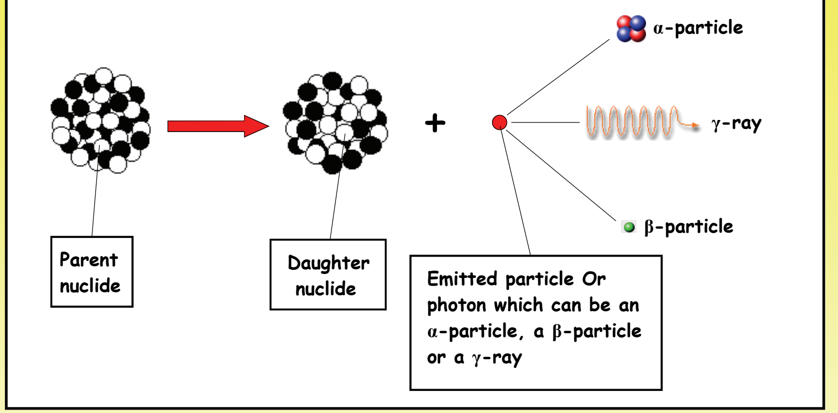
- ***Candidates should be able to :***

  - *Describe the **spontaneous** and **random** nature of radioactive decay of unstable nuclei.*
  - *Describe the **nature**, **penetration** and **range** of **α-particles, β-particles and γ-rays**.*
  - *Define and use the quantities **activity** and **decay constant**.*
  - *Select and apply the equation for **activity** :* $A = \lambda N$
  - *Select and apply the equations :* $A = A_0 e^{-\lambda t}$, $N = N_0 e^{-\lambda t}$
    *Where **A** is the **activity** and **N** is the **number of undecayed nuclei**.*
  - *Define and apply the term half-life.*
  - *Select and use the equation :* $\lambda T_{\frac{1}{2}} = 0.693$
  - *Compare and contrast **decay of radioactive nuclei** and **decay of charge on a capacitor in a CR-circuit**.*
  - *Describe the use of radioactive isotopes in **smoke alarms**.*
  - *Describe the technique of **radioactive dating (i.e. carbon dating)**.*

RADIOACTIVITY

- This is the process in which an **unstable** atomic nucleus **spontaneously** loses energy by emitting **particles and/or energy** and so potentially becomes **more stable**.



The **decay, or disintegration,** results in an atom of one type, called the **PARENT** nuclide, transforming to an atom of a different type, called the **DAUGHTER** nuclide.

The three types of radiation emitted by radioactive materials are :

- **ALPHA (α)-PARTICLES.**
- **BETA (β)-PARTICLES.**
- **GAMMA (γ)-RAYS.**

- An **α-particle** is a **helium nucleus** consisting of **2p + 2n**. It is a relatively **massive, positively** charged particle of matter.
- A **β-particle** is a **high speed (high energy) electron**. It is a very **Light** ($m_{\alpha} \approx 7500\ m_{\beta}$), **negatively** charged particle of matter.
- A **γ-ray** is a **high energy** photon of **electromagnetic radiation** of very short **wavelength (high frequency)**.

BASIC CHARACTERISTICS OF α, β AND γ-RADIATION

- An **α-PARTICLE** is a **HELIUM NUCLEUS** consisting of **2p + 2n**. It is a relatively **MASSIVE, POSITIVELY** charged particle of matter.

Alpha particle: 2 protons & 2 neutrons

- A **β-PARTICLE** is a **HIGH SPEED (HIGH ENERGY) ELECTRON**. It is a very **LIGHT ($m_\alpha \approx 7500\ m_\beta$)**, **NEGATIVELY** charged particle of matter.

Beta particle: The same as an electron

- A **γ-RAY** is a photon of **ELECTROMAGNETIC RADIATION** of very short **WAVELENGTH** (high **FREQUENCY**).

Gamma ray: not a particle, it's a burst of energy

RADIATION	SYMBOL	MASS (In terms of proton mass)	CHARGE (In terms of proton charge)	SPEED
α-particles	$^4_2\alpha$ ^4_2He	4	+2e	'slow' ($10^6\ m\ s^{-1}$)
β-particles	β^- e^-	1/1840	-e	'fast' ($10^8\ m\ s^{-1}$)
γ-rays	γ	0	0	$3 \times 10^8\ m\ s^{-1} = c$

THE GEIGER-MULLER (G-M) TUBE

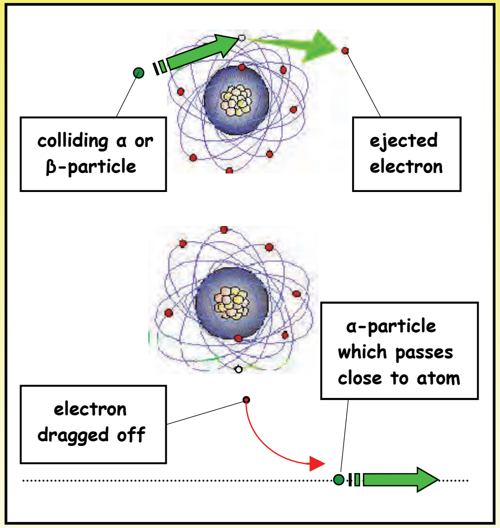
- This is a device which is used in conjunction with an amplifier and counter (called a scalar) to detect **α, β** and **γ-radiation**. It works by detecting the ionisation caused by these radiations as they pass through the air.

