Thinking Pathways Education

⚛️ Radioactivity Study Guide

Secondary 4 • O-Level Physics Syllabus

This study guide is a complete, student-friendly summary of **Radioactivity** for Secondary 4 students, aligned to the **SEAB O-Level** syllabus. It covers **atomic structure**, **radioactive decay**, and **nuclear reactions** with the key definitions, comparisons, and exam-style reminders you need. Use it to revise concepts, practise equations, and sharpen common exam points.

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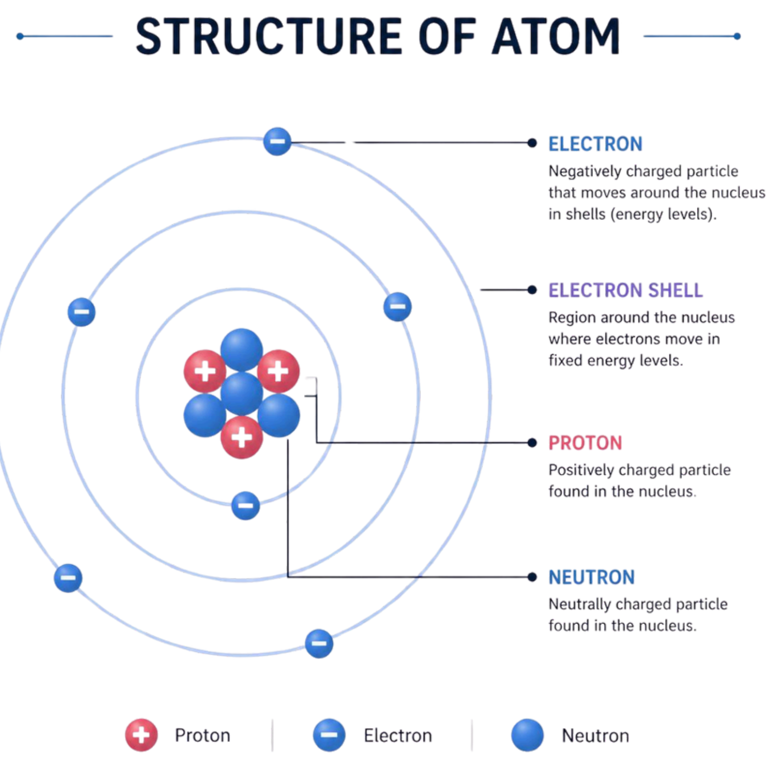
1. Atomic Structure and Nuclide Notation ⚛️

Structure of an atom

- **Nucleus**: contains **protons** and **neutrons** (together called **nucleons**).
- **Electrons**: move around the nucleus in shells/energy levels; they have very small mass compared to nucleons.
- Most of the atom is empty space; most of the mass is concentrated in the **nucleus**.

Key terms

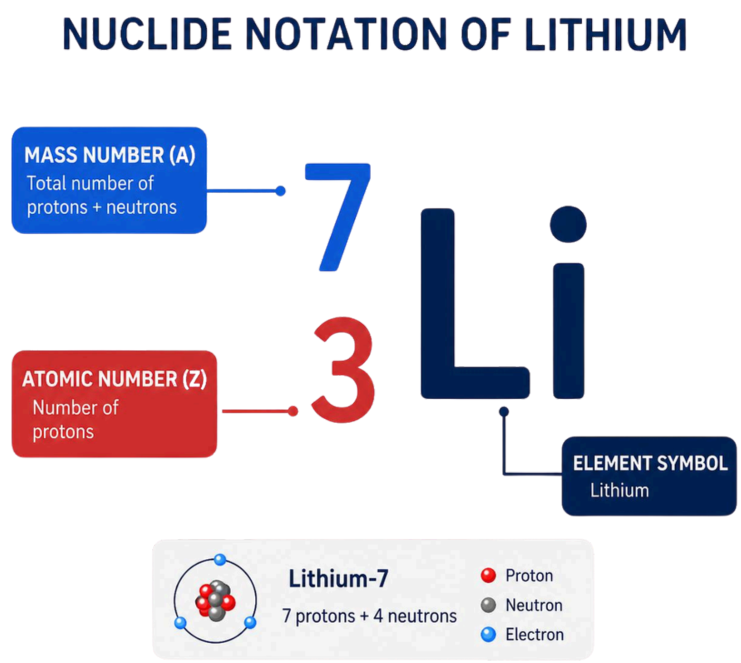
- **Proton number (Z)**: number of **protons** in the nucleus (defines the element).
- **Nucleon number (A)**: total number of **nucleons** in the nucleus, i.e. `A = protons + neutrons`.
- **Number of neutrons**: `neutrons = A − Z`.



