OCR A Level Physics

Your notes

Radioactivity

Contents

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Radioactive Decay

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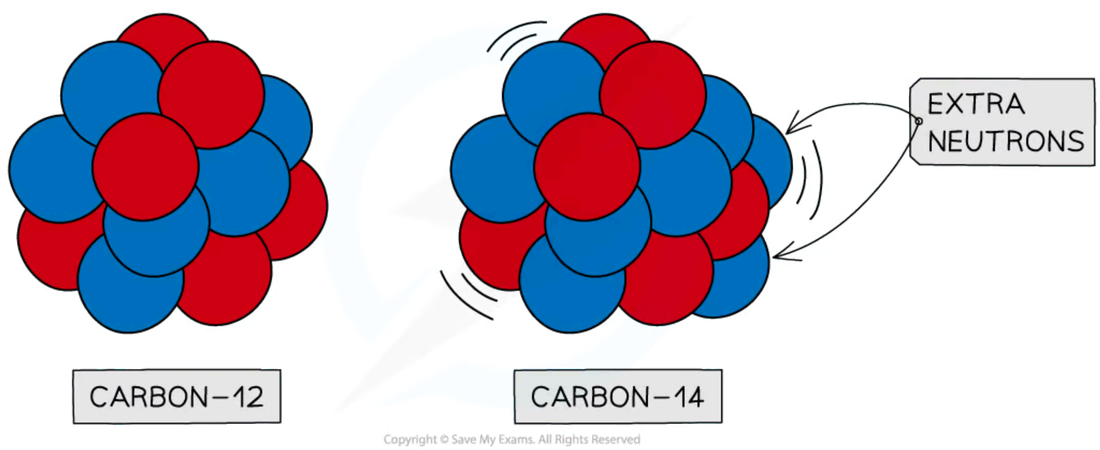
Radioactive Decay

Unstable Nuclei

- Some atomic nuclei are **unstable**
- This is because of an imbalance in the forces within the nucleus
  - Forces exist between the particles in the nucleus
- Carbon-14 is an **isotope** of carbon which is unstable
  - It has two extra neutrons compared to stable carbon-12



Carbon-12 is stable, whereas carbon-14 is unstable. This is because carbon-14 has two extra neutrons

- Some isotopes are unstable because of their large size or because they have too many or too few neutrons

Radiation

- Unstable nuclei can emit radiation to become more stable
  - Radiation can be in the form of a high energy particle or wave

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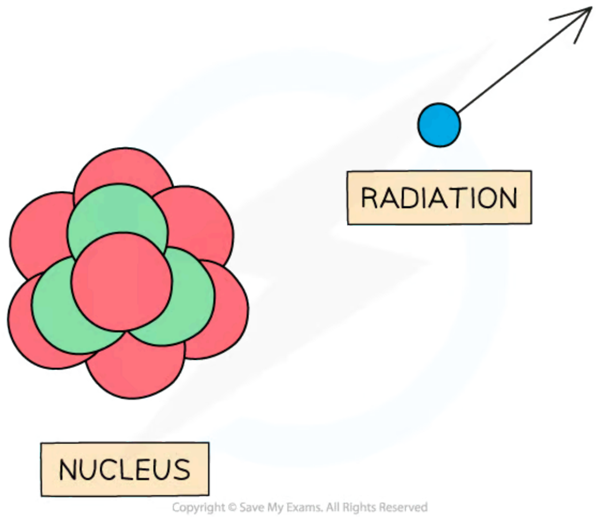

Unstable nuclei decay by emitting high energy particles or waves

- As the radiation moves away from the nucleus, it takes some energy with it
  - This reduces the overall energy of the nucleus
  - This makes the nucleus more **stable**
- The process of emitting radiation is called **radioactive decay**
- Radioactive decay is a **random** process
  - This means it is not possible to know exactly when a particular nucleus will decay

Worked Example

Which of the following statements is **not** true?

A. Isotopes can be unstable because they have too many or too few neutrons

B. The process of emitting particles or waves of energy from an unstable nucleus is called radioactive decay

C. Scientists can predict when a nucleus will decay

D. Radiation refers to the particles or waves emitted from a decaying nucleus

Answer: C

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- Answer A is **true.** The number of neutrons in a nucleus determines the stability
- Answer B is **true.** This is a suitable description of radioactive decay
- Answer D is **true.** Radiation is about emissions. It is different to radioactive particles
- Answer C is **not true**
  - Radioactive decay is a random process
  - It is not possible to predict precisely when a particular nucleus will decay

Examiner Tips and Tricks

The terms **unstable**, **random** and **decay** have very particular meanings in this topic. Remember to use them correctly when answering questions!

Simulating the Random Nature of Radioactive Decay

- Radioactive decay is defined as:

  The spontaneous disintegration of a nucleus to form a more stable nucleus, resulting in the emission of an alpha, beta or gamma particle

- Radioactive decay is a **random** process, which means that:
  - There is an **equal probability** of any nucleus decaying
  - It cannot be known **which particular nucleus will decay next**
  - It cannot be known **at what time a particular nucleus will decay**
  - The rate of decay is **unaffected** by the surrounding conditions
  - It is only possible to estimate the **proportion** of nuclei decaying in a given time period
- Radioactive decay is a **spontaneous** process, which means that:
  - The decay of nuclei is not affected by the presence of other nuclei in the sample
  - External factors such as pressure do not have an effect on the decay

- The random nature of radioactive decay can be demonstrated by observing the count rate of a Geiger-Muller (GM) tube
  - When a GM tube is placed near a radioactive source, the counts are found to be irregular and cannot be predicted

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- Each count represents a decay of an unstable nucleus
- These fluctuations in count rate on the GM tube **provide evidence for the randomness of radioactive decay**

The variation of count rate over time of a sample radioactive gas. The fluctuations show the randomness of radioactive decay

Simulating this Random Nature

- The **random nature** of **unstable** nuclei can be simulated in many ways:
  - Rolling lots of dice
  - Flipping coins
  - Making popcorn

Rolling lots of dice

- Each **die** represents **unstable undecayed nuclei** in a **sample**
- Roll the dice and remove all the dice that land with a six facing up

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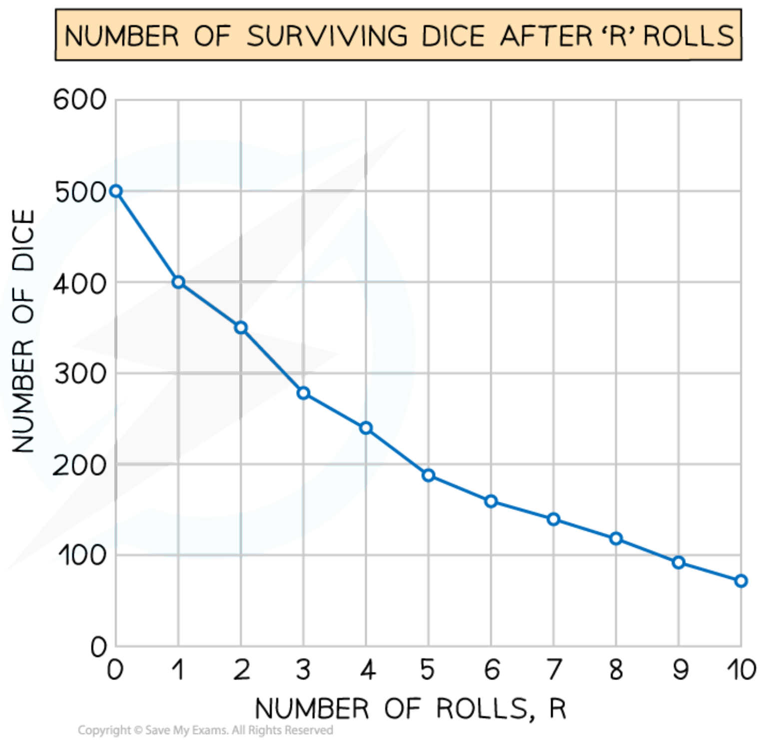
    - The dice with a six have now decayed into stable nuclei of a different element
    - They are no longer part of the sample
- Repeat this process again
- Keep repeating
- The number of dice that are removed each time is completely random