IONISATION

- **α** and **β-particles** are **fast-moving** and **electrically charged**.

  If **α or β-particles** collide with atoms, they may cause one or more electrons to be knocked out of the atoms, which are then said to be **ionised**.

  An **α-particle** can also cause ionisation if it passes close enough to an atom to drag an electron off by electrostatic attraction.



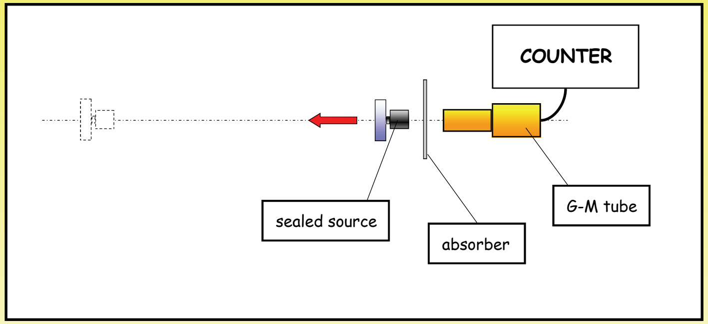
In any ionising event the **α-particle** or **β-particle** will lose some energy and after many such events, the **α** or **β** will lose all its energy and so come to a standstill and cause no further ionisation.

PENETRATING POWER AND RANGE OF α, β AND γ-RADIATION

- A **G-M tube** connected to a **ratemeter** is used in the experiments which follow. It must be remembered that the count recorded by the G-M tube will be caused by the radiation from the **source** plus that due to **background radiation**. With no source present, The background radiation count is taken several times over a 1 minute period and the **average background count rate** is calculated.

The actual or **corrected count rate** is then given by :

corrected count rate = count rate from source − background radiation count rate



ALPHA (α)-PARTICLES

- When a sealed **α-particle** source (e.g. americium-241) is placed close to the window of a G-M tube, a high count rate is observed. If **a sheet of paper** is placed between the source and the G-M tube the count rate is found to fall to that due to **background radiation** which shows that the paper must have absorbed the radiation.

- When the paper is removed and the **α-particle** source is moved **away from** the G-M tube, it is found that the count rate falls to the background radiation level when the source has been moved about 5 cm away. This shows that **the range of α-particles in air is about 5 cm.**

BETA (β)-PARTICLES

- When a **β-particle** source (e.g. strontium-90) is used, it is found that paper will not stop the β-particles. Increasing thicknesses of aluminium are interposed between the source and the G-M tube and it is found that the count rate is reduced to background radiation level by about **3 mm of aluminium.**

- Without the absorber, it is also found that moving the source about 50 cm away from the G-M tube reduces the count rate to background radiation level. This shows that **the range of β-particles in air is about 50 cm.**

GAMMA (γ) - RAYS

- Repeating the experiments with a **γ-ray** source (e.g. cobalt-60) shows that γ-rays are much more penetrating than α or β-particles. Although the intensity is significantly reduced, γ-rays are not stopped completely even by **thick pieces of lead** and their range in air is **almost infinite.**

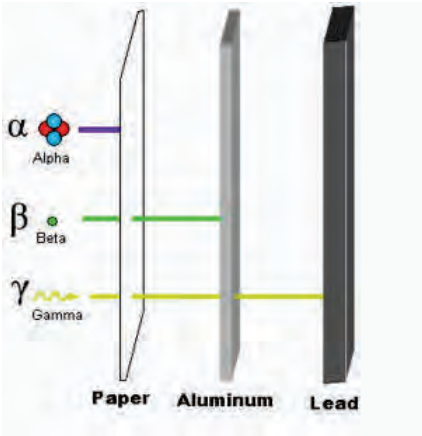
EXPLAINING THE DIFFERENT PENETRATIONS OF THE THREE RADIATIONS

- Because the **α-particle** is a **heavy, relatively slow-moving particle,** with a charge of **+2e,** it interacts strongly with matter and causes **intense ionisation.** For this reason it is stopped by **a sheet of paper** and has lost all its energy after travelling **5-10 cm in air.**

- The **β-particle** is about **7000 times lighter** and **much faster** than the **α-particle.** Since it only spends a short time in the vicinity of an air molecule and has a charge of only **−1e**, it causes **less intense ionisation** than the **α-particle.** This accounts for its **greater penetrating power** and its range of about **50 - 100 cm in air.**

- Since **a γ-ray** photon is moving at the **speed of light** and it has **no charge,** it interacts very weakly with matter and causes **little ionisation.** For this reason it can only be stopped by **thick lead** and it will travel **a very long way in air** before losing all its energy.

