Detectors

The energy loss of particles in matter can be used detect and identify those particles. There are different types of “detectors”:

- Gas-filled counters

- Semi-conductor counters

  (Germanium, Silicon, NaI,….)

- Scintillation counters

  (Organic & Inorganic: Solid, liquid)

Figures in this presentation are from “Introductory nuclear physics” by Keneth Krane.

Gas-filled counters

An electric field is used to separate and count the ions (or electrons) formed by the passage of radiation through the detector

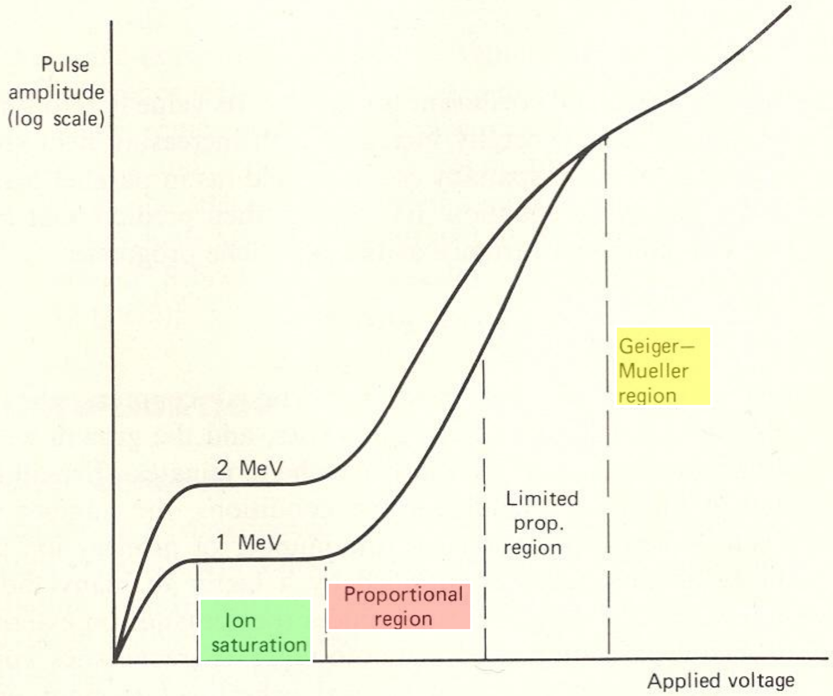


Figure 6-2 The different regions of operation of gas-filled detectors. The observed pulse amplitude is plotted for events depositing two different amounts of energy within the gas.

Proportional counter – Geiger Mueller Counter

In the proportional counter the amplitude of the signal formed is proportional to the energy deposited.

$$\mathscr{E}(r) = \frac{V}{r \ln(b/a)} \qquad (6\text{-}3)$$

where V = voltage applied between anode and cathode

a = anode wire radius

b = cathode inner radius.

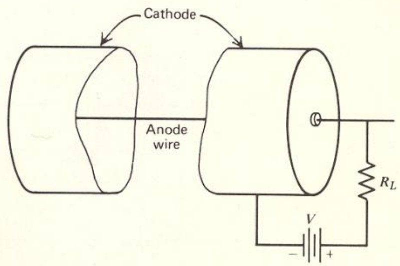


Figure 6-3 Basic elements of a proportional counter. The outer cathode must also provide a vacuum-tight enclosure for the fill gas. The output pulse is developed across the load resistance R_L.

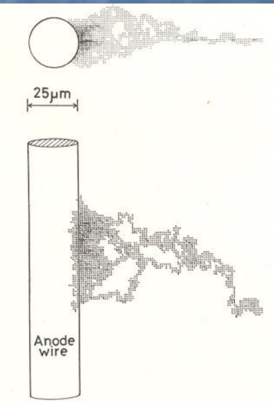
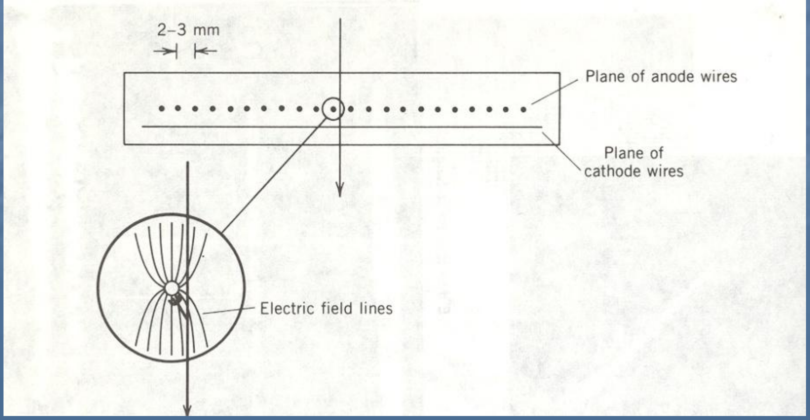