Nuclide notation

Format: $^{A}_{Z}X$ where **X** is the element symbol, **A** is nucleon number, and **Z** is proton number.

Example (Lithium-7): $^{7}_{3}Li$ so **Z = 3** protons and **neutrons = 7 − 3 = 4**.



2. Atomic Stability

Some nuclei are **unstable** because the balance between **electrostatic repulsion** (between positively charged protons) and the attractive **strong nuclear force** is not favourable. When the nucleus is too large or has an unsuitable proton-to-neutron ratio, it may become unstable and undergo **radioactive decay** to become more stable.

3. Radioactive Decay

> **Definition: Radioactive decay** is the process where an **unstable nucleus** emits **radiation** to become more stable.

- **Random**: you cannot predict **which nucleus** will decay next or the exact time it will decay.
- **Spontaneous**: decay happens by itself and is not affected by external conditions like temperature, pressure, or chemical state.

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4. Types of Radioactive Radiation ☢️

Alpha (α) radiation

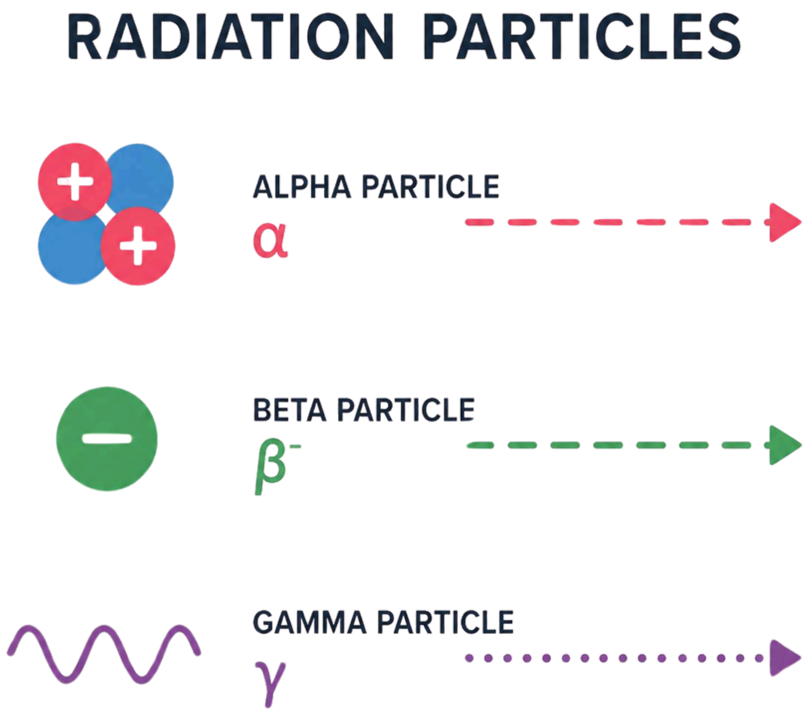
- **Nature**: a helium nucleus (2 protons + 2 neutrons).
- **Symbol notation**: $^{4}_{2}He$ or α.
- **Charge**: **+2**.
- **Mass**: relatively large (about **4 u**).

Beta (β) radiation

- **Nature**: a fast-moving electron (for O-Level, usually $\boldsymbol{\beta^-}$).
- **Symbol notation**: $^{0}_{-1}e$ or β.
- **Charge**: **−1**.
- **Mass**: very small (about **1/1836** of a proton; often taken as ~0 in equations).

