

Nuclear physics

IGCSE Physics 0625 · Unit 5 revision notes

The nuclear atom, isotopes, fission and fusion, then alpha, beta and gamma radiation, decay equations, half-life and safe use.

25 definitions to learn word for word, 12 equations in their own column, 15 diagrams and graphs. Read it, cover it, test yourself.

1. 5.1a The atom
2. 5.1b The nucleus and isotopes
3. 5.1c Nuclear fission and fusion
4. 5.2a Detection of radioactivity
5. 5.2b The three types of nuclear emission
6. 5.2c Radioactive decay
7. 5.2d Half-life
8. 5.2e Uses and safety of radioactive sources

■ Definitions (mark-scheme wording) ■ Equations ■ Exam traps ■ Extended = Extended tier only

5.1a The atom

Definitions

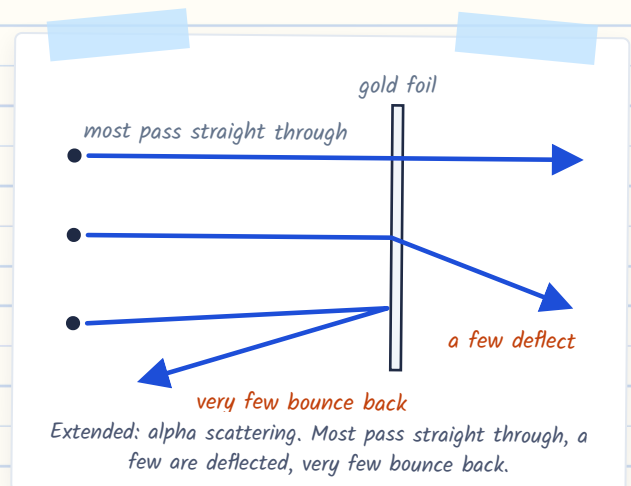
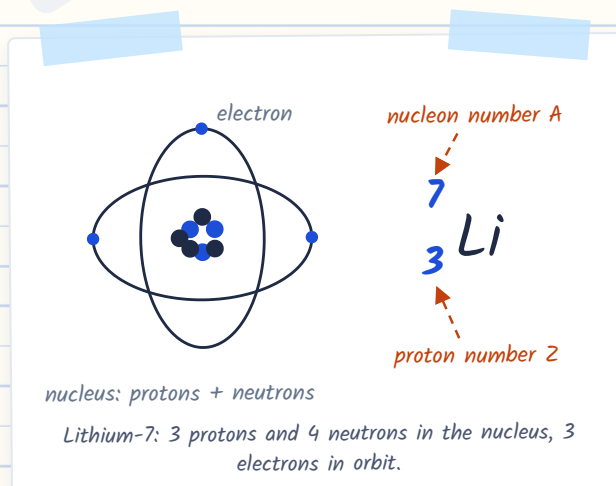
Atom: a small, dense, positively charged nucleus surrounded by negatively charged electrons in orbit.

Positive ion: an atom that has lost one or more electrons.

Negative ion: an atom that has gained one or more electrons.

Key points

- ✓ The nucleus contains **protons and neutrons** and almost all the mass; electrons orbit far outside it.
- ✓ Most of the atom is **empty space**; the nucleus is about 10^{-15} m across, the atom about 10^{-10} m.
- ✓ A neutral atom has **equal numbers of protons and electrons**.
- ✓ **Extended** in alpha scattering, **most** alpha particles passed **straight through** gold foil: the atom is mostly empty space.
- ✓ **Extended** **a few** were deflected: the nucleus is **positively charged** (repels alpha).
- ✓ **Extended** **very few** bounced back: the nucleus is **very small** and contains most of the **mass**.



Watch out!

- ! Extended: bouncing back shows the nucleus is **small and massive**; deflection shows it is **positive**. Match each result to its conclusion.
- ! An ion forms by losing or gaining **electrons**, never protons.

5.1b The nucleus and isotopes

Definitions

Proton number (atomic number) Z : the number of protons in the nucleus.

Nucleon number (mass number) A : the total number of protons and neutrons in the nucleus.

Nucleon: a proton or a neutron.

Nuclide: a particular type of nucleus with a given number of protons and neutrons, written ${}^A_ZX$.

Isotopes: atoms of the same element with the same number of protons but different numbers of neutrons.

