# Detecting Ionising Radiation

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# Interaction with Matter

**α, β, γ and X-rays interact with matter in 2 major ways:**

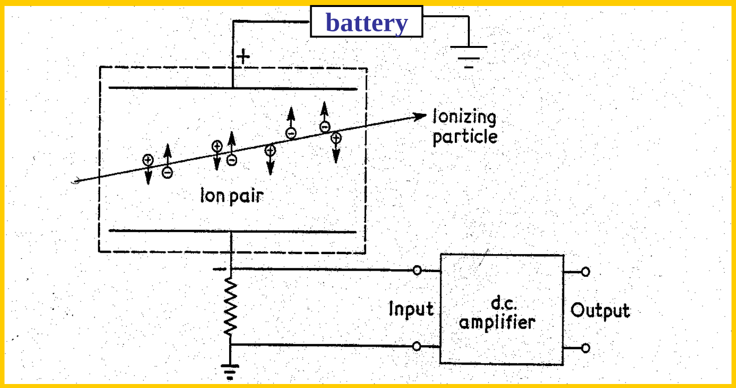
**Ionisation: removal of an electron from an atom leaving an ion.**

**Excitation: addition of energy to the atom, giving an excited state.**

**We can take advantage of these properties to devise a range of detectors.**
**In general detectors utilise one of the following principles:**

- **Ionisation in gases**
- **Ionisation in solids/liquids**
- **Changes in chemical systems**

# Ionisation in Gases: The Ion Chamber



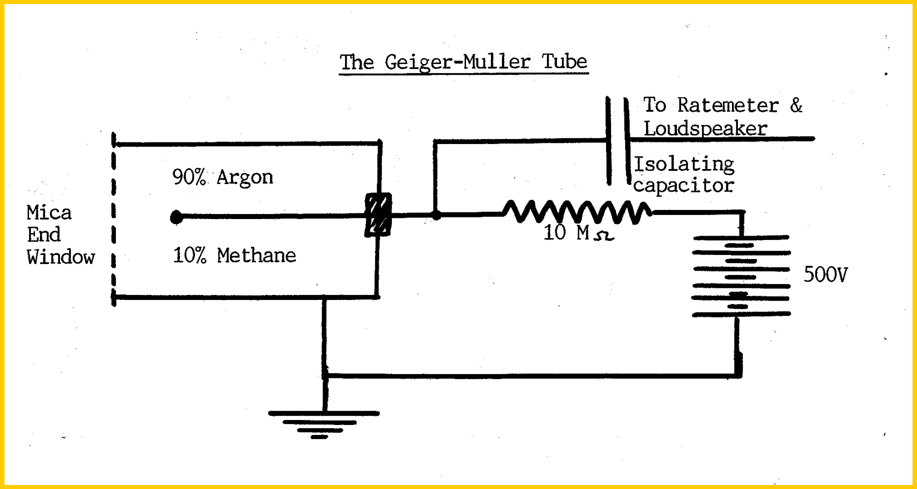

- **Low voltage (30 – 100 V)**
- **Air filled vented to atmosphere**
- **Radiation entering produces ion pair**
- **Ion pair drift to respective electrodes**
- **Produces very small current $10^{-14}$A**
- **Tissue equivalent (Z=7.5)**
- **Flat response to gamma energies**

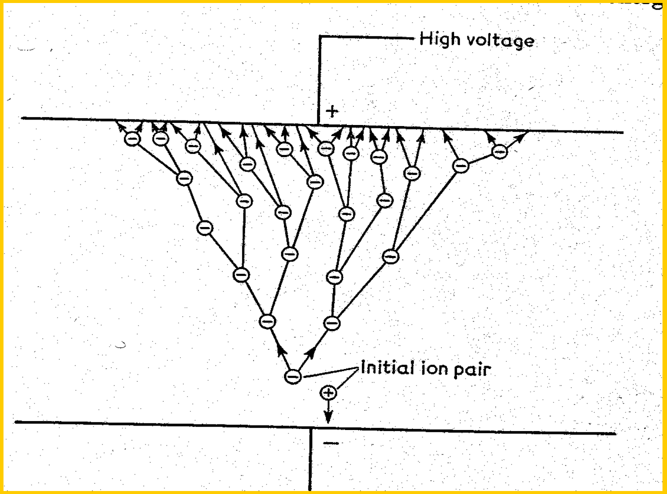
- **Advantages:**
- **Used as a doserate monitor**
- **Can measure gamma > 12 keV and beta > 70 keV (with cf applied)**
- **Detects neutrons (~ 8% efficiency)**

