(air) = 6.6\ mm/Pa \quad or \quad \sim 7x10^{-8}\, m\ at\ 1atm$$

$$q_e\, \varepsilon \sim \frac{FIP}{7x10^{-8}\, m} \sim 200\ MV/m$$

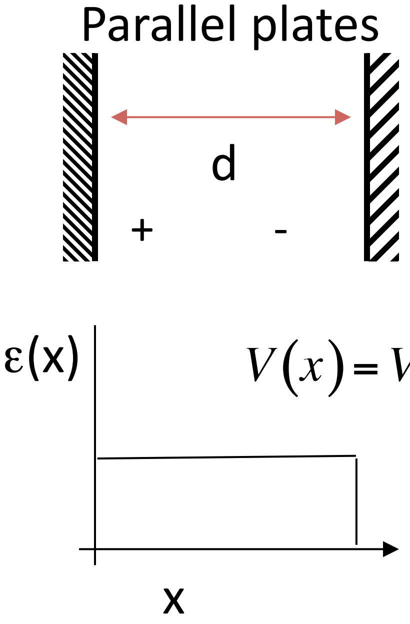
This value is too large for a nominal detector and so no multiplication of/by molecular ions. However, a few MV/m = keV/mm is achievable.

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 – Multiplication on Wires

Proportional counters are gas filled and generally use wire anodes (recent devices use thin lines on printed circuit boards).

a)



$$V(x) = V_0\left(1 - \frac{x}{d}\right)$$

b)