Number of rolls	Number of dice surviving	Activity (Bq)
0	500	–
1	401	99
2	350	51
3	280	70
4	238	42
5	190	48
6	160	30
7	139	21
8	120	19
9	95	25
10	72	23
11	66	6
12	50	16



Flipping Coins

- Start with 10 coins in a bag
- **One coin** represents **one nucleus** in the **sample**
- Shake the bag and tip out the coins
- When the coin lands on a tail
    - that nucleus has decayed into a **stable nucleus**
    - it is no longer part of the **sample**
- The coins that land on a head is still **unstable** and have not yet **decayed**

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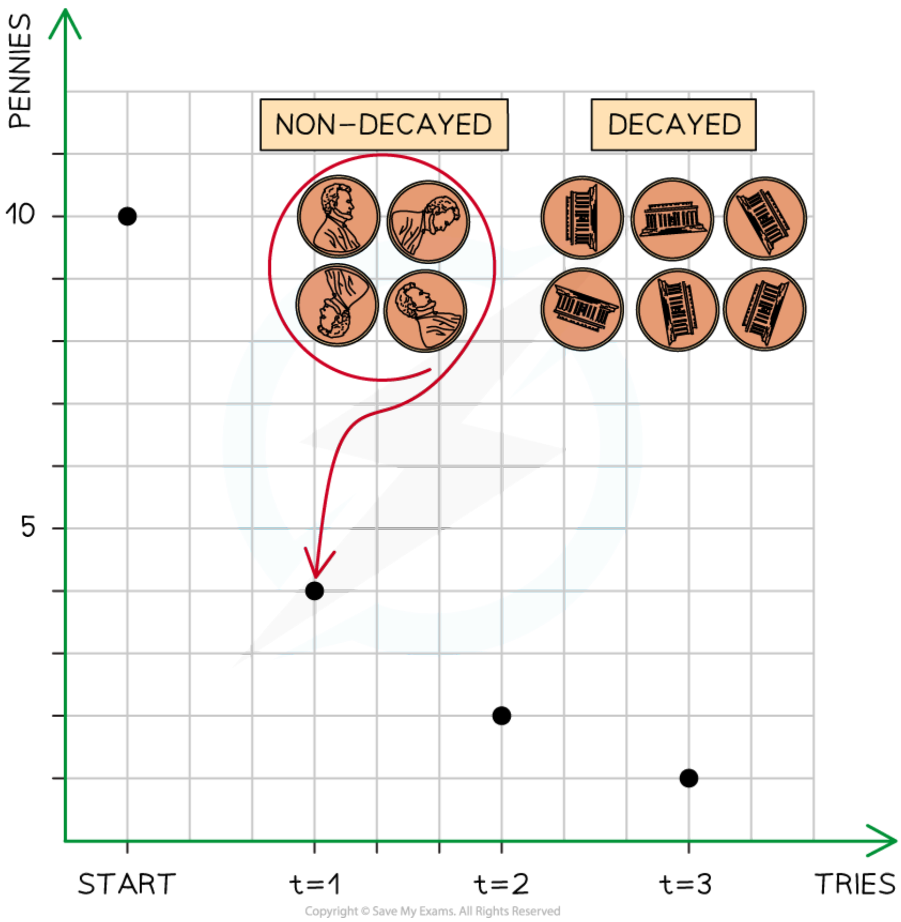

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Making Popcorn

- Each **popcorn kernel** represents **one undecayed nucleus** in the **sample**
- When the popcorn is cooked in a microwave **each pop** represents a **single decay**
- At the **start**, there are lots of un popped kernels and the **popping rate** is **high**
- As the amount of **un popped kernels decreases**, so does the **popping rate**

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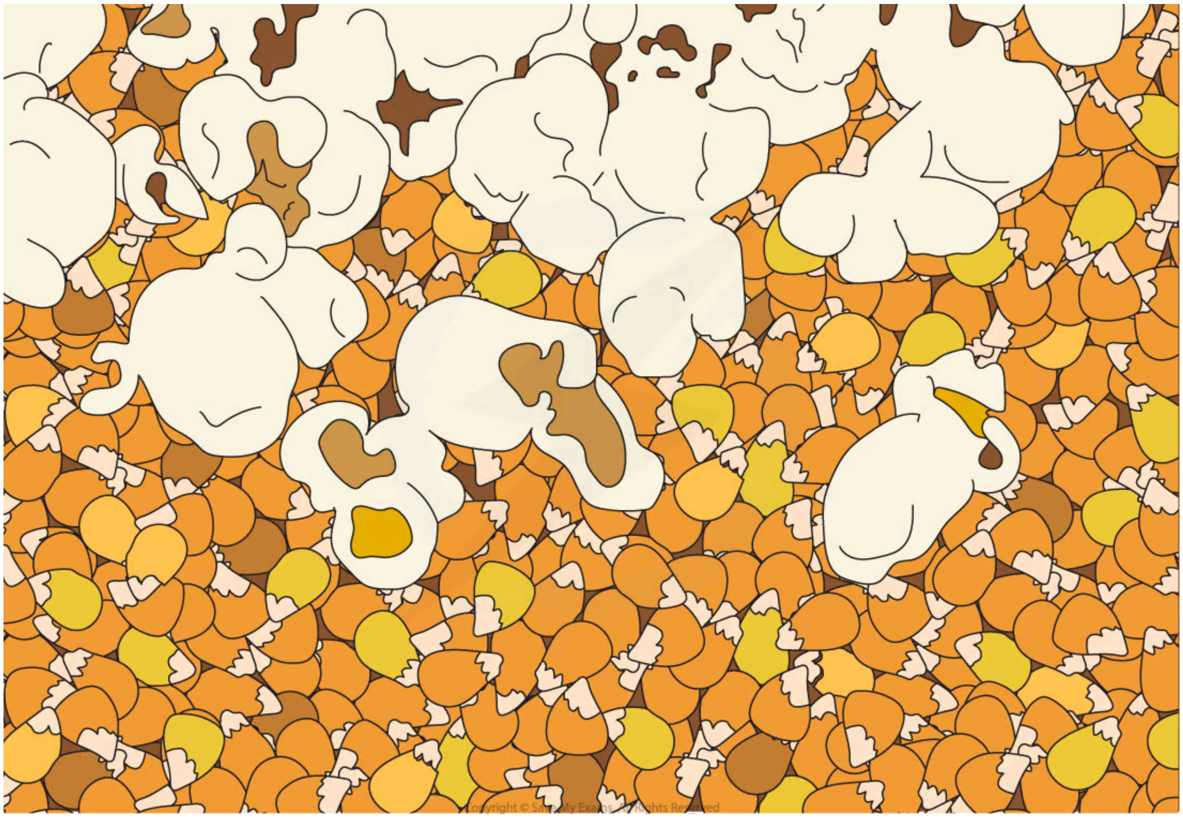

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Examiner Tips and Tricks

It is important to understand how each of these simulations work as you may be asked questions about them in your examination.

