Cambridge IGCSE · Physics 0625 · Notes

Radioactivity

Read online at **pastopic.com/cambridge/physics-0625/notes/radioactivity**

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Read first: The nuclear model of the atom, **Electromagnetic effects**

What you need to know

Some nuclei are unstable. Sooner or later each one changes and throws out radiation: an alpha-particle, a beta-particle or gamma radiation. This topic is about detecting that radiation, telling the three kinds apart, writing the changes as equations, using half-life, choosing the right source for a job, and staying safe. It builds on protons, neutrons, nuclide notation and isotopes from the nuclear model of the atom, and (for the magnetic field part) on the left-hand rule from electromagnetic effects. The parts marked **Extended only** are tested on Papers 2 and 4 only. By the end of it you should be able to:

Detecting radioactivity

1. **Say what background radiation is**: the ionising radiation that is around us all the time, even when no radioactive source is being used.
2. **Name the main sources of background radiation**: radon gas in the air, rocks and buildings, food and drink, and cosmic rays from space.
3. **Know that ionising nuclear radiation is measured with a detector connected to a counter.**
4. **Use count rates in counts/s or counts/minute.**
5. **Extended only:** use a measurement of background radiation to work out a corrected count rate (the count rate due to the source alone).

The three types of emission

6. **Describe the emission of radiation from a nucleus as spontaneous and random in direction.**
7. **Identify alpha (α), beta (β) and gamma (γ) emissions** from what they are, how strongly they ionise and how far they penetrate. Here "beta" always means the negative beta-particle, an electron.
8. **Extended only:** describe how α-particles, β-particles and γ-radiation are deflected in electric fields and in magnetic fields.
9. **Extended only:** explain why they ionise differently, using their kinetic energy and their electric charge.

Radioactive decay

10. **Know that radioactive decay is a change in an unstable nucleus** that can give out α-particles or β-particles and/or γ-radiation, and that it is spontaneous and random.
11. **State that in α-decay or β-decay the nucleus becomes a nucleus of a different element.**

12. **Extended only:** know that an isotope can be radioactive because its nucleus has too many neutrons and/or is too heavy.
13. **Extended only:** describe what α-decay, β-decay and γ-emission do to the nucleus (it becomes more stable, and β-decay reduces the excess of neutrons); in β-emission a neutron changes into a proton and an electron.
14. **Extended only:** write decay equations in nuclide notation for the emission of α-particles, β-particles and γ-radiation.

Half-life

15. **Define half-life** as the time taken for half the nuclei of that isotope in any sample to decay, and use it in simple calculations, including with tables and decay curves (Core calculations leave out background radiation).
16. **Extended only:** work out a half-life from data or a decay curve that still includes background radiation.
17. **Extended only:** explain how the type of radiation and the half-life decide which isotope is used for smoke alarms, irradiating food to kill bacteria, sterilising equipment with gamma rays, measuring and controlling the thickness of materials, and diagnosing and treating cancer with gamma rays.

Safety

18. **State the effects of ionising radiation on living things**: cell death, mutations and cancer.
19. **Describe how radioactive materials are moved, used and stored safely.**
20. **Extended only:** explain the safety precautions in terms of less exposure time, more distance between the source and living tissue, and shielding that absorbs the radiation.

Understand it

A quick reminder: nuclide notation and isotopes

A nucleus is written ${}^{A}_{Z}\mathrm{X}$, where X is the chemical symbol, Z is the **proton number** (atomic number) and A is the **nucleon number** (mass number, protons + neutrons). So

$$\text{number of neutrons} = A - Z.$$

Isotopes are atoms of the same element (same number of protons) with different numbers of neutrons. Carbon-12 and carbon-14 are isotopes of carbon: both have 6 protons, but carbon-14 has 8 neutrons and carbon-12 has 6. Some isotopes are stable; others are radioactive.

Why some nuclei decay

The protons in a nucleus repel each other, and the neutrons help hold it together. A nucleus with the wrong balance is **unstable**: it has too many neutrons for its protons, or it is simply too heavy (very large nuclei, such as uranium or radium). Sooner or later an unstable nucleus changes into a more stable one and gives out radiation. This is **radioactive decay**.

Decay is:

- **spontaneous**: nothing sets it off, and heating, cooling, pressure, dissolving or chemical reactions make no difference to it;
- **random**: you cannot predict **which** nucleus will decay next or **when**. Every nucleus of that isotope has the same chance of decaying in the next second. The radiation also leaves in a random direction.

Because decay is random, a detector's readings go up and down around an average even from a steady source. With huge numbers of nuclei the average behaviour is very predictable, which is why half-life works.

