

4 • Atomic structure

AQA • GCSE • Physics

Atomic structure: the unstable nucleus

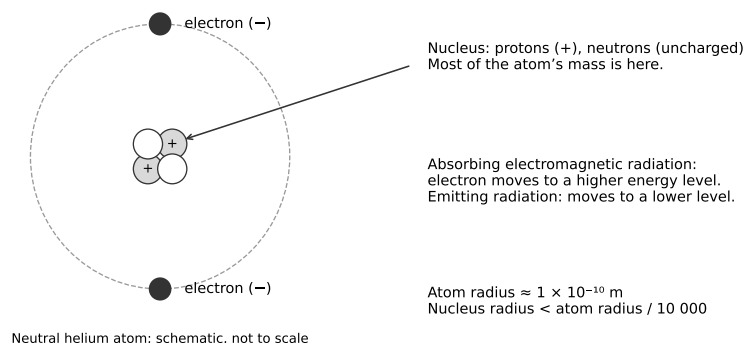
Radioactivity is over a century old, yet it still treats cancer, powers grids and demands strict safety rules. This reference covers **AQA GCSE Physics 8463, topic 4.4 Atomic structure**.

How the exam treats this topic:

- Paper 1 (4.1–4.4) carries this topic. Equation-sheet support depends on the examination series. Practise notation, balanced equations, graphs and explanations as well as calculations.
- Background radiation, half-life hazards, uses and fission/fusion are **physics only**.
- Net-decline ratios after several half-lives are **Higher Tier**.
- You must write **balanced nuclear equations** for single alpha and beta decay (balance atomic numbers and mass numbers; daughter naming not required).

The structure of an atom; isotopes

An atom is very small: radius about 1×10^{-10} m. Its structure:



- **Nucleus:** positively charged, with protons and neutrons; most of the atom's mass, but a radius **less than 1/10 000** of the atom's.
- **Electrons:** negative, arranged in energy levels. Absorbing electromagnetic radiation moves an electron to a higher level, **further** from the nucleus; emission moves it to a lower level, **closer**.

Notation: ${}_Z^AX$ where Z = **atomic number** (protons) and A = **mass number** (protons + neutrons). In a neutral atom, electrons = protons; atoms have no overall charge.

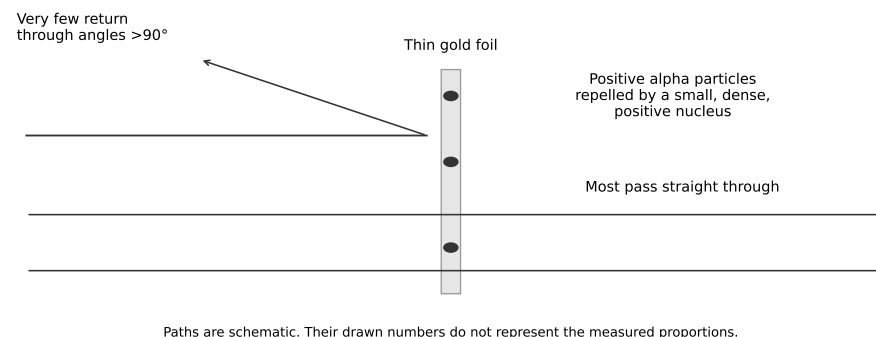
- **Isotopes** : atoms of the **same element** (same Z) with **different numbers of neutrons** (different A).
- Neutrons in the nucleus = $A - Z$.
- Atoms that lose one or more outer electrons become **positive ions**.

Worked example. Carbon-14: ${}_{6}^{14}\text{C}$.

- Protons = 6; electrons = 6 (neutral); neutrons = $14 - 6 = 8$.
- Carbon-12 has 6 neutrons – same element, different neutrons: isotopes.

The development of the model of the atom

New **experimental evidence** can change or replace a scientific model:



1. Before the electron's discovery: atoms were **tiny spheres** that could not be divided.
2. Electron discovered $\rightarrow$ the **plum pudding model**: a ball of positive charge with negative electrons embedded in it.
3. **Alpha scattering** (Rutherford): most alpha particles passed straight through, a few bounced back $\rightarrow$ the mass and positive charge must be concentrated in a tiny centre $\rightarrow$ the **nuclear model** replaced the plum pudding model.
4. **Bohr** adapted it: electrons orbit at **specific distances**; his calculations agreed with observations.
5. Further work showed the positive charge comes in whole-number units – the **proton**; **Chadwick's** experiments (about 20 years later) proved the **neutron**.