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Alpha, Beta & Gamma Radiation

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Alpha, Beta & Gamma Particles

- Some elements have nuclei that are unstable
  - This tends to be when the number of nucleons does not balance
- In order to become more stable, they emit particles and/or electromagnetic radiation
  - These nuclei are said to be **radioactive**
- There are three different types of radioactive emission: Alpha, Beta and Gamma

Alpha Particles

- **Alpha (α) particles** are high energy particles made up of **2 protons and 2 neutrons** (the same as a helium nucleus)
- They are usually emitted from nuclei that are too large

- Alpha is a **low** penetrating type of radiation
  - Alpha particles have a range of a few cm in air

Beta Particles

- **Beta (β^-) particles are high energy electrons** emitted from the nucleus
  - β^- particles are emitted by nuclei that have too many **neutrons**
- Beta is a **moderately** ionising type of radiation
  - This is due to it having a charge of +1e
  - This means it is able to do some slight damage to cells (less than alpha but more than gamma)
- Beta is a **moderately** penetrating type of radiation

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- Beta particles have a range of around 20 cm - 3 m in air, depending on their energy
- Beta can be stopped by a few millimetres of **aluminium** foil

Gamma Rays

- **Gamma (γ) rays are high energy electromagnetic waves**
- They are emitted by nuclei that need to lose some energy

- Gamma is a **highly** penetrating type of radiation
    - Gamma particles have a range of around 1– 10 cm in lead or several metres in concrete
- If these particles hit other atoms, they can knock out electrons, **ionising the atom**
- This can cause chemical changes in materials and can damage or kill living cells

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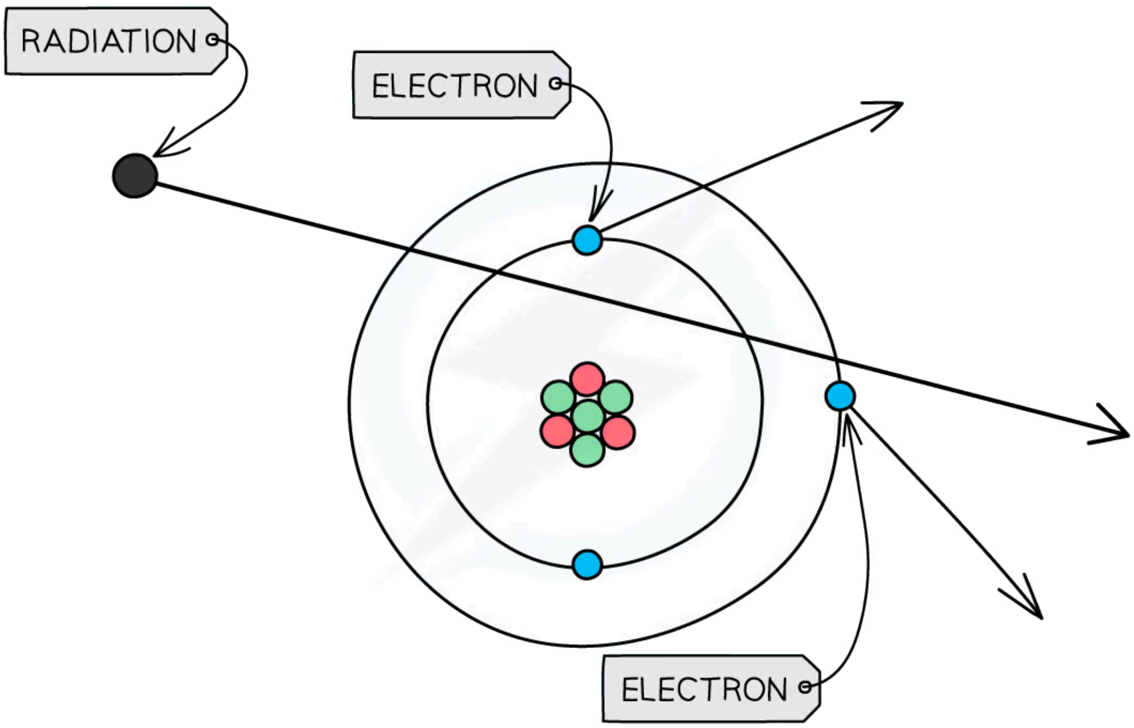

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When radiation passes close to atoms, it can knock out electrons, ionising the atom

- The properties of the different types of radiation are summarised in the table below

Particle	Composition	Mass / u	Charge / e	Speed / c
Alpha (α)	2 protons + 2 neutrons	4	+2	0.05
Beta minus (β^-)	Electron (e^-)	0.0005	−1	> 0.99
Beta plus (β^+)	Positron (e^+)	0.0005	+1	> 0.99
Gamma (γ)	Electromagnetic wave	0	0	1

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- *u* is the atomic mass unit (see "Atomic Mass Unit (u)")
- e is the charge of the electron: 1.60×10^{-19} C
- c is the speed of light: 3×10^{8} m s^{-1}

Worked Example

Three successive radioactive decays are shown in the diagram below; each one results in a particle being emitted.
The first decay results in the emission of β-particle. The second decay results in the emission of an α-particle. The third decay results in the emission of another β-particle.

$${}^{237}_{92}W \xrightarrow{\beta-} X \xrightarrow{\alpha} Y \xrightarrow{\beta+} Z$$

Nuclides W and Z are compared.
Which nuclide of Z is formed at the end of this decay?

A. ${}^{237}_{90}Z$ **B.** ${}^{233}_{92}Z$ **C.** ${}^{237}_{89}Z$ **D.** ${}^{233}_{90}Z$

Answer: D

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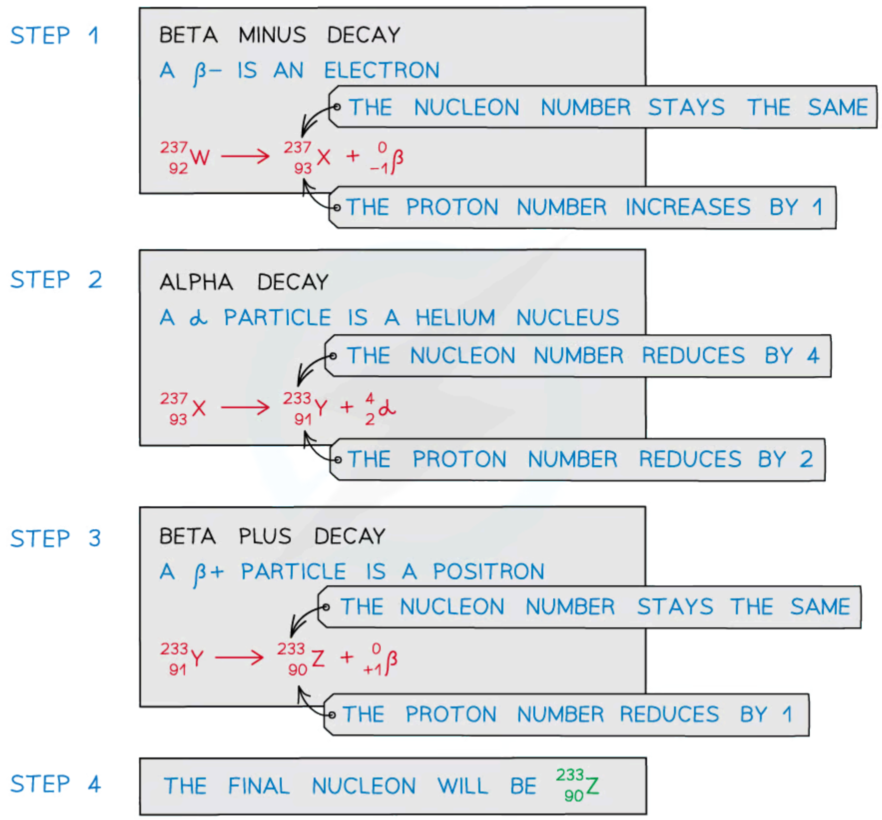

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Examiner Tips and Tricks

It is important to be confident with the properties of each type of radiation and how they can be written as symbols.