Detecting radiation and background radiation

The radiation is **ionising**: as it passes through matter it knocks electrons out of atoms, leaving ions behind. Detectors use this. A detector (such as a Geiger–Müller tube) is connected to a **counter**, which counts each particle or ray that is detected. The **count rate** is the number of counts per unit time, in **counts/s** or **counts/minute**: 300 counts in 5 minutes is $300 \div 5 = 60$ counts/minute.

Even with no source nearby, the counter keeps clicking. This is **background radiation**, always present from our surroundings. Its main sources:

Natural	From human activity
radon gas in the air (the biggest single part)	medical uses, such as X-rays
rocks and buildings (for example granite)	nuclear power and nuclear waste
food and drink (all living things contain some radioactive isotopes)	fallout from nuclear weapons tests and accidents
cosmic rays from space	

Mobile phones, microwaves, radio waves, infrared, visible light and sound are **not** sources: they are not ionising nuclear radiation.

Extended only: corrected count rate. A reading near a source includes background, so

$$\text{corrected count rate} = \text{measured count rate} - \text{background count rate}.$$

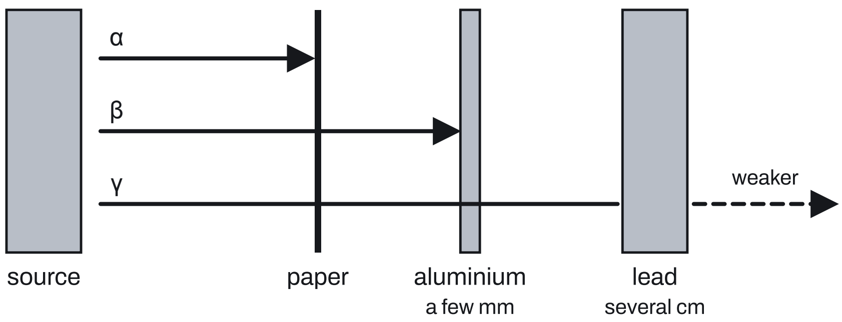
If a detector reads 347 counts/minute near a source and the background is 22 counts/minute, the source alone gives $347 - 22 = 325$ counts/minute. Always put both rates into the same units first.

The three emissions

	Alpha (α)	Beta (β)	Gamma (γ)
What it is	a helium nucleus: 2 protons + 2 neutrons	a fast-moving electron from the nucleus	an electromagnetic wave
Symbol	${}^{4}_{2}\alpha$ or ${}^{4}_{2}\mathrm{He}$	${}^{0}_{-1}\beta$ or ${}^{0}_{-1}\mathrm{e}$	${}^{0}_{0}\gamma$
Relative charge	$+2$	-1	0

	Alpha (α)	Beta (β)	Gamma (γ)
Mass	large (about 4 nucleons)	tiny (about $\frac{1}{1800}$ of a nucleon)	none
Ionising effect	strongest	medium	weakest
Penetration (stopped by)	least: a sheet of paper, or a few cm of air	medium: a few mm of aluminium	most: never fully stopped; reduced greatly by thick lead or concrete

The two ends of the table go together: **the more strongly it ionises, the less it penetrates**. Every ion it makes costs it some energy, so an alpha-particle, which ionises heavily, runs out of energy after a few centimetres of air.



Extended only: why alpha ionises most. Two reasons, both needed:

- **Charge.** An alpha-particle has charge $+2$, twice the size of a beta-particle's -1, so it pulls electrons out of atoms more strongly. Gamma has no charge, so it ionises least.
- **Kinetic energy and speed.** An alpha-particle is emitted with more kinetic energy than a beta-particle, and it has so much more mass that it moves far more slowly. It spends longer near each atom it passes and has plenty of energy to lose, so it makes many ions over a short path.

In coulombs, a beta-particle's charge is -1.6×10^{-19} C, so an alpha-particle's is $+2 \times 1.6 \times 10^{-19} = +3.2 \times 10^{-19}$ C.

You can use penetration to find out what a source emits. Put a detector near the source and measure the count rate with paper, then aluminium, then lead in between:

- a big drop when paper is added means **alpha** is present (no change means no alpha);
- a big drop when a few mm of aluminium is added means **beta** is present;
- counts (above background) that still get through the aluminium, or through lead, mean **gamma** is present.

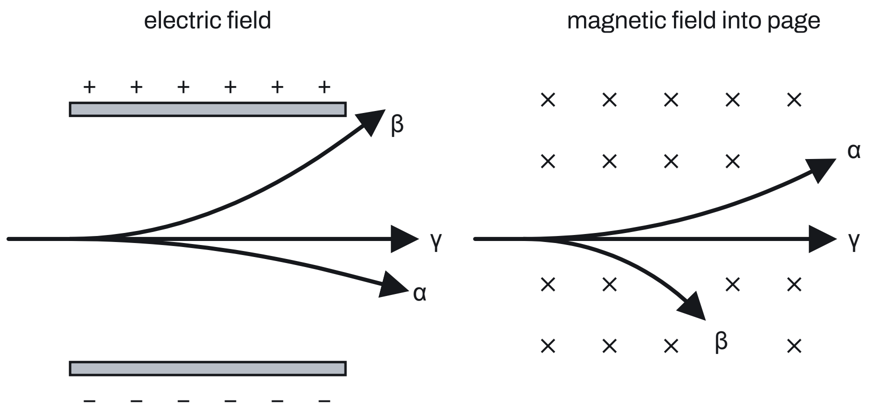
Extended only: deflection in electric and magnetic fields

Alpha and beta are charged, so fields push them sideways; gamma is uncharged and goes straight on.

- **Electric field** (between two charged plates): the positive alpha-particles move towards the **negative** plate; the negative beta-particles move towards the **positive** plate.

- **Magnetic field**: a moving charged particle is a current, so the left-hand rule from electromagnetic effects gives the force. For an alpha-particle the "current" points the way it moves. For a beta-particle (negative) the current points **opposite** to its motion, so it curves the **opposite way** to alpha. In a magnetic field the paths are curves (arcs of circles).

In both fields the **beta-particles are deflected much more** than the alpha-particles, because their mass is so much smaller (even though their charge is only half as big). On a drawing, the beta path must bend more sharply (a smaller radius) than the alpha path, and bend in the opposite direction.



For the right-hand diagram: the beam moves to the right and the field is into the page. For the alpha-particles, point the first finger into the page (field) and the second finger to the right (current): the thumb points up, so the alpha-particles curve **upwards**. The beta-particles' current points to the left, so they curve **downwards**, and more tightly.

Decay changes the nucleus

Alpha decay. The nucleus loses 2 protons and 2 neutrons. Its proton number falls by 2 and its nucleon number falls by 4, so it becomes a **different element**. This makes a heavy nucleus smaller and more stable.

Beta decay. Inside the nucleus, **a neutron changes into a proton and an electron**:

$$\text{neutron} \rightarrow \text{proton} + \text{electron}.$$

The electron is shot out as the beta-particle. Charge is conserved: $0 = (+1) + (-1)$. The nucleon number stays the same (one neutron swapped for one proton), the proton number goes **up by 1**, so again the nucleus becomes a **different element**. It now has one neutron fewer and one proton more, which reduces the **excess of neutrons** and makes it more stable. The beta-particle comes from the **nucleus**, not from the electron shells.

Gamma emission. The nucleus gives out energy as an electromagnetic wave, often straight after an alpha or beta decay. Gamma has no charge and no mass, so the proton number and nucleon number **do not change**: the element stays the same, but the nucleus has less energy and is more stable.

Extended only: decay equations

A decay equation must **balance**: the nucleon numbers on the top add up to the same total on both sides, and so do the proton numbers on the bottom.

Alpha decay of polonium-210 (84 protons) gives lead:

$$^{210}_{84}\mathrm{Po} \;\rightarrow\; ^{206}_{82}\mathrm{Pb} + ^{4}_{2}\alpha$$

Top: $210 = 206 + 4$. Bottom: $84 = 82 + 2$.

Beta decay of phosphorus-32 (15 protons) gives sulfur:

$$^{32}_{15}\mathrm{P} \;\rightarrow\; ^{32}_{16}\mathrm{S} + ^{0}_{-1}\beta$$

Top: $32 = 32 + 0$. Bottom: $15 = 16 + (-1)$.

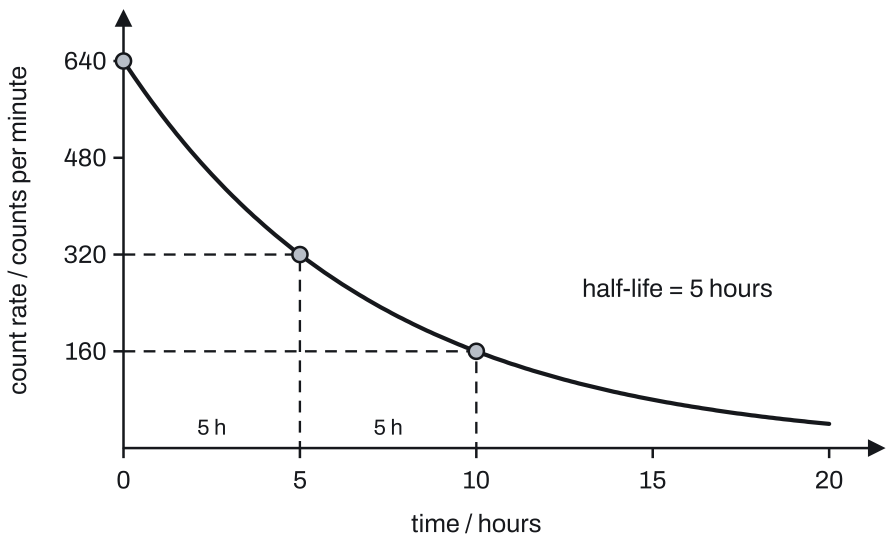
Gamma emission leaves both numbers alone, so the nucleus keeps its symbol: $^{A}_{Z}\mathrm{X} \rightarrow ^{A}_{Z}\mathrm{X} + ^{0}_{0}\gamma$.

To find the new element, work out its proton number and look it up (the question usually gives the symbol).

Half-life

You can't say when one nucleus will decay, but in a large sample a fixed fraction decays in each second. As the sample shrinks, fewer nuclei are left to decay, so the count rate falls, quickly at first and then more slowly. The **half-life** of an isotope is **the time taken for half the nuclei of that isotope in any sample to decay**. After one half-life, half the nuclei are left; after two, a quarter; after three, an eighth, and so on. The count rate (activity) and the mass of the isotope halve in the same time.

Half-lives range from fractions of a second to billions of years, and each isotope's half-life is fixed: it does not depend on how much you have or on temperature.



Reading a half-life from a decay curve:

1. Pick a starting count rate on the curve (the value at time 0 is easiest) and halve it.

2. Draw lines across to the curve and down to the time axis for both values.
3. The time between them is the half-life. Check it with a second pair: here $640 \rightarrow 320$ takes 5 hours, and $320 \rightarrow 160$ also takes 5 hours.

Extended only: with background included. If the counts include background, the curve levels off at the background rate instead of going down to zero. Subtract the background from your values first, halve the **corrected** rate, then add the background back to find where to read the graph.

Extended only: choosing a source

Two things decide which isotope is used:

- **Type of radiation**, from how far it needs to go and how much ionising it should do.
- **Half-life**: long enough that the source doesn't fade away before or while it is used; short enough (for anything put inside a body or the environment) that it doesn't stay radioactive for long afterwards.

Use	Radiation	Why that radiation	Half-life
Smoke alarm	alpha	strongly ionises the air between two plates, making a small current; smoke absorbs the alpha-particles, the current falls and the alarm sounds; its short range means little escapes the alarm	long (hundreds of years), so the alarm works for years without a new source
Measuring and controlling thickness of paper, card, plastic or thin aluminium sheet	beta	partly absorbed by the sheet, so the count rate changes noticeably when the thickness changes; alpha would be stopped by any thickness, gamma would pass through almost unchanged	long (years), so the count rate falls only because of thickness, and the source needn't be replaced often
Thickness of thick metal sheet	gamma	only gamma gets through enough to be measured	long
Irradiating food to kill bacteria; sterilising medical equipment	gamma	penetrates the packaging and the whole item, killing bacteria inside; the food or equipment does **not** become radioactive	long, so the source keeps a steady output for years
Diagnosing cancer (a tracer inside the body)	gamma	passes out of the body to a detector outside; ionises weakly, so does least harm	short, from minutes to a few days: long enough for the scan, then soon gone
Treating cancer with a beam from outside the body	gamma	penetrates deep into the body to reach the tumour; the beam is aimed at the tumour from several directions	long (years), so the output is steady

The same reasoning handles other uses you might be given, such as finding a leak in an underground pipe (gamma, which passes through the soil to the detector, with a half-life of hours to days).

Safety

Ionising radiation damages living cells: it can **kill cells**, cause **mutations** (changes to DNA) and cause **cancer**. It does not cause infections or electric shocks, and it does not make you hot.

How radioactive materials are handled:

- **Moving and using**: pick sources up with long tongs, holding them at arm's length and pointing away from people; use them for as short a time as possible; never touch them or eat and drink nearby.
- **Storing**: in a **lead-lined box**, in a locked cupboard or room with a radiation warning sign, away from people, and put back straight after use. Lead is used because it **absorbs** radiation well.
- Workers can wear a badge (a film badge or dosimeter) that records how much radiation they receive.