Explain the evidence that changed the model: if the pudding were right, alpha particles should all pass through with small deflections (B1); some bounced almost straight back (B1), which is only possible if the mass and positive charge sit in a tiny, dense, positive nucleus (B1).

Radioactive decay and nuclear radiation

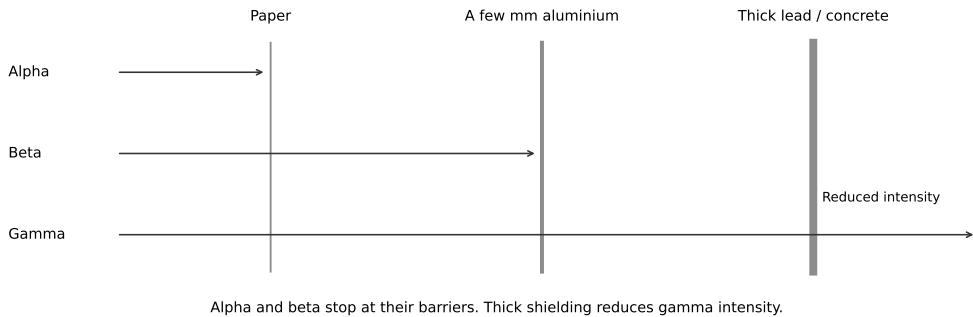
Some nuclei are **unstable**. They give out radiation as they change to become more stable – a **random** process called **radioactive decay**.

- **Activity** : the rate at which a source decays; unit **becquerel** (Bq).
- **Count-rate** : detector counts per second, after allowing for background where needed. A detector usually records only some emissions: its count rate is not automatically the source activity in Bq.

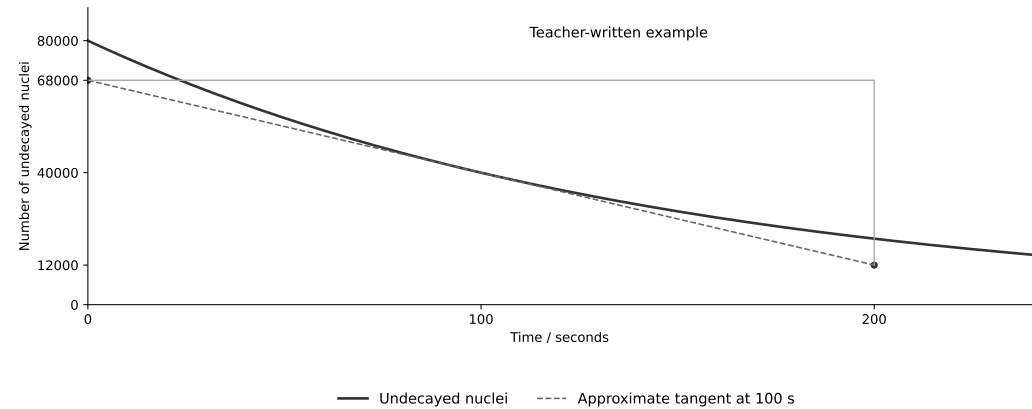
Radiation	Identity	Ionising power	Shielding
alpha α	helium nucleus	strong	paper / skin
beta β	fast electron	medium	mm of aluminium
gamma γ	EM radiation	weak	thick lead reduces it

Alpha contains two protons and two neutrons and travels only a few centimetres in air. Beta is emitted when a neutron changes into a proton; its range in air is longer. Gamma has the greatest range of these three and is reduced, not completely stopped, by thick lead or concrete. A nucleus can also emit a neutron; detailed neutron properties are not required here.

Choose a source for a use by matching these properties: alpha for ionisation smoke alarms (smoke reduces the ionisation current); beta for thickness control (partly absorbed by the sheet); gamma for tracers (escapes the body) and sterilising (penetrates packaging and damages microorganisms). A sealed source reduces contamination risk; it does not justify ignoring handling precautions.



Activity from a graph. On a graph of the number of undecayed nuclei against time, draw a tangent at the stated time. Its downward gradient is the rate of decrease in the number of nuclei; activity is the positive magnitude, in Bq. Read two widely separated points on the tangent, not two arbitrary points on the curve.