The relative penetrating powers of the three ionising radiations are summarised in the diagram shown opposite.



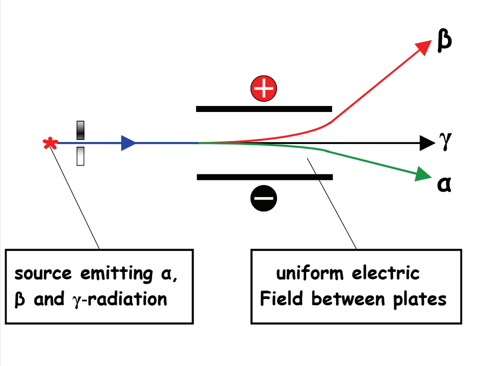
EFFECT OF ELECTRIC AND MAGNETIC FIELDS

ELECTRIC FIELD

The **β-particles** are negatively charged and so deflect towards the positive plate.

The **α-particles** are positively charged and so defect towards the negative plate.

The γ-**rays** are uncharged and and so pass through the plates without deflection.



<u>NOTE</u> : For a given field strength - **β-deflection >> α-deflection**

This is because - $m_β \approx 1/7000 \times m_α$

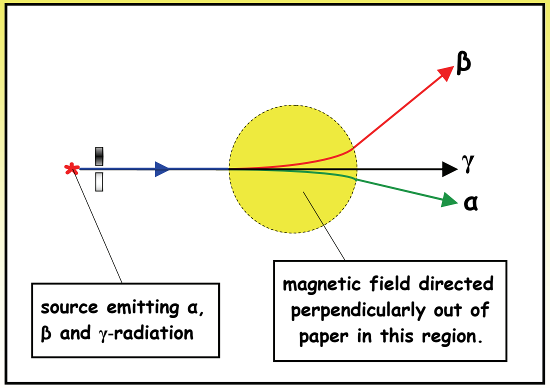
MAGNETIC FIELD

Fleming's left-hand rule gives the direction of the force acting on the moving **α's** and **β's**.

It should be noted that **β's (e's)** moving **to the right** is equivalent to **conventional current** moving **to the left**.

For a given magnetic flux density,

β-deflection >> α-deflection



- **PRACTICE QUESTIONS (1)**

1 **(a) Explain** why you would expect **β-particles** to travel further through **air** than **α-particles**.

(b) Explain why you would expect **β-particles** to travel further through **air** than through a **metal**.

2 **Explain** why the **most strongly ionising** radiation **(α-particles)** are the **least penetrating**, whilst the **least ionising (γ-rays)** are the **most penetrating**.

3 A beam of radiation from a radioactive substance passes through **paper** and is then stopped by an **aluminium plate of thickness 5 mm**.

(a) What **type** of radiation is in the beam ?

(b) Describe a **further test** you could do to check your answer in **(a)**.

THE *RANDOM* AND *SPONTANEOUS* NATURE OF RADIOACTIVE DECAY

- If we listen to the clicks from a Geiger counter which is placed close to a weak radioactive source, we notice that the clicks are totally **haphazard** and **irregular**. The clicks from the counter are completely **random** and it is impossible to predict when the next click will be heard. This shows that :

RADIOACTIVE DECAY IS A RANDOM PROCESS.

- In **stable** nuclei, the effects of the **repulsive** electrostatic forces between protons and the **attractive** strong nuclear forces between all nucleons are **balanced**.

  The atoms of radioactive materials have **unstable** nuclei in which the repulsive forces are greater than the attractive forces and these nuclei emit radiation **(α, β or** γ**)** in order to become more stable.

RADIOACTIVE DECAY IS SPONTANEOUS.

- When we use the term **spontaneous** in relation to radioactive decay, we mean that it just happens of its own accord (i.e. nothing can be done to nucleus to make it decay or to stop it from decaying).

- We cannot predict when a particular nucleus is going to decay, since there is no change in the nucleus which would indicate that it is about to decay.

- Radioactive decay is completely **unaffected** by temperature, pressure, humidity, chemical combination or any other external influence.

  The fact that each nucleus in a sample of radioactive material decays independently from its neighbours is due to the fact that neighbouring nuclei do not interact with one another. This is because the strong force through which they would interact is a very short-range force.

- The fact that the decay of a nucleus is a **spontaneous** and **random** process means that it is impossible to predict when a individual nucleus will decay. However, there are always huge numbers of nuclei present in a sample of radioactive material **(e.g. 1 mole = 238 g of uranium-238 will contain an incredible 6.02 x 10^{23}nuclei!!)** and so statistical methods can be applied to calculate what fraction of a substance will have decayed, on average, in a given time interval.

ACTIVITY (A) AND DECAY CONSTANT (λ)

The **ACTIVITY (A)** of a radioactive sample is **the rate at which the nuclei of the sample decay**.

