Topic 4: Atomic structure

AQA GCSE Physics 8463 · spec 4.4 · sheets 4.1–4.7

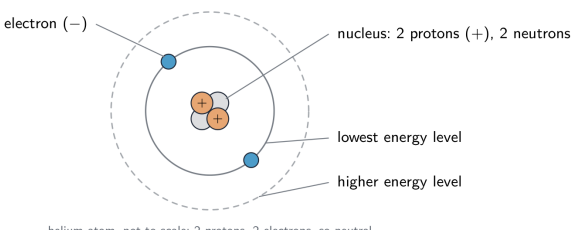
Atomic structure: the nucleus and radioactivity

- describe the structure of atoms and **isotopes**, and how the model of the atom developed;
- compare alpha, beta and gamma radiation, and write balanced nuclear equations;
- use **half-life**, and explain the hazards of **contamination** and irradiation;
- (physics only) explain background radiation, medical uses of radiation, fission and fusion.

The structure of an atom and isotopes

- The **nucleus** is positively charged and contains protons and neutrons. It contains almost all the mass of the atom, but its radius is less than $\frac{1}{10\,000}$ of the radius of the atom.
- **Electrons** are negatively charged and are arranged at different distances from the nucleus, in energy levels. If an electron absorbs electromagnetic radiation, it moves to a higher energy level, further from the nucleus; if it emits radiation, it moves to a lower level.

Figure: The structure of an atom and isotopes



helium atom, not to scale: 2 protons, 2 electrons, so neutral

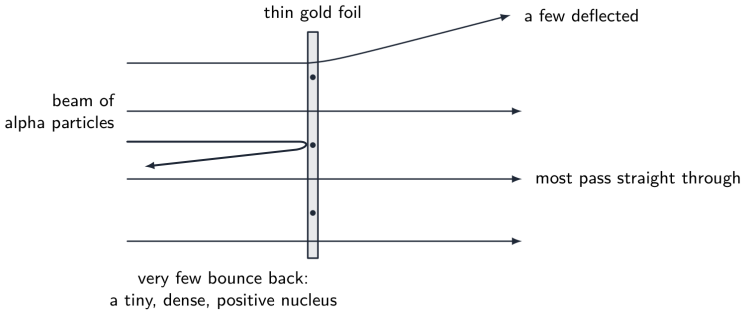
atom radius about 1×10^{-10} m; the nucleus is less than $1/10\,000$ of that

- An atom: a small positive nucleus of protons and neutrons, with electrons in energy levels.
- Match each part of the diagram to the text.

The development of the model of the atom

- Scientific models change when new experimental evidence does not fit them.
- 1.
- Before the electron was discovered, atoms were thought to be tiny spheres that could not be divided. 2.
- J.

Figure: The development of the model of the atom



- Alpha scattering: most particles pass through; a few rebound from a tiny dense nucleus.
- Match each part of the diagram to the text.

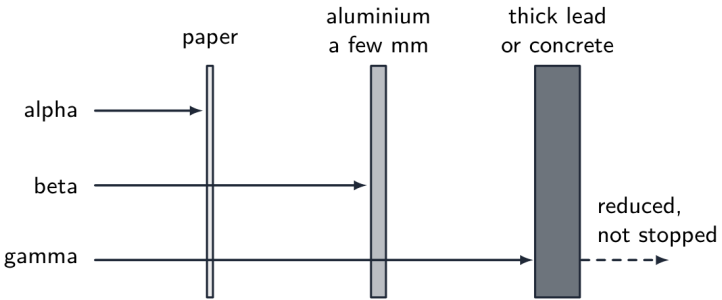
Radioactive decay and nuclear radiation

- The **activity** of a source is the rate at which its nuclei decay, measured in **becquerel** (Bq). 1 Bq is one decay per second.
- **Count-rate** is the number of decays recorded each second by a detector, such as a Geiger–Müller tube.
- Smoke alarms use alpha: it ionises the air strongly and is stopped by smoke.

Radioactive decay and nuclear radiation (2)

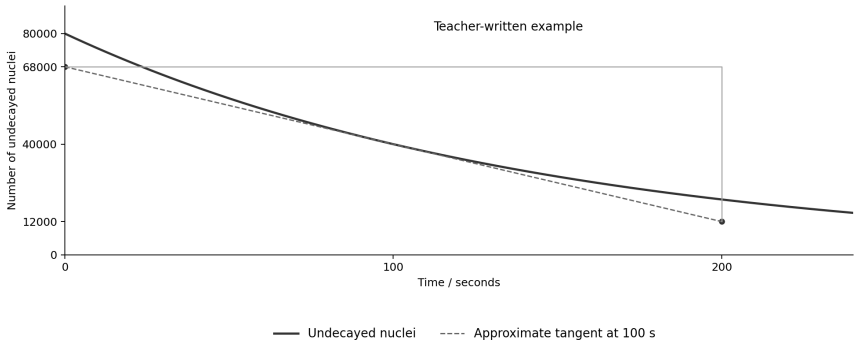
- Paper thickness gauges use beta: some passes through paper, and the amount depends on the thickness.
- Medical tracers use gamma: it passes out of the body to a detector.

Figure: Radioactive decay and nuclear radiation



- Penetration: alpha stopped by paper, beta by aluminium, gamma reduced by thick lead.
- Match each part of the diagram to the text.

Figure: Radioactive decay and nuclear radiation (2)



- Number of undecayed nuclei against time, with a tangent drawn at 100 s to find the **activity**.
- Read the axes and units first.