Gamma (γ) radiation

- **Nature**: high-energy **electromagnetic wave** (photon).
- **Symbol notation**: $^{0}_{0}\gamma$ or γ.
- **Charge**: **0**.
- **Mass**: **0** (no rest mass).



5. Properties Comparison Table 📊

Radiation Type	Nature	Charge	Ionising Effect	Penetrating Power
Alpha (α)	Helium nucleus (2p + 2n)	+2	Very strong	Low
Beta (β)	Fast electron	−1	Moderate	Medium
Gamma (γ)	Electromagnetic wave	0	Weak	High

6. Ionising Effect 💡

Ionising effect is the ability of radiation to remove electrons from atoms/molecules, forming **ions**.

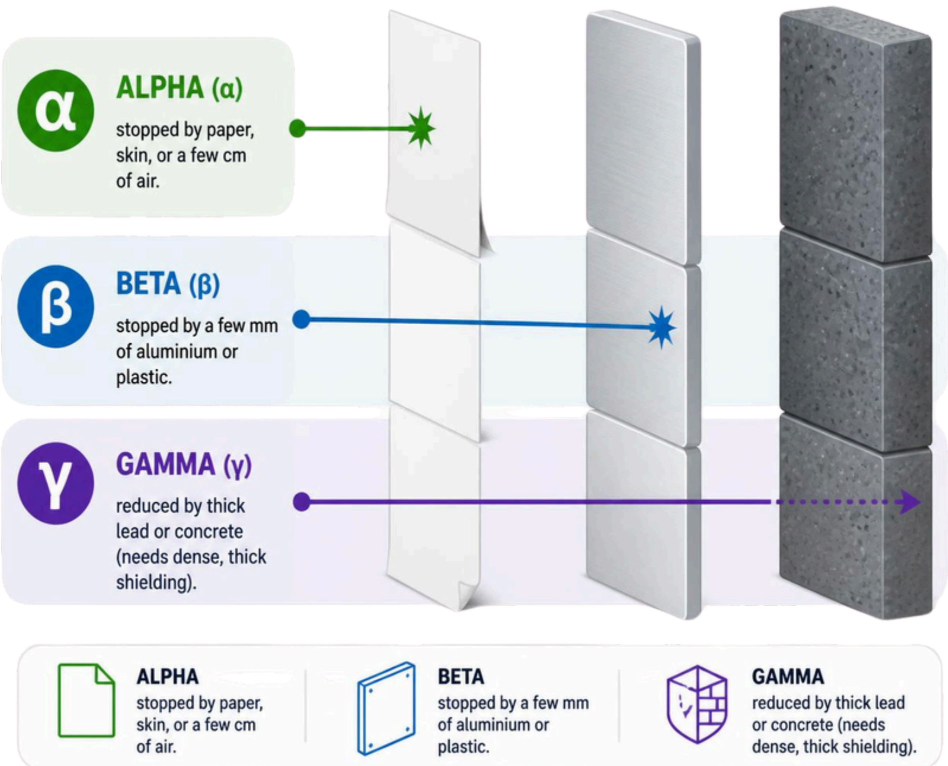
Order of ionising effect: α > β > γ.

- **Alpha** is strongly ionising because it has **high charge** and relatively **large mass**, causing frequent collisions.
- **Beta** is less ionising because it is lighter and interacts less strongly per collision.
- **Gamma** is weakly ionising because it is an electromagnetic wave and interacts less often with matter.

7. Penetrating Power 🛡️

Order of penetrating power: γ > β > α.

- **Alpha (α)**: stopped by **paper**, skin, or a few cm of air.
- **Beta (β)**: stopped by a few mm of **aluminium** or plastic.
- **Gamma (γ)**: reduced by thick **lead** or **concrete** (needs dense, thick shielding).



8. Radioactive Decay Equations 🧮

When writing decay equations, apply **conservation of nucleon number (A)** and **conservation of proton number (Z)**: the total **A** and total **Z** must be the same on both sides of the equation.

(a) Alpha decay

- **Change in A**: decreases by **4**.
- **Change in Z**: decreases by **2**.