Activity is measured in **decays second^{-1} (or hour^{-1} or day^{-1})**.

$$A = dN/dt$$

- An activity of **1 decay s^{-1} is 1 BEQUEREL (Bq)**

- The **activity (A)** of a radioactive sample at any given time is directly proportional to the **number of undecayed nuclei present** at that time. Thus, for a sample having **(N)** undecayed nuclei, the activity **(A)** is given by :

$$\underset{(s^{-1},\, h^{-1},\, d^{-1})}{A} = \underset{(s^{-1},\, h^{-1},\, d^{-1})}{\lambda} N$$

- If in a problem, instead of the **number (N) of nuclei present**, you are given the **mass (m)** of the radioactive sample, **N** can be calculated from :

$$N = mN_A/A_r$$

Where, N_A = **Avogadro constant.**
And A_r = **Relative atomic mass.**

The **DECAY CONSTANT** (λ) is defined as **the fraction of the total number of nuclei present in a sample of radioactive material which decays per second.**

$$\lambda = \frac{A}{N}$$

(λ has units of **second**$^{-1}$ or **hour**$^{-1}$ or **day**$^{-1}$)

To illustrate the meaning of **decay constant** (λ) consider the following example :

A radioactive sample containing **2.0 x 10^{8}** undecayed nuclei has an initial activity of **5.0 x 10^{4} Bq.**

- This means that **5.0 x 10^{4}** nuclei will decay each second.
- So the fraction of the total number of nuclei present which decays per second is : $\frac{5.0 \times 10^4}{2.0 \times 10^8} = 2.5 \times 10^{-4}\ s^{-1}$.

Thus **2.5 x 10^{-4} s^{-1}** is the **DECAY CONSTANT (λ)**.

NOTE ON ACTIVITY AND COUNT RATE

- **Activity cannot be measured directly.** This is because we can't easily detect all the radiation emitted from a sample (some escapes past the detector and some may be absorbed in the sample).
- So, measurements give a **COUNT RATE (R)** which is significantly less than the activity (A).
- Also, if the level of **BACKGROUND RADIATION** is significant, then it must be subtracted to give the **CORRECTED COUNT RATE.**

• PRACTICE QUESTIONS (2)

1 A sample consists of **1.5 x 10^{6}** undecayed nuclei of a nuclide having a decay constant of **2.5 x 10^{-4} s^{-1}.** Calculate :

(a) The initial **activity** of the sample.

(b) The **activity** after **10 s** have elapsed.

2 A piece of radium gives a **received count rate** of **20 counts per minute** in a detector. It is known that the counter detects only **10%** of the decays from the sample. If the sample contains **1.5 x 10^{9} atoms**, calculate the **decay constant** of this form of radium.

3 A **thorium-230** source has a mass of **8.75 mg.** The nuclei in the atoms of the source decay by emitting an alpha particle.
If the decay constant for this nuclide is **2.75 x 10^{-13} s^{-1}** and the Avogadro constant, N_A = **6.02 x 10^{23} mol^{-1}**, calculate :

(a) The **initial number of nuclei (N_0)** contained in the source.

(b) The **initial activity (A_0)** of the source.

4 **Uranium-238** has a decay constant of **4.88 x 10^{-18} s^{-1}.** If one atom of this nuclide has a mass of **3.95 x 10^{-25} kg,** calculate :

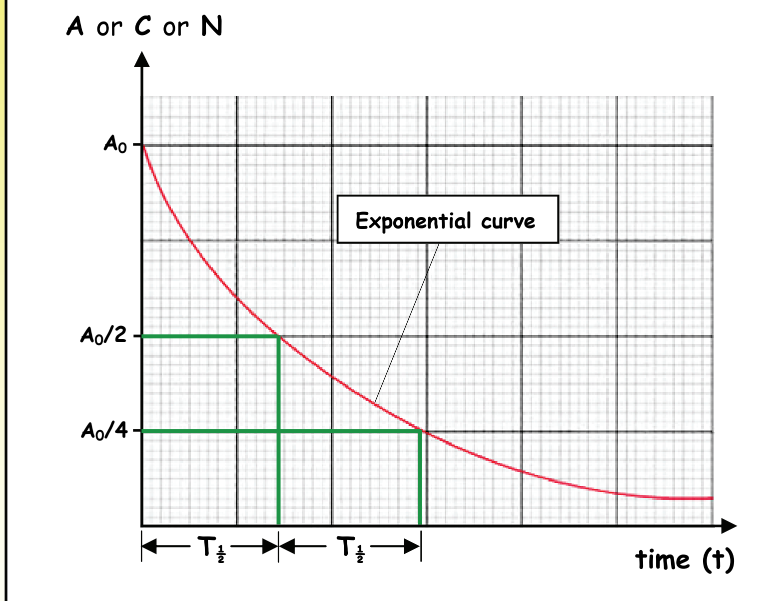
(a) The **number of uranium atoms** which would give an activity of **2.0 x 10^{4} Bq.**

(b) The **mass of uranium-238** which would give an activity of **2.0 x 10^{4} Bq.**

