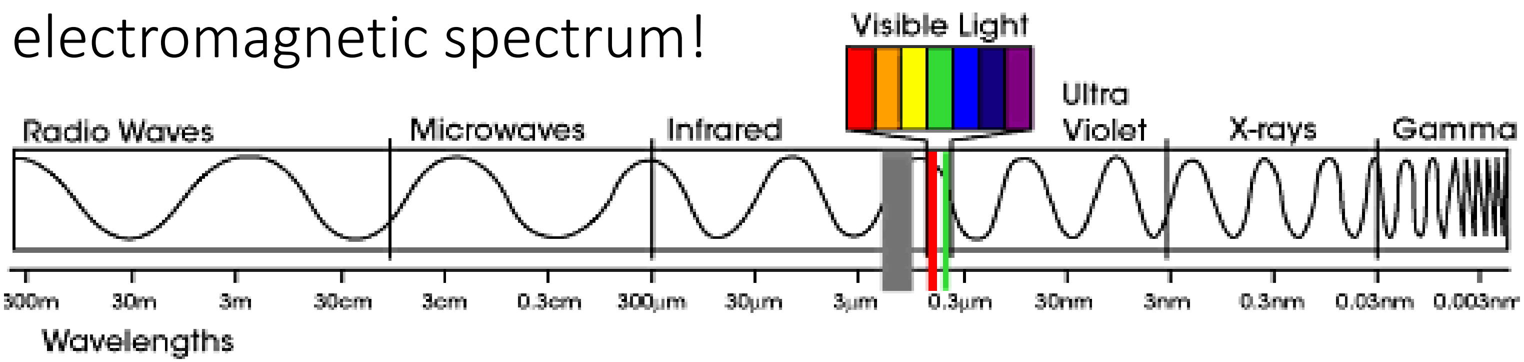
Radioactivity

Lecture 6

Detectors and Instrumentation

The human organs

- Neither humans nor animals have an organ for detecting radiation from radioactive decay!
- We can not hear it, smell it, feel it or see it!
- Eyes are reduced to a very small section of the electromagnetic spectrum!



- Skin can only feel the heat in case of intense energy release (Pierre Curie experiments)
- One needs instrument for the detection of radioactivity!

Radioactivity in our daily life

Radioactivity is not only an extreme phenomenon associated with nuclear bombs and nuclear reactors but also with a number of daily utensils and activities. We don’t notice it, but we can detect it!

What do you think, radioactive or not ????

Salt from the underground US nuclear Waste Isolation Pilot Plant (WIPP) 1999-2015

Dinosaur bone 70 Ma old

Uranium Ore I

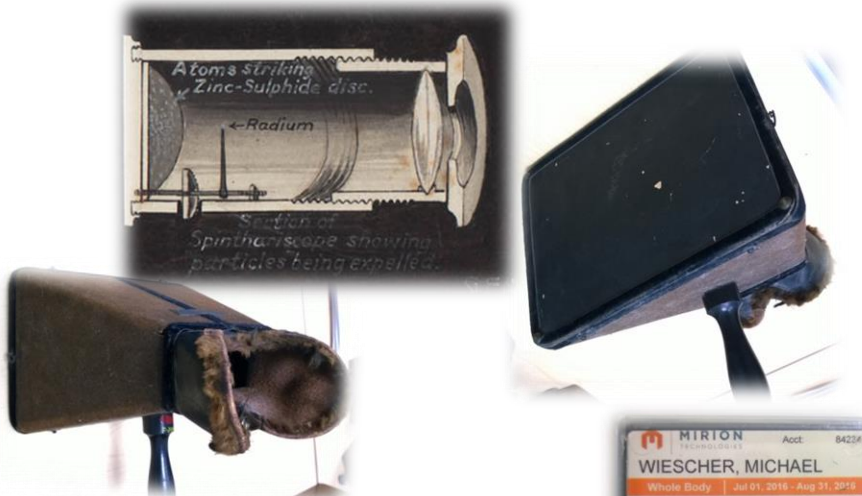
Uranium Ore II

Trinitite from Nuclear Bomb test 1945

Basis of Instruments

- A radiation detector is based on the detection of secondary effects caused by radiation
- Radiation effects depend on the kind of radiation, not every radiation detector is sensitive to each kind.
- Radiation ionizes material by energy deposition, ionization can be measured by electric current
- Radiation excites atoms by energy deposition, de-excitation via light emission can be measured