Investigating the Absorption of Alpha, Beta & Gamma Radiation

Aim of the Experiment

- The aim of this experiment is to investigate the penetration powers of different types of radiation using either radioactive sources or simulations

Variables:

- Independent variable = Absorber material

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- Dependent variable = Count rate
- Control variables:
  - Radioactive source
  - Distance of GM tube to source
  - Location / background radiation

Equipment	Purpose
Radioactive sources (α, β and γ)	Used for testing
Ruler	To control the distance between the sources and the GM tube
Mount for radioactive sources	To hold the sources securely
Geiger–Muller tube and counter	For measuring count rate
Tongs	For safe handling of the sources
Selection of absorber materials: Paper, different thicknesses of aluminium, different thicknesses of lead	To be changed as the independent variable. Increasing intervals of 0.5 mm
Lead lined container for storing sources when not in use	For safety and to ensure results are not affected by sources not being tested

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Method

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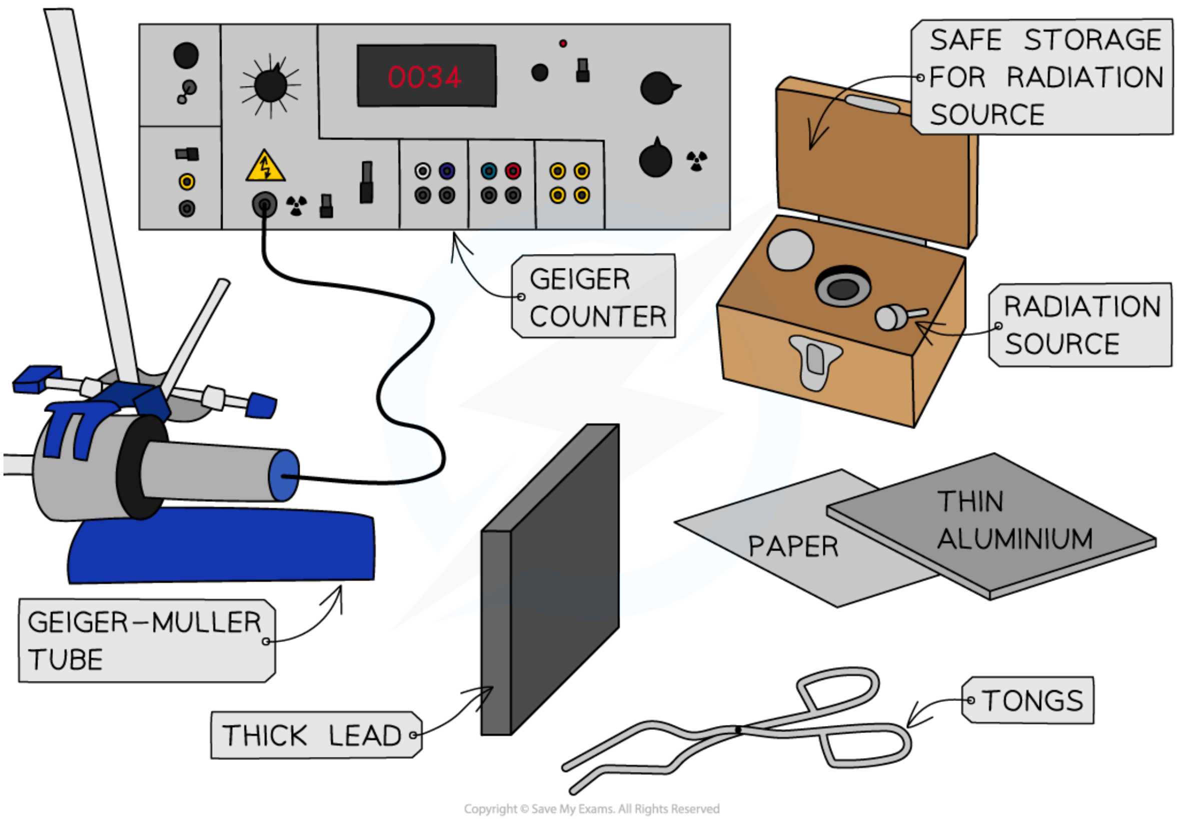

Investigating radiation apparatus

1. Connect the **Geiger-Müller tube** to the **counter** and, without any sources present, **measure background radiation** over a one minute period
2. Repeat this three times, and take an average
3. Now place a radioactive source **a fixed distance** of 3 cm away from the tube and take another reading over a one minute interval
4. Now take a set of **absorbers**: some paper, several different thicknesses of aluminium (increasing in 0.5mm intervals) and different thickness of lead
5. One at a time, place these absorbers between the source and the tube and take another reading over a one minute interval
6. Repeat the above experiment for other radioactive sources

Results

- **Alpha radiation** will be **absorbed** by the **paper**

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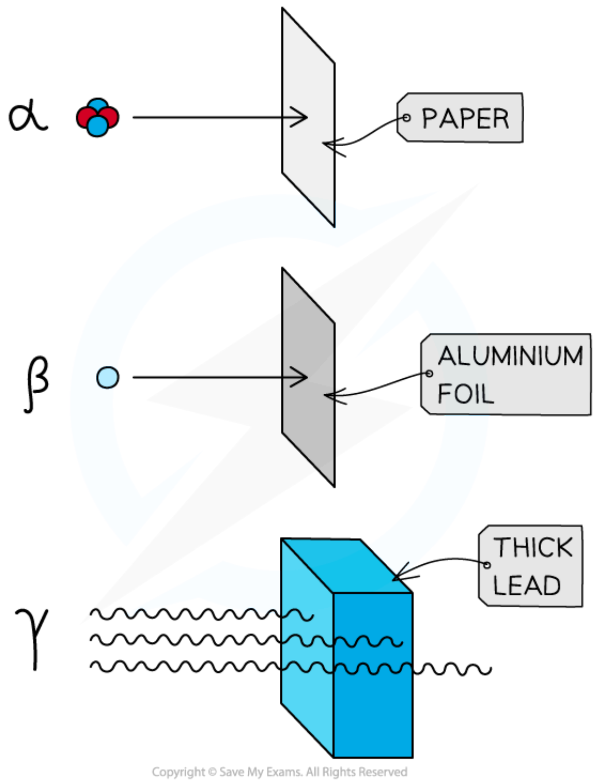
- **Beta radiation** will be **absorbed** by the **aluminium foil**
- Some **gamma radiation** will be **absorbed** by the **thick lead**



Penetrating power of alpha, beta and gamma radiation

Safety Considerations

- When not using a source, keep it in a lead lined container
- When in use, try and keep a good distance (a metre or so) between yourself and the source
- When handling the source, do so using tweezers (or tongs) and point the source away from you

Examiner Tips and Tricks

It is common for you to be asked questions on this practical. Make sure you are familiar with the safety procedures and why you would measure the background radiation first before completing the experiment.

Your notes

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Alpha & Beta Decay Equations

Your notes

Alpha & Beta Decay Equations

- Radioactive decay events can be shown using a **decay equation**
- A decay equation is similar to a chemical reaction equation
  - The particles present before the decay are shown **before** the arrow
  - The particles produced in the decay are shown **after** the arrow
- During decay equations the sum of the mass and atomic numbers **before** the reaction must be the same as the sum of the mass and atomic numbers **after** the reaction
- The following decay equation shows Polonium-212 undergoing alpha decay
  - It forms Lead-208 and an alpha particle
  - An alpha particle can also be written as a helium nucleus (Symbol He)

$$^{A}_{Z}X \rightarrow \,^{A-4}_{Z-2}Y + \,^{4}_{2}\alpha$$

$$\text{e.g.} \quad ^{212}_{84}Po \rightarrow \,^{208}_{82}Pb + \,^{4}_{2}\alpha$$

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The polonium nucleus emits an alpha particle, causing its mass and charge to decrease. This means it changes into a new element

Alpha Decay

- During alpha decay an alpha particle is emitted from an unstable nucleus
- A completely **new element** is formed in the process

