The Activity Of A Radioactive Nucleus

Activity = the number of nuclei decaying per second

Symbol	Unit
A	Becquerel (Bq)

1 Bq = 1 disintegration per second

The Law Of Radioactive Decay

Activity depends on ???

Random process … **Therefore impossible to …**

Huge numbers (10^{23}??) … **Therefore …**

Activity α *N*

***N* = number of radioactive nuclei**

Rate of decay …

The Law Of Radioactive Decay

$A \alpha N$

1,000,000	radioactive nuclei	Activity = 80 Bq
500,000	radioactive nuclee	Activity = 40 Bq
250,000	radioactive nuclei	Activity = 20 nuclei

Etc.

The Law Of Radioactive Decay

Rate of decay = λN

λ = decay constant

Each radioactive isotope has its own λ

Half-Life

… a knock-on effect of the Law of Radioactive Decay

The time taken
for half the undecayed nuclei to decay

or

The time taken
for the activity to halve

Half-Life Values

… from fractions of a second to thousands of years

Lead-214 = 27 min

Carbon-14 = 5,800 y

Uranium-238 = 4.5×10^9 y

Radon-220 = 54.5 s

Example $T_{1/2}$ **= 3 hours**

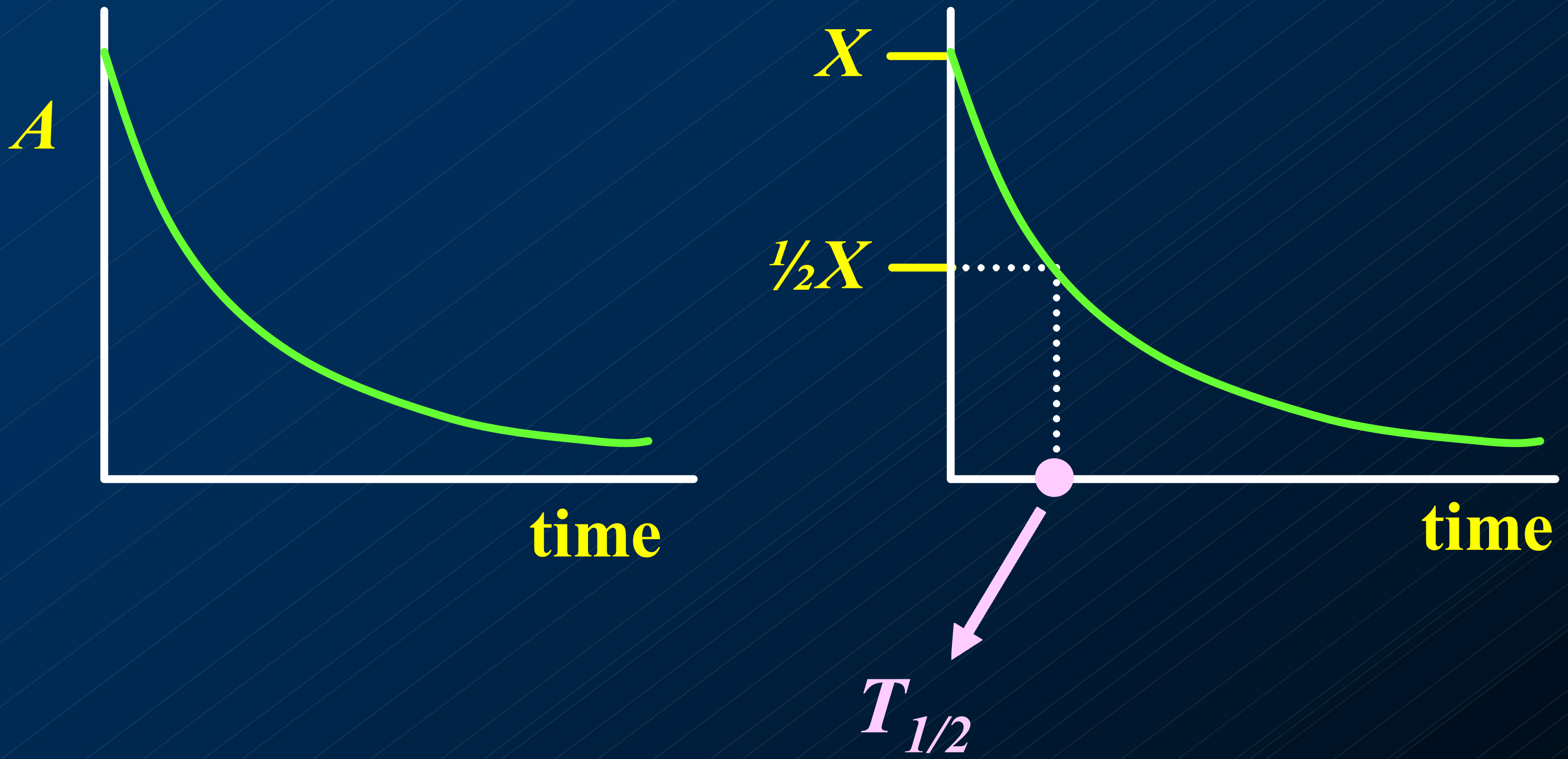
Say … 1,000,000 radioactive nuclei … now !!