- **Disadvantages:**
- **Low currents = expensive electronics**
- **Very slow response times**
- **Susceptible to high humidity or moisture**
- **Susceptible to air pressure changes**
- **Contamination by radioactive gases**

# The Geiger – Muller Tube


- **Operation similar to ion chamber – gas ionisation**
- **Major Differences –**
- **Low pressure gas ~ $10^{-3}$ Atm**
- **High voltage across electrodes > 500 V**
- **HV causes avalanche / cascade effect**



**Advantages**

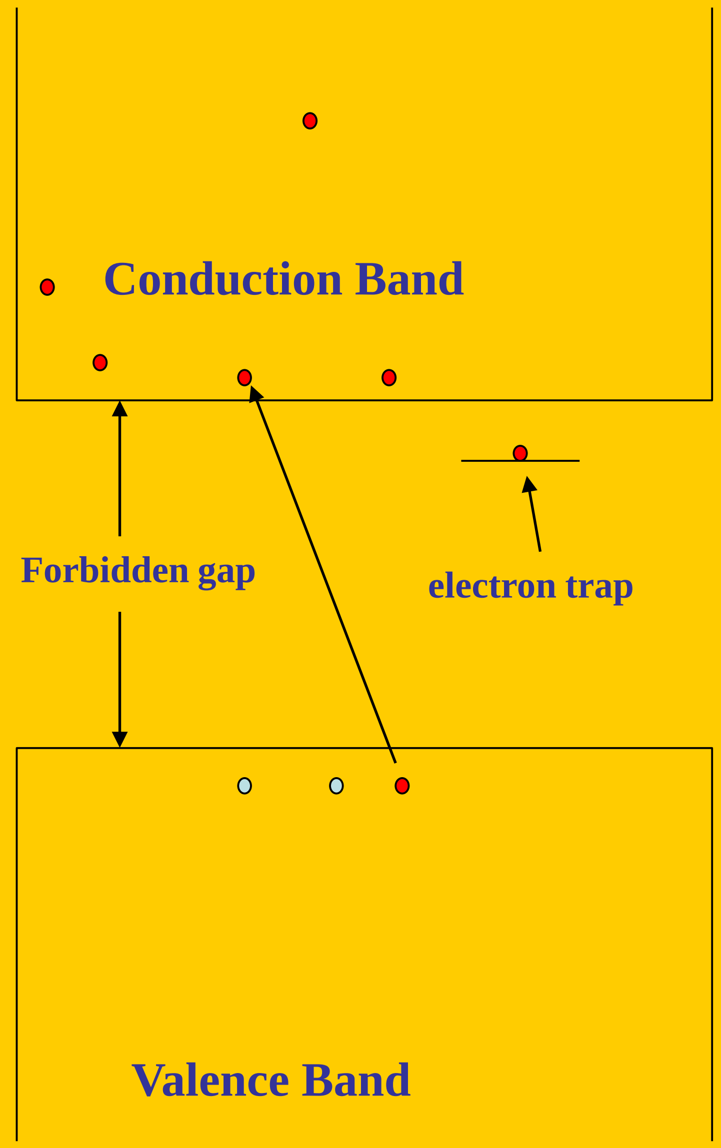
- **Higher currents = cheaper electronics required**
- **Easily replaceable tubes**
- **Audible and visible outputs**
- **Not susceptible to atmospheric changes – humidity etc**
- **Sensitive – best used as a contamination monitor**

**Disadvantages**

- **Cannot be used as a doserate monitor**
- **Requires quenching to stop runaway cascade**
- **fragile end windows**
- **No energy discrimination**