Figure 6-4 Orthogonal views of an avalanche triggered by a single electron as simulated by a Monte Carlo calculation. The density of the shading indicates the concentration of electrons formed in the avalanche. (From Matoba et al.[3])



Position sensitive PPAC

Scintillation detectors

The disadvantage of gas filled counters is their low efficiency. This can be overcome by going to detectors with higher densities (solids, liquids).

However to be a workable solid detector we need:

1) material must support high E (to collect the e^- and ions)
2) little or no current must flow in the absence of radiation
3) e^- must be easily removed by radiation and must be able to travel

(1) & (2): Insulator → SEMICONDUCTORS ← (3): conductor

Bulk material in large size was long unavailable. → Scintillation counters (1950)

↓

e^- formed by the ionization ≠ e^- that form the pulse

Principle of scintillation detectors

1) Incident radiation interact with material
2) Atoms are raised to excited states
3) Excited states emit visible light: fluorescence
4) Light strikes photosensitive a surface
5) Release of a photoelectron

↓

multiplication

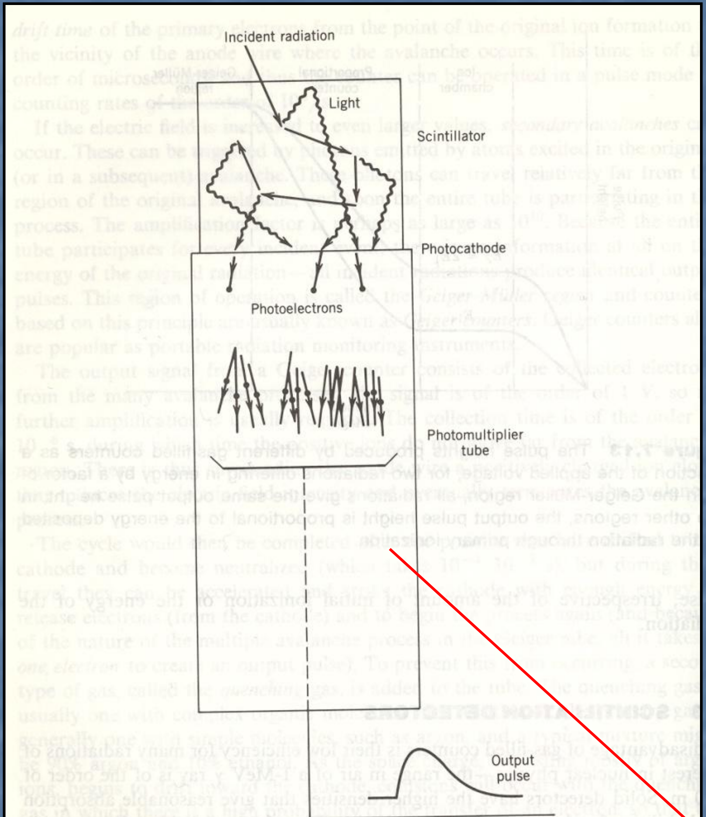
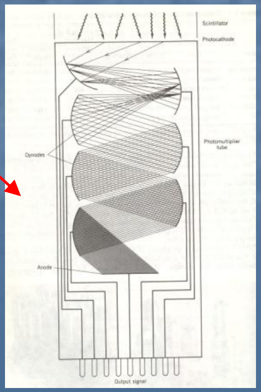


Figure 7.14 The basic processes in a scintillation detector.