RADIOACTIVE DECAY GRAPHS AND EQUATIONS

- If either **ACTIVITY (A)** or **CORRECTED COUNT RATE (C)** or **NUMBER OF UNDECAYED NUCLEI PRESENT (N),**

  is plotted against **TIME (t)** for a given sample of a radioactive material, an **EXPONENTIAL DECAY CURVE** is obtained as shown below :



- The graph shows that the **ACTIVITY (A)** or **CORRECTED COUNT RATE (C)** or **NUMBER OF UNDECAYED NUCLEI PRESENT (N),** of a radioactive sample **DECREASES EXPONENTIALLY** with **TIME (t).**

HALF-LIFE ($T_{\frac{1}{2}}$)

The **HALF-LIFE ($T_{\frac{1}{2}}$)** of a radioactive sample is defined as :

- **The mean time taken for half of the nuclei originally present to decay.**

OR

- **The mean time taken for the activity of the sample to decrease to half its initial value.**

The mathematical equation which represents the decay graph is of the form :

$$x = x_0 e^{-\lambda t}$$

In terms of **undecayed nuclei,** the equation is :

$$N = N_0 e^{-\lambda t}$$

- N: number of undecayed nuclei at any time (t).
- N_0: number of undecayed nuclei at time (t) = 0.
- λ: Decay constant.

- The units of **(λ)** and **(t)** must be **COMPATIBLE.**
  If λ is in s^{-1}, then **t** must be in **s.**
  If λ is in **day**$^{-1}$, then **t** must be in **day** and so on...

- **'e'** is the exponential function and you'll need to learn how to use the **(e^x) key** on your calculator in order to solve problems.

- We sometimes deal with **CORRECTED COUNT RATE (C)** or **ACTIVITY (A)** rather than **NUMBER OF UNDECAYED NUCLEI (N)**, and the decay equation then becomes :

$$C = C_0 e^{-\lambda t} \quad \textbf{OR} \quad A = A_0 e^{-\lambda t}$$

RELATIONSHIP BETWEEN HALF-LIFE ($T_{\frac{1}{2}}$) AND DECAY CONSTANT (λ).

Consider the equation : $A = A_0 e^{-\lambda t}$

When 1 half-life has elapsed (i.e. when $t = T_{\frac{1}{2}}$), the initial Activity, A_0 will have decreased to $A_0/2$.

Therefore : $A_0/2 = A_0 e^{-\lambda T_{\frac{1}{2}}}$

Dividing both sides By A_0 gives : $1/2 = e^{-\lambda T_{\frac{1}{2}}}$

From which : $2 = e^{\lambda T_{\frac{1}{2}}}$

Taking natural logs of both sides gives : $\ln 2 = \lambda T_{\frac{1}{2}}$

$0.693 = \lambda T_{\frac{1}{2}}$

From which :

$$\lambda = \frac{0.693}{T_{\frac{1}{2}}}$$

<u>NOTE</u> : When using this equation, **the units of (λ) and ($T_{\frac{1}{2}}$) must be COMPATIBLE**.

EXTRA NOTE ON GRAPHICAL REPRESENTATION OF RADIOACTIVE DECAY

- The natural logarithm function, **ln x, is the inverse exponential function** (i.e. If **y** = **e**^{x}, then **ln y** = **x**).

- Therefore, $N = N_0 e^{-\lambda t}$

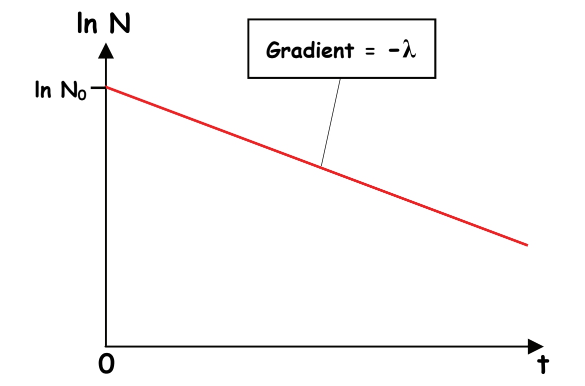
May be expressed as : $\ln N = \ln N_0 - \lambda t$

Re-arranging this gives : $\ln N = -\lambda t + \ln N_0$

And comparing with the equation for a straight line : $y = mx + c$

It can be seen that the graph of **ln N** against **t** is a straight line with :

gradient = $-\lambda$ *and* **y-intercept = $\ln N_0$**



LINK BETWEEN RADIOACTIVE DECAY AND CAPACITOR DISCHARGE

The rate at which **charge** flows out of a **discharging capacitor** (i.e. current) is proportional to the **charge** on the capacitor.

The rate at which **the number of nuclei** of a radioactive nuclide decreases (a activity) is proportional to the **number of nuclei** present.

- The **radioactive decay** and **capacitor discharge** equations follow identical patterns and are both of the type :

$$x = x_0 e^{-Kt}$$

Radioactive decay :

$$N = N_0 e^{-\lambda t}$$

Capacitor discharge :

$$Q = Q_0 e^{-t/CR}$$

- The difference between the mathematics of these equations is in the way the constant (K) is entered.