## Ionisation in solids/liquids

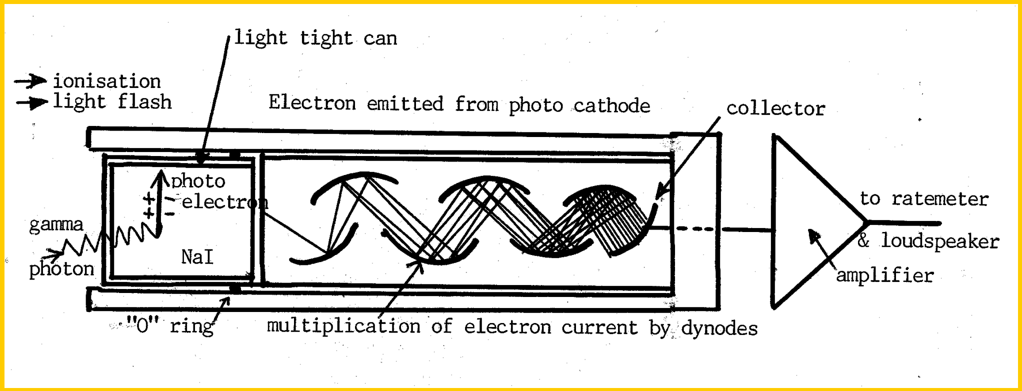
- **Work on the principle of fluorescence (scintillation)**
- **Efficiency depends on electron density**
- **Sodium Iodide (NaI) has high electron density**
- **Liquid scintillation counters – use a solvent/fluor combination**
- **Semiconductor detectors**




- **Single atoms or molecules display energy levels**
- **When these come together to form a solid the discrete levels become energy *bands***
- **Top 2 bands are the Valence and Conduction**
- **Valence band is nearly full, conduction nearly empty**
- **Forbidden region has no electrons in pure crystal**
- **'Size' (in eV) of FR depends on type of solid**
- **Impurities or dopants introduce electron 'traps'**
- **Excitation leaves the valence band with a 'hole'**
- **Conduction electron drops down to the valence band emitting a photon of light**
- **Introduction of dopants increases the efficiency**

## Sodium Iodide:

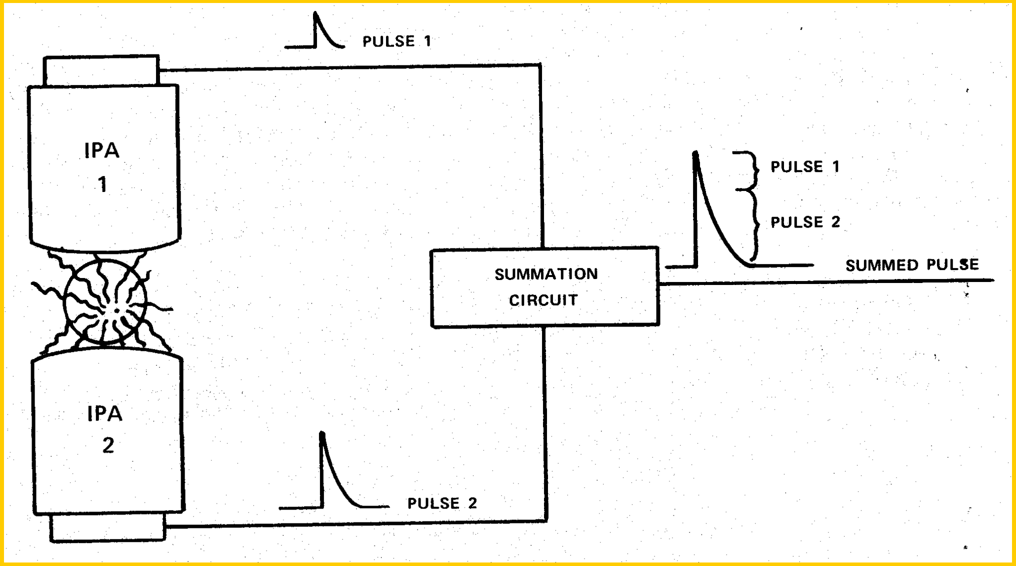
- Used for gamma and X-rays
- Type 41 (gamma) energies > 25 keV
- Type 42b (x-rays) energies 5 – 60 keV




# Mini 900 Scintillation Monitor – Type 42

**Liquid scintillation counter:**

- **Sample (e.g. swab) dissolved in fluor/solvent cocktail**
- **Light flashes from excited fluor molecules detected by two pm tubes in a coincidence circuit**
- **Generally used for beta emitters**