The collection of early instrumentation



Early Scintillator screens for visual counting

Geiger Counter 1955 version

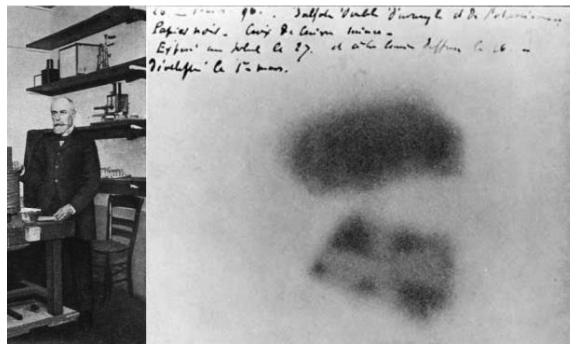
Dosimeter 1955 version

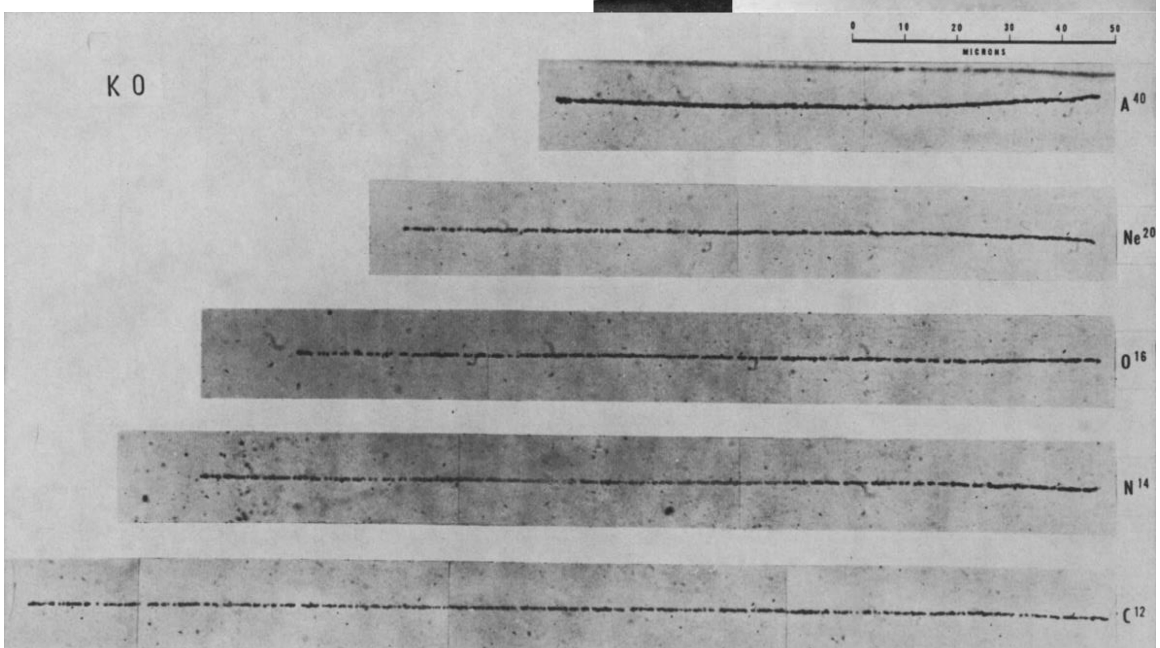
Dosimeters today

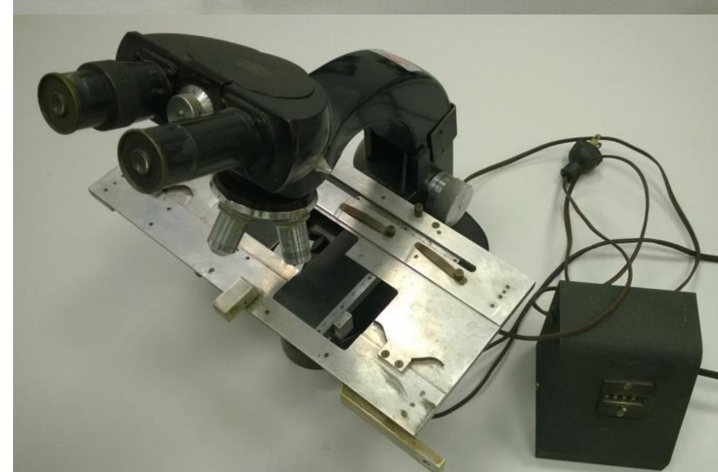
Geiger Counter 2015 version

Photographic plates

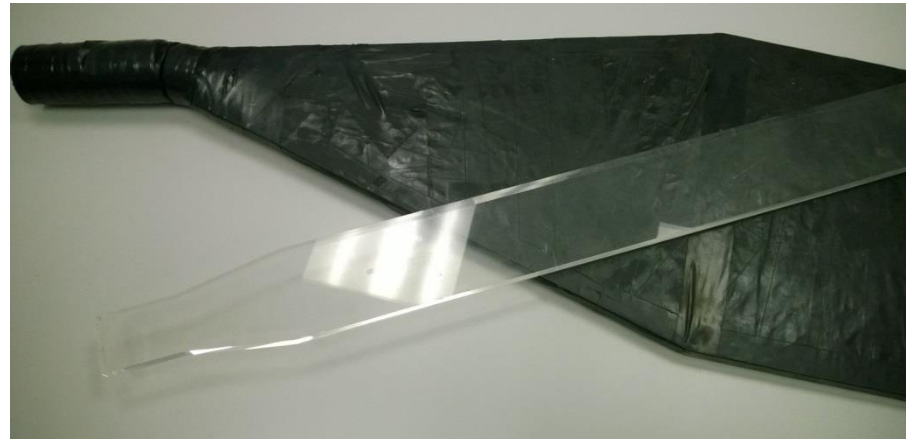
Powerful tool after the first discovery by Becquerel for nearly 80 years, complemented by cloud chambers for tracking particle trajectory