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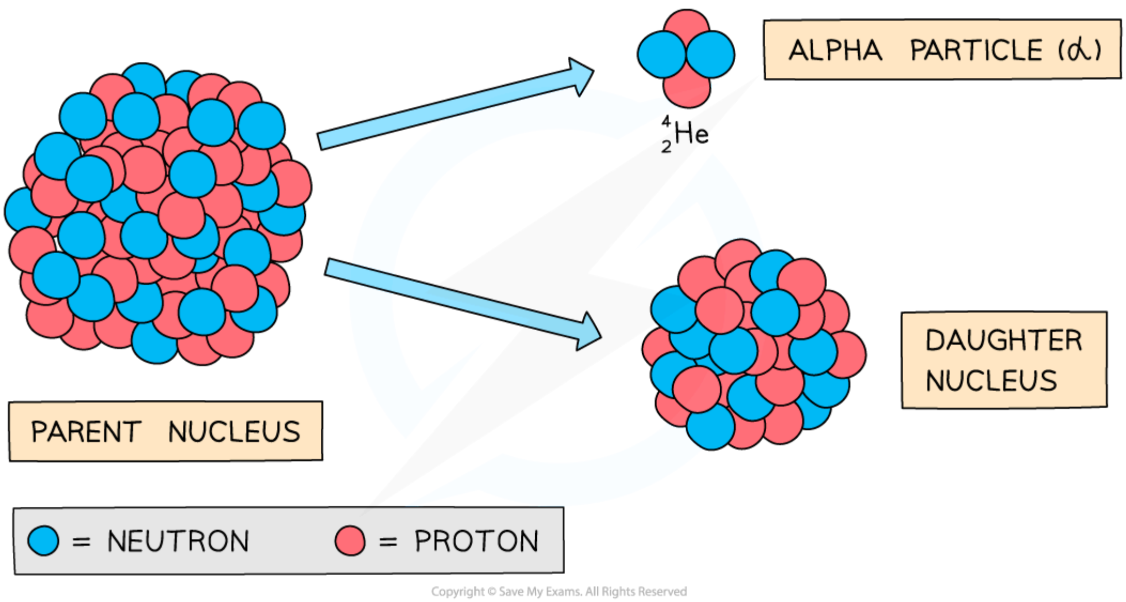

Your notes

Alpha decay usually happens in large unstable nuclei, causing the overall mass and charge of the nucleus to decrease

- An alpha particle is a **helium nucleus**
  - It is made of 2 protons and 2 neutrons
- When the alpha particle is emitted from the unstable nucleus, the mass number and atomic number of the nucleus changes
  - The mass number **decreases** by 4
  - The atomic number **decreases** by 2
- The charge on the nucleus also decreases by 2
  - This is because protons have a charge of +1 each

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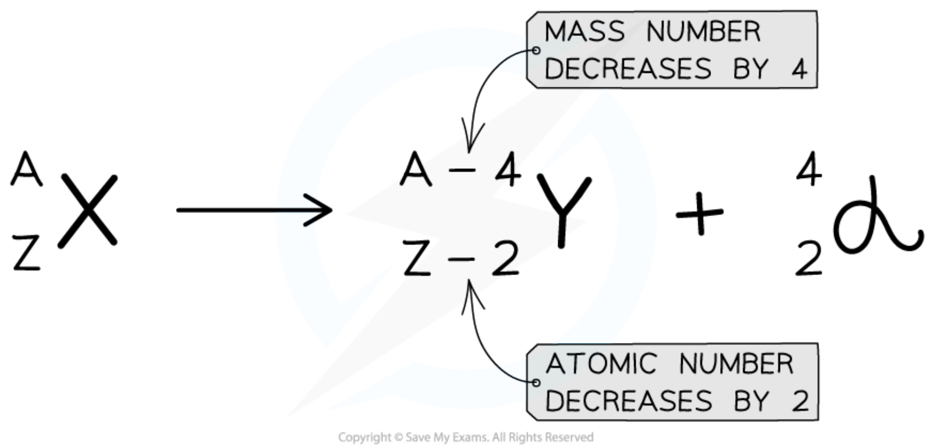
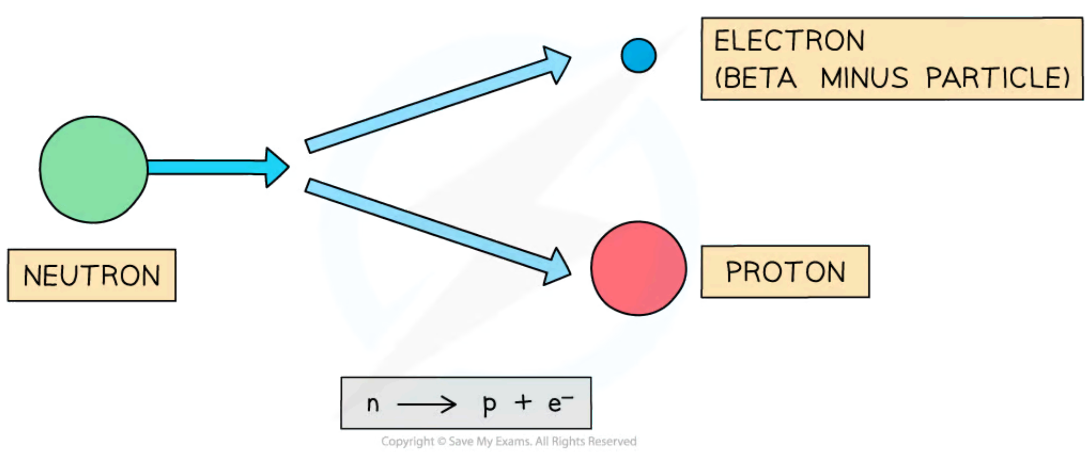


Alpha decay equation

Beta Decay

- During **beta** decay, a **neutron** changes into a **proton** and an **electron**
    - The electron is **emitted** and the proton **remains** in the nuclei
- A completely new element is formed because the **atomic number** changes



Beta decay often happens in unstable nuclei that have too many neutrons. The mass number stays the same, but the atomic number increases by one

- A beta particle is a high-speed **electron**
- It has a mass number of 0

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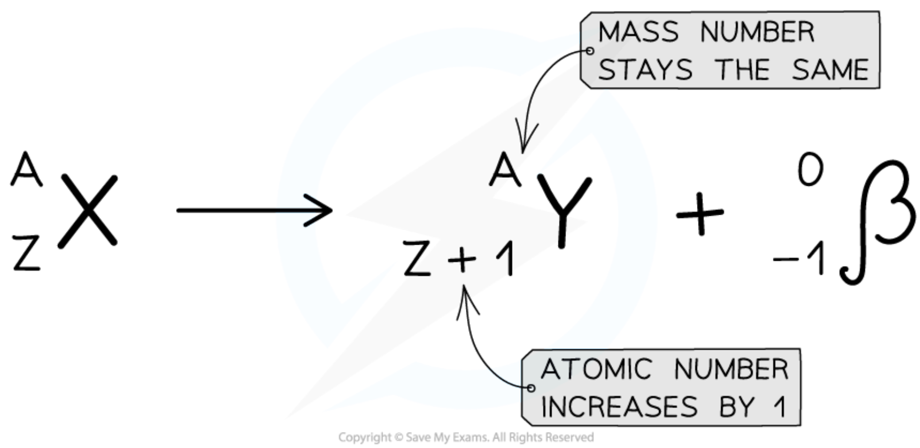
- This is because the electron has a negligible mass, compared to neutrons and protons
- Therefore, the **mass number** of the decaying nuclei **remains the same**
- Electrons have an atomic number of -1
  - This means that the new nuclei will **increase its atomic number by 1** in order to maintain the overall atomic number before and after the decay
- The following equation shows carbon-14 undergoing beta decay
  - It forms nitrogen-14 and a beta particle
  - Beta particles are written as an electron in this equation



$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta $$

Beta decay equation

Worked Example

A nucleus with 84 protons and 126 neutrons undergoes alpha decay. It forms lead, which has the element symbol Pb.

A: ${}^{206}_{82}Pb$ B: ${}^{208}_{82}Pb$ C: ${}^{210}_{84}Pb$ D: ${}^{214}_{86}Pb$

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Which of the isotopes of lead pictured is the correct one formed during the decay?