Worked example (teacher-written). The approximate tangent passes through (0 s, 68000) and (200 s, 12000).

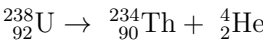
$$\text{activity} = \frac{\text{decrease in number of nuclei}}{\text{time interval}} = \frac{68000 - 12000}{200 \text{ s} - 0 \text{ s}} = 280 \text{ Bq}$$

This is an estimate from a drawn tangent. AQA June 2024 8463/1H Q09.5 requires the same method on its own graph at 300 s; its official answer is 7.1×10^{20} Bq. Those are different graphs and data.

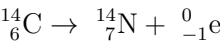
Nuclear equations

Balance **mass numbers** (top) and **atomic numbers** (bottom) on both sides:

- **Alpha decay:** the nucleus loses 4 from the top and 2 from the bottom.



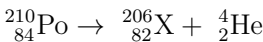
- **Beta decay:** a neutron turns into a proton; mass number **unchanged**, atomic number **+1**; the beta particle is ${}^0_{-1}\text{e}$.



- **Gamma emission:** changes neither number.

Worked example. Polonium-210 decays by alpha emission. Write the equation.

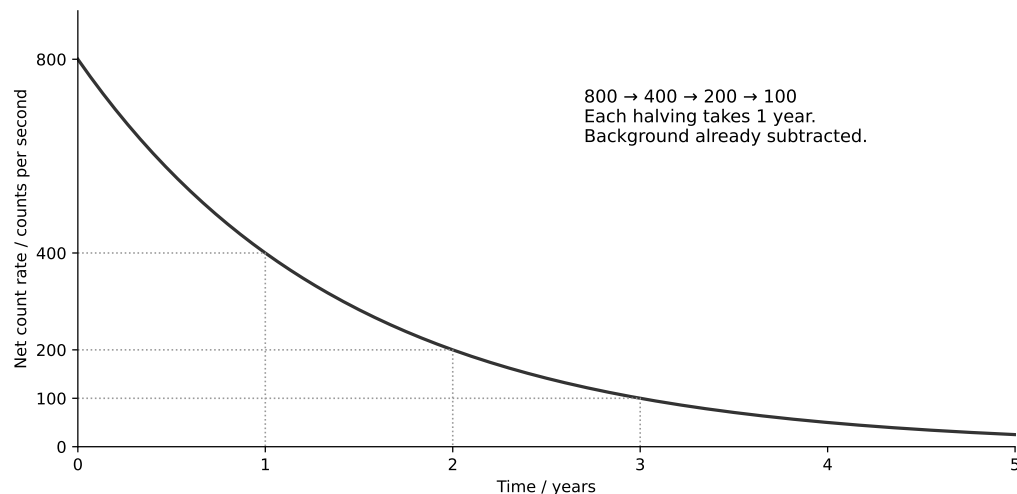
- Alpha removes 4 and 2: $A : 210 - 4 = 206$; $Z : 84 - 2 = 82$.



- Check both rows balance ✓ (the daughter's name is not required).

Half-lives and the random nature of decay

Decay is **random**: it cannot be predicted for any one nucleus; only the average behaviour of many is predictable.



Half-life : the time for (a) the number of nuclei of the isotope in a sample to halve, or (b) the net count rate / activity to fall to **half** its initial level. Subtract background from detector readings first and keep the detector geometry unchanged.

- From a graph: read the time for the count rate to halve – repeat over several halvings and average.
- After n half-lives, the fraction remaining is $1/2^n$ (HT: express as a ratio).

Worked example. A sample's activity falls from 800 Bq to 200 Bq in 12 years.

- Halvings: $800 \rightarrow 400 \rightarrow 200$ is two halvings.

$$t_{1/2} = \frac{12 \text{ years}}{2} = 6 \text{ years}$$

Actual AQA demand, June 2025 8463/1H Q07.4: polonium-210 has a half-life of 138 days. The number of atoms falls from 256 000 to 16 000: four halvings, so the time is $4 \times 138 = 552$ days. Q07.5 compares equal numbers of Po-209 and Po-210 atoms: the longer-lived Po-209 has lower activity. The equal-population condition matters.

Radioactive contamination

- **Contamination** : unwanted radioactive atoms **on or inside** an object or person. The hazard lasts as long as the atoms are there, decaying on or in the body.