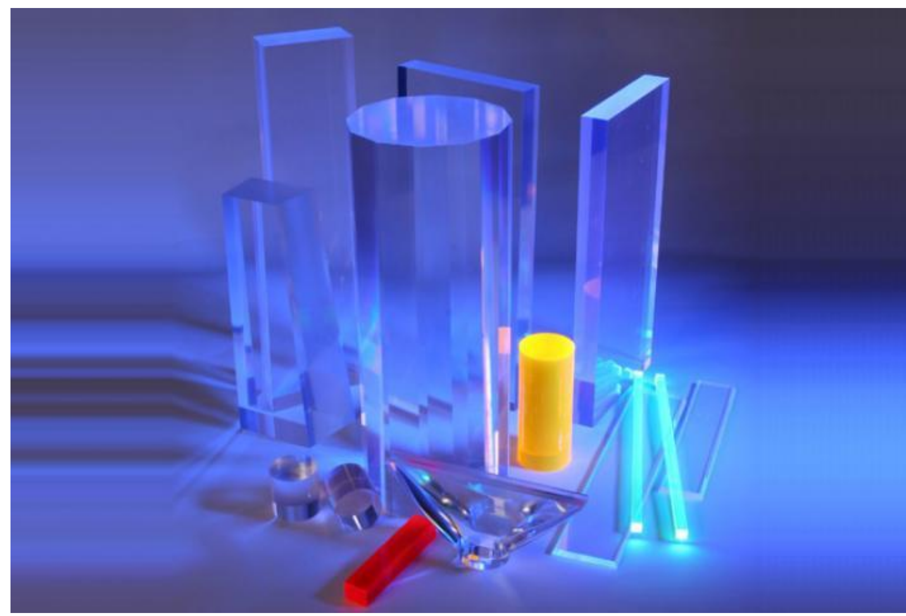






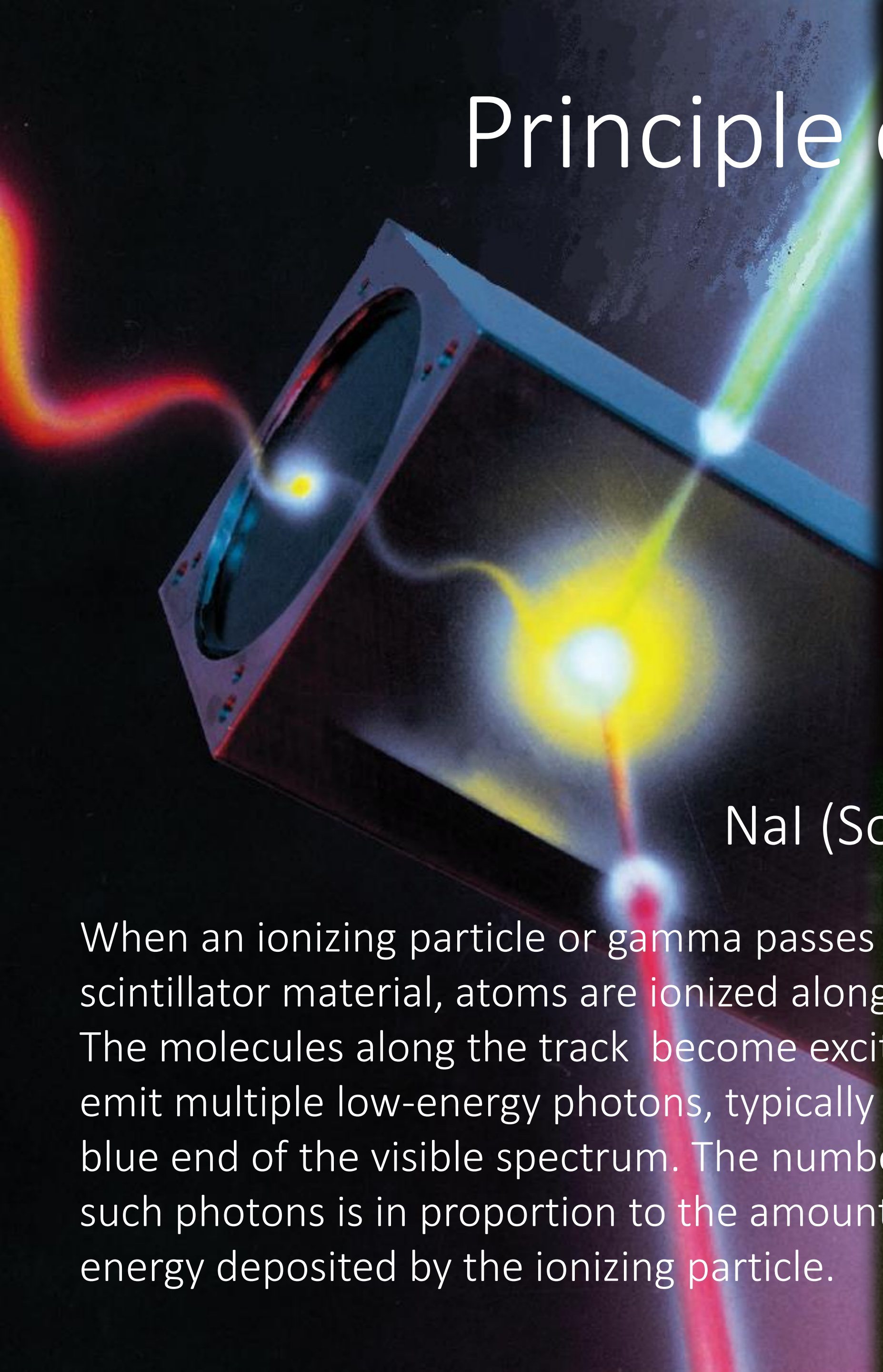
Scintillators





Mostly salt crystal, but increasingly also plastic material that emits light when hit by radiation, ZnS, NaI, CsI, BaF_2, BGO, ….

