

Detecting ionizing radiation

References: physics.nist.gov → physical reference data
 Radiation Detection & Measurement, Knoll

I. What is ionizing radiation?

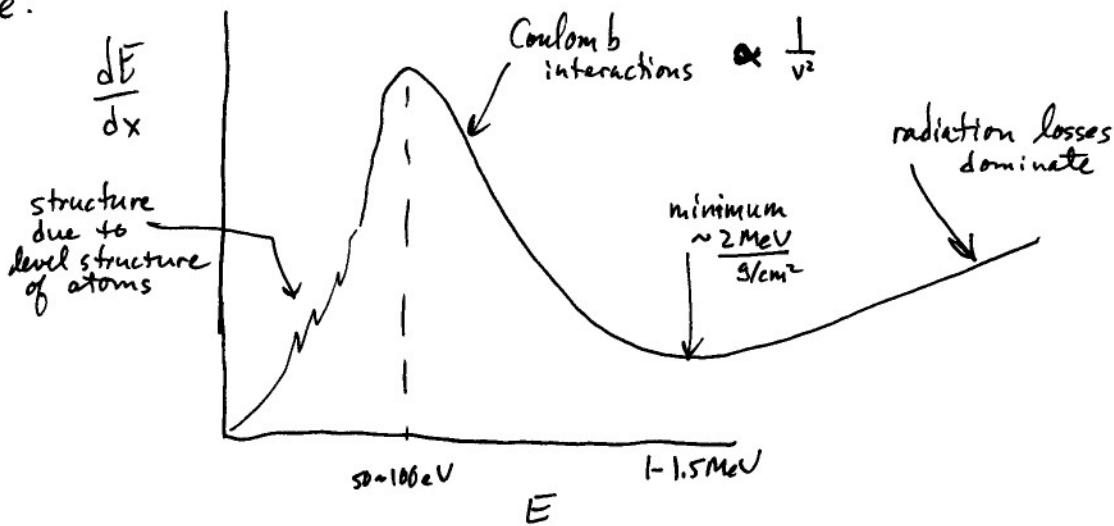
Two distinct categories:

- A. electromagnetic $\xleftarrow[\text{x-rays}]{\text{UV}}$ atomic processes make these
- B. charged particles electrons, muons, protons, alpha nuclear processes make those

Common characteristic is that energy is high enough so that radiation can tear electrons from atoms as the radiation passes through matter. $\geq 10 \text{ eV}$

Charged particle interactions are small angle Coulomb scattering which ionize the target material, and bremsstrahlung radiation resulting from large angle scattering near atomic nuclei.

For electrons, the loss of energy per thickness (dE/dx) looks like:



Example: Let's use a chunk of plastic to stop a 1.5 MeV electron. How thick should it be?

approximation: $\frac{dE}{dx} \rho t = 1.5 \text{ MeV}$

$$2 \frac{\text{MeV}}{\text{g/cm}^2} \times 1 \frac{\text{g}}{\text{cm}^3} \times t = 1.5 \text{ MeV}$$

$$t = \frac{1.5}{2} \approx 0.75 \text{ cm}$$

(Actually the average range is 0.72 cm for 1.5 MeV electrons)

Charged particles undergo a continuous energy loss process while traversing material. They leave behind a trail of ionization.

Electromagnetic interactions:

photoelectric effect
Compton scattering
pair production } 3 relevant loss processes

Photoelectric interaction results in the destruction of original radiation, and the conversion of its energy into an excited ion and an energetic free electron. The excited ion can lose energy through several processes. The energetic electron is an energetic charged particle, whose energy loss was previously described.

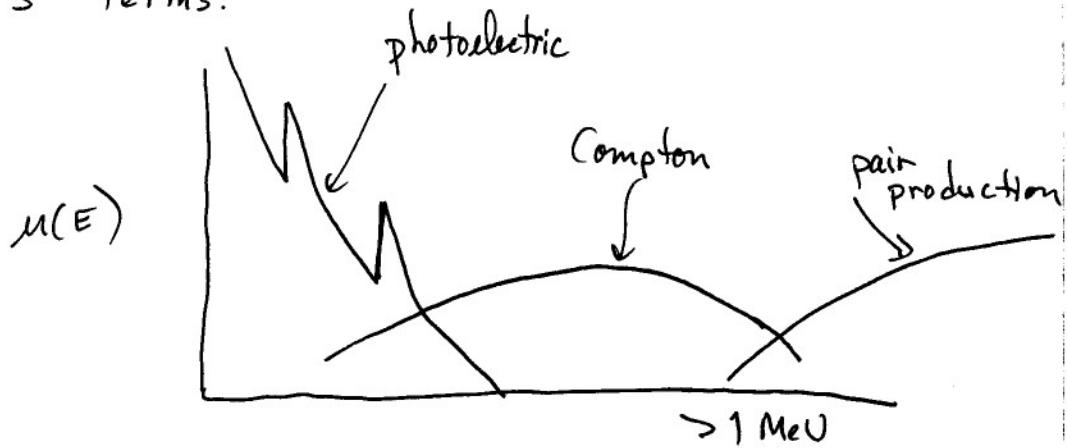
In Compton scattering, the incoming photon transfers part of its energy to an electron. The photon may or may not escape the target material. The energetic electron from the Compton interaction usually loses its energy in the target material.