Nuclear equations

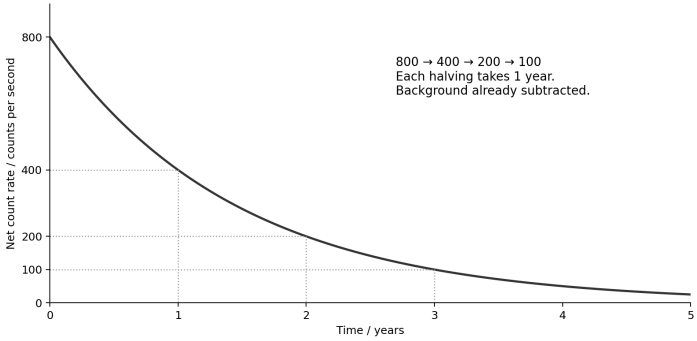
- **Alpha decay**: the mass number decreases by 4 and the atomic number by 2. An alpha particle is written $^{4}_{2}\mathrm{He}$.
- **Beta decay**: a neutron changes into a proton and an electron. The mass number stays the same and the atomic number increases by 1. A beta particle is written $^{0}_{-1}\mathrm{e}$.
- **Gamma emission** does not change the mass number or the atomic number; the nucleus loses energy.

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

Half-lives and the random nature of decay

- **Radioactive decay** is random: you cannot predict when a particular nucleus will decay.
- But with very many nuclei, the overall pattern is predictable.
- The **half-life** of a radioactive isotope is the time it takes for the number of nuclei in a sample to halve, or the time it takes for the count rate (or **activity**) from a sample to fall to half its starting level.
- To find a **half-life** from a graph, read the time for the count rate to fall from any value to half that value.

Figure: Half-lives and the random nature of decay



- A decay curve: count rate halves every **half-life** (1 year in this example).
- Read the axes and units first.

Radioactive contamination

- **Contamination** is the unwanted presence of radioactive atoms on or inside other materials. The atoms keep decaying, so the danger continues until they are removed or have decayed.
- **Irradiation** is exposing an object to nuclear radiation. The irradiated object does not become radioactive, and the exposure stops when the source is removed.

Background radiation (physics only)

- natural sources, such as rocks (radon gas) and cosmic rays from space;
- man-made sources, such as fallout from nuclear weapons testing and nuclear accidents.

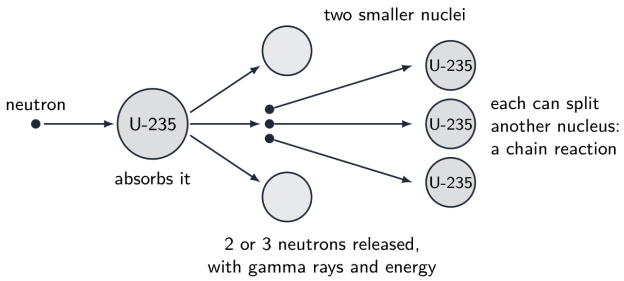
Uses of nuclear radiation (physics only)

- Exploring the body: a tracer that emits gamma radiation, such as technetium-99m, is injected or swallowed. The gamma rays pass out of the body to a camera. The **half-life** must be long enough for the scan (technetium-99m has a half-life of 6 hours) but short enough that the patient's dose stays low.
- Destroying unwanted tissue: beams of gamma rays from outside the body, or radioactive implants placed inside a tumour, kill cancer cells (radiotherapy).

Nuclear fission and fusion (physics only)

- The nucleus usually has to absorb a neutron first; spontaneous **fission** is rare.
- It splits into two smaller nuclei of roughly equal size, and gives out two or three neutrons and gamma rays. Energy is released, and all the products have kinetic energy.
- The released neutrons can cause more fissions: a chain reaction. In a nuclear reactor, control rods absorb some neutrons to keep the reaction steady; in a nuclear weapon, the chain reaction is uncontrolled.

Figure: Nuclear fission and fusion (physics only)



- **Fission**: a neutron splits a U-235 nucleus into two fragments, releasing neutrons and gamma rays.
- Match each part of the diagram to the text.

Sources for this lesson

- AQA, *GCSE Physics (8463) specification*, section 4.4 Atomic structure.
- H. Geiger and E. Marsden, "On a diffuse reflection of the α-particles", *Proceedings of the Royal Society A*, 82 (1909); E. Rutherford, "The scattering of α and β particles by matter and the structure of the atom", *Philosophical Magazine*, 21 (May 1911).
- AQA, *GCSE Physics* Paper 1 Higher, June 2024 and June 2025 (**activity** and polonium questions, adapted).

Common errors

- Swapping mass number and atomic number.
- Changing the mass number in beta decay; it stays the same.
- Saying the whole sample has gone after two half-lives; a quarter remains.

Common errors (2)

- Forgetting to subtract the background count.
- Saying an irradiated object becomes radioactive.
- Calling gamma the most dangerous radiation in every case; alpha inside the body is the most harmful.
- Mixing up **fission** (splitting large nuclei) and **fusion** (joining light nuclei).

Key terms

- **Isotopes**: atoms of the same element with different numbers of neutrons.
- **Activity**: the rate at which nuclei in a source decay, in **becquerel**.
- **Half-life**: the time for the number of nuclei, or the count rate, to halve.

Key terms (2)

- **Contamination**: unwanted radioactive atoms on or inside a material.
- **Irradiation**: exposure to nuclear radiation, without becoming radioactive.
- **Fission**: the splitting of a large nucleus.
- **Fusion**: the joining of two light nuclei.

Check yourself

- 1.
- How many protons, neutrons and electrons are in an atom of $^{23}_{11}\text{Na}$? 2.
- Which radiation is stopped by paper, and which is the most penetrating? 3.
- Radium-226 ($^{226}_{88}\text{Ra}$) decays by alpha emission.