Principle of Scintillators

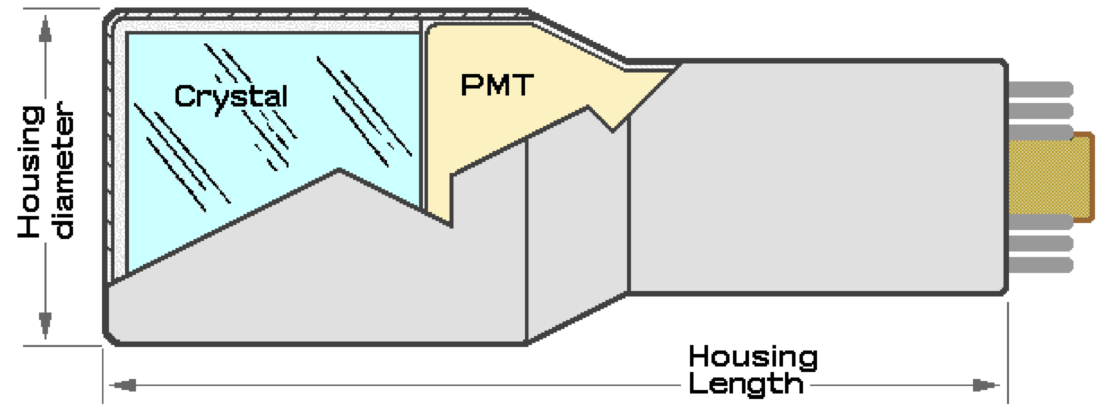


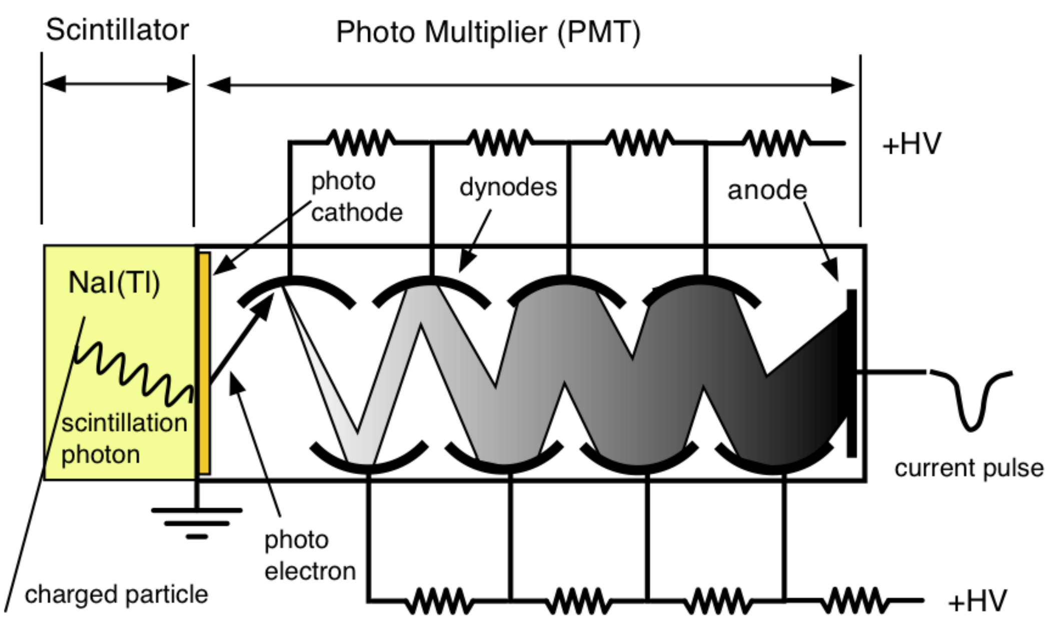
NaI (Sodium Iodide) detector for γ radiation

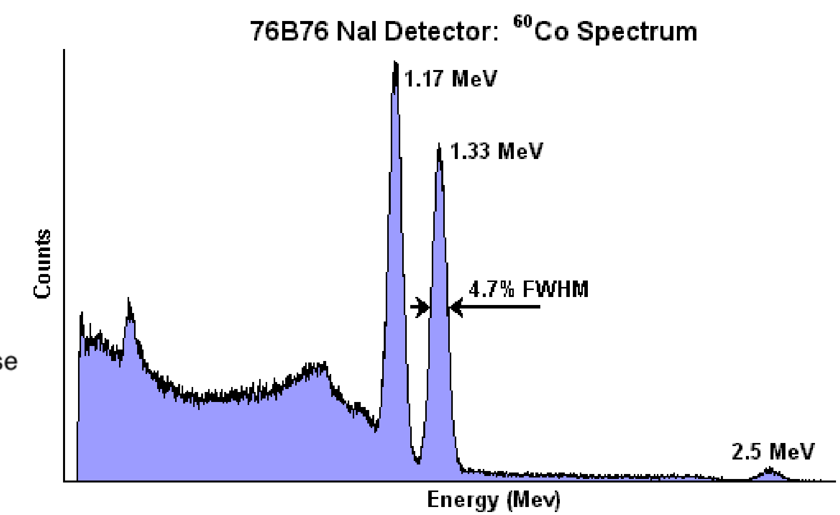
When an ionizing particle or gamma passes into the scintillator material, atoms are ionized along a track. The molecules along the track become excited and emit multiple low-energy photons, typically near the blue end of the visible spectrum. The number of such photons is in proportion to the amount of energy deposited by the ionizing particle.