Equations

$$A = Z + N$$

nucleon number = protons + neutrons

$$N = A - Z$$

number of neutrons

Key points

- ✓ Relative charges: proton **+1**, neutron **0**, electron **-1**.
- ✓ Z fixes the **element**.
- ✓ **Extended** the relative charge on a nucleus equals its proton number, **+2**.
- ✓ **Extended** the relative mass of a nucleus equals its nucleon number **A** (proton and neutron each 1; electron about 1/1836, negligible).
- ✓ Isotopes have the **same chemistry** (same electrons) but different mass; some are radioactive.
- ✓ Nuclide notation: nucleon number A on **top**, proton number Z at the **bottom**.

particle	charge	mass	where
proton	+1	1	nucleus
neutron	0	1	nucleus
electron	-1	1/1836	orbits

values relative to the proton

Relative charge and mass of the particles in an atom.



6 p, 6 n
stable



6 p, 8 n
radioactive

same Z , different A

Isotopes of carbon: same proton number (6), different neutron numbers (6 and 8).

Watch out!

- ! A counts protons **and** neutrons: carbon-14 has $14 - 6 = 8$ neutrons, not 14.
- ! Isotopes differ in **neutrons**, not protons (a different Z is a different element).

5.1c Nuclear fission and fusion Extended

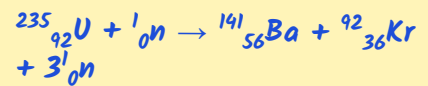
Definitions

Nuclear fission: Extended the splitting of a large, unstable nucleus (e.g. uranium-235) into two smaller nuclei and two or three neutrons, releasing energy.

Nuclear fusion: Extended the joining of two light nuclei (e.g. hydrogen isotopes) to form a heavier nucleus, releasing energy.

Chain reaction: Beyond the syllabus: neutrons released by one fission cause further fissions.

Equations



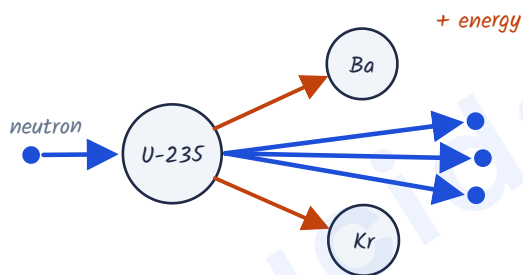
Extended one fission of uranium-235



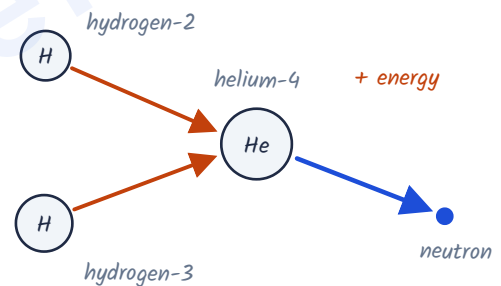
Extended fusion of hydrogen isotopes

Key points

- ✓ Extended fission is started when a nucleus **absorbs a neutron**; used in **nuclear power stations**.
- ✓ Extended fusion powers the **Sun** and other stars; it needs very high temperature and pressure.
- ✓ Extended both release energy because the total mass of the products is slightly **less** than that of the reactants.
- ✓ Extended nucleon number and proton number are **conserved** in the nuclide equation (top and bottom rows balance).



Extended: fission. A neutron splits U-235 into two smaller nuclei plus 2 or 3 neutrons, which can cause more fissions.



Extended: fusion. Two light nuclei join to form helium, releasing energy (the Sun).

Watch out!

- ! Extended: fission **splits** heavy nuclei; fusion **joins** light nuclei. Do not swap the words.
- ! Extended: check nuclide equations: the top numbers and the bottom numbers must each add up on both sides.

5.2a Detection of radioactivity

Definitions

Background radiation: ionising radiation from natural and artificial sources that is always present around us.

Count rate: the number of decays detected per unit time (counts/s or counts/minute).

Corrected count rate: *Extended* the measured count rate minus the background count rate.