	CONSTANT
Radioactive decay	**Decay constant (λ)**
Discharging capacitor	**1/CR** Where ***C*** = capacitance of the capacitor. And **R** = resistance of resistor through which capacitor discharges.

MOLAR MASS AND AVOGADRO CONSTANT REMINDER

- For an element with a **MASS (or NUCLEON) NUMBER (A),**
  - Its **MOLAR MASS (M)** is its **MASS NUMBER in g**.
  - **1 MOLE** of the element contains N_A atoms (where N_A = Avogadro constant),
  - Mass **(m)** of the element contains **$(m/M)N_A$** atoms.

PRACTICE QUESTIONS (3)

1 The radioisotope nitrogen-13 has a half-life of **10 min**. A sample initially contains **1000** undecayed nuclei.

(a) Write down an equation to show how the **number of undecayed nuclei (N)**, depends on **time (t)**.

(b) How many nuclei will remain after : **(i) 10 min, (ii) 20 min, (iii) 40 min ?**

2 Suppose an experiment is started with **1000** undecayed nuclei of a radioisotope for which the decay constant, λ = **0.02 s^{-1}**. How many nuclei will remain undecayed after **20 s**.

3 A sample of a radioisotope, for which λ = **0.1 s^{-1}**, contains **5000** undecayed nuclei at the start of an experiment.

(a) How many undecayed nuclei will remain after **50 s** ?

(b) What is the radioisotope's **activity** after **50 s** ?

4 The decay constant of a particular radioisotope is known to be **3×10^{-4} s^{-1}**. Calculate the time taken for the **activity** of a sample of this substance to decrease to **$\frac{1}{8}$th** of its initial value.

5 **Cs-137** is a radioactive isotope of caesium which has a half-life of **35 years**. A sample of this isotope has a mass of **1.0×10^{-3} kg**.

(a) Calculate the **number of atoms** in the sample.

(b) Calculate the **number of atoms** of the isotope **remaining** in the sample after **70 years**.

6 **(a)** Calculate the **number of atoms** present in **1.0 kg** of $^{226}_{88}Ra$.

(b) The isotope $^{226}_{88}Ra$ has a half-life of **1620 years**.

For an initial mass of **1.0 kg** of this isotope, calculate :

(i) The **mass** of the isotope remaining after **1000 years**.

(ii) The **number of atoms** of the isotope remaining after **1000 years**.

USES OF RADIOISOTOPES

1. RADIOACTIVE (CARBON-14) - DATING

- Living plants and trees contain a small percentage of the radioisotope **CARBON-14**, which is formed in the atmosphere due to the interaction of cosmic rays with nitrogen. The cosmic rays knock neutrons out of nuclei and these neutrons then collide with nitrogen nuclei to form the carbon-14 nuclei.

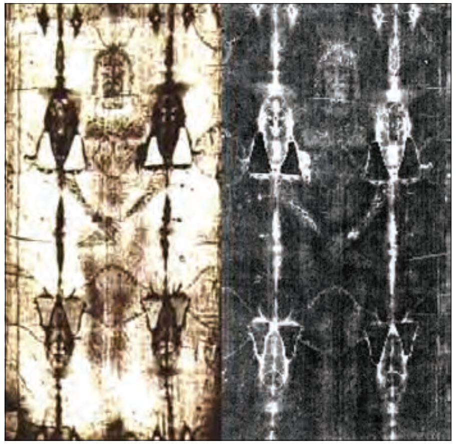
  Carbon dioxide from the atmosphere is taken up by living plants by the process of photosynthesis. As a result, a small percentage of the carbon content of plants is carbon-14. All living organisms ingest this carbon from the plants, either directly or indirectly.

  Once the plant has died, no more carbon is taken in and the proportion of carbon-14 decreases as the nuclei decay with a **half-life of 5570 years**.

  Any material manufactured from dead organisms (e.g. wooden structures), or even the dead organism itself can be dated by measuring the amount of carbon-14 in a sample of the material and comparing this to the amount contained in a fresh sample of the same mass.

  Since **activity** is proportional to the **number of undecayed atoms**, measuring the activity of the dead sample and comparing it to the activity of a fresh sample of the same mass enables the age of the sample to be calculated.

It should be noted that the count rates involved in carbon-dating are very small and since the **percentage of carbon-14 in the atmosphere has not always been constant**, this form of dating can only be said to be accurate to the **nearest 100 years**.



Carbon-14 dating has shown that the **Shroud of Turin** is actually only about **600 years old**, sparking great controversy about its authenticity.

Carbon-14 dating used on the mummy wrappings of the Egyptian pharaoh, **Tutankhamum** showed that it was **3300 years old**.

WORKED EXAMPLE

The ratio of **carbon-14 to carbon-12 atoms** in a sample of the linen wrappings on an Egyptian mummy was found to be **0.60 : 10^{12}**. Given that the half-life of **carbon-14** is **5570 years**, and that the ratio in modern linen of the same type is **1.00 : 10^{12}**, calculate the age of the mummy.