$$1{,}000{,}000 \xrightarrow{3} 500{,}000 \xrightarrow{3} 250{,}000 \xrightarrow{3} 125{,}000 \xrightarrow{3}$$

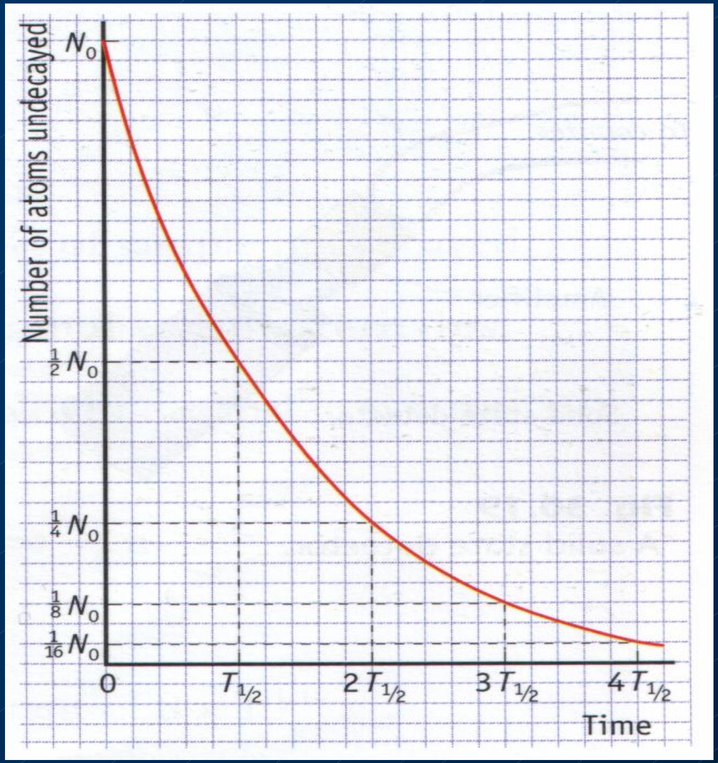
$T_{1//2}$ is independent of N_0

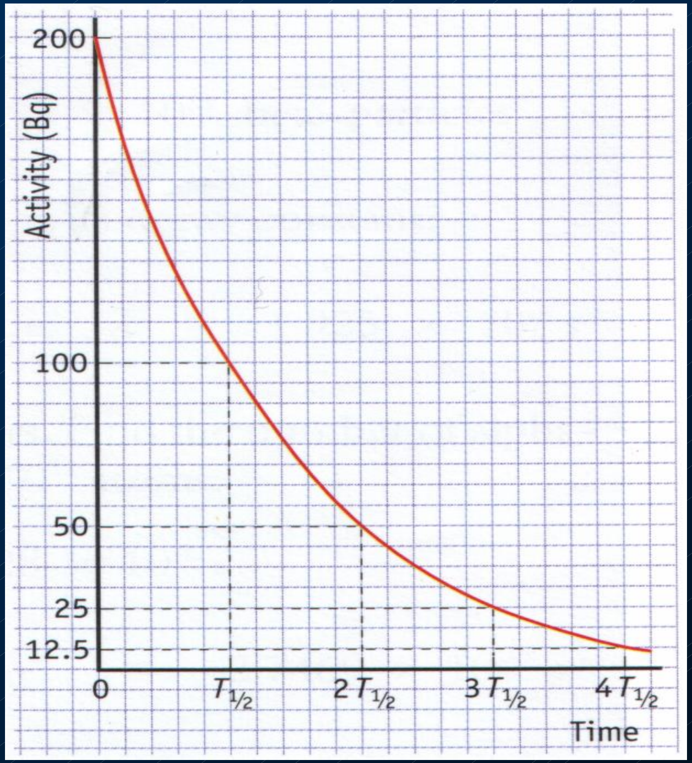
(due to Law of Radioactive Decay)

Graph Activity vs. Time



Graph Activity vs. Time





P4 **A radioactive isotope has a half-life of 5 years. What fraction of the original sample will remain after 20 years? What fraction of the original sample will have decayed in 20 years?**

20 years = 4 half-lives

1 2 3 4

1 → 🗁 → 🗏 → ⌨

→

1/16th remains undecayed

15/16ths has decayed

P4 A radioactive isotope has a half-life of 5 years. What fraction of the original sample will remain after 20 years? What fraction of the original sample will have decayed in 20 years?