There are organic (liquid or solid) and inorganic scintillators (NaI)

Semiconductor detectors

Ge and Si are solid semiconductor materials (they form solid crystals with valence-4 atoms). They can be "doped" to control electrical conductions

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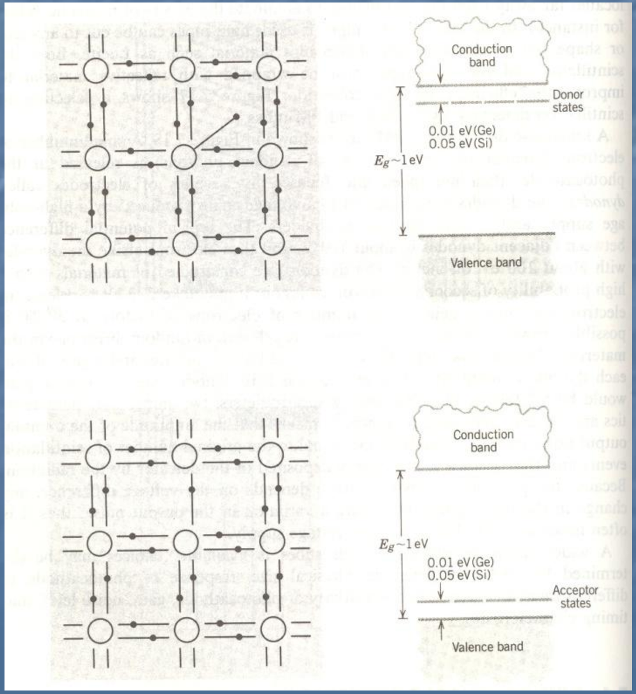
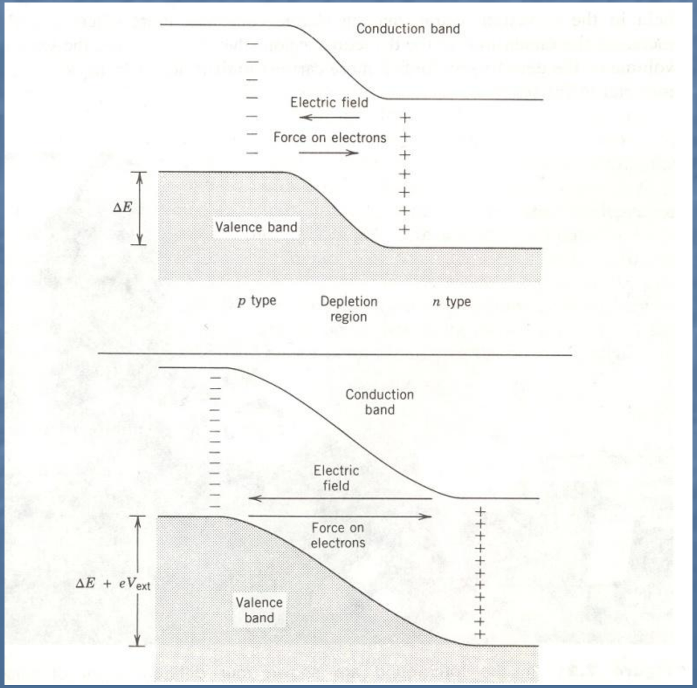
With valence 3 or 5 atoms introduced into the lattice