Photomultiplier (PMT)

Efficient optical coupling is required between crystal and PMT

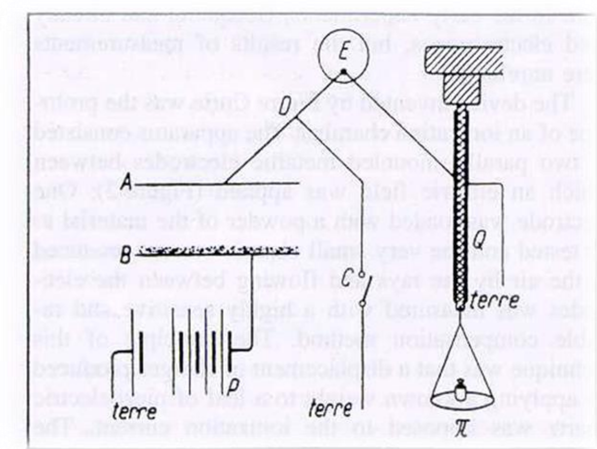




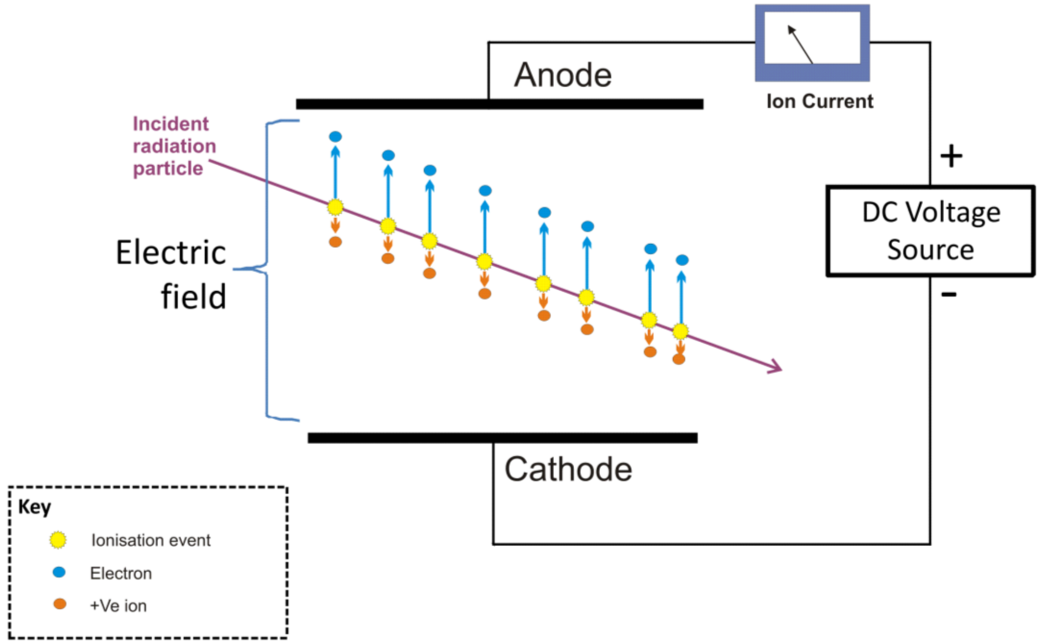


Principle of Ionization chamber

Pierre Curie invented the prototype of an ionization chamber.



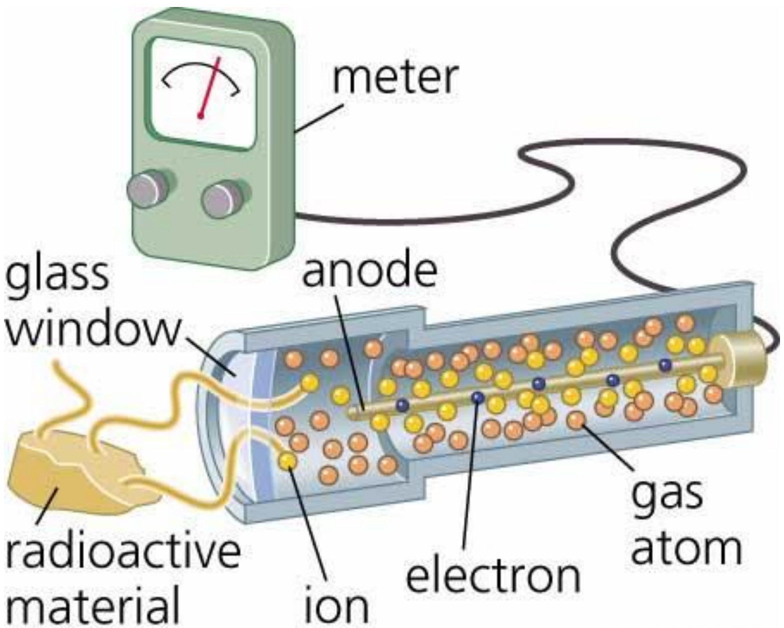
Nuclear radiation has sufficient energy to ionize atoms in a gas, generating free negatively charge electrons and free positively charged ions that can be separated by electrical potential and detected.



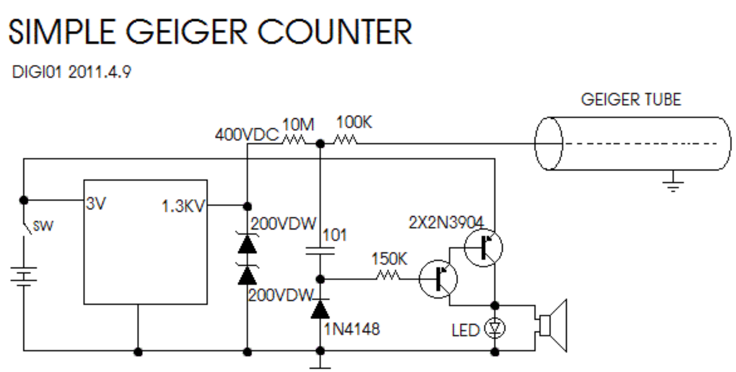
The apparatus consisted of two parallel-mounted metallic electrodes between which an electric field was applied.