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Answer: A

Step 1: Calculate the mass number of the original nucleus

- The mass number is equal to the number of protons plus the number of neutrons
- The original nucleus has 84 protons and 126 neutrons

$$84 + 126 = 210$$

- The mass number of the original nucleus is 210

Step 2: Calculate the new atomic number

- The alpha particle emitted is made of two protons and two neutrons
- Protons have an atomic number of 1, and neutrons have an atomic number of 0
- Removing two protons and two neutrons will reduce the atomic number by 2

$$84 - 2 = 82$$

- The new nucleus has an atomic number of **82**

Step 3: Calculate the new mass number

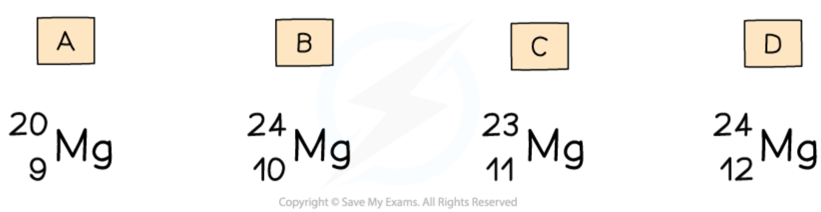
- Protons and neutrons both have a mass number of 1
- Removing two protons and two neutrons will reduce the mass number by 4

$$210 - 4 = 206$$

- The new nucleus has a mass number of 206

Worked Example

A nucleus with 11 protons and 13 neutrons undergoes beta decay. It forms magnesium, which has the element symbol Mg.



Which is the correct isotope of magnesium formed during the decay?

Answer:

Step 1: Calculate the mass number of the original nucleus

- The mass number is equal to the number of protons plus the number of neutrons

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- The original nucleus has 11 protons and 13 neutrons

$$11 + 13 = 24$$

- The mass number of the original nucleus is 24

Step 2: Calculate the new atomic number

- During beta decay a neutron changes into a proton and an electron
- The electron is emitted as a beta particle
- The neutron has an atomic number of 0 and the proton has an atomic number of 1
- So the atomic number increases by 1

$$11 + 1 = 12$$

- The new nucleus has an atomic number of 12

Step 3: Calculate the new mass number

- Protons and neutrons both have a mass number of 1
- Changing a neutron to a proton will not affect the mass number
- The new nucleus has a mass number of 24 (the same as before)

Examiner Tips and Tricks

It is easy to forget that an alpha particle **is** a helium nucleus. The two are interchangeable, so don't be surprised to see either used in the exam. You are not expected to know the names of the elements produced during radioactive decays, but you do need to be able to calculate the mass and atomic numbers by making sure they are balanced on either side of the reaction.

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Activity & The Decay Constant

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Activity & The Decay Constant

- Since radioactive decay is spontaneous and random, it is useful to consider the average number of nuclei which are expected to decay per unit time
  - This is known as the **average decay rate**
- As a result, each radioactive element can be assigned a **decay constant**
- The decay constant λ is defined as:

  The probability, per second, that a given nucleus will decay

- When a sample is highly radioactive, this means the number of decays per unit time is very high
  - This suggests it has a high level of **activity**
- Activity, or the number of decays per unit time can be calculated using:

$$A = \frac{\Delta N}{\Delta t} = -\lambda N$$

- Where:
  - A = activity of the sample (Bq)
  - ΔN = number of decayed nuclei
  - Δt = time interval (s)
  - λ = decay constant (s^{-1})
  - N = number of nuclei remaining in a sample
- The activity of a sample is measured in **Becquerels** (Bq)
  - An activity of 1 Bq is equal to one decay per second, or 1 s^{-1}
- This equation shows:
  - The greater the decay constant, the greater the activity of the sample
  - The activity depends on the number of undecayed nuclei remaining in the sample
  - The minus sign indicates that the number of nuclei remaining decreases with time - however, for calculations it can be omitted

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Worked Example

Americium-241 is an artificially produced radioactive element that emits α-particles. A sample of americium-241 of mass 5.1 μg is found to have an activity of 5.9×10^5 Bq.

(a) Determine the number of nuclei in the sample of americium-241.

(b) Determine the decay constant of americium-241.

Answer:

Part (a)

Step 1: Write down the known quantities

- Mass = 5.1 μg = 5.1×10^{-6} g
- Molecular mass of americium = 241
- N_A = Avogadro constant

Step 2: Write down the equation relating number of nuclei, mass and molecular mass

$$\text{Number of nuclei} = \frac{mass \times N_A}{molecular\ mass}$$

Step 3: Calculate the number of nuclei

$$\text{Number of nuclei} = \frac{(5.1 \times 10^{-6}) \times (6.02 \times 10^{23})}{241} = 1.27 \times 10^{16}$$

Part (b)

Step 1: Write the equation for activity

Activity, $A = \lambda N$

Step 2: Rearrange for decay constant λ and calculate the answer

$$\lambda = \frac{A}{N} = \frac{5.9 \times 10^5}{1.27 \times 10^{16}} = 4.65 \times 10^{-11}\ \text{s}^{-1}$$

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Examiner Tips and Tricks

There are lots of new symbols and definitions in this unit. Make sure you are clear on what each symbol means.

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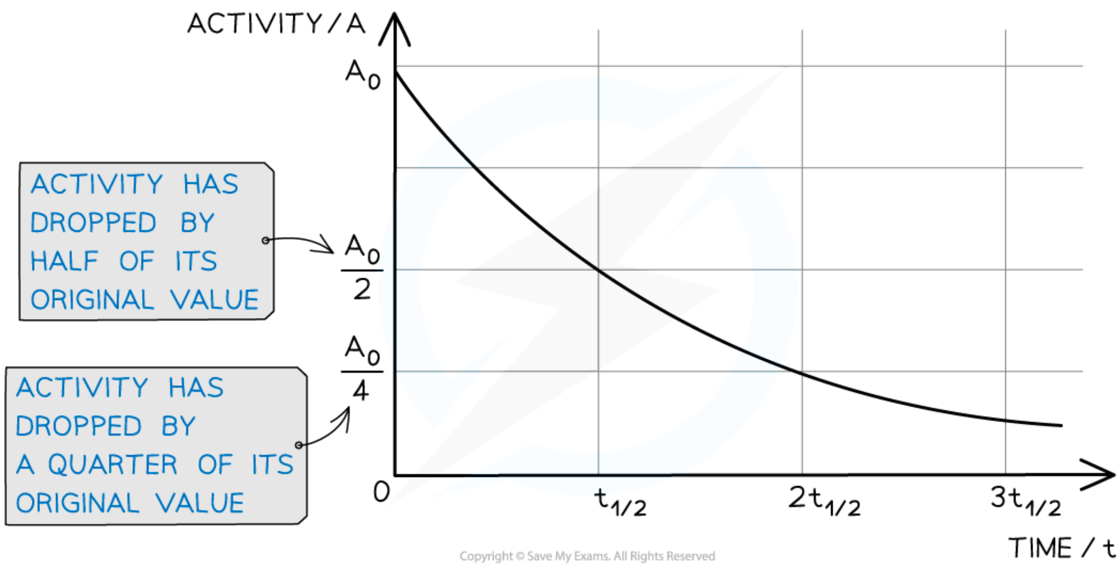
Half-Life

Half-Life

- Half life is defined as:

    The time taken for the initial number of nuclei to reduce by half

- This means when a time equal to the half-life has passed, the activity of the sample will also half
- This is because activity is proportional to the number of undecayed nuclei, $A \propto N$



When a time equal to the half-life passes, the activity falls by half, when two half-lives pass, the activity falls by another half (which is a quarter of the initial value)

Determining the Half-Life of an Isotope

- To find an expression for half-life, start with the equation for exponential decay:

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

- Where:
    - N = number of nuclei remaining in a sample
    - N_0 = the initial number of undecayed nuclei (when t = 0)

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- λ = decay constant (s^{-1})
- t = time interval (s)
- When time t is equal to the half-life $t_{½}$, the activity N of the sample will be half of its original value, so N = ½ N_0

$$\frac{1}{2} N_0 = N_0 e^{-\lambda t_{½}}$$

- The formula can then be derived as follows:

Divide both sides by N_0: $$\frac{1}{2} = e^{-\lambda t_{½}}$$

Take the natural log of both sides: $$\ln\left(\frac{1}{2}\right) = -\lambda t_{½}$$

Apply properties of logarithms: $$\lambda t_{½} = \ln(2)$$

- Therefore, half-life $t_{½}$ can be calculated using the equation:

$$t_{½} = \frac{\ln 2}{\lambda} \simeq \frac{0.693}{\lambda}$$

- This equation shows that half-life $t_{½}$ and the radioactive decay rate constant λ are inversely proportional
- Therefore, the shorter the half-life, the larger the decay constant and the **faster** the decay

Worked Example

Strontium-90 is a radioactive isotope with a half-life of 28.0 years. A sample of Strontium-90 has an activity of 6.4×10^9 Bq. Calculate the decay constant λ, in s^{-1}, of Strontium-90.