Equations

$$\text{count rate} = \text{counts} / \text{time}$$

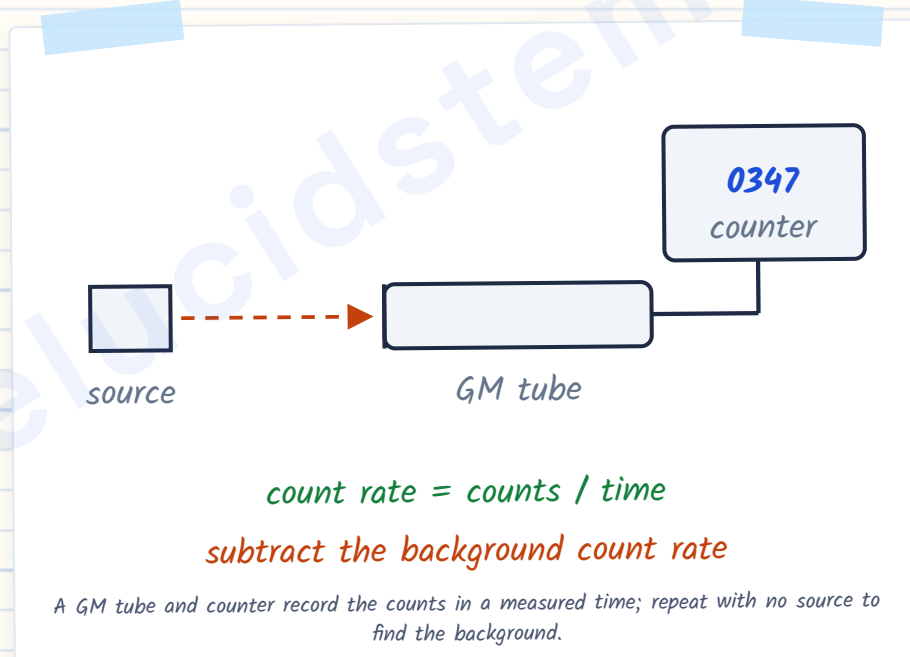
counts per second or per minute
counts/s

$$\text{corrected} = \text{measured} - \text{background}$$

Extended corrected count rate
counts/s

Key points

- ✓ Natural sources: **radon gas** (largest), rocks and buildings, **cosmic rays**, food and drink.
- ✓ Beyond the syllabus: artificial sources: medical X-rays and scans, nuclear power and weapons testing.
- ✓ Detect ionising radiation with a **Geiger-Müller (GM) tube** connected to a counter or ratemeter.
- ✓ *Extended* measure the background count **with no source present** first, over a long time.
- ✓ *Extended* always **subtract the background** from every reading before analysing a source (e.g. finding half-life).



Watch out!

- ! *Extended*: forgetting to subtract the background before halving the count rate for half-life.
- ! Background radiation is **always** present; a zero reading means the detector is off.

5.2b The three types of nuclear emission

Definitions

Alpha particle (α): a helium nucleus: two protons and two neutrons (charge +2).

Beta particle (β): a fast-moving electron emitted from the nucleus (charge -1).

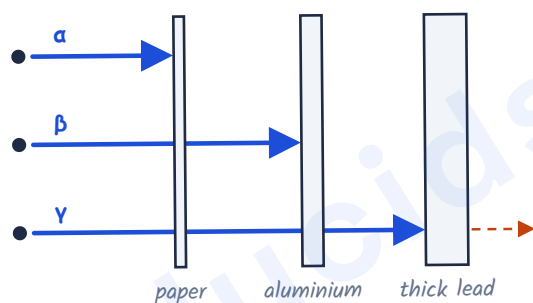
Gamma ray (γ): high-frequency electromagnetic radiation emitted from the nucleus (no charge, no mass).

Ionising radiation: radiation that knocks electrons out of atoms, turning them into ions.

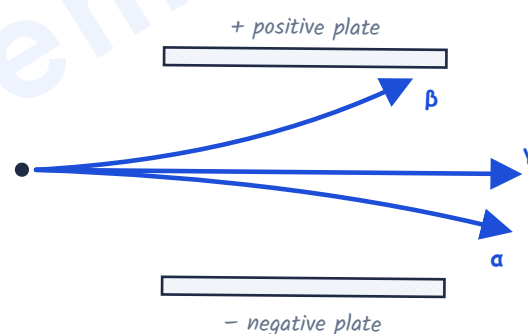
Radioactive emission: spontaneous and random (in time and in direction): it cannot be predicted when a particular nucleus will decay, and is not affected by temperature or chemistry.

Key points

- ✓ **Ionising power:** alpha strongest, beta medium, gamma weakest.
- ✓ **Penetration:** alpha stopped by **paper** or a few cm of air; beta by a few mm of **aluminium**; gamma only reduced by thick **lead** or concrete.
- ✓ The more ionising the radiation, the **less penetrating** it is (it loses energy faster).
- ✓ **Extended** in electric and magnetic fields alpha and beta deflect in **opposite** directions (opposite charges).
- ✓ **Extended** beta deflects **more** than alpha (much smaller mass); gamma is **not deflected** (uncharged).
- ✓ **Extended** alpha is most ionising: it has a **large charge** (+2) and a **large kinetic energy**, which it loses quickly in many ionising collisions; gamma (uncharged) ionises least.