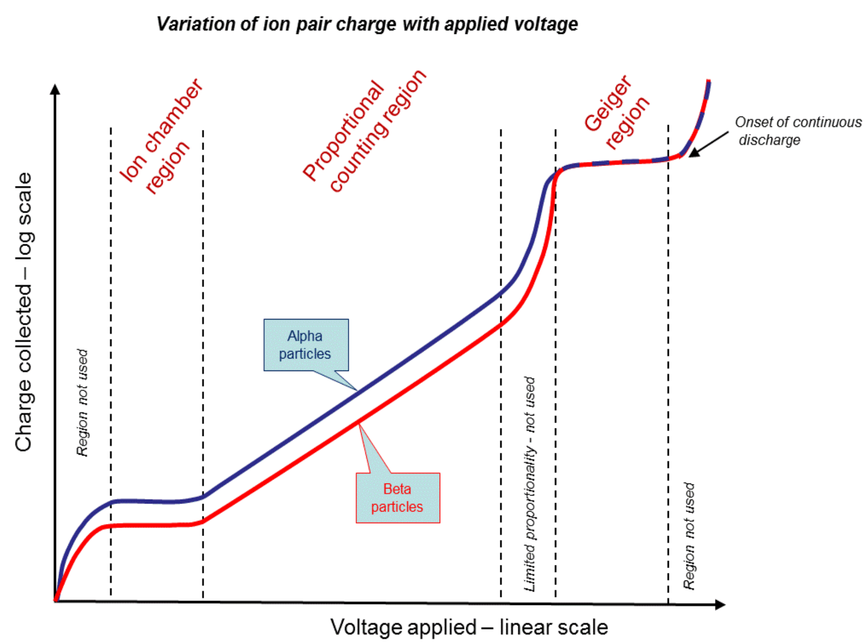
One electrode was loaded with a powder of the material to be tested and the very small electric current produced in the air by the rays and flowing between the electrodes was measured with a highly sensitive and reliable weight compensation method. Today the electrical current can be directly measured and corresponds to the level of radioactivity.