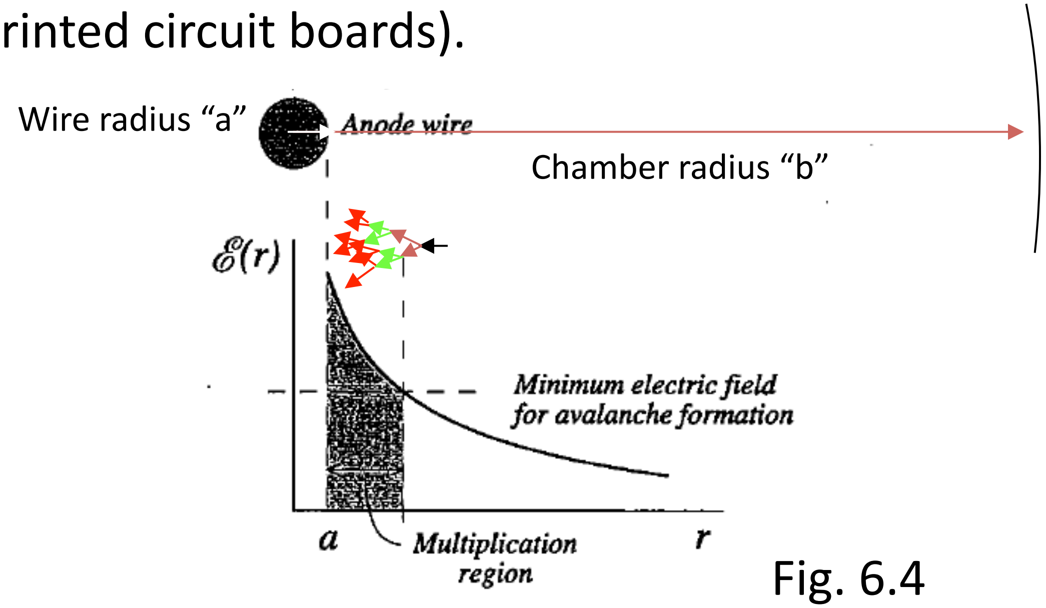


Fig. 6.4

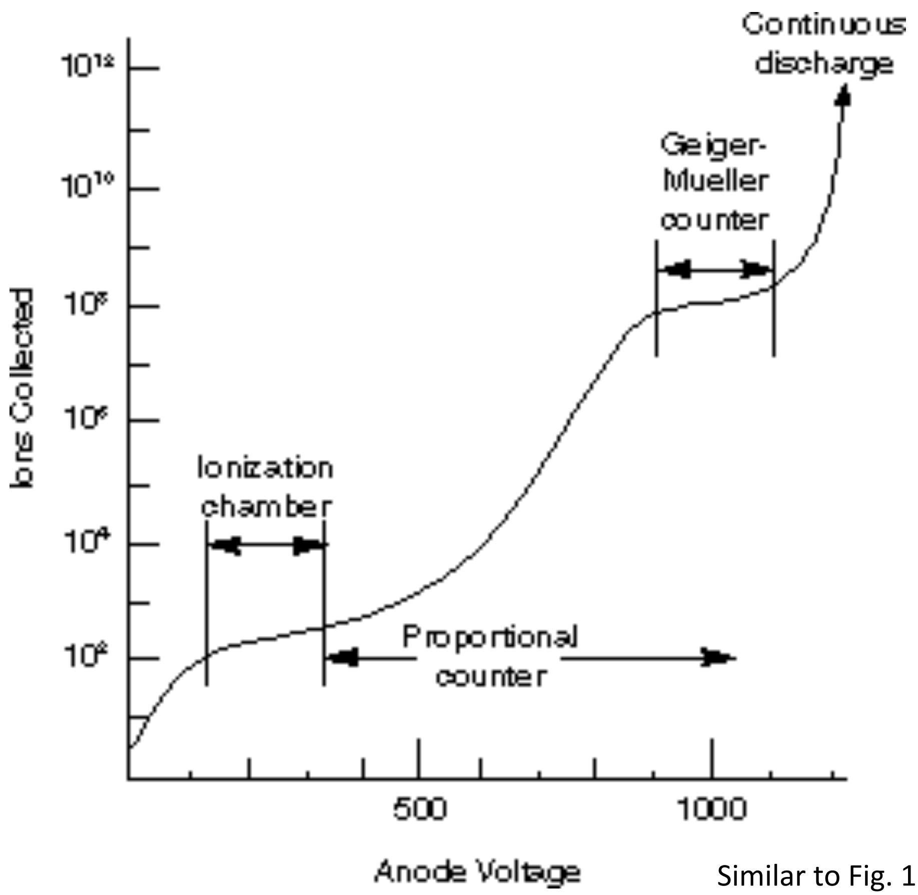
Knoll, 3rd Ed.

$$\varepsilon(r) = \frac{V_0}{r \ln(b/a)}$$

Typical Case: wire radius, a = 80 μm @ 2 kV & chamber radius 2cm

Gas-Filled Detectors – Multiply Electrons

The multiplication of the electrons in a radiation detector can increase the signal even though ½ 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

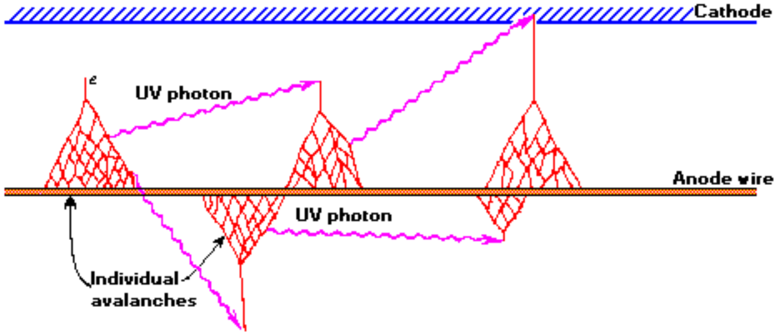
Recombination at the wall leads to "after pulse"

$He^+ + e^-\text{ (wall)} \rightarrow He^* \rightarrow He + h\nu\text{ (UV)}$

$He^+ + M \rightarrow He + M^+$

$M^+ + e^-\text{ (wall)} \rightarrow M^* \rightarrow M + h\nu\text{ (IR)}$

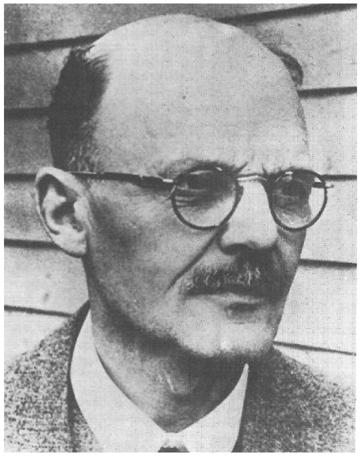
GM tubes are sealed … "M" gets burned up over time.



Beware of cartoon !

Related to Fig. 18.4 in text

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.



Geiger-Müller-Zählrohr: