IGCSE PHYSICS 0625 · CHAPTER 11 NOTES · ~11 MIN READ

Nuclear physics

The atom and nucleus, alpha, beta and gamma radiation, half-life calculations, decay equations, fission and fusion, and radiation safety.

Atomic structure | Nuclide notation & isotopes | Background radiation | Alpha, beta, gamma | Decay equations | Half-life | Uses & safety | Fission & fusion

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No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

IN 30 SECONDS

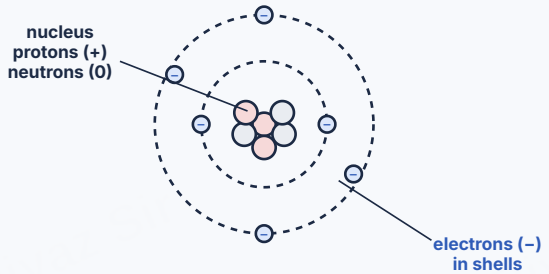
- An atom has a tiny, dense, positive **nucleus** (protons + neutrons) with **electrons** in shells around it.
- **Isotopes** have the same number of protons but different numbers of neutrons.
- **Alpha** (stopped by paper) ionises most. **Beta** (stopped by aluminium). **Gamma** (reduced by thick lead) is the most penetrating.
- Decay is **random and spontaneous**. **Half-life** is the time for half the nuclei to decay.
- EXT Decay and fission/fusion equations must balance both the **top (A)** and **bottom (Z)** numbers.

BY THE END YOU CAN

- Describe the structure of the atom and use nuclide notation.
- Tell alpha, beta and gamma apart by their nature, ionisation and penetration.
- Use half-life with tables and graphs and correct for background radiation. EXT
- Write balanced decay equations. EXT
- Describe fission and fusion, and explain the uses and dangers of radiation.

1 The atom

Inside the atom



protons = electrons, so the atom is neutral · the nucleus is tiny but holds ~all the mass

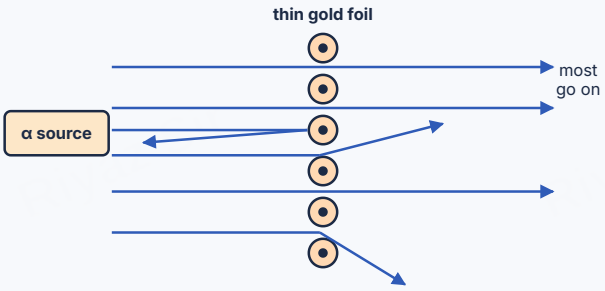
A nucleus of protons and neutrons, with electrons in shells. The nucleus is tiny but holds almost all the mass.

Particle	Relative charge	Relative mass	Where
proton	+1	1	nucleus
neutron	0	1	nucleus
electron	−1	about 1/1836	in shells around the nucleus

- A neutral atom has **equal numbers of protons and electrons**.
- An atom that **loses** electrons becomes a **positive ion**. An atom that **gains** electrons becomes a **negative ion**.

Evidence for the nucleus

EXTENDED

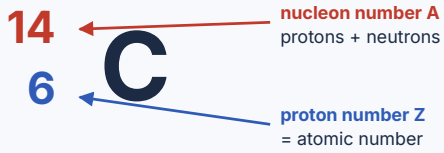


most α pass straight through → the atom is mostly empty space
a few are deflected → the nucleus is positive and repels α
very few bounce back → the nucleus is tiny, dense and has most of the mass

Rutherford's alpha-scattering experiment. A beam of α particles is fired at very thin gold foil.

- Most α particles went **straight through**, so most of an atom is empty space.
- A few were **deflected**, so the centre of the atom is **positive** and repels the positive α particles.
- Very few bounced **straight back**, so the positive nucleus is **tiny, dense** and has **most of the mass**.

Nuclide notation and isotopes



neutrons = A − Z = 14 − 6 = 8

isotopes: same Z (same element), different A

Nucleon number A on top (protons + neutrons). Proton number Z on the bottom.

Proton number (Z) — the number of protons in the nucleus. It decides the element. EXT It is also the charge of the nucleus.

Nucleon number (A) — the number of protons plus neutrons. EXT It decides the mass of the nucleus.

$$\text{neutrons} = A - Z$$

nucleon number minus proton number

Isotopes — atoms of the same element (same Z) with different numbers of neutrons (different A).

WORKED EXAMPLE

How many protons, neutrons and electrons are in a neutral atom of $^{14}_{6}C$? How does it differ from $^{12}_{6}C$?

1. protons = Z = **6**
2. neutrons = A − Z = 14 − 6 = **8**
3. electrons = **6** (neutral atom)
4. **$^{12}_{6}C$ has 6 neutrons, so the two are isotopes with different numbers of neutrons**

2 Radioactivity

Background radiation

Background radiation — ionising radiation that is always around us.

- Natural sources: **radon gas** (from rocks), **rocks and buildings**, **food and drink**, and **cosmic rays** from space.
- It is detected with a **Geiger–Müller tube** connected to a counter. The reading is a **count rate** in counts per second or counts per minute.
- EXT **Corrected count rate = measured count rate − background count rate.**

WORKED EXAMPLE

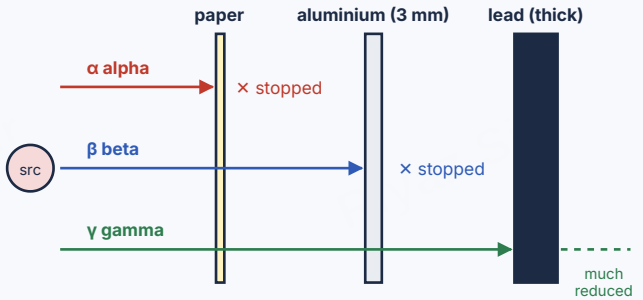
EXT **A source gives 156 counts per minute. The background is 12 counts per minute. Find the corrected count rate.**

1. **corrected = 156 − 12 = 144 counts per minute**

Alpha, beta and gamma

Radioactive decay — the spontaneous and random change of an unstable nucleus, giving out radiation. **Spontaneous** means nothing outside causes it (not heat, not pressure). **Random** means you cannot tell when one particular nucleus will decay, or in which direction the radiation goes.

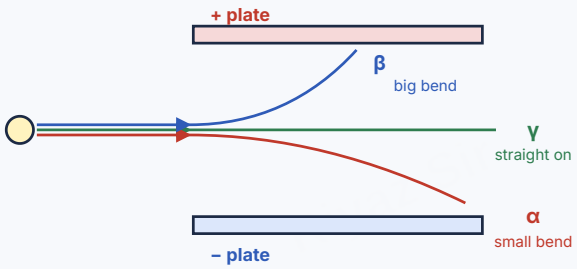
	Alpha (α)	Beta (β)	Gamma (γ)
what it is	2 protons + 2 neutrons (a helium nucleus)	a fast electron from the nucleus	an electromagnetic wave
charge	+2	−1	0
ionising power	strongest	medium	weakest
stopped by	paper, a few cm of air	a few mm of aluminium	only reduced by thick lead or concrete
range in air	a few cm	about 1 m	very long



most ionising, least penetrating: α → β → γ (least ionising, most penetrating)
(thick lead or concrete reduces γ, but never stops it completely)

The more strongly radiation ionises, the less it penetrates. Alpha is the most ionising and the least penetrating.

- **Ionisation** means knocking electrons off atoms to make ions. This can damage living cells.
- EXT Alpha particles are big and heavily charged, so they ionise strongly and lose their energy over a very short distance.



α (+) is pulled to the − plate, β (−) to the + plate; γ has no charge
β bends more because it is far lighter than α

EXT In an electric field α bends towards the negative plate, β bends towards the positive plate (much more, because it is far lighter), and γ is not deflected. A magnetic field also deflects α and β but not γ.

Radioactive decay

- Alpha and beta decay change the nucleus into a **different element**. Gamma emission does not change the element — it just takes away spare energy.
- EXT Nuclei are unstable if they have **too many neutrons** or are **too heavy**. Emitting radiation makes the nucleus more stable.
- EXT In beta decay a neutron changes into a proton and an electron: **n → p + e**. The electron is emitted.

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

EXT alpha decay: A falls by 4 and Z falls by 2

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

EXT beta decay: A stays the same and Z rises by 1

EXAM TIP

In every equation, the top numbers add up to the same total on both sides, and so do the bottom numbers.

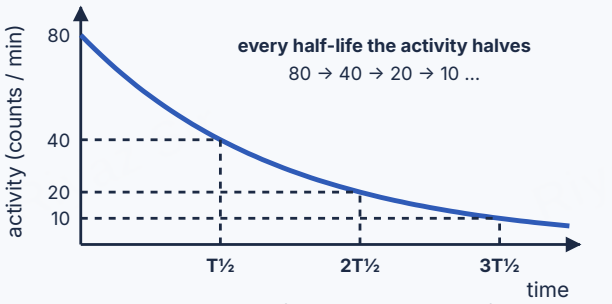
WORKED EXAMPLE

EXT **Complete:** $^{210}_{84}Po \rightarrow {}^{?}_{82}Pb + {}^{4}_{2}He$

1. Top numbers: 210 = ? + 4, so ? = **206**
2. Bottom numbers: 84 = 82 + 2 ✓
3. $^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$

Half-life

Half-life — the time taken for half the nuclei of a radioactive isotope in a sample to decay. It is also the time for the count rate (activity) to fall to half.



half-life = time for the activity (or the number of nuclei) to fall to half

Every half-life the activity halves: 100%, 50%, 25%, 12.5%, and so on. It never quite reaches zero.