1 2 3 4

1 → → → →

$1/2^4$ undecayed

Note: After *n* half-lives $1/2^n$ of the original sample remains undecayed.

P6 **The activity of a sample of a radioactive isotope decreases to 1/32 of its original value after 250 years. What is its half-life?**

$$1/32 = 1/2^5$$

→ **5 half-lives**

→ $T_{1/2} = 50$ **years**

P7 The isotope Sr-90 decays by beta-emission and has a decay constant of 8×10^{-10} s^{-1}. Calculate the number of atoms present in a sample of that isotope which emits 2.4×10^{4} beta-particles per second.

$$\text{Rate of decay} = \lambda N$$

$$2.4 \times 10^{4} = (8 \times 10^{-10})\, N$$

$$N = 3 \times 10^{13} \quad \text{nuclei}$$

P9 The half-life of U-235, which is an alpha-emitter, is 8×10^8 years. Find the number of alpha-particles emitted per second from a sample containing 2.6×10^{24} atoms.

Numb

=

$$T_{1/2} = 0.693 \div \lambda$$

Rate of decay $= \lambda\,(2.6 \times 10^{24})$

Rate of decay $= (0.693 \div T_{1/2})\,(2.6 \times 10^{24})$

$= 7.1 \times 10^{7}$ Bq

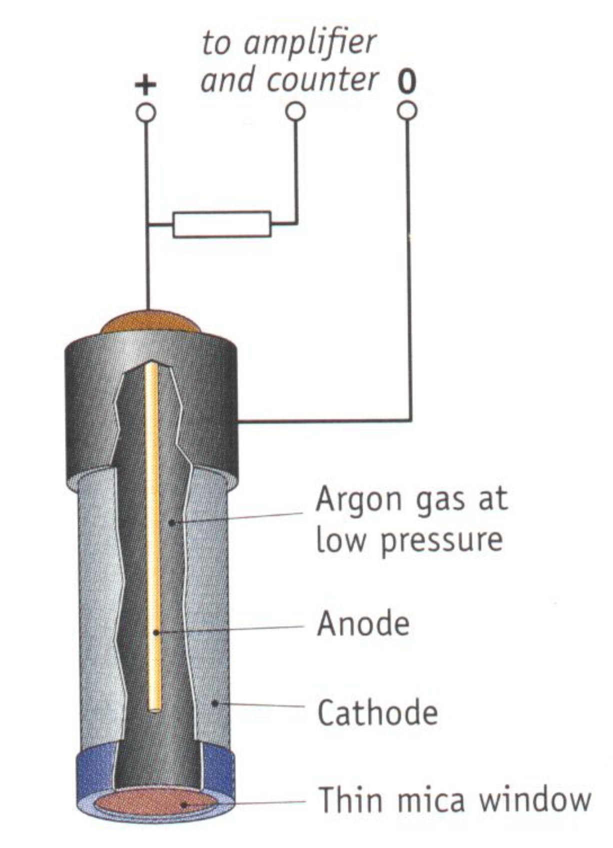
Detecting Nuclear Radiation

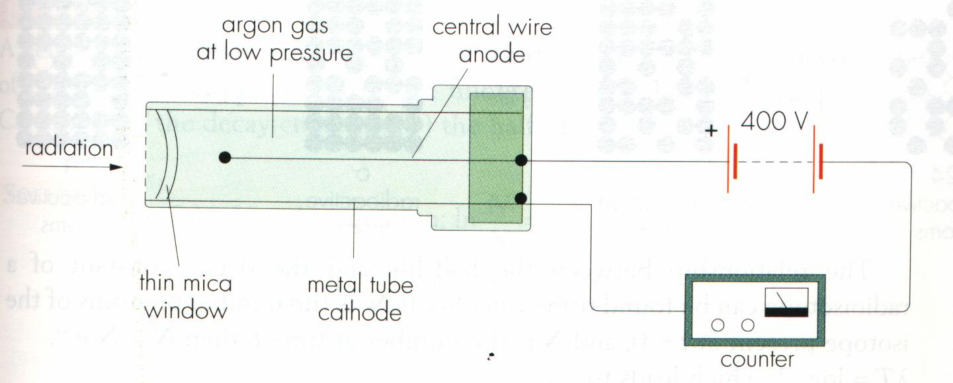
Geiger Müller Tube
(GM-tube)

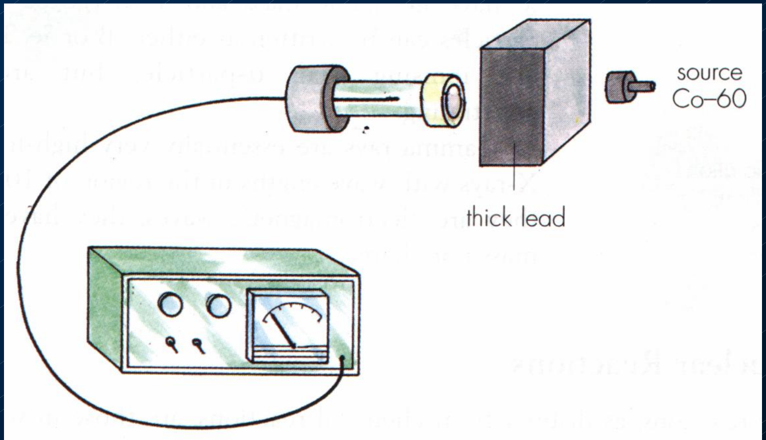
Solid State Detector

GM - Tube

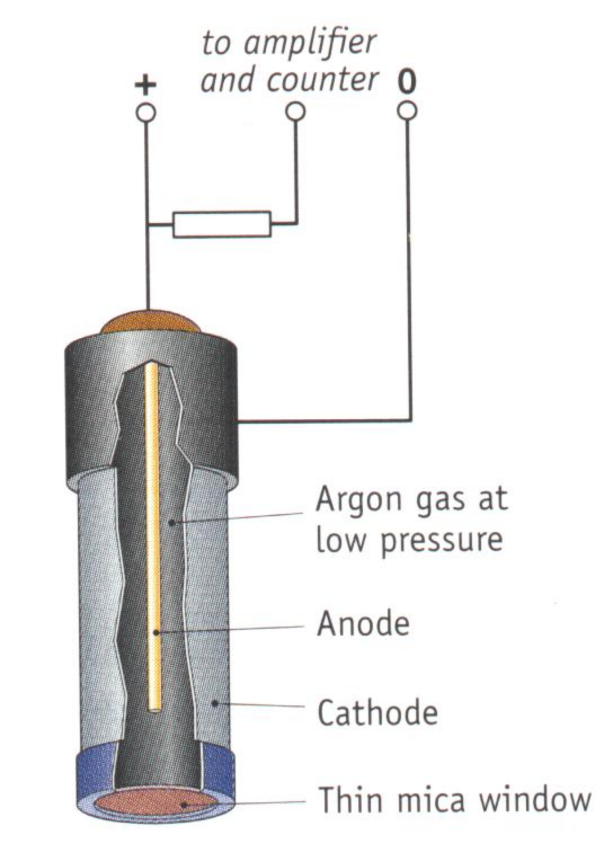
1908 Hans Geiger
1928 Geiger & Müller ..Improved version





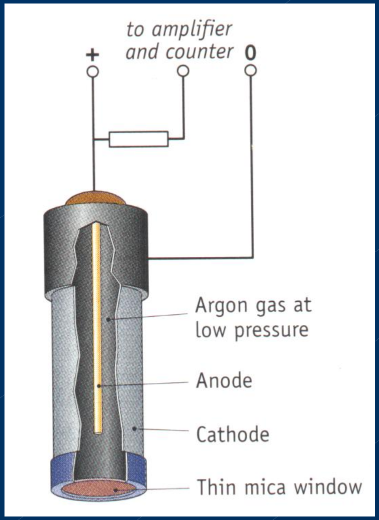


GM - Tube



Parts

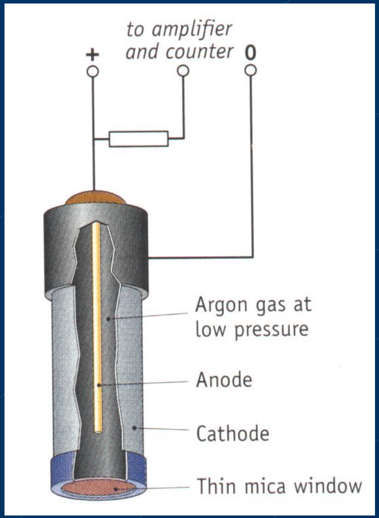
- Tube (Cathode)
- Thin wire (Anode)
- Argon gas at low pressure
- Thin mica window
- 450 V
- Amplifier & Counter



GM - Tube

How It Works

- Radiation in through thin window
- Radiation ionises the argon gas
- Electrons accelerated by p.d. to thin wire (and ions accelerated to tube)
- Avalanche Effect (Electrons .. collisions .. → huge number of electrons & ions)
- Electrons reach wire = Pulse of current
- Current pulse is counted on Scalar



GM - Tube Counters

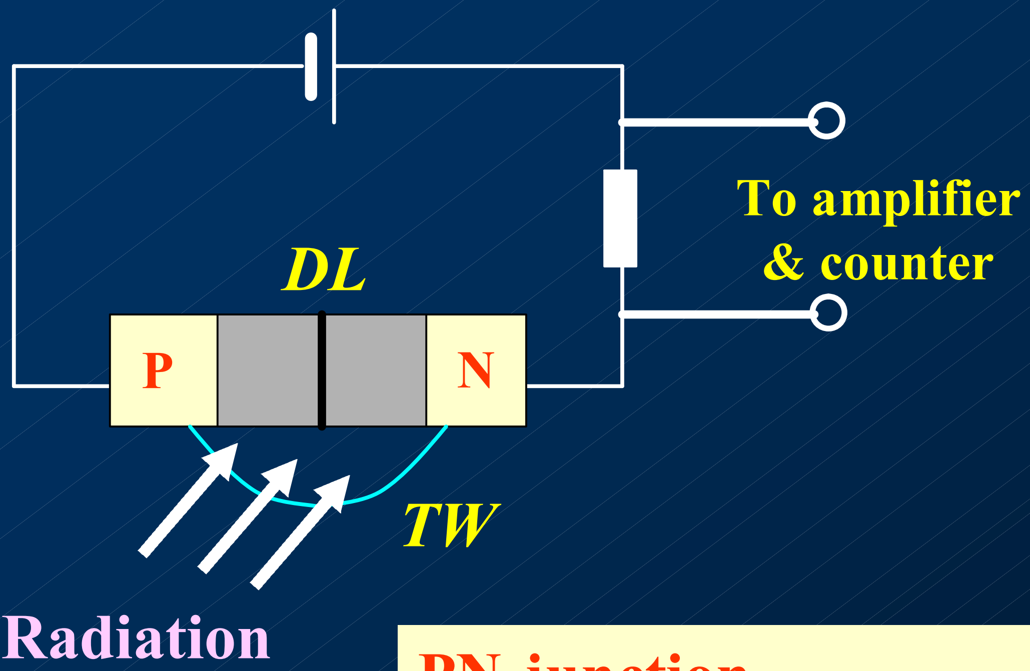
Scalar

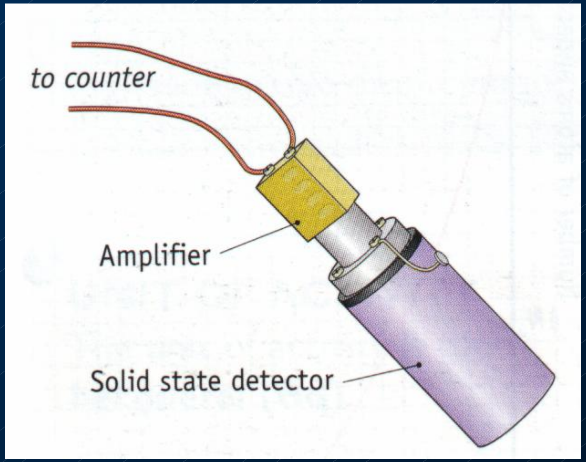
Gives total number of counts

Ratemeter

Gives number of counts per second

Solid State Detector



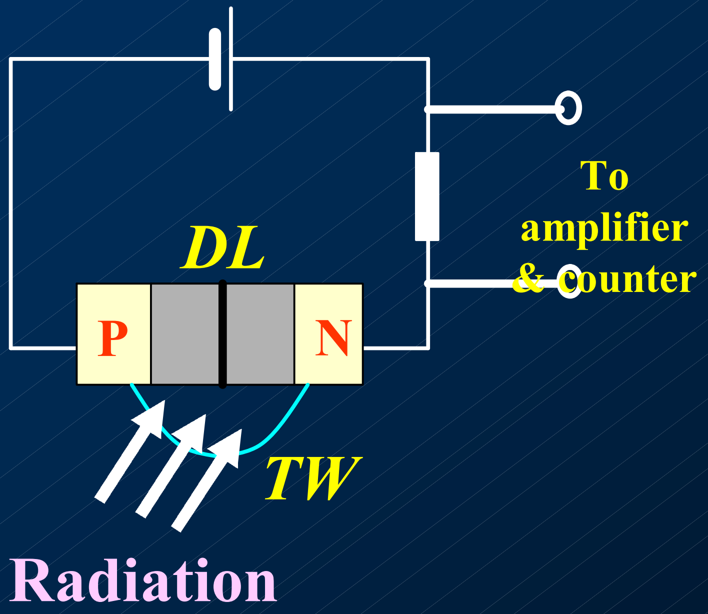


PN-junction
Suitable material (e.g. GaAS)
Junction near the surface

Reverse biased
Thin window

Solid State Detector

How It Works



- Reverse biased
  → *DL* → No conduction
- Radiation into *DL*
- Producing electron-hole pairs (e^-, h^+)
- Pd moves these (e^-, h^+) pairs
- = current pulse
- that is amplified and counted (Scalar)

Detectors: Effectiveness In Detecting α, β, γ

	GM-tube	Solid State Detector
α	**Good** if window is thin	**Very good**
β	**Very good**	**Good** if suitable material used for junction
γ	**Poor** (causes little ionisation)	**Good** if suitable material used for junction

Artificial Radioactivity

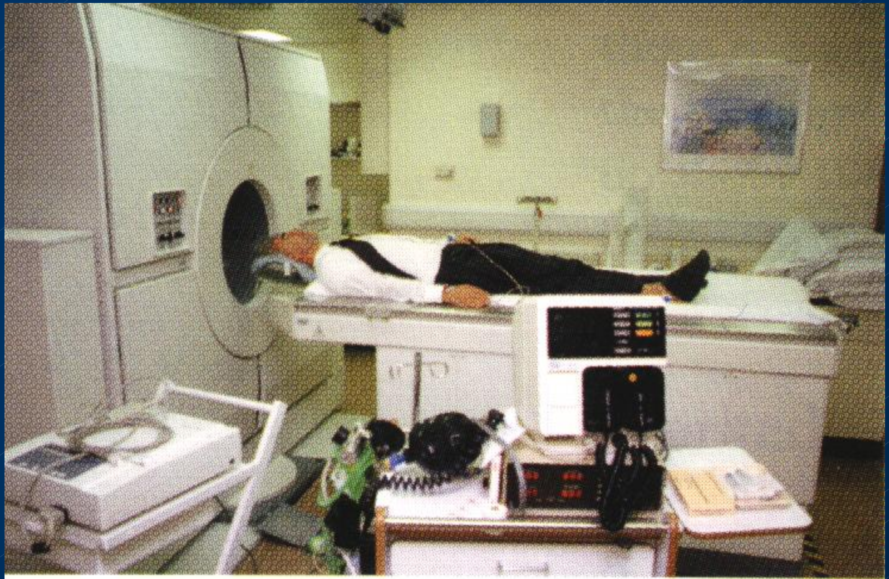
Many isotopes are made radioactive by bombarding their nuclei with neutrons

Done in Nuclear Reactors

Uses Of Radioisotopes

- Medical Imaging
- Medical Therapy
- Food Irradiation
- As Radioactive Tracers
- Carbon Dating
- Industry – thickness of objects, fullness of containers, find leaks, etc.
- Smoke Detectors
- etc.

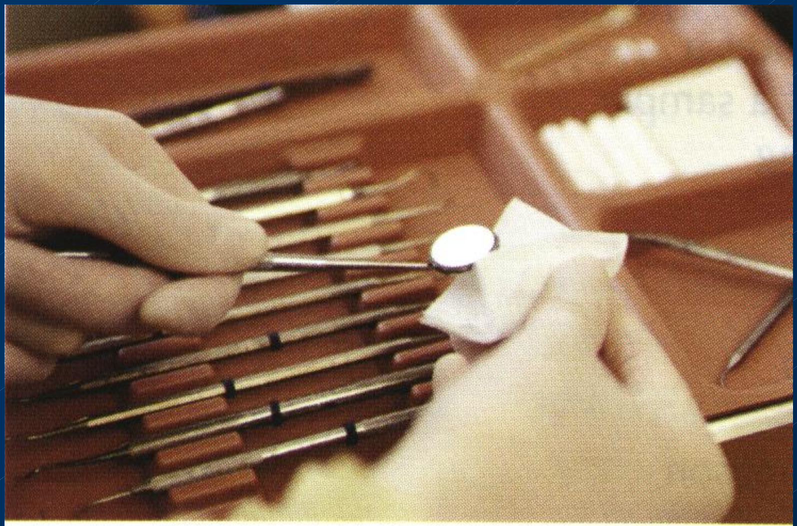
Uses Of Radioisotopes



Radiation has many uses in medicine

- ✓ Cancer cells are more easily damaged than healthy cells
- ✓ High doses directed at cancer cells
- ✓ Co-60
- ✓ X-rays also used

Uses Of Radioisotopes



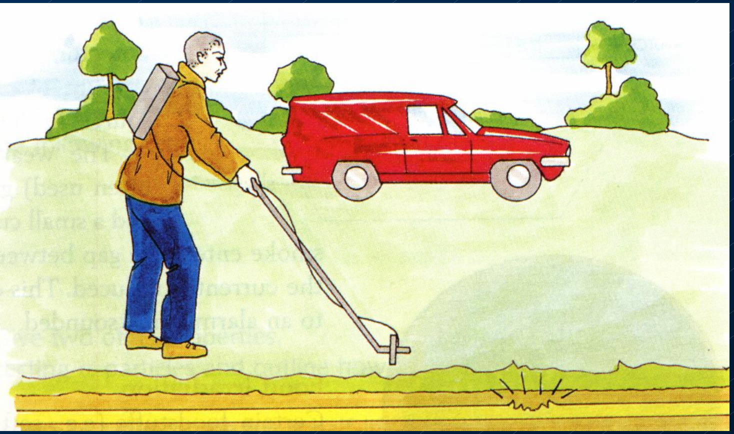
γ-rays are used to sterilise medical equipment

- ✓ **Bacterial killed by radiation**
- ✓ **Sterilise medical equipment**
- ✓ **Sterilise food**

Uses Of Radioisotopes

Short half-life

Tracers



- Pipes for leaks
- Medical
- Agriculture

Technicium-99 (β)

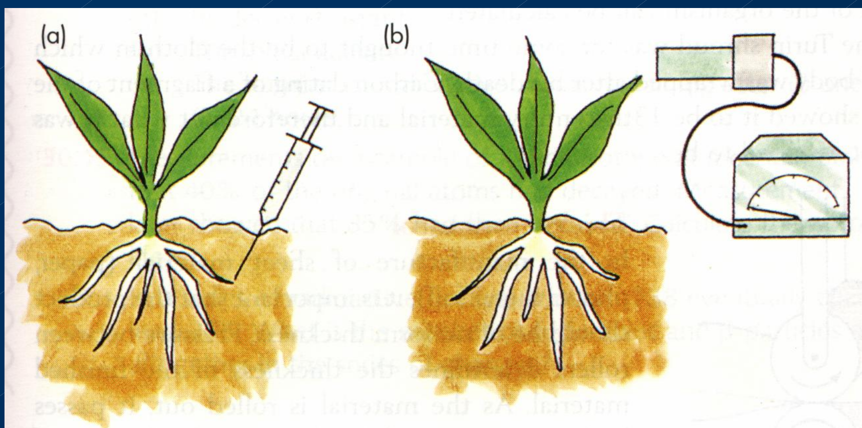
(Injected to check the functioning of brain, kidneys, bones)

Xenon-133 (β) … a gas

(Inhaled to check the functioning of the lungs)

Uses Of Radioisotopes — Tracers

Uptake of fertiliser by a plant … Phosphorous-32

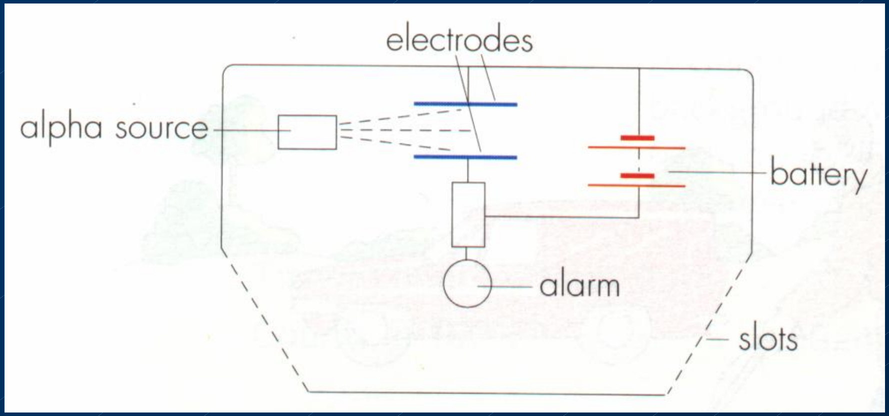


- Radioactive fertiliser injected into soil
- Leaves checked for radioactivity

Uses Of Radioisotopes

Smoke Detector

Am-241 (α)



Ionises the air … Current flows

Smoke clings to ions

Current is reduced

Triggers alarm

Uses Of Radioisotopes

Carbon Dating

C-14 $T_{1/2} = 5730$ y

- All living things (plants & animals)
- Have a fixed amount of C-14
- On dying … C-14 levels decrease
- Things dated by measuring the C-14 to C-12 ratio

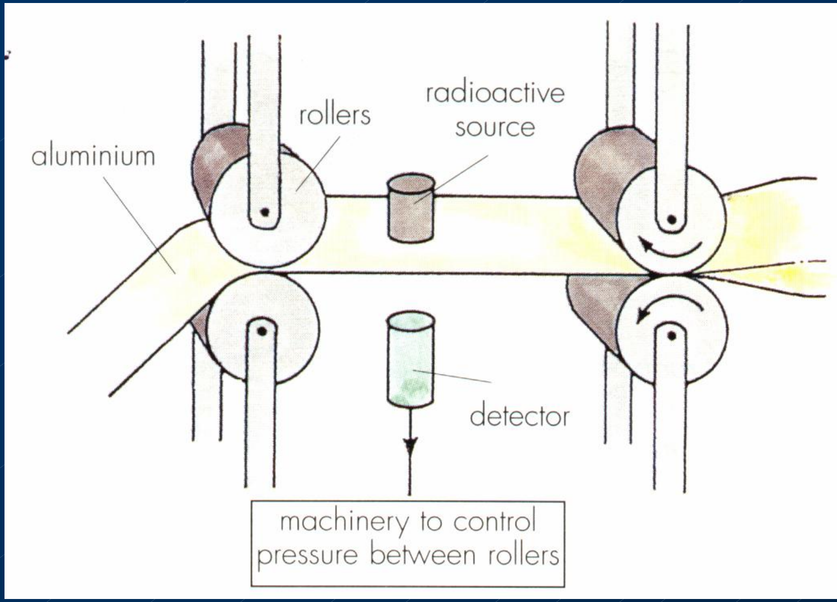
Uses Of Radioisotopes

Carbon Dating

Turin Shroud
shown to be 13th century

Uses Of Radioisotopes

Thickness Control



Sheet … metal, paper, plastic

Too … thick / thin

Less / more radiation

Activates pressure rollers to …

Uses Of Radioisotopes

- Medical Imaging
- Medical Therapy
- Food Irradiation
- As Radioactive Tracers
- Carbon Dating
- Industry – thickness of objects, fullness of containers, find leaks, etc.
- Smoke Detectors
- etc.

Unified Atomic Mass Unit

The $^{12}C_6$ atom has 12 unified atomic mass units (*u*)

Therefore 1 *u* is

□th the mass of the $^{12}C_6$ atom

The Mole

A mole of $^{12}C_6$ has a mass of 12 g

A mole of C-12 contains 6.02×10^{23} atoms.

A mole of any substance contains 6.02×10^{23} particles.

Avogadro's Number

The Mole

$^{235}U_{92}$

1 mole = 235 g

235 g contains 6.02 x 10^{23} atoms (*or* nuclei)

$^{60}Co_{29}$

1 mole = 60 g

60 g contains 6.02 x 10^{23} atoms (*or* nuclei)

P10 How many atoms are there in 10 kg of $^{207}Pb_{82}$?

1 mole = 207 g

0.207 kg	has	6.02×10^{23} atoms
1 kg	has	$6.02 \times 10^{23} \div 0.207$ atoms
10 kg	has	$(6.02 \times 10^{23} \div 0.207) \times 10$ atoms

$= 2.9 \times 10^{25}$ atoms

P11 **The decay constant of U-235 which is an alpha-emitter is $2.75 \times 10^{-17}\ s^{-1}$. Find the number of alpha-particles emitted per second from a 1 kg sample of this substance.**

Number of α's per second

$$= \text{Rate of decay} = \lambda N$$

$$= (2.75 \times 10^{-17})\ (6.02 \times 10^{23} \times 1000/235)$$

$$= 7.0 \times 10^{7}$$