The relative number of C-14 atoms in the linen has dropped from 1.00 to 0.6.

$$\lambda = \frac{0.693}{T_{\frac{1}{2}}} = \frac{0.693}{5570\ \text{y}} = 1.24 \times 10^{-4}\ \text{y}^{-1}.$$

$$N = N_0\, e^{-\lambda t}$$

$$0.60 = 1.00 \times e^{-1.24 \times 10^{-4}\, t}$$

Taking natural logs of both sides :

$$\ln 0.60 = -1.24 \times 10^{-4}\, t$$

$$-0.511 = -1.24 \times 10^{-4}\, t$$

$$t = \frac{0.511}{1.24 \times 10^{-4}} = \boxed{\textbf{4121 years}}$$

- **PRACTICE QUESTIONS (4)**

1 A piece of wood is taken from an archaeological artefact. **10 mg** of carbon is extracted from the wood and this yields **66 counts** over a period of **12 hours** from the carbon-14 present in the sample.

If the equilibrium decay rate of carbon-14 is **14 disintegrations per min per gram** of freshly-prepared carbon, calculate the **age of the wood**. (half-life of carbon-14 = **5570 years**).

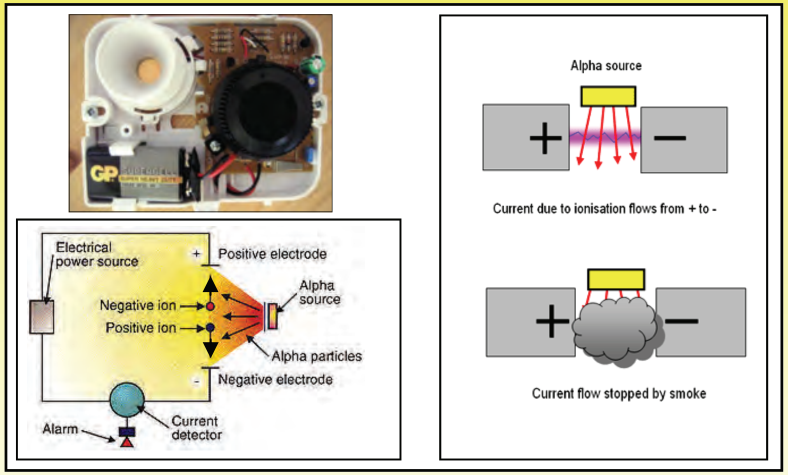
> **HINT** : Note that the equilibrium decay rate is expressed in disintegrations **min^{-1} g^{-1}** and that you are given the number of counts from only **10 mg** over **12 hours**.

2 A wooden sample from an ancient, excavated shield is found to have an activity of **0.090 Bq**. A sample of living wood of the same mass has an activity of **0.105 Bq**.

Given that the half-life of carbon-14 is **5570 years**, calculate the **age of the shield sample.**

2. IONISATION SMOKE DETECTOR

- As we already know, radiation causes ionisation of the air through which it passes and **α-particles are the most ionising**. Smoke detectors make good use of this process.



- In the diagrams shown above, alpha-particles from a weak, **americium-241** source pass through an **ionisation chamber**. This is an air-filled space between two electrodes in which the alpha particles cause ionisation of the air molecules which produces a small, constant current which is registered by the **current detector**.
- Smoke entering the chamber **absorbs** the alpha-particles, reducing the amount of ionisation and hence reducing the detected current. The electronic circuitry senses this reduction in the current and sets off the alarm.

NOTE

- Americium-241 has a **half-life of 432 years**, so it easily outlasts the lifetime of the smoke detector.
- The source is only **weakly radioactive** and the fact that the alpha particles are **stopped by the plastic outer covering** and in any case only have a **range of 5-10 cm in air**, makes the smoke detector totally safe.
- An alpha-particle source is used because alphas will cause **enough ionisation** to give a detectable current.

• HOMEWORK QUESTIONS

1 A narrow beam of ionising radiation from a radioactive source was directed at a detector at a distance of **30 cm** from the source. The detector reading was unchanged when a **5 mm** thick **aluminium** plate was placed between the source and the detector.

(a) What **type of radiation** was emitted by the source ?

(b) With the source at a constant distance from the detector, discuss the effect on the detector reading of :

(i) Placing a second, identical **aluminium** plate in the path of the beam.

(ii) Placing a **lead** plate of thickness **10 mm** in the path of the beam.

2 The radioisotope $^{218}_{84}Po$ has a half-life of **3 min**, emitting **a-particles** according to the equation :

$$^{218}_{84}Po \longrightarrow {}^{X}_{Y}Pb + {}^{4}_{2}He$$

(a) What are the values of **X** and **Y** ?

(b) If **N atoms** of the Po-218 emits a-particles at the rate of **5.12×10^{4} s^{-1}**, what will be the rate of emission after $\frac{1}{2}$ hour ?