Donor states: n-type semiconductor
Acceptor states: p-type semiconductor

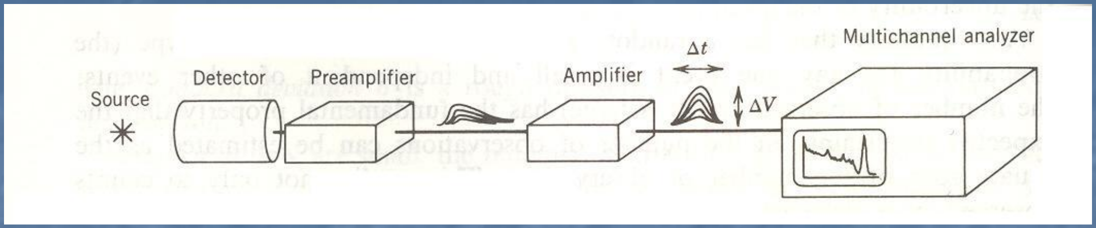


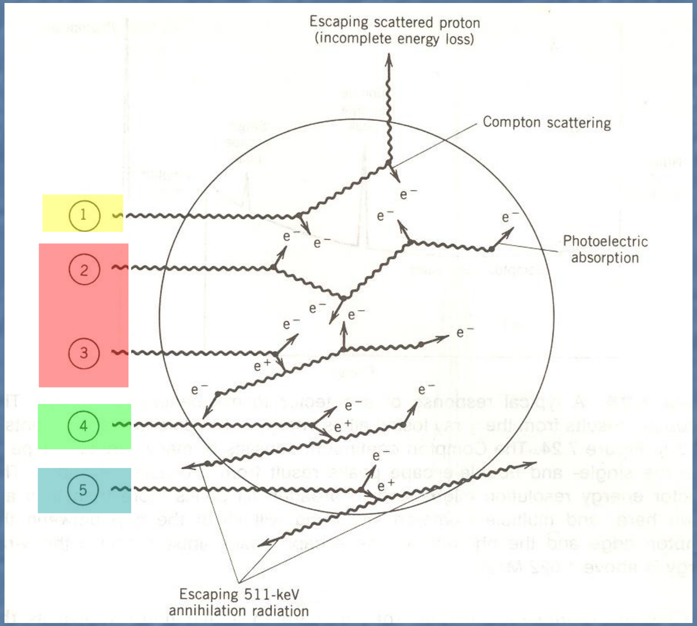


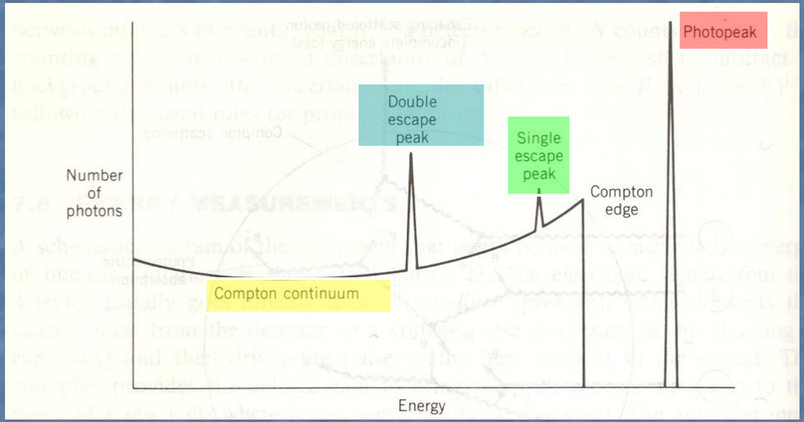
n- and p-type brought into contact

Junction under reverse bias

Energy measurement







What is the shape of the spectrum for a large detector?