Answer:

Step 1: Convert the half-life into seconds

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28 years = 28 × 365 × 24 × 60 × 60 = 8.83×10^8 s

Step 2: Write the equation for half-life

$$t_{½} = \frac{ln\ 2}{\lambda}$$

Step 3: Rearrange for λ and calculate

$$\lambda = \frac{ln\ 2}{t_{½}} = \frac{ln\ 2}{8.83 \times 10^8} = \mathbf{7.85 \times 10^{-10}\ s^{-1}}$$

Examiner Tips and Tricks

Make sure you are confident with the meanings of all the definitions and symbols in this unit. It is easy to get confused when completing an examination question.

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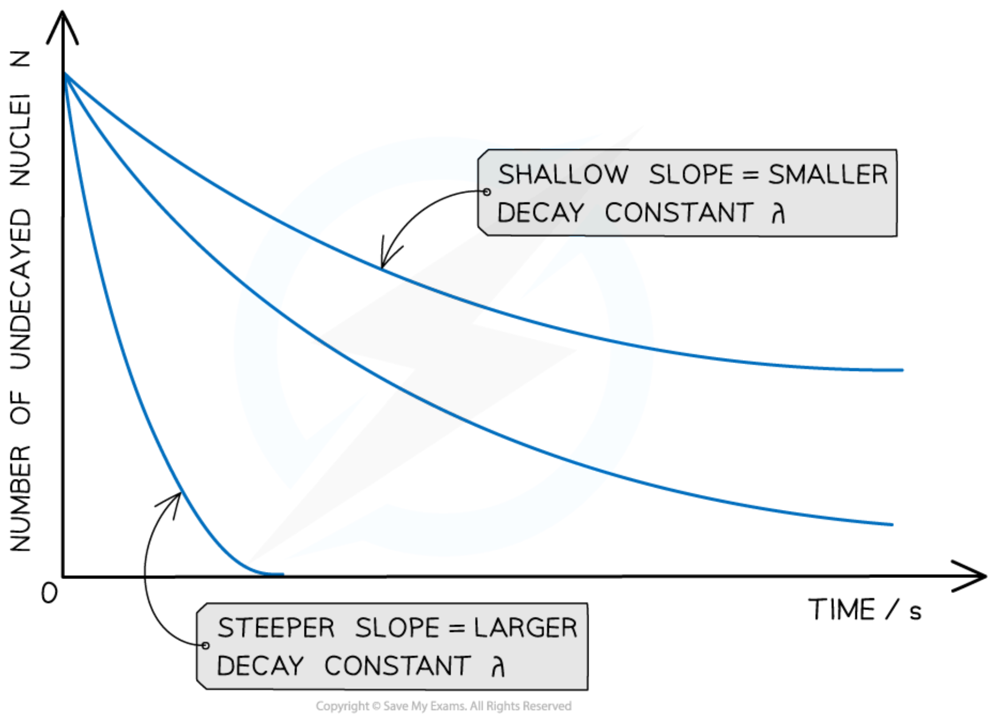
Radioactive Decay Equations

Radioactive Decay Equations

- In radioactive decay, the number of undecayed nuclei falls very rapidly, without ever reaching zero
  - Such a model is known as **exponential decay**
- The graph of number of undecayed nuclei against time has a very distinctive shape:



Radioactive decay follows an exponential pattern. The graph shows three different isotopes each with a different rate of decay

- **The key features of this graph are:**
  - The steeper the slope, the larger the decay constant λ (and vice versa)
  - The decay curves always start on the y-axis at the initial number of undecayed nuclei (N_0)

Equations for Radioactive Decay

- The number of undecayed nuclei *N* can be represented in exponential form by the equation:

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

- Where:
  - N_0 = the initial number of undecayed nuclei (when t = 0)
  - N = number of undecayed nuclei at a certain time t
  - λ = decay constant (s^{-1})
  - t = time interval (s)
- The number of nuclei can be substituted for other quantities.
- For example, the activity A is directly proportional to N, so it can also be represented in exponential form by the equation:

$$A = A_0 e^{-\lambda t}$$

- Where:
  - A = activity at a certain time t (Bq)
  - A_0 = initial activity (Bq)
- The received count rate C is related to the activity of the sample, hence it can also be represented in exponential form by the equation:

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

- Where:
  - C = count rate at a certain time t (counts per minute or cpm)
  - C_0 = initial count rate (counts per minute or cpm)

The exponential function e

- The symbol e represents the exponential constant
  - It is approximately equal to e = 2.718
- On a calculator, it is shown by the button e^x
- The inverse function of e^x is ln(y), known as the natural logarithmic function
  - This is because, if e^x = y, then x = ln(y)

Worked Example

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Strontium-90 decays with the emission of a β-particle to form Yttrium-90.The decay constant of Strontium-90 is 0.025 year $^{-1}$. Determine the activity A of the sample after 5.0 years, expressing the answer as a fraction of the initial activity A_0.

Answer:

Step 1: Write out the known quantities

- Decay constant, λ = 0.025 year $^{-1}$
- Time interval, t = 5.0 years
- Both quantities have the same unit, so there is no need for conversion

Step 2: Write the equation for activity in exponential form

$$A = A_0 e^{-\lambda t}$$

Step 3: Rearrange the equation for the ratio between *A* and *A*₀

$$\frac{A}{A_0} = e^{-\lambda t}$$

Step 4: Calculate the ratio A/A_0

$$\frac{A}{A_0} = e^{-(0.025 \times 5)} = 0.88$$

Therefore, the activity of Strontium-90 decreases by a factor of 0.88, or 12%, after 5 years

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Modelling Radioactive Decay

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Modelling Radioactive Decay

Iterative Modelling

- We can use:
  - a **spreadsheet** to model the **exponential decay** of nuclei
  - the **activity equation** to calculate the remaining number of undecayed nuclei

$$A = \frac{\Delta N}{\Delta t} = -\lambda N$$

- Where:
  - A = activity of the sample (Bq)
  - ΔN = number of decayed nuclei
  - Δt = time interval (s)
  - λ = decay constant (s^{-1})
  - N = number of nuclei remaining in a sample

Procedure

1. Start with a given number of undecayed nuclei, N_0 in the sample

- N_0 = 1000 is a logical number to start with

2. Choose a very small interval of time, Δt

- This should be significantly shorter than the half-life of the isotope chosen

3. Calculate the number of nuclei decaying, ΔN during the time period

- $\frac{\Delta N}{\Delta t} = -\lambda N$
- So, $\Delta N = (\lambda \Delta t) \times N$

4. Calculate the number of undecayed nuclei, N now left at the end of the time period, Δt

- $N_0 - \Delta N = N$

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5. Repeat this process by iterating your value for N as your new N_0 for many values of Δt

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Example

Step 1: $N_0 = 1000$

Step 2: $\Delta t = 0.10$ s

Step 3: $\Delta N = (\lambda \Delta t) \times N$

- λ = decay constant = 0.693 s^{-1}
- So, $\Delta N = (0.693 \times 0.1) \times N$
- $\Delta N = 0.0693N$

Step 4: $N_0 - \Delta N = N$

- $1000 - 0.0693N = N$
- So, $1000 = N + 0.0693N$
- $1000 = 1.0693N$
- Therefore, $N = \dfrac{1000}{1.0693} = 935.2$

Step 5: $N_0 = 935.2$

- In the second iteration, N_0 = previous N
- $\Delta t = 0.10$ s as before
- So, $N = \dfrac{N_0}{1.0693}$ for all iterations

