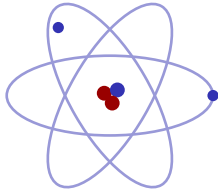


Nuclear Physics

IGCSE Physics ■ Topic 5

IGCSE Physics



What we will cover

- 1 The nuclear atom
- 2 Nucleus, isotopes, fission & fusion
- 3 Radioactivity
- 4 Three types of radiation
- 5 Decay & half-life
- 6 Recap





The nuclear atom

A tiny positive **nucleus** (protons and neutrons) holds nearly all the mass. Electrons orbit in shells.

- proton number Z – the element
- nucleon number A – protons + neutrons

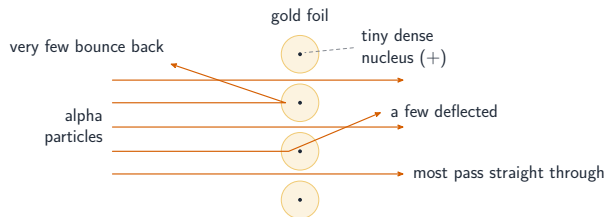
Isotopes have the same Z , different A – same chemistry, different nuclear behaviour.

Ions

An atom is neutral, but it can gain or lose electrons to become an **ion** .

- Lose one or more electrons → a positive ion (now there are more protons than electrons).
- Gain one or more electrons → a negative ion.

Alpha-scattering evidence



Alpha particles α on gold foil:

- most pass straight $\rightarrow$ mostly empty
- a few deflect $\rightarrow$ positive nucleus
- a very few bounce back $\rightarrow$ tiny, heavy nucleus

What alpha scattering showed, and what a nucleus contains

the experiment

alpha particles α – small, fast, positive – fired at a very thin **gold foil**

most passed straight through

so the atom is **mostly empty space**

a few deflected

so there is a **concentrated positive charge**

a very few bounced back

so that charge is in a **tiny, massive nucleus**

nucleons

the nucleus holds **protons** (positive) and **neutrons** (neutral); their total is the nucleon number A

isotopes

same proton number, different neutron number – so the same chemistry and different mass

Each observation supports **one** conclusion. State the pair together – that is how the mark scheme is written.

Inside the nucleus

Nucleons : **protons** (+1) and **neutrons** (0). Notation ${}^A_Z\text{X}$.

- Z = proton number; A = nucleon number; neutrons = $A - Z$
- **isotopes** : same Z , different A



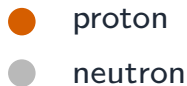
carbon-12

6 protons, 6 neutrons

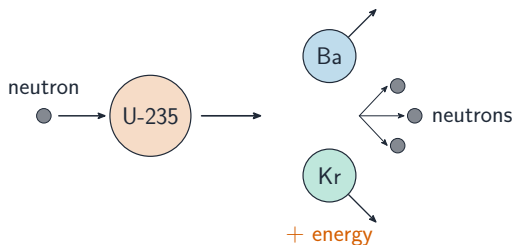


carbon-14

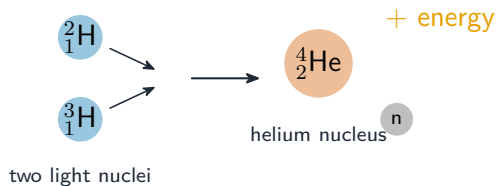
6 protons, 8 neutrons



Fission and fusion



***fission** : a heavy nucleus splits*



***fusion** : light nuclei join (the Sun)*

Both lose a little mass, turned into energy; the A and Z numbers balance on each side.

Fission and fusion, in detail

nuclear fission

a **large** nucleus splits when it absorbs a neutron, giving out energy

the equation



the chain reaction

those **three** neutrons can split three more nuclei – controlled in a reactor by absorbing some of them

nuclear fusion

two **light** nuclei join to make a heavier one, also giving out energy

where it happens

in the Sun, joining hydrogen nuclei into helium

why it is hard here

the nuclei repel, so fusion needs **enormous temperature and pressure**

Both release energy because the products are **more stable** than the reactants – fission for heavy nuclei, fusion for light ones.