Example: ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

(b) Beta (β⁻) decay

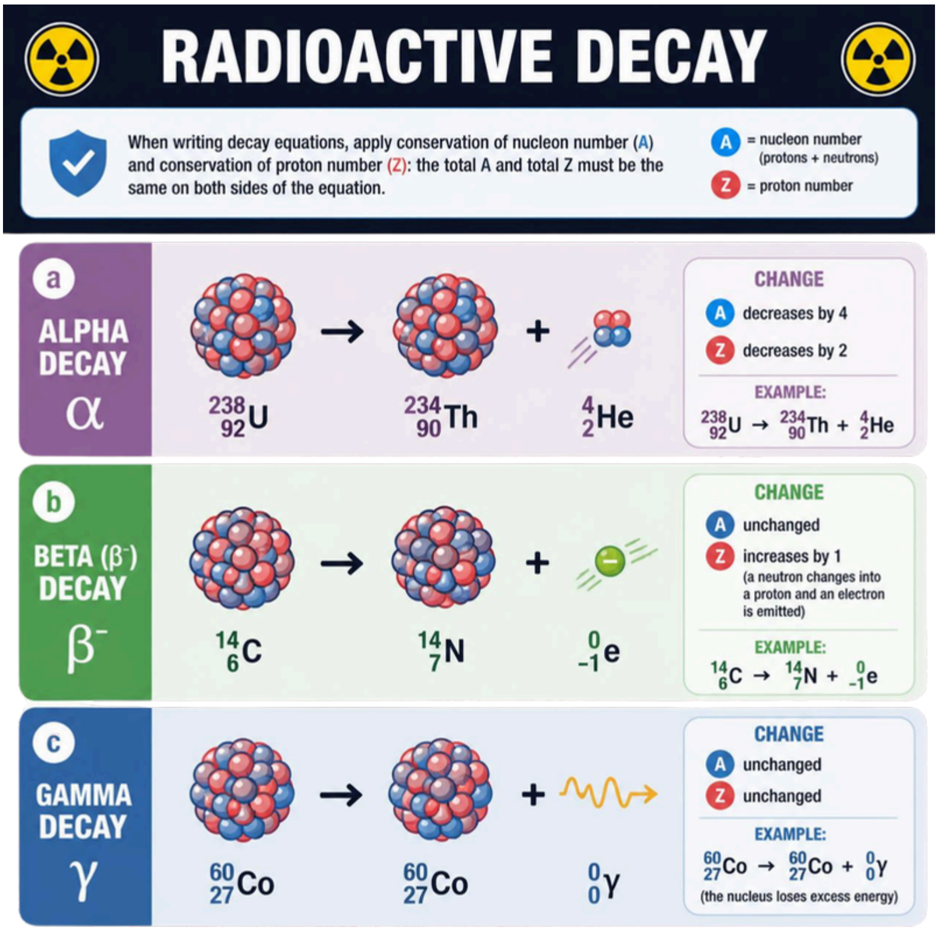
- **Change in A**: unchanged.
- **Change in Z**: increases by **1** (a neutron changes into a proton and an electron is emitted).

Example: ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

(c) Gamma decay

- **Change in A**: unchanged.
- **Change in Z**: unchanged.

Example: ${}^{60}_{27}Co \rightarrow {}^{60}_{27}Co + {}^{0}_{0}\gamma$ (the nucleus loses excess energy).



9. Background Radiation

Background radiation is the low-level radiation that is always present in the environment, even when no radioactive source is nearby.

- Rocks and soil (e.g. granite; radon gas from the ground).
- Cosmic rays from space (higher at high altitude and during flights).
- Medical sources (X-rays, radiotherapy, nuclear medicine).
- Food and living things (small amounts of natural isotopes such as potassium-40).
- Man-made sources (industry, research; small contributions compared to natural sources in most cases).

10. Geiger–Müller Tube

A Geiger–Müller (G–M) tube is used to detect and measure ionising radiation by producing an electrical pulse when radiation enters the tube. It detects radiation; it does not block or stop radiation (shielding must be provided separately).