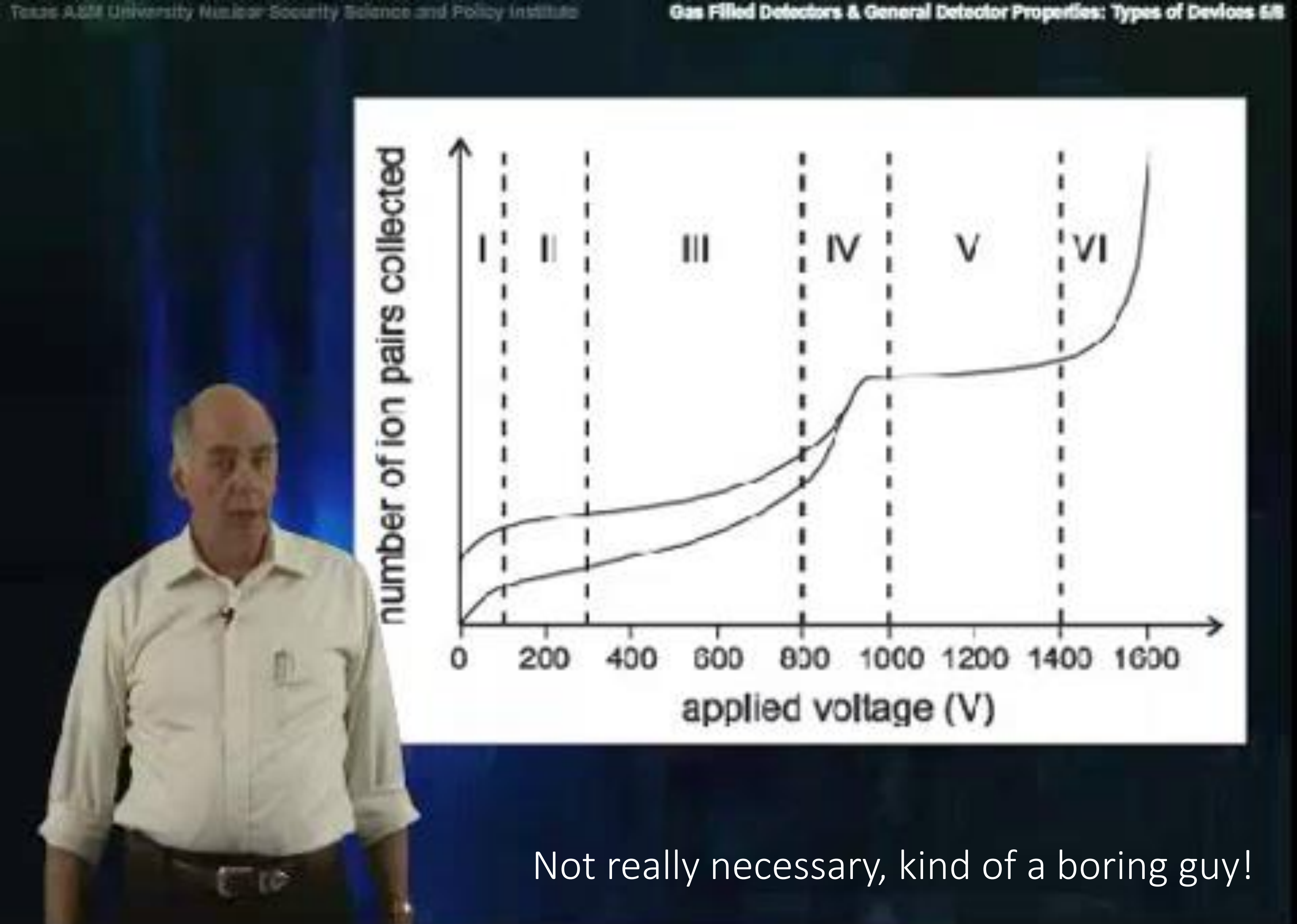
Geiger or Geiger-Müller Counter



Variation of ionization counter, instead of two parallel plates, cathode (-) and anode (+) the anode is now a central wire in a cylindrical geometry, attracting electrons from the ionized gas and measuring the current proportional to the ionization, which is proportional to the intensity of the radiation. There ate different modes of operation depending on the applied voltage for charge collection.



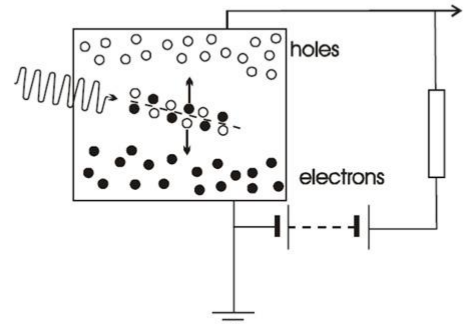




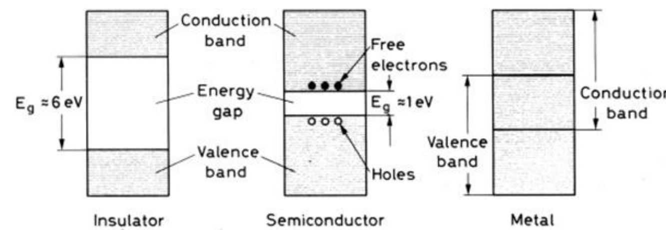
Not really necessary, kind of a boring guy!

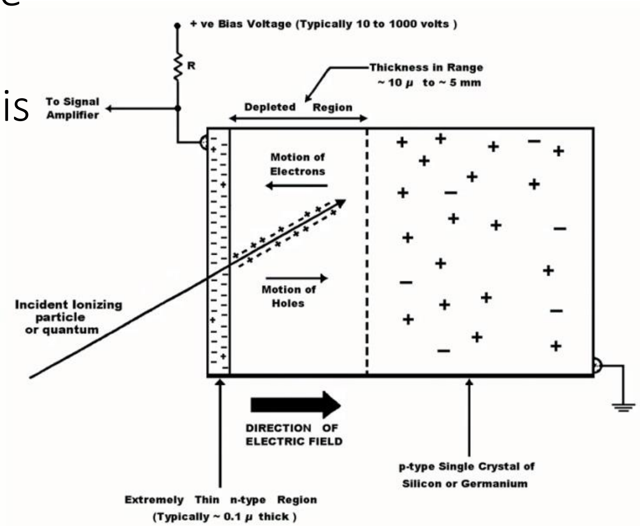
Semiconductor counter principle

Si for particles, Ge for gamma detection



Semiconductor detectors are solid-state devices that operate essentially like ionization chambers. The charge carriers in semiconductors are not electrons and ions, as in gas counters, but electrons and holes. Radiation incident upon the semiconducting junction produces electron-hole pairs as passing energy to the electrons to jump the band-gap. Electrons and holes are swept away under the influence of the electric field, and the proper electronics can collect the charge in a pulse. The sensitive volume of a semiconductor detector, which is also known as the *depleted region*, is an electronically conditioned region in the semiconductor material in which released electrons and holes move freely. **The number of electron-hole pairs correspond to the energy of the radiation. This allows accurate measurement of radiation energy and spectroscopy of radiation.**