Radioactivity

An **unstable** nucleus **decays**, giving out radiation. Decay is **spontaneous** and **random**.

Background radiation (radon, rocks, cosmic rays) is always present – subtract it:

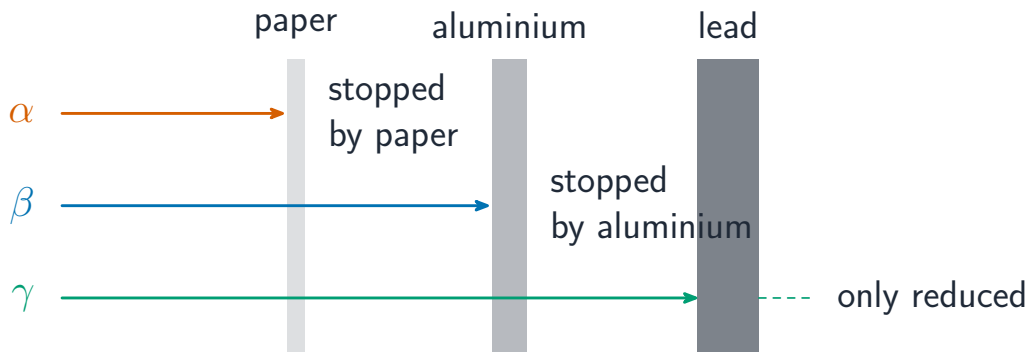
250 next to source, 30 background

corrected = 220 counts/min



Three types of radiation

- α – He nucleus (+2): most **ionising** , stopped by paper
- β – fast electron (-1): aluminium
- γ – EM wave (0): least ionising, only reduced by lead



Why alpha ionises most and penetrates least

alpha

charge +2, and **slow and heavy** – so it interacts strongly and often

the consequence

most ionising, and **least penetrating**: stopped by paper or a few cm of air

beta

charge -1 , fast and light – moderate on both counts; stopped by a few mm of aluminium

gamma

no charge, an electromagnetic wave – least ionising, most penetrating; reduced by thick lead or concrete

the explanation

ionising power comes from **charge** and from how long the particle spends near each atom

deflection

in a field alpha and beta bend in **opposite** directions, and gamma not at all

Ionising power and penetration are **inversely** related, and both follow from the same cause. Explain from charge and speed, never by listing.

Why the three radiations differ

Alpha

Charge $+2$, slow and heavy: it pulls hard on the electrons it passes, so it is the most **ionising** and the least penetrating – easily **absorbed** by paper or skin.

Beta

Charge -1 , fast and light: it ionises less and travels further, stopped by a few millimetres of aluminium.

Gamma

No charge, no mass – a wave. Least ionising, most penetrating; only thick lead or concrete reduces it much.

The reasoning

Explain from charge and **kinetic energy**, not from a memorised list: it is the charge that does the ionising and the mass that stops the particle.

Ionising power and penetration run in opposite directions – an ionising particle loses its energy quickly, which is exactly why it stops.

Deflection in fields

Charged α and β bend **opposite** ways; the lighter β bends more. Uncharged γ is **not** deflected.

α is ${}^4_2\text{He}^{2+}$; β is an electron (or positron); γ is a photon. Charge and mass decide the bend.

Deflection, detection and safe use

In fields

Because alpha and beta particles are charged, they are deflected by an **electric field** and by a **magnetic field** – in *opposite* directions, since the charges are opposite. Gamma is undeflected.

Detecting it

Radiation is measured with a **detector** joined to a counter – a Geiger–Müller tube – and the background count is subtracted first.

Reducing the dose

Less **exposure** time, more distance, and shielding. All three, wherever a source is handled.

Nuclide notation

A **nuclide** is written ${}^A_Z\text{X}$: nucleon number above, proton number below.

Gamma is used to **sterilise** sealed equipment and food precisely *because* it penetrates – the property that makes it dangerous makes it useful.



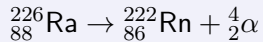
Decay equations

$$\alpha : {}^A_Z\text{X} \rightarrow {}^{A-4}_{Z-2}\text{Y} + {}^4_2\alpha$$

$$\beta : {}^A_Z\text{X} \rightarrow {}^A_{Z+1}\text{Y} + {}^0_{-1}\beta$$

γ emission: only energy leaves, A and Z unchanged.