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11. Half-life ⏱️

> **Half-life is the time taken for the number of undecayed nuclei (or the activity/count rate) of a radioactive sample to decrease to half its original value.**

Important points

- **Half-life is a constant for a given isotope and is not affected by temperature, pressure, or chemical state.**
- **After each half-life, the remaining amount becomes half of what it was (repeated halving).**
- **You can use mass, number of nuclei, or count rate/activity—they all halve in the same way (Note: If using count rate, always subtract the background count rate first before doing the halving calculations)**.

Half-life calculations

Worked example: A sample has an initial mass of 80 g and a half-life of 2 days.

- **After 2 days (1 half-life): 40 g remains.**
- **After 4 days (2 half-lives): 20 g remains.**
- **After 6 days (3 half-lives): 10 g remains.**

12. Uses of Radioactive Isotopes 🏥

(a) Medical tracer

- **Purpose: track the movement of a substance in the body (e.g. blood flow, organ function) using a detector outside the body.**
- **Suitable source characteristics: gamma emitter (escapes the body to be detected), short half-life (reduces dose), and chemically suitable for the body process being studied.**

(b) Thickness control (paper/foil)

- **Purpose: monitor and control thickness during manufacturing by measuring how much radiation passes through the material.**
- **Suitable source characteristics: typically a beta emitter with long half-life (partly absorbed; changes in thickness cause noticeable changes in count rate).**

(c) Smoke detector

- **Purpose: detect smoke by monitoring ionisation in air; smoke reduces the ionisation current and triggers the alarm.**
- **Suitable source characteristics: a weak alpha emitter with long half-life (strongly ionising but low penetrating, so it is contained safely inside the detector).**

a Medical tracer

Purpose:
track the movement of a substance in the body (e.g. blood flow, organ function) using a detector outside the body.

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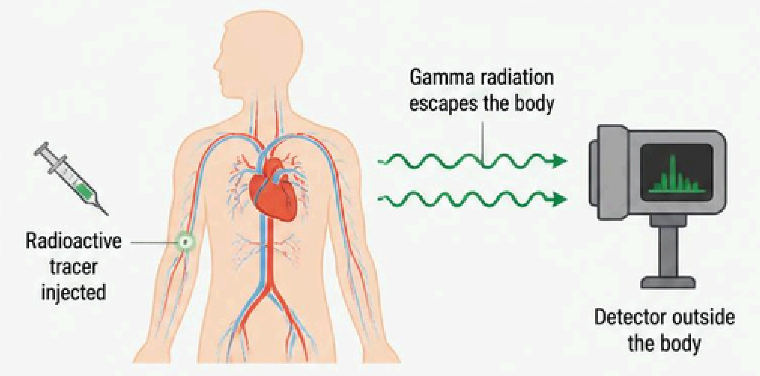
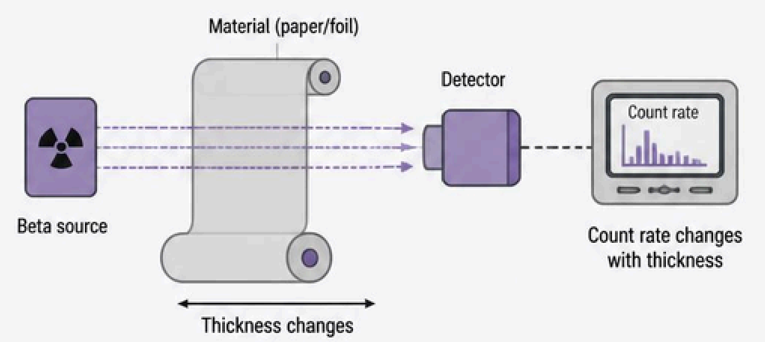


b Thickness control (paper/foil)

Purpose:
monitor and control thickness during manufacturing by measuring how much radiation passes through the material.

Suitable source characteristics:
typically a beta emitter (partly absorbed; changes in thickness cause noticeable changes in count rate).