**Liquid Scintillation Counter - Advantages:**

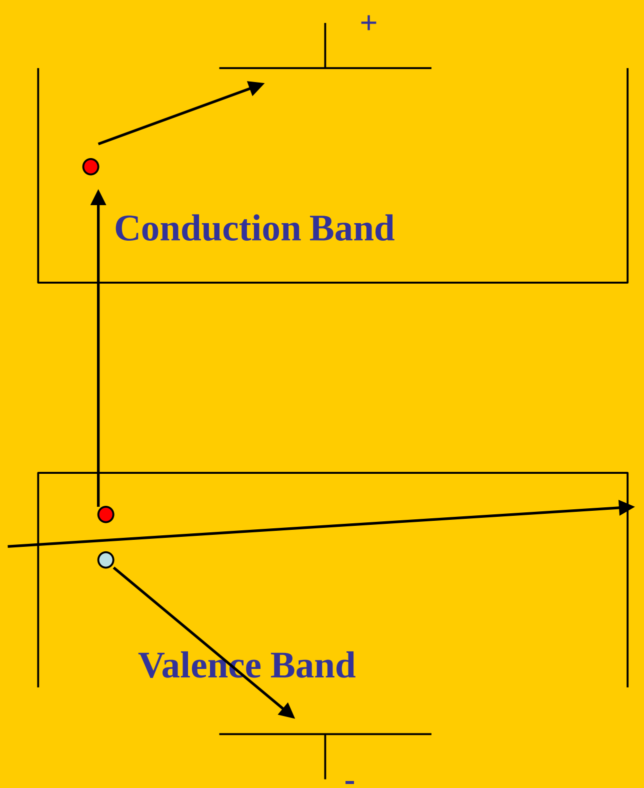
- **Will detect tritium**
- **High efficiencies (30 – 100%)**
- **Can use biodegradable solvents**
- **Can count large batches of samples**
- **Generally very accurate**

**Disadvantages:**

- **Bulky equipment – not portable**
- **Expensive**
- **Quenching**
- **Regular calibration required**
- **No in-situ counting**

## Semiconductor Detectors

- Two main types Silicon or Germanium
- Generally used for gamma/X-rays
- Reverse biased diodes – typically p-i-n junctions




- Typical reverse bias voltage of > 1000V
- Electrons excited from VB to CB are swept up by electric field - a current pulse
- Pulse size is prop. to energy of the radiation
- Detector/MCA combination = spectrometer

## Semiconductor Detectors:

**Advantages –**

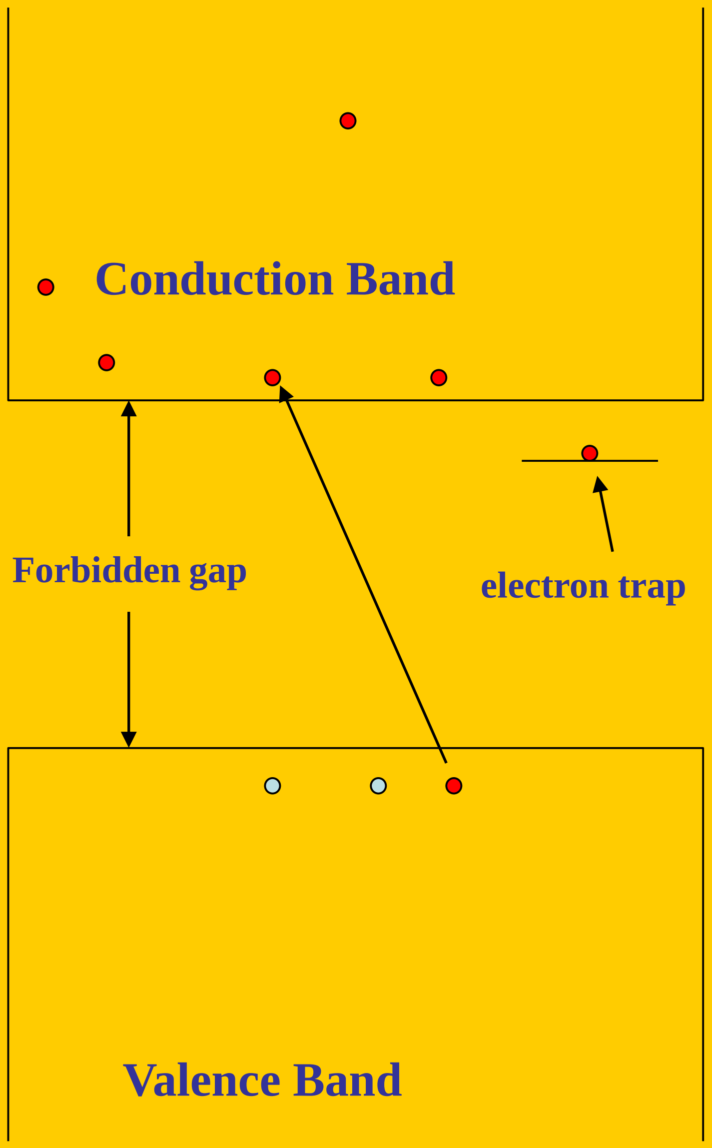
- **Very high electron densities**
- **Very sensitive**
- **Electron/hole energy low (2.9 eV for germanium)**
- **Pulse height proportional to energy of radiation**
- **Spectrometer + isotope library = analysis of unknown sources!**