3 **Fig 1.** shows a cross-section through a smoke detector mounted on the ceiling.

The radioactive source in the detector is **americium-241**, which emits **alpha-particles.** The air inside the chamber is ionised by the particles, allowing the air to conduct. Any smoke in the chamber absorbs the ions and reduces the conductivity of the air.

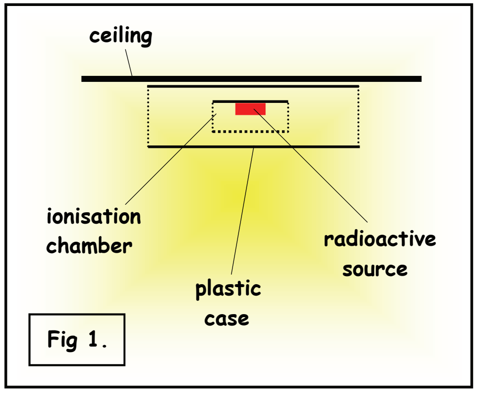


Fig 1.

(a) A typical smoke detector contains **2.9×10^{-10} kg** of americium-241.

(i) Show that the **number (N)** of americium nuclei in the source is about **7×10^{14}**.

(ii) Americium has a half-life of about **450 y (1.5×10^{10}s)**. Show that the **decay constant** is about **5×10^{-11} s^{-1}**.

(iii) Calculate the **activity** of the source.

(b) It is advised that the smoke detector be replaced after **5 years**, when about **5×10^{12}** nuclei will have decayed.

(i) Use the equation **$A = -\lambda N$**, to show that this is the number of nuclei which will have decayed.

(ii) Explain why the equation in (i) will not give an **accurate** answer but only an **adequate approximation** to it.

4 The radioactive nuclide $^{42}_{19}K$ decays by emission of a beta-particle. **Fig 2.** shows the apparatus used to measure the half-life of the nuclide.

A Geiger-Muller (GM)-tube connected to a counter is placed a short distance in front of the potassium source and the count per minute is recorded once every hour.

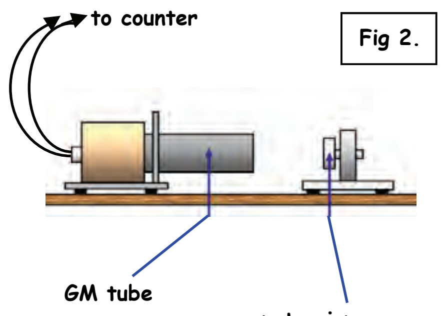


Fig 2.

(a) The activity of the potassium source is proportional to the count rate minus the background count rate, that is :

activity = constant x (count rate - background count rate).

(i) Explain the meaning of the terms **activity** and **background count rate.**

(ii) Suggest, with a reason, **one** of the factors which affect the value of the **constant** in the equation above.

(b) **(i)** The radioactive decay law in terms of the count rate (C) corrected for background can be written in the form :

$$\boxed{C = C_0 e^{-\lambda t}}$$

Where λ **is the decay constant.**

Show how the law can be written in the linear form : $\boxed{\ln C = -\lambda t + \ln C_0}$

(ii) **Fig 3.** shows the graph of **ln C** against **time t** for the beta-decay of potassium.

Use data from the graph to estimate the **half-life in hours** of the potassium nuclide.

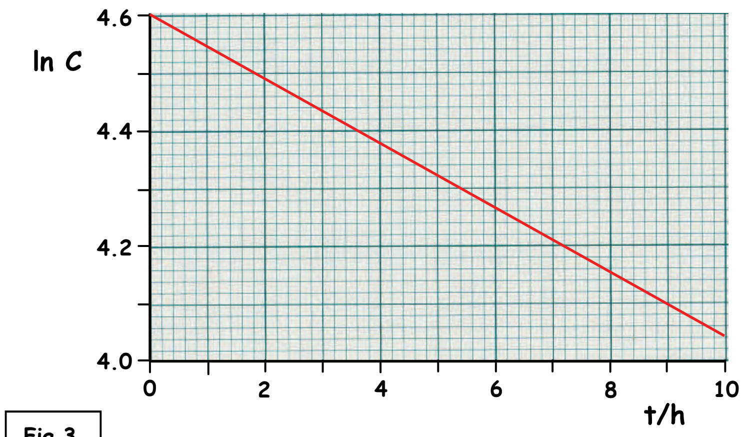


Fig 3.

(c) State **three** ways in which decay by emission of a **alpha-particle** differs from decay by emission of a **beta-particle.**

(OCR A2 Physics - Module 2824)

5 A radioactive source has a half-life of **20 days.** Calculate the **activity** of the source after **70 days** have elapsed if its initial activity is **10^{10} Bq.**

6 A radioisotope of nitrogen decays with a half-life of **7.4 s.**

(a) What is the **decay constant** for this nuclide ?

(b) A sample of the radioisotope initially contains **5000** nuclei. How many will remain after **14.8 s** ?

(c) How many nuclei will remain after **20 s** ?