Coincidence measurement

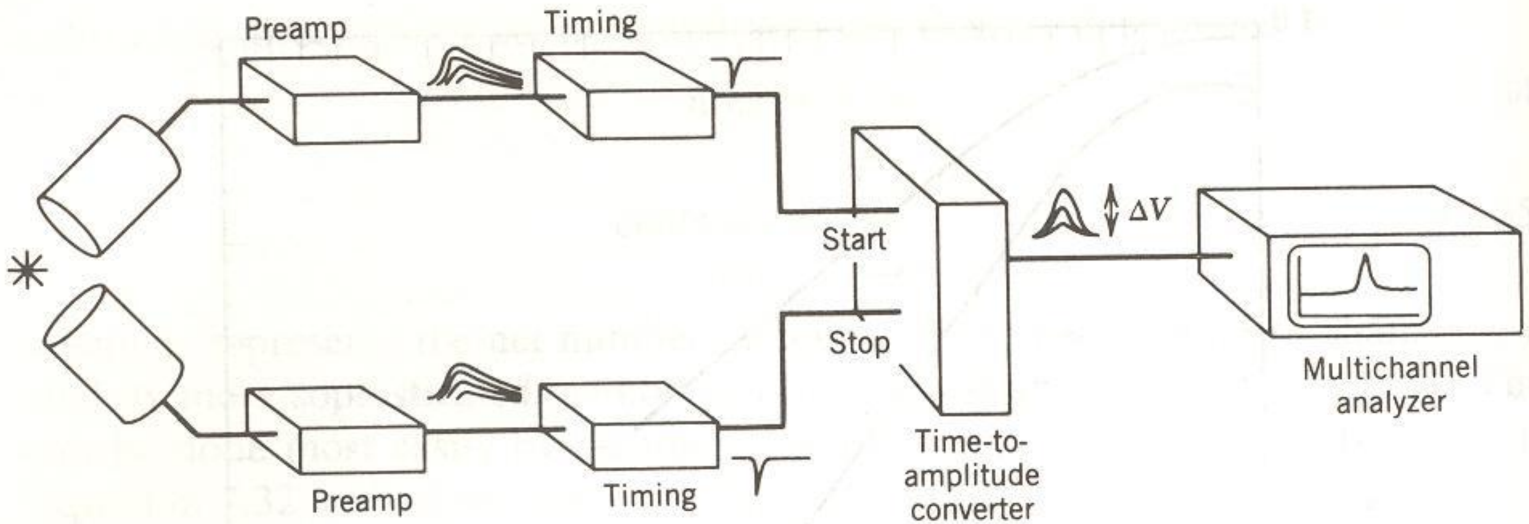


Figure 7.29 Schematic diagram of equipment to determine whether two radiations from the source are in time coincidence (that is, whether they come close enough together in time to originate from the same nucleus in a sequential or cascade emission). The short rise time of each preamp signal triggers a timing circuit; the fast timing signals start and stop a time-to-amplitude converter (TAC), the output of which has a pulse height ΔV that is proportional to the time difference between the start and stop pulses. The spectrum of pulse heights (and therefore of times) can be displayed on a MCA.

Magnetic spectrographs & counter telescopes

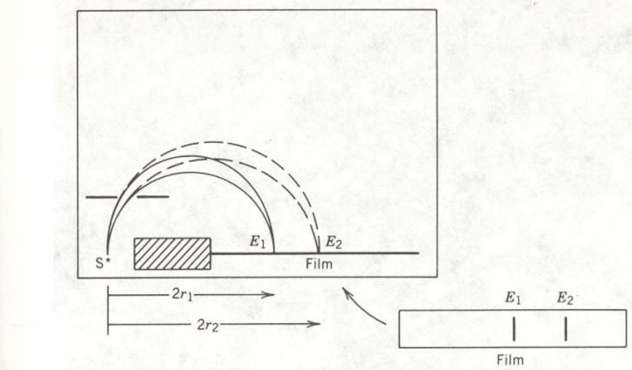


Figure 7.36 A simple magnetic spectrometer. There is a uniform magnetic field B perpendicular to the plane of the paper. The momentum of the particle determines the radius of curvature r of its path. There is also a focusing effect, as particles emitted in a narrow range of angles are focused to a common point on the film.

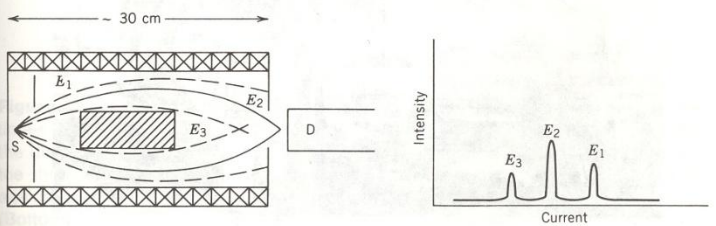


Figure 7.37 A magnetic "lens" spectrometer designed for electrons. The operation is very similar to that of an optical lens. The coils produce a magnetic field along the axis of the system. Particles of a unique energy E_2 are focussed on the exit slit and reach the detector; particles of different energies are not recorded. Changing the current in the coils allows different energy groups to be brought into focus and observed by the detector.