${}^{226}_{88}\text{Ra}$ emits α



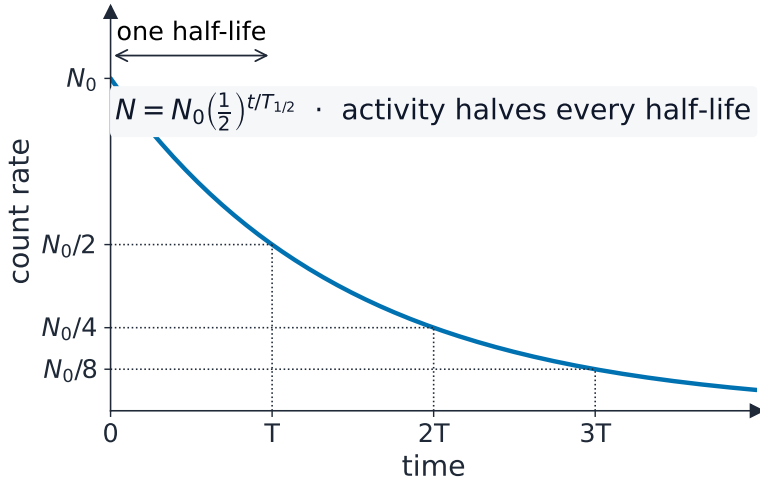
Half-life

Half-life : the time for half the unstable nuclei (or the count rate) to halve.

800 $\rightarrow$ 100 **counts/min**, $T = 5$ **days**

three halvings $\Rightarrow$ 15 days

Half-life, in detail



800 $\rightarrow$ 100 counts/min, $T = 5$ days three halvings $\Rightarrow$ 15 days

Half-life, and why it needs a large sample

the definition

the time for **half** the undecayed nuclei in a sample to decay

decay is random

we cannot say when one nucleus will decay, or follow it

so we use a sample

a large number of nuclei behaves predictably even though each one does not

the pattern

after one half-life $\frac{1}{2}$ remains, after two $\frac{1}{4}$, after three $\frac{1}{8}$

reading a graph

find the time for the count rate to halve – and it is the **same** wherever you start

background radiation

subtract it from every reading before working out the half-life

“The same wherever you start” is what makes half-life meaningful, and forgetting to subtract background is what makes an answer wrong.

Uses and safety

Match the source to the job:

- smoke alarms – α
- **sterilising** – penetrating γ
- thickness gauge – β

Lower the **dose** : less **time**, more **distance**, **shielding** (lead).

Handle with tongs; store in a lead box.

Keeping the dose low

the hazard

ionising radiation harms **living cells** – it can cause cell death, **mutations** and cancer

dose

the amount of radiation received; the aim is always to keep it **as low as reasonably achievable**

time

spend as little time near the source as possible

distance

use tongs or a long handle – intensity falls with the square of distance

shielding

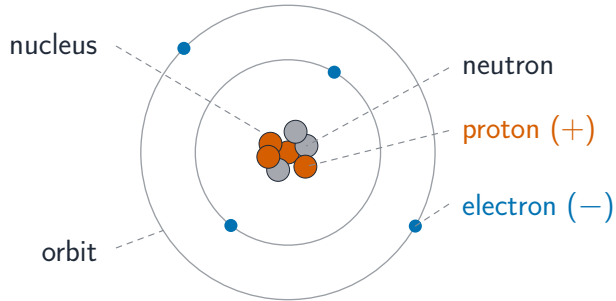
lead or concrete between you and the source

storage

keep sources in a **lead-lined** container, labelled, and locked away when not in use

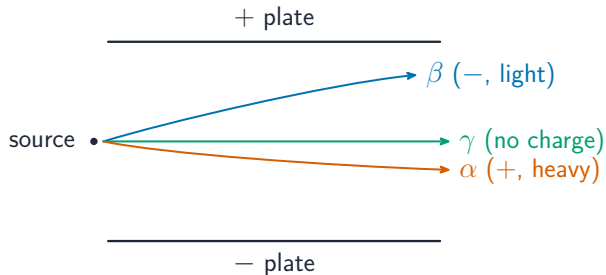
Time, distance, shielding is the whole answer to any handling question. Naming all three earns the marks; describing one at length does not.