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Purpose:
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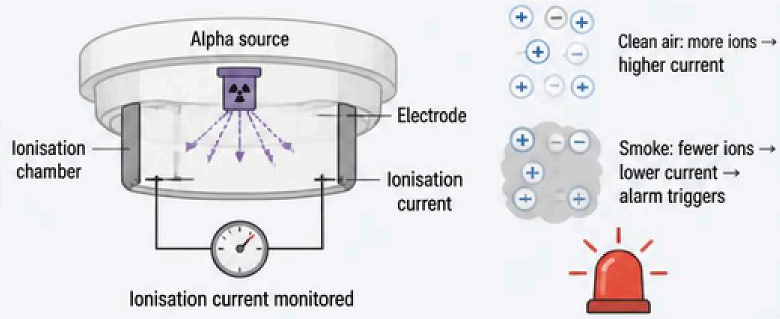

13. Dangers of Radioactivity ⚠️

Effects on living tissue

- Radiation can ionise molecules in cells, damaging cell structures and DNA.
- Can cause mutations (genetic changes), which may lead to inherited defects.
- Can cause cancer due to uncontrolled cell division after DNA damage.

Precautions

- Time: minimise exposure time.
- Distance: maximise distance from the source (intensity decreases with distance).
- Shielding: use suitable materials (paper/Al/lead depending on radiation).
- Use tongs, lead-lined containers, and film badges/dosimeters where appropriate.

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14. Nuclear Fission ⚡

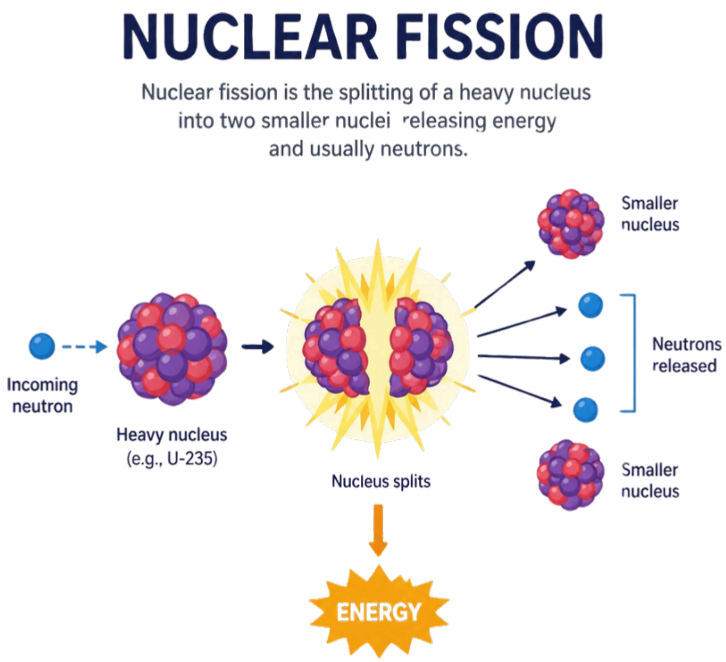
> **Nuclear fission** is the splitting of a heavy nucleus into two smaller nuclei, releasing energy and usually neutrons.

In a common example, a slow neutron is absorbed by uranium-235, making it unstable and causing it to split into smaller nuclei and more neutrons.

Example equation: $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + \text{energy}$

Chain reaction: the neutrons produced can trigger further fission in other U-235 nuclei, causing a self-sustaining reaction if conditions are right (e.g. sufficient fuel and neutron moderation/control).

Fission is used in nuclear power stations to produce heat, which generates steam to drive turbines and produce electricity.



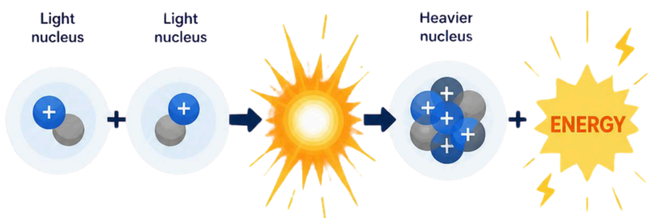
15. Nuclear Fusion ☀️

Nuclear fusion is the joining of two light nuclei to form a heavier nucleus, releasing a large amount of energy.