Penetration: alpha stopped by paper, beta by a few mm of aluminium, gamma only reduced by thick lead.



Extended: between charged plates alpha bends slightly towards -, beta bends strongly towards +, gamma goes straight.

	alpha	beta	gamma
nature	He nucleus	electron	EM wave
charge	+2	-1	0
ionising	strong	medium	weak
stopped by	paper	3 mm Al	thick lead

Summary of the three emissions.

Watch out!

- ! Gamma is **reduced** by thick lead, never completely stopped.
- ! Beta is an electron **from the nucleus**, not one of the orbiting electrons.

5.2c Radioactive decay

Definitions

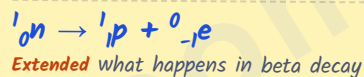
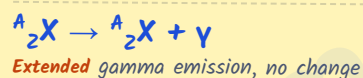
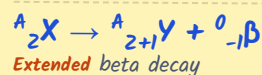
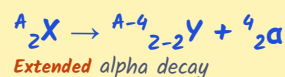
Radioactive decay: a spontaneous and random change in an unstable nucleus that can result in the emission of α -particles or β -particles and/or γ -radiation.

Beta decay: **Extended** a neutron in the nucleus changes into a proton and an electron; the electron is emitted.

Key points

- ✓ Alpha and beta decay change the nucleus into a **different element** (Z changes).
- ✓ **Extended** unstable nuclei decay to become **more stable**.
- ✓ **Extended** alpha decay: A falls by 4, Z falls by 2.
- ✓ **Extended** beta decay: A **unchanged**, Z rises by 1; the number of excess neutrons **falls**.
- ✓ **Extended** gamma emission: **no change** in A or Z; the nucleus just loses energy.
- ✓ **Extended** isotopes with **too many neutrons** tend to decay by beta emission; very heavy nuclei by alpha.

Equations

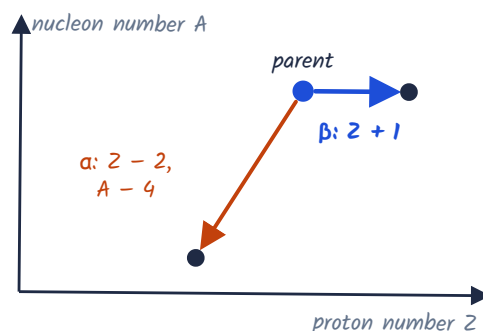


alpha: $A - 4$, $Z - 2$



beta: A same, $Z + 1$

Extended: decay equations. Top numbers and bottom numbers each balance.



Extended: decay moves a nucleus on a chart of A against Z: alpha 4 down and 2 left, beta 1 right, gamma not at all.

Watch out!

- ! **Extended:** in beta decay the **proton number goes up** by 1 (a neutron becomes a proton); A stays the same.
- ! Gamma emission does **not** change the element.

5.2d Half-life

Definitions

Half-life: the time taken for half the nuclei of that isotope in any sample to decay.

Half-life (from activity): the time taken for the count rate (activity) of a sample to fall to half its initial value.

Equations

$$N = N_0 \times \left(\frac{1}{2}\right)^n$$

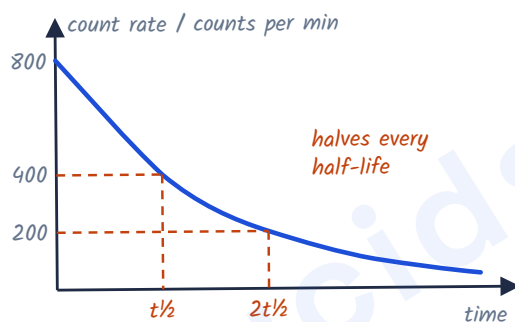
amount left after n half-lives

$$n = t / t_{1/2}$$

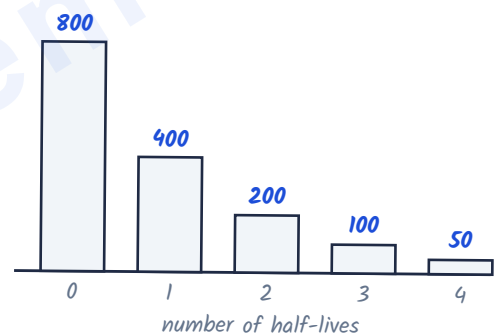
number of half-lives in time t

Key points

- ✓ Each half-life the number of undecayed nuclei (and the count rate) **halves**.
- ✓ From a decay curve: read the time for the count rate to fall from any value to **half** that value.
- ✓ The curve never reaches zero; after n half-lives $\left(\frac{1}{2}\right)^n$ of the sample remains.
- ✓ Half-lives range from fractions of a second to billions of years; each isotope has a fixed value.
- ✓ **Extended** subtract the **background count rate** from the data before finding the half-life.