Table of Results

- It is important to details your iteration as a table of results

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Time/s	Number of Undecayed Nuclei, N
0	1000
0.1	935.2
0.2	874.6
0.3	917.9
0.4	764.9
0.5	715.3
0.6	669.0
0.7	625.6
0.8	585.1
0.9	547.1
1.0	511.7

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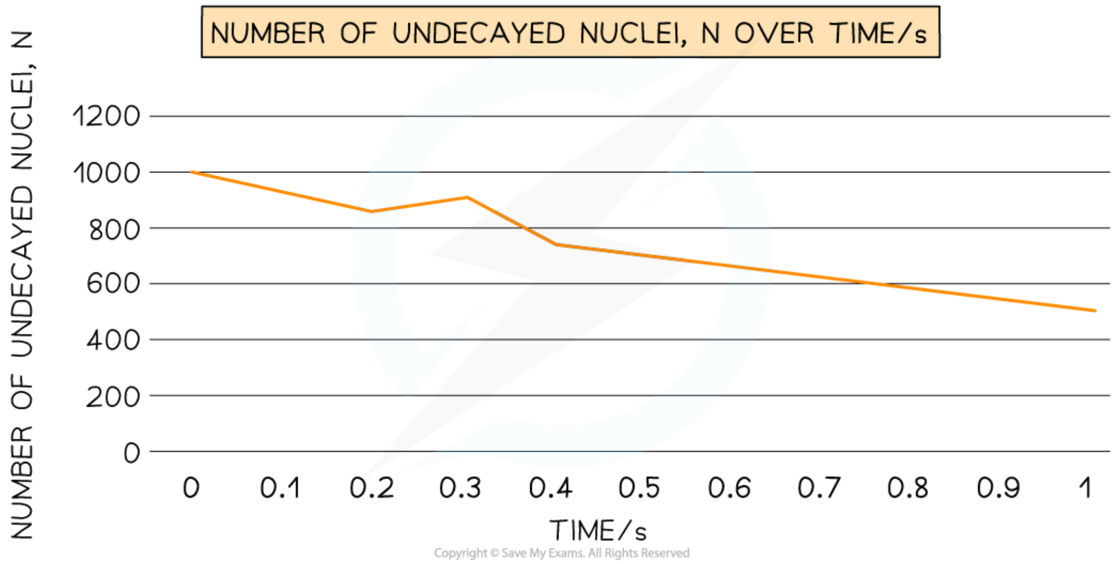

Examiner Tips and Tricks

It is really important to keep your final answer in your calculator and use that as the next value of N_0 for the iteration. If you clear your calculator and round your answer, this will significantly change your value of N .

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Radioactive Dating

- The isotope carbon-14 is commonly used in radioactive dating
- It forms as a result of cosmic rays knocking out neutrons from nuclei, which then collide with nitrogen nuclei in the air:

$$^{1}n + ^{14}N \rightarrow ^{14}C + ^{1}p$$

- Plants take in carbon dioxide from the atmosphere for photosynthesis, including the radioactive isotope carbon-14
- Animals and humans take in carbon-14 by eating the plants
  - Therefore, all living organisms absorb carbon-14, but after they die they do not absorb any more
- The proportion of carbon-14 is constant in living organisms as carbon is constantly being replaced during the period they are alive
- When they die, the activity of carbon-14 in the organic matter starts to **fall**, with a half-life of around 5730 years
- Samples of living material can be tested by comparing the current amount of carbon-14 in them and compared to the initial amount (which is based on the current ratio of carbon-14 to carbon-12), and hence they can be dated

Reliability of Carbon Dating

- Carbon dating is a highly reliable ageing method for samples ranging from around 1000 years old up to a limit of around 40 000 years old
  - Therefore, for very young, or very old samples, carbon dating is not the most reliable method to use
- This can be explained by looking at the decay curve of carbon-14:

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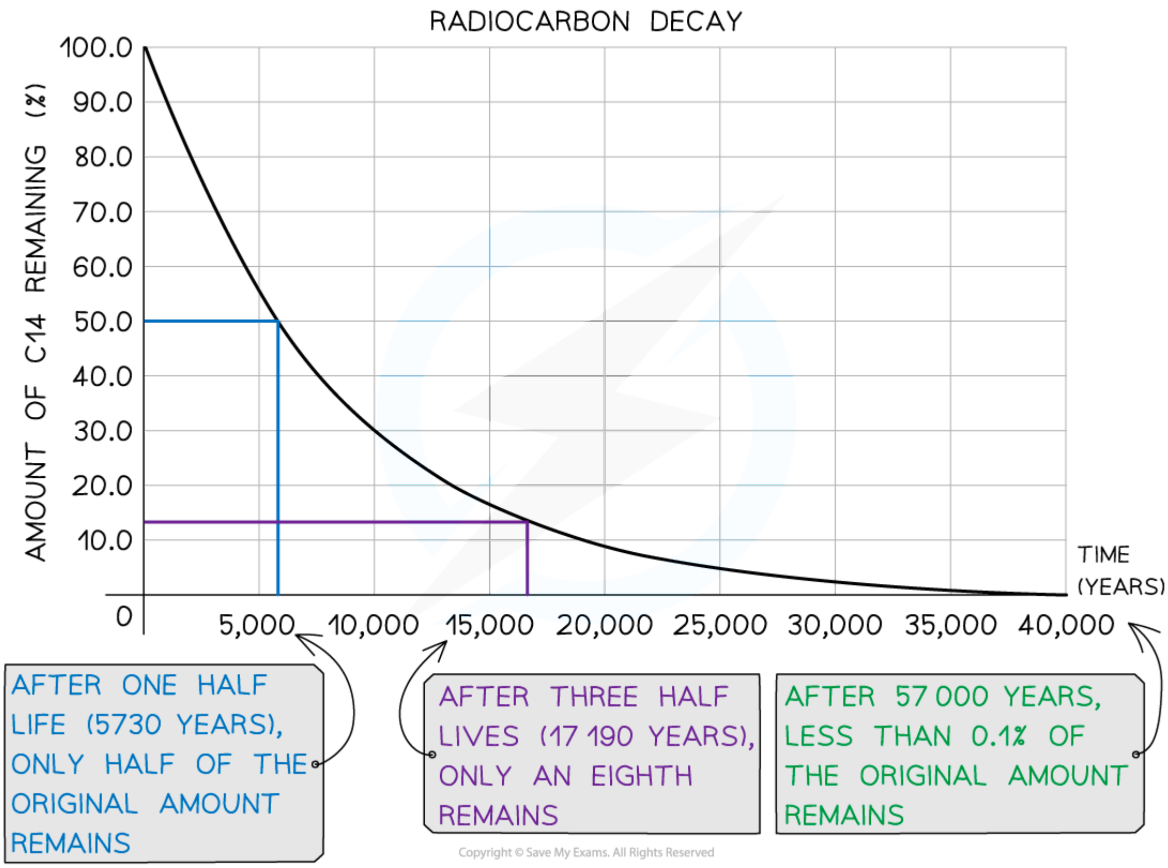

Carbon-14 decay curve used for carbon dating

- If the sample is less than 1000 years old:
  - The activity of the sample will be too high
  - So, it is difficult to accurately measure the small change in activity
  - Therefore, the ratio of carbon-14 to carbon-12 will be too high to determine an accurate age
- If the sample is more than 40 000 years old:
  - The activity will be too small and have a count rate similar to that of background radiation
  - So, there will be very few carbon-14 atoms remaining, hence very few decays will occur
  - Therefore, the ratio of carbon-14 to carbon-12 will be too small to determine an accurate age
- Carbon dating uses the currently known ratio of carbon-14 to carbon-12, however, scientists cannot know the level of carbon-14 in the biosphere thousands of years ago

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- Therefore, this makes it difficult to age samples which are very old

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Examiner Tips and Tricks

It is important to have good knowledge and understanding of Carbon dating; how it works and its limitations.

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