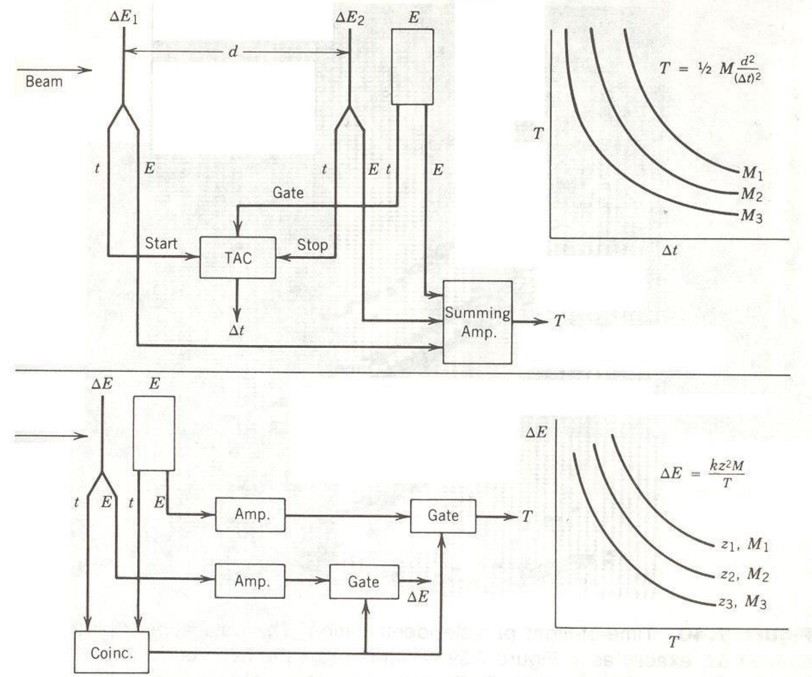


Figure 7.39 Two different examples of counter telescopes. (Top) In the time-of-flight technique, a TAC measures the time that it takes the particle to travel the distance d between the two ΔE detectors; a summing amplifier adds together the three energy losses to determine the energy of the particle. Plotting energy against Δt gives a family of hyperbolas that determine the mass of the particle. (Bottom) The $\Delta E \cdot T$ technique also gives a family of hyperbolas, which determine both z and M.

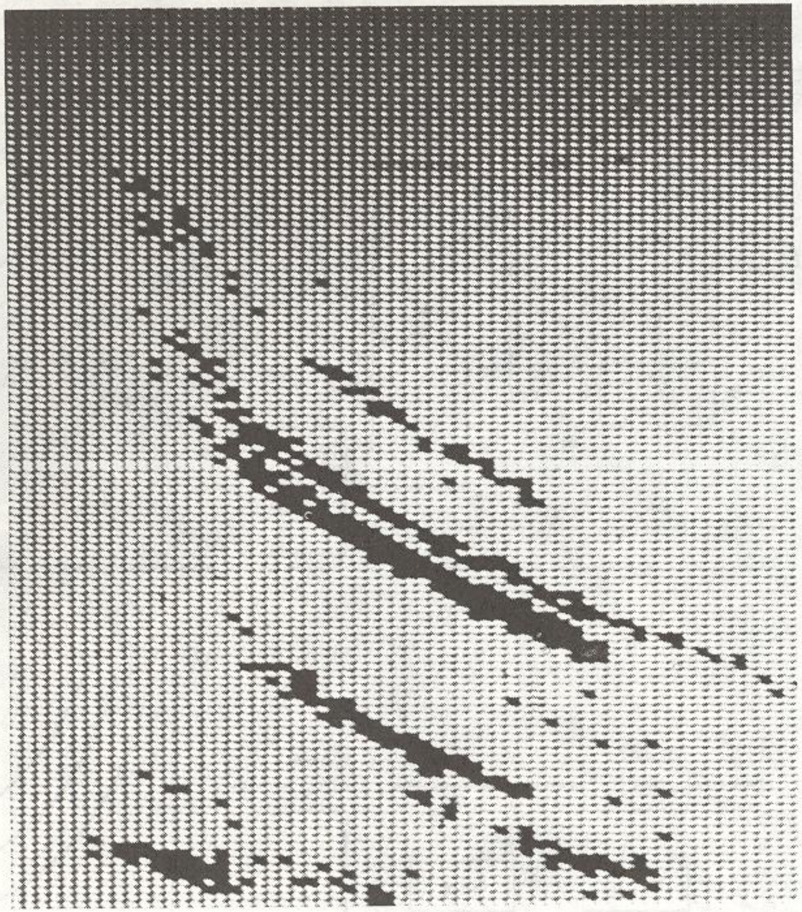


Figure 7.40 Time-of-flight particle identification. The data appear plotted as T against Δt, exactly as in Figure 7.39. From the top, the hyperbolas show ^{16}O, ^{13}C, ^{12}C, ^{7}Li, ^{6}Li, and ^{4}He. From W. F. W. Schneider et al., *Nucl. Instrum. Methods* **87**, 253 (1970).