**Disadvantages –**

- **Very expensive! – both crystals and electronics**
- **Require cooling (Ge to liquid nitrogen temperatures)**
- **Require long setup times**
- **Generally not portable – swab samples**

## Personal Monitoring

- **Thermoluminescence Detectors – TLD**
- **Optically Stimulated Luminescence – OSL**
- **Film badges**
- **Personal Radiation Detectors - PRD**




# Thermoluminescence Detector

- **Similar mechanism to scintillation detector**
- **Use LiF or CaF crystals**
- **Impurities are introduced to form meta stable 'electron traps' in the gap region**
- **Electrons will stay trapped until heated to 200 $^{o}$C**
- **After heating electrons drop back to valence band emitting a flash of light – pm detector**
- **Dose received given by the 'glow curve'**
- **Heating also 'zeros' the TLD – reusable**

- **More expensive than other personal devices**
- **Accuracy is poor for low doses (+/- 15%)**
- **Memory effects**

## Film Badge Dosimeters

- Photographic emulsion of silver halide deposited onto a plastic sheet
- When exposed to radiation the film will blacken (developed)
- Density of blackened area gives a measure of the dose received
- Combination of emulsions can increase the measurable dose range
- A set of filters used to discriminate between types of radiation
- Usually 4/5 filters – OW, Cu, Sn/Pb, Al, Plastic etc

## Film Badge Dosimeters

**Advantages –**

- **Cheap**
- **Permanent record**
- **Sensitive to low energy gammas - < 20 keV**
- **Discrimination**

**Disadvantages –**

- **Messy developing chemicals**
- **Not as accurate as other techniques**
- **Degradation of film**
- **Only by used once**

## Optically Stimulated Luminescence (OSL)

- **$Al_2O_3$ is the scintillation crystal**
- **Instead of heat a laser is used to stimulate the luminescence**
- **Luminescence is proportion to exposure**
- **Filters used for type discrimination**
- **Imaging filter used to determine static or dynamic exposure**
- **Photon sensitivity is 5 keV – 40 MeV**
- **Beta sensitivity is 150 keV – 10 MeV**
- **Exposure range 10 µSv to 10 Sv**


**OSL – Advantages**

- **Can be re-measured, allows archiving**
- **More accurate than TLD**
- **Large exposure range**
- **Long shelf life**

**Disadvantages –**

- **More expensive**
- **2 month wearing period**

**Personal Radiation Detectors (PRD)**

- **Small portable devices designed to give an instant reading**
- **Generally use GM tube or solid state (silicon)**
- **Can set an alarm level**
- **Are not very accurate**
- **Can be expensive**

# Suitability

**Tritium - only practical means is a wipe test**

**- use swab which is soluble in scintillant**

**- assume 10% pickup**

**- swab area of 100 cm$^2$**

**- measure in a LSC ~ 30 – 60% efficient**

**- LSC must be calibrated**

## Suitability – beta emitters

**$C^{14}$, $S^{35}$, $P^{32}$, $P^{33}$ etc**

**- portable GM mini monitor**

**- use shielding to determine relative energy**

**- also LSC for accurate results**

**Suitability – X-ray / gamma emitters**

**$I^{125}$, $Cr^{51}$, $Na^{22}$ etc – scintillation monitor**