WORKED EXAMPLE

A sample has a half-life of 6 hours and a count rate of 800 counts per minute. What is the count rate after 18 hours?

1. 18 ÷ 6 = 3 half-lives
2. **800 → 400 → 200 → 100 counts per minute**

WORKED EXAMPLE

EXT **A count rate is measured as 640, 320, 160 and 80 counts per minute at 0, 10, 20 and 30 minutes. Find the half-life.**

1. The count rate halves every 10 minutes
2. **half-life = 10 minutes**

COMMON MISTAKE

Halving the time instead of the count. After two half-lives a quarter is left (not none).

Uses of radiation

EXTENDED

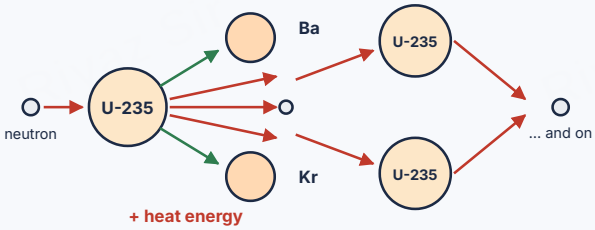
Use	Radiation	Why
smoke alarm	alpha	alpha ionises the air so a small current flows; smoke absorbs it and the current falls; alpha cannot leave the alarm; long half-life
thickness of paper or foil	beta	more of the beta is absorbed by thicker sheet, so the count falls
sterilising food and surgical tools	gamma	passes through packaging and kills bacteria
medical tracer	gamma	passes out of the body to be detected; a short half-life means it soon disappears
treating cancer	gamma	penetrates the body and kills cancer cells

Safety

- Ionising radiation causes **cell death, mutations and cancer**.
- Handle sources with **tongs**. Store them in **lead-lined boxes**, keep them away from people and label them with the **hazard symbol**.
- EXT Reduce exposure by: **limiting time** near the source, **increasing distance** (radiation spreads out), and using **shielding** (lead or concrete).

3 Fission and fusion EXT

Nuclear fission



chain reaction: neutrons released split more nuclei (controlled in a reactor)

A neutron splits a uranium-235 nucleus into two smaller nuclei, 2 or 3 more neutrons and energy. The neutrons go on to split more nuclei: a chain reaction.

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

the top numbers (236) and bottom numbers (92) balance

- In a nuclear power station the chain reaction is **controlled**. The energy heats water to make steam for a turbine.

Nuclear fusion



two light nuclei join: needs ~10^7 °C and enormous pressure
(this is how the Sun and other stars shine)

Two light nuclei join to make a heavier one and release energy. This needs a very high temperature and pressure.

$$^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + \text{energy}$$

top 5 = 5, bottom 2 = 2

- Fusion powers the Sun and other stars. Researchers are working to use it for electricity, but it needs extreme temperatures to push positive nuclei close enough to join.

	Fission	Fusion
what happens	a large nucleus splits	small nuclei join
example	uranium-235	hydrogen isotopes
conditions	needs a neutron	needs about 10 million °C and a huge pressure
where	nuclear power stations	the Sun and stars

Riyaz Sir

4 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. State the relative charges of a proton, a neutron and an electron.
2. How many neutrons are in $^{14}_{6}C$?
3. Which radiation is most penetrating?
4. Name two sources of background radiation.
5. A source has a half-life of 12 days. What fraction is left after 36 days?
6. What is an isotope?

EXAM-STYLE

7. EXT A source gives a measured 340 counts per minute. The background is 40 counts per minute and the half-life is 2.0 hours. Find the measured count rate after 4.0 hours.
8. Explain why a smoke alarm uses an alpha source. [3]
9. EXT Describe and explain what the alpha-scattering experiment showed about the atom. [4]
10. EXT Write the decay equation for $^{90}_{38}Sr$ emitting a beta particle. The new element is yttrium (Y).
11. Explain why gamma rays, not alpha, are used as a medical tracer. [2]

Show answers

1. +1, 0, −1
2. 14 − 6 = 8
3. gamma
4. radon gas, rocks, food and drink, cosmic rays (any two)
5. 36 ÷ 12 = 3 half-lives, $(½)^3$ = 1/8
6. An atom of the same element with a different number of neutrons.
7. corrected = 340 − 40 = 300
   4.0 h = 2 half-lives: 300 → 150 → 75
   measured = 75 + 40 = 115 counts per minute
8. Alpha ionises the air, so a small current flows
   smoke absorbs the alpha particles, so the current drops and the alarm sounds
   alpha cannot escape from the alarm, so it is safe
9. Most α went straight through, so the atom is mostly empty space
   a few were deflected through large angles, so the nucleus is positive
   very few bounced back, so the nucleus is small and dense
   the nucleus has most of the mass
10. $^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + {}^{0}_{-1}e$
11. Gamma passes out of the body so it can be detected
    alpha would be stopped inside the body and do more damage to cells

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