Pair production results in the destruction of the photon and the production of an electron positron pair. This process has a threshold energy $> 1 \text{ MeV}$. A nucleus participates in the process to conserve energy and momentum.

Because a photon can traverse matter without any interaction, we describe the interaction via a probability to interact. The transmitted fraction of a beam of photons (probability of no interaction) is described by a mass attenuation coefficient:

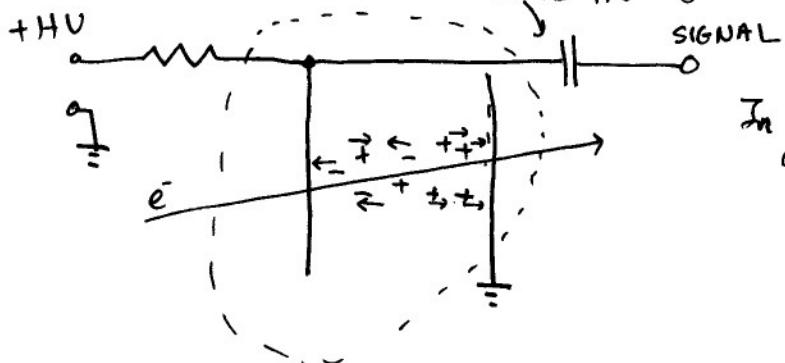
$$\text{transmit fraction} = e^{-\mu(E)t}$$

where $\mu(E)$ is the mass attenuation coefficient and has units cm^2/g . Typically μ is a sum of 3 terms:



II Detection Strategies:

- A. Gas volume containing an electric field, which moves charges over to electrodes, where the charge can be sensed.

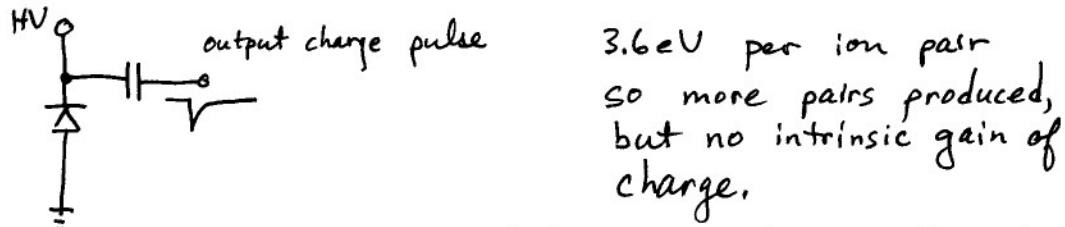


In a gas, it costs $20-30 \text{ eV}$ on average to make an electron-ion pair.

Depending on the HV, charges move towards electrodes in different ways.

1. At low voltage, most charge fails to reach electrodes
2. At higher voltage, ions and electrons are collected
→ this is called an ionization chamber
3. At higher levels, electrons are accelerated enough
that some are able to further ionize the gas.
The collected charge is amplified linearly.
This is called a proportional chamber
4. At higher energies, the multiplication is severe
enough that the whole volume of gas breaks
down. There is a loss of proportionality
between initial and final ionizations. This
is called a Geiger counter.

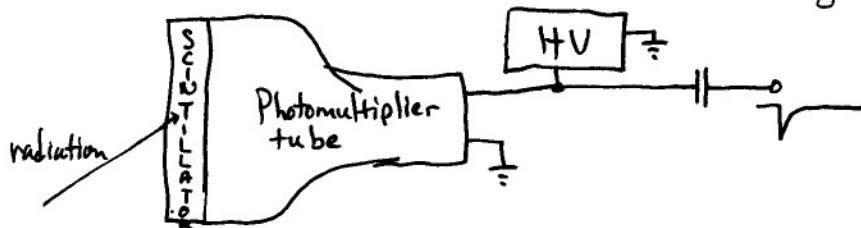
- B. Same idea as a gas volume target, but use a semiconductor solid target material.