Decay curve: 800 to 400 counts/min takes one half-life, 400 to 200 another of the same length.



Halving ladder: after 1, 2, 3, 4 half-lives, $1/2$, $1/4$, $1/8$, $1/16$ of the original remains.

Watch out!

- ! After two half-lives a **quarter** remains, not none.
- ! Read the half-life between **any** value and half of it, not just from the start.

5.2e Uses and safety of radioactive sources

Definitions

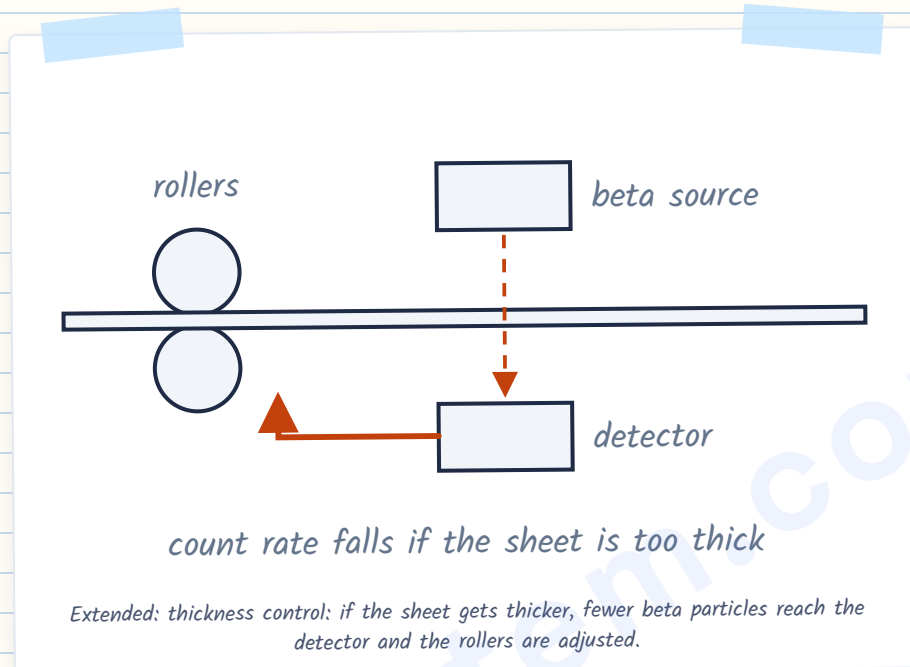
Radioactive tracer: **Extended** a radioactive isotope put into a system so that its path can be followed by detecting its radiation.

Sterilisation: **Extended** killing bacteria on equipment or food using gamma radiation.

Key points

- ✓ **Extended Smoke alarms:** alpha (ionises air, short range); long half-life so it lasts for years.
- ✓ **Extended Thickness control:** beta (partly absorbed by paper or foil); count rate changes with thickness.

- ✓ **Extended** Sterilising equipment, irradiating food to kill bacteria and treating cancer: gamma (penetrates, kills cells and bacteria).
- ✓ **Extended** Diagnosing cancer (tracers): gamma emitter with a **short half-life** (hours), so it leaves the body quickly.
- ✓ Beyond the syllabus: **Dating**: carbon-14 (half-life about 5700 years) in once-living material.
- ✓ **Dangers**: ionising radiation causes cell death, mutations and **cancer**.
- ✓ **Safe handling**: move sources with **tongs**, never point them at people, store them in **lead-lined boxes**.
- ✓ **Extended** all safety precautions reduce exposure: shorten the **time**, increase the **distance**, use **shielding** to absorb the radiation.



Watch out!

- ! **Extended**: tracers inside the body must be **gamma** (to escape) with a **short** half-life; alpha would be very harmful inside.
- ! **Extended**: choose by both **type** (penetration) and **half-life**, and say why for each.