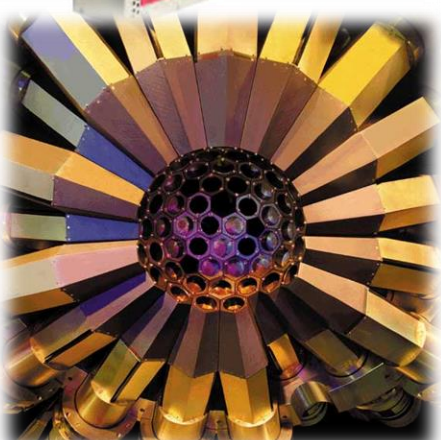




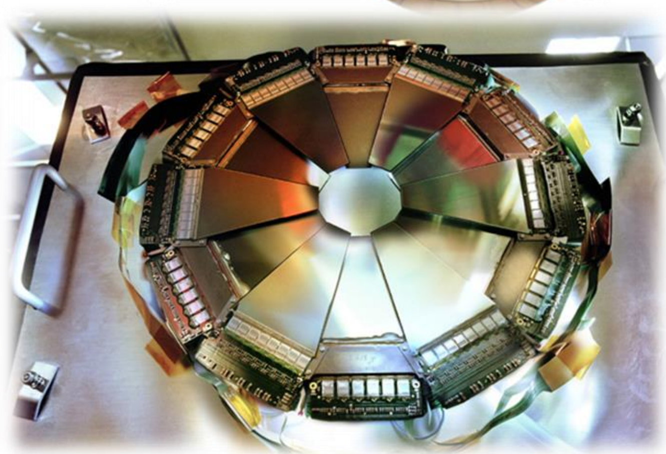
Commercial semiconductor detectors

Single Si detectors

Single liquid nitrogen cooled Ge detectors



Multiple Ge detector array, Gammasphere

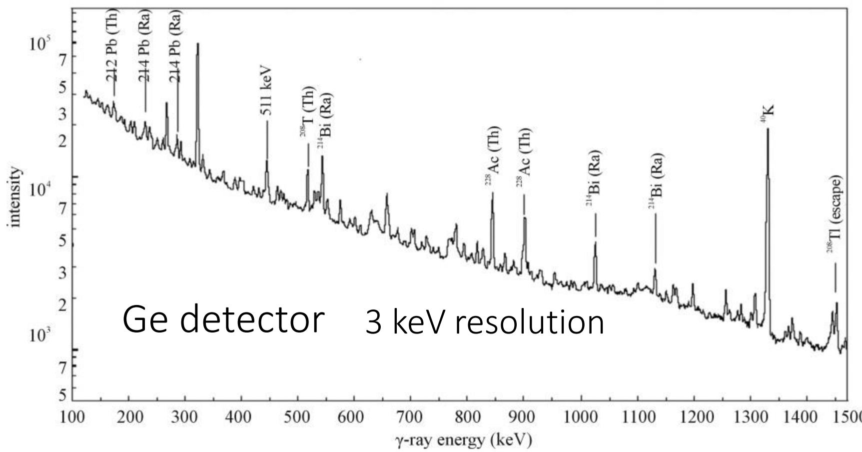


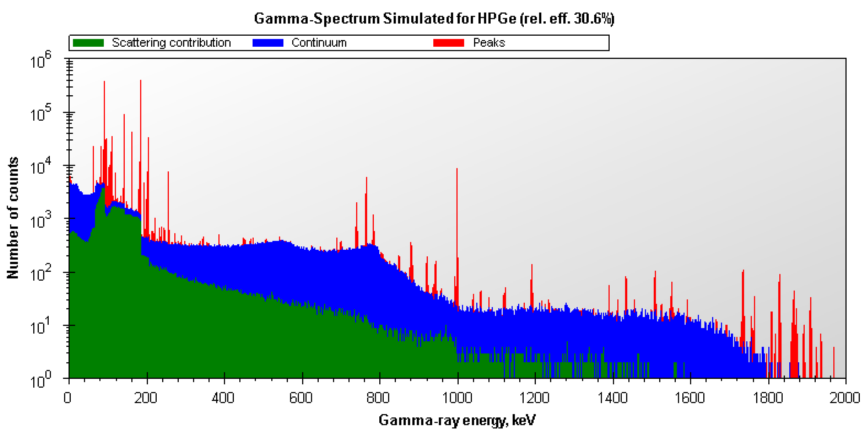
Multiple Si detector disk array

Spectroscopy and Spectra

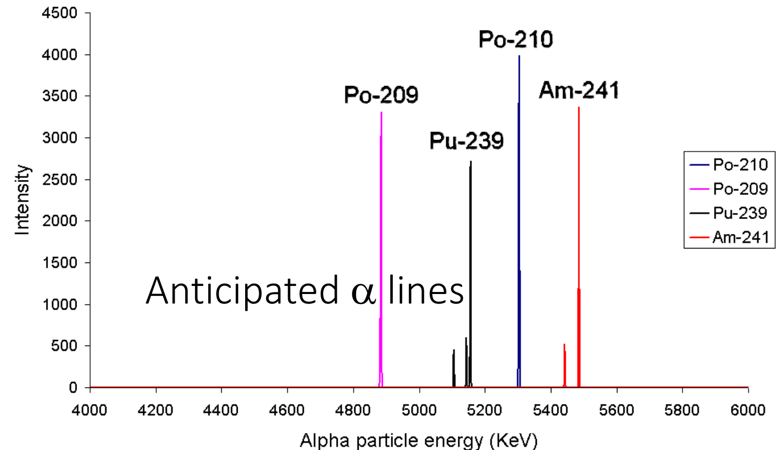
In spectroscopy one sorts the radiation events by its nature: α, β, γ and its respective energy

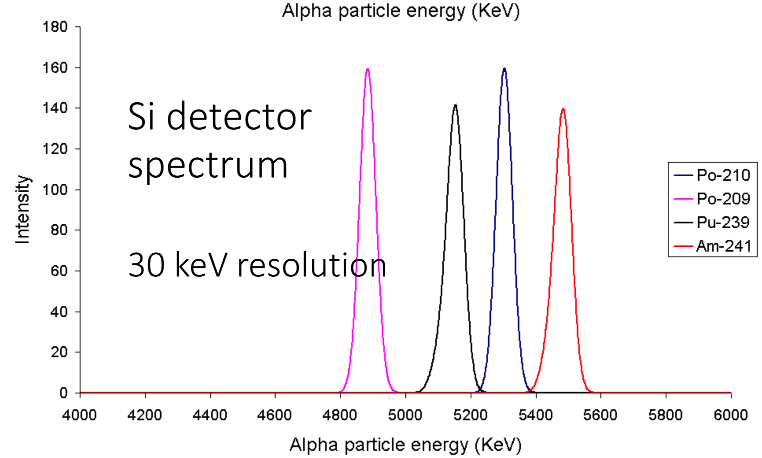
Spectrum of the environmental γ-background from the natural decay chains from long-lived radioactive Isotopes.





Spectrum of the environmental α-background from the natural decay chains from long-lived radioactive Actinides





Background components in γ-spectrum are generated by inelastic scattering from emitted particles and photon scattering in materials