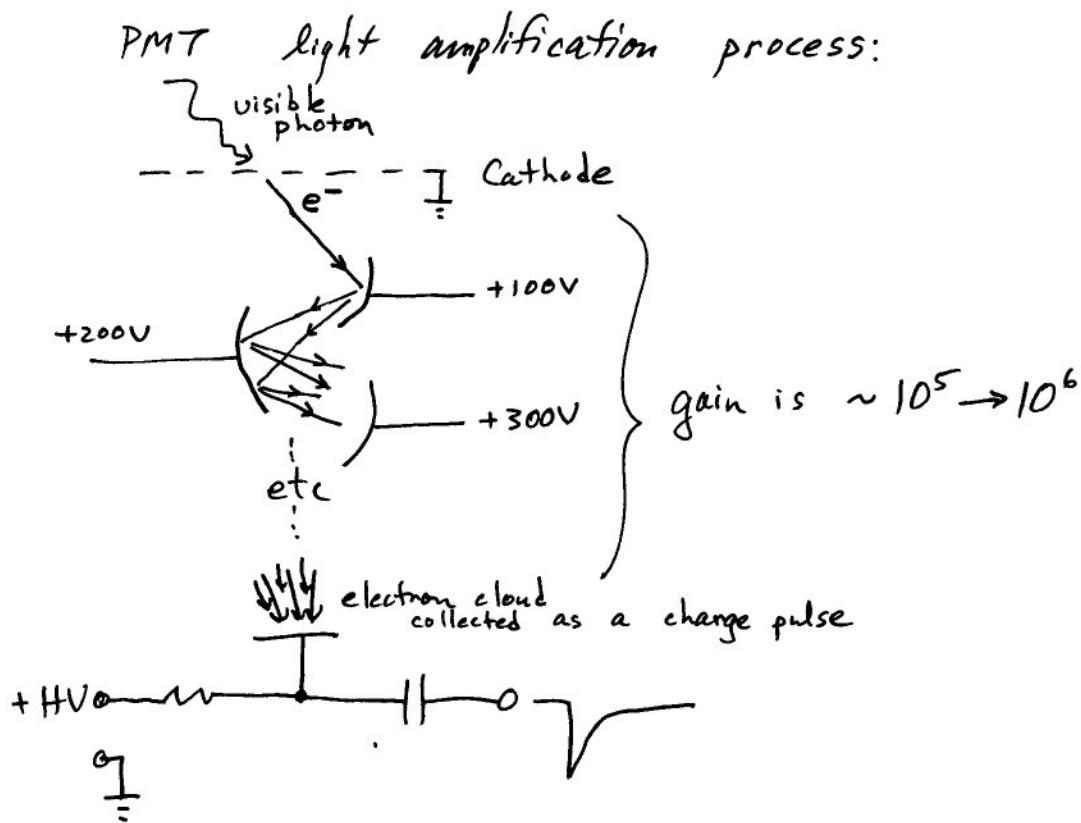


3.6 eV per ion pair
so more pairs produced,
but no intrinsic gain of
charge.

People use silicon diodes to catch charged particles,
large germanium diodes to catch photons
Germanium diodes operate at liquid nitrogen temperatures.

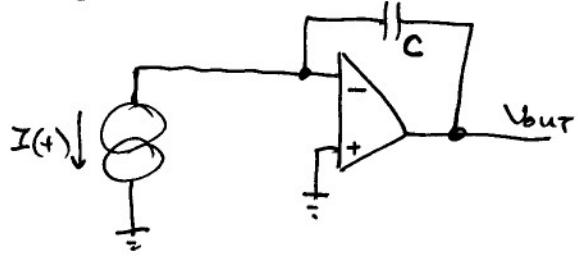
- C. Convert ionization to visible light, then amplify the light.



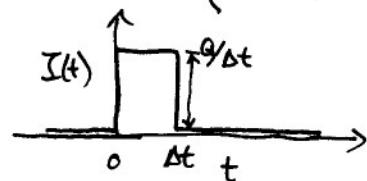


How to detect a charge pulse of 10^6 electrons or
 $1.6 \times 10^{-19} \frac{C}{e^-} \times 10^6$ electrons = 0.16 pC ?

Charge sensitive amplifier:



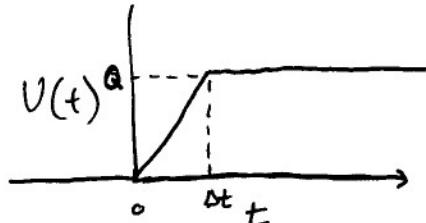
$$I(t) = \begin{cases} \frac{Q}{\Delta t} & 0 < t < \Delta t \\ 0 & \text{else} \end{cases}$$



$$C \dot{V}_{out} = I(+) \quad (1)$$

$$\dot{V}_{out} = \frac{I(t)}{C} \quad \text{so} \quad \int_0^t \dot{V}_{out} dt' = \frac{1}{C} \int_0^t I(t') dt'$$

$$V(t) - V(0) = \frac{1}{C} \begin{cases} \frac{Q}{\Delta t} t & 0 < t < \Delta t \\ Q & t > \Delta t \\ 0 & t < 0 \end{cases}$$



Simple charge sensitive amplifier almost works.
But it needs DC feedback; choose R large