Example equation: $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy}$ **(deuterium + tritium).**

Fusion happens in the Sun and other stars.

It requires extremely high temperature (and pressure) so nuclei have enough kinetic energy to overcome electrostatic repulsion.



16. Fission vs Fusion Comparison

Fission	Fusion
Splits a heavy nucleus into smaller nuclei.	Combines light nuclei into a heavier nucleus.
Triggered by absorbing a neutron; can form a chain reaction.	Needs very high temperature to overcome repulsion.
Used in power stations today.	Powers the Sun/stars; controlled power generation is challenging.
Produces radioactive waste (fission products).	Produces stable products (e.g., Helium) / Does not directly produce radioactive waste.

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17. Common O-Level Exam Points

Must remember

- Ionising vs penetrating: α is most ionising but least penetrating; γ is least ionising but most penetrating.
- Nature: α is a helium nucleus, β is a fast electron, γ is an electromagnetic wave.
- In decay equations, conserve nucleon number (A) and proton number (Z).
- Beta (β^-) decay: A stays the same, Z increases by 1.
- Gamma emission changes neither A nor Z—it is energy release from an excited nucleus.
- When using count rate data, remember to subtract background radiation before finding half-life.

18. Summary Tables 📊

Symbol	Nature	Charge	Ionising Effect	Penetrating Power
α	Helium nucleus (2p + 2n)	+2	Very strong	Low
β	Fast electron	−1	Moderate	Medium
γ	Electromagnetic wave	0	Weak	High

Decay type	Change in A	Change in Z
Alpha (α)	−4	−2
Beta (β^-)	0	+1
Gamma (γ)	0	0

19. Quick Revision Questions & Answers ❓✅

1. Explain why some nuclei are unstable in terms of forces in the nucleus.

In large nuclei, electrostatic repulsion between many protons increases, while the strong nuclear force is short-range; if attraction cannot balance repulsion (or the neutron-to-proton ratio is unsuitable), the nucleus becomes unstable.

2. State what is meant by random and spontaneous radioactive decay.

Random: cannot predict which nucleus decays next or when. Spontaneous: decay occurs by itself and is not affected by external conditions.

3. A nuclide is written as $^{23}_{11}Na$. How many protons, neutrons, and electrons does a neutral atom have?

Protons = 11. Neutrons = 23 − 11 = 12. Electrons (neutral atom) = 11.

4. Why is alpha radiation strongly ionising but weakly penetrating?

α has +2 charge and relatively large mass, so it causes many ionisations in a short distance and loses energy quickly; therefore it is stopped easily (low penetration).

5. Arrange α, β, γ in order of (i) ionising effect and (ii) penetrating power.

(i) Ionising: α > β > γ. (ii) Penetrating: γ > β > α.

6. Complete the equation: $^{210}_{84}Po \rightarrow$ ____ $+ \ ^{4}_{2}He$.

It is alpha decay, so A decreases by 4 and Z decreases by 2: $^{210}_{84}Po \rightarrow \ ^{206}_{82}Pb + \ ^{4}_{2}He$.

7. In β^- decay, what happens to A and Z, and why?

A stays the same, Z increases by 1 because a neutron changes into a proton and an electron (β^-) is emitted.

8. A detector measures 520 counts/min near a source and 40 counts/min background. What is the corrected count rate?

Corrected count rate = 520 – 40 = 480 counts/min.

9. A sample has a half-life of 3 days. If its corrected count rate is 800 counts/min now, what will it be after 9 days?

9 days is 3 half-lives, so it halves 3 times: 800 → 400 → 200 → 100 counts/min.

10. Describe how a chain reaction occurs in nuclear fission and state one use of fission.

Fission releases neutrons that can cause further fission in nearby fuel nuclei, making a chain reaction. Use: electricity generation in nuclear power stations.

Keep practising decay equations and comparisons—consistent revision will make Radioactivity one of your most scoring topics. ✅

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