The atom



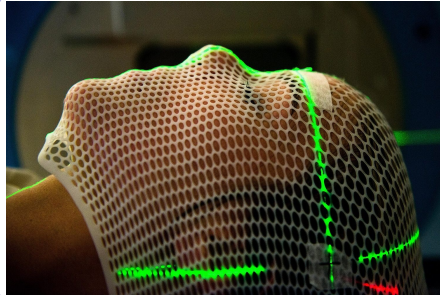
The nuclear atom: a tiny dense nucleus of protons and neutrons, with electrons in orbits around it

Deflection in fields, continued



Alpha and beta bend in opposite directions; the lighter beta bends more, and uncharged gamma is not deflected

Uses of radioactivity



Radiotherapy: a mesh mask holds the patient still while alignment lasers aim gamma rays precisely at a tumour to treat cancer

Matching the source to the job

the rule

choose by the **type of radiation** and by the **half-life**

smoke alarms

an **alpha** source – easily blocked, so it is safe outside the alarm, and a **long** half-life means it lasts for years

thickness control

a **beta** source – the amount passing through a sheet of paper or metal changes with its thickness

sterilising

gamma rays, which penetrate the sealed packaging to kill **bacteria** inside

medical tracers

a **short** half-life, so the patient's dose falls quickly once the scan is done

radiocarbon dating

carbon-14's half-life of 5730 years matches the age range being measured

Every choice pairs **penetration** with the barrier it must cross, and **half-life** with how long the source must last.

Tracers, gauges, and half-life from a graph

Choosing the isotope

- a **medical tracer** : a **radioactive** gamma emitter with a **short** half-life, injected into the body; gamma escapes to a detector outside, and the activity soon falls to a safe level
- thickness gauge: a beta source; what passes through changes with thickness
- smoke alarm: an alpha source with a long half-life

Half-life with background

- 1 measure the background count rate with the source removed
- 2 subtract it from **every** reading
- 3 plot the corrected count rate; read the time for it to halve from any value

Relative charges: proton +1, neutron 0, electron -1; relative masses 1, 1, negligible.

Exam tips

- The **nucleon number** (top) is protons + neutrons; the **proton number** (bottom) is protons only. Number of neutrons = nucleon number – proton number.
- **Isotopes** have the same proton number but different nucleon numbers – the same element with a different number of neutrons.
- Rank the radiations two ways: **alpha** is the most ionising but least penetrating (stopped by paper); **gamma** is the least ionising but most penetrating (needs thick lead). Beta is in between (stopped by a few mm of aluminium).
- In every **decay equation** the top numbers must balance and the bottom numbers must balance. Alpha decay: $A - 4$, $Z - 2$. Beta decay: A unchanged, $Z + 1$.
- Always subtract the **background count rate** before using a source's readings. After n half-lives the count rate has halved n times – count the halvings rather than guessing from the total time.



Topic 5 – key takeaways

1

Nucleus

${}^A_Z\text{X}$; isotopes share Z

2

Radiation

α (paper), β (Al), γ (lead)

3

Decay

A & Z balance; α , β , γ

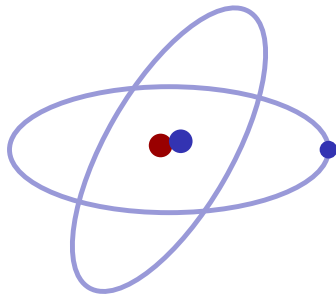
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Half-life

count rate halves each half-life

Check yourself

- 1 How many neutrons in $^{197}_{79}\text{Au}$?
- 2 Which radiation is stopped by paper?
- 3 $^{24}_{11}\text{Na}$ emits β – the new proton number?
- 4 After 2 half-lives, what fraction is left?



Answers 1. $197 - 79 = 118$ 2. alpha 3. 12 4. one quarter