- **Irradiation** : exposing an object to radiation. The irradiated object **does not become radioactive**.

Contamination can continue to irradiate tissue while the radioactive atoms remain. Exposure from an external source ends when that source is removed or effectively shielded. Compare the source activity, radiation type, distance, exposure time and whether material is inside the body; contamination is not always the larger dose. External alpha has low penetration and is stopped by skin, but internally its strong ionisation can damage nearby living tissue.

Precautions: hold sources with **tongs**, keep them at a **distance**, limit **time** near them, point them away from people, store in lead-lined boxes. Findings on radiation effects are **published and peer-reviewed** so they can be checked.

Background radiation (physics only)

Background radiation is around us all the time:

- **natural**: rocks (radon gas), cosmic rays from space, food and naturally occurring isotopes in the body;
- **man-made**: fallout from weapons testing, nuclear accidents, medical uses.

Dose depends on **occupation and location** (high altitude, certain industries). Dose unit: sieverts ($1000 \text{ mSv} = 1 \text{ Sv}$; recall not required).

Measurements of a sample must **subtract the background count-rate** first.

Half-life hazards and uses of radiation (physics only)

Half-life and hazard: for equal numbers of unstable nuclei, a shorter half-life means greater activity. Amount and exposure conditions also matter. A long-lived source may require secure storage for many years. A medical tracer should remain active long enough for the investigation, then decay quickly to reduce further dose. A smoke-alarm source must remain useful for years.

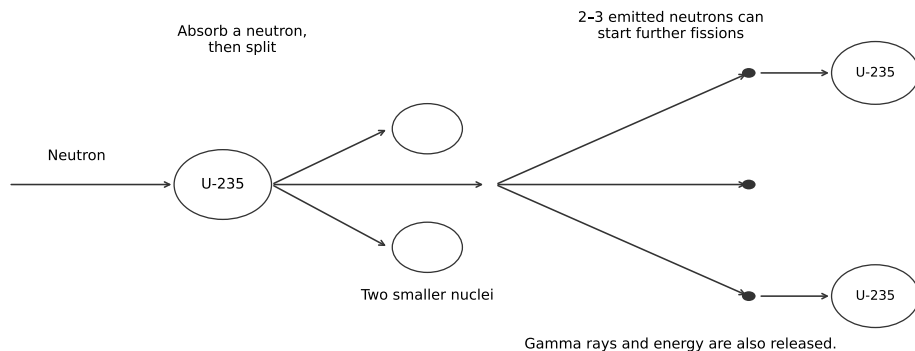
Medical uses (each = exploration or destruction):

- **Exploration**: a gamma-emitting tracer (e.g. technetium-99m) injected so organs show on a scan; gamma escapes the body; a suitable short half-life limits dose after the scan.
- **Destruction**: focused gamma beams or implanted sources kill cancer cells (radiotherapy); beta for skin conditions.

Evaluating risk: compare the dose and consequence of the procedure against the risk of the illness – with numbers from the question.

Nuclear fission and fusion (physics only)

Fission : the splitting of a **large, unstable** nucleus (uranium-235, plutonium-239).



- Spontaneous fission is rare: the nucleus usually **absorbs a neutron** first.
- It splits into **two smaller nuclei of roughly equal size**, releasing **two or three neutrons** and **gamma rays**; **energy is released** and all products carry kinetic energy.
- The released neutrons can cause further fissions – a **chain reaction**. A reactor **controls** it (control rods absorb neutrons); a weapon's explosion is an **uncontrolled** chain.
- You must draw or interpret the diagram: neutron in → two fragments + neutrons out → branching chain.

Fusion : **two light nuclei join** to form a heavier nucleus; some mass converts into the energy of radiation. To join, the positive nuclei must approach closely despite their electrical repulsion. Do not describe fusion as chemical bonding or claim that every fusion system is waste-free.

Checklist before you call this topic done

- Find protons, neutrons and electrons from A, Z ; identify isotopes and ions.
- Explain how experimental evidence changed atomic models.
- Compare $\alpha/\beta/\gamma$ properties and select suitable sources for a use.
- Balance single alpha/beta equations and check both rows.
- Find half-life and (HT) net decline; find activity from a tangent gradient.
- Subtract background; distinguish detector counts from source activity.
- Compare irradiation/contamination hazards and precautions.
- (physics only) Explain background, medical uses, half-life choices and fission/fusion.