Extended only: every precaution works in one of three ways.

- **Less time** near the source means fewer particles and rays reach you, so a smaller dose.
- **More distance** from the source: the radiation spreads out, so less reaches you, and alpha and beta are absorbed by the air over a short range.
- **Shielding** (lead, thick concrete, lead aprons) absorbs the radiation before it reaches you. Paper or thin plastic would stop alpha but not gamma, so a gamma source needs lead.

Key facts and formulas

There is no formula sheet in the IGCSE Physics exam, so you must learn all of these.

Formula	Status
Count rate $= \dfrac{\text{number of counts}}{\text{time}}$, in counts/s or counts/minute	Learn it
Corrected count rate $=$ measured count rate $-$ background count rate (Extended)	Learn it
Number of half-lives $n = \dfrac{\text{time}}{\text{half-life}}$	Learn it
Amount left after n half-lives $= \text{starting amount} \times \left(\frac{1}{2}\right)^n$ (for mass, number of nuclei or corrected count rate)	Learn it
Fraction decayed $= 1 - \left(\frac{1}{2}\right)^n$	Learn it
Neutrons $= A - Z$ (nucleon number $-$ proton number)	Learn it
$\alpha = {}^{4}_{2}\text{He}$, $\beta = {}^{0}_{-1}\text{e}$, $\gamma = {}^{0}_{0}\gamma$ (Extended)	Learn it

Formula	Status
α-decay: A falls by 4, Z falls by 2; β-decay: A same, Z rises by 1; γ: no change (Extended)	Learn it
In β-decay: neutron $\rightarrow$ proton $+$ electron (Extended)	Learn it
Charge on $\alpha = +2 \times 1.6 \times 10^{-19} = +3.2 \times 10^{-19}$ C (Extended)	Learn it

Useful halvings to know: $\frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \frac{1}{16}, \frac{1}{32}$ after 1, 2, 3, 4, 5 half-lives, so 12.5% left means 3 half-lives and 6.25% means 4.

How to do it

We have tagged 244 questions on this topic (221 different, 2021–2025, Papers 1–4). Two of them only touch fission or fusion and are not counted below. 53 questions mix more than one type, so the counts add up to more than the total.

Question type	Questions
Write or complete a decay equation, or state the change in the nucleus	48
Calculate with half-life (amount or fraction left, time taken, half-life)	47
State and compare properties of alpha, beta and gamma	40
Find the half-life from a decay graph or table	39
State safety precautions and effects of ionising radiation	31
Correct a count rate for background radiation	29
Define background radiation and name its sources	21
Choose a source (radiation and half-life) for a use and explain	19
Predict or draw deflection in electric and magnetic fields	18
Describe decay as random and spontaneous; define half-life	15
Identify emissions from absorption or range data	11
Detect radiation (detector and counter, count-rate units, cloud chamber)	4

1. Write or complete a decay equation, or state the change in the nucleus (48 questions)

Core (Paper 1): alpha and beta decay change the nucleus into a **different element**; gamma emission does not.

Extended:

1. **Write the particle's symbol**: ${}^{4}_{2}\alpha$ (or ${}^{4}_{2}\mathrm{He}$) for alpha, ${}^{\ 0}_{-1}\beta$ (or ${}^{\ 0}_{-1}\mathrm{e}$) for beta.
2. **Balance the top numbers** (nucleon numbers): the new nucleus has $A-4$ after alpha, A after beta.
3. **Balance the bottom numbers** (proton numbers): the new nucleus has $Z-2$ after alpha, $Z+1$ after beta.
4. **Use the right symbol** for the new nucleus (it is a different element, so never repeat the parent's symbol), and check both totals once more.

Variations you will meet:

- **"State the change in the nucleus during β-decay"**: a neutron changes into a proton and an electron, and the electron is emitted. Charge is conserved because $0=+1+(-1)$.
- **Count the particles in the new nucleus**: protons $=$ new Z, neutrons $=$ new $A-$ new Z. After alpha decay the nucleus has 2 fewer protons and 2 fewer neutrons; after beta decay 1 more proton and 1 fewer neutron.
- **Pick the right equation** from four: check the particle's numbers and that both rows balance.
- **Which decay makes the proton number fall by 1?** An alpha decay (-2) followed by a beta decay $(+1)$, in either order.
- **A decay series** (a chain of decays): each step where A stays the same and Z rises by 1 is a beta decay; each step where A falls by 4 is an alpha decay.
- **Why gamma doesn't change the equation**: gamma has no charge and no mass, so A and Z are unchanged; it only carries away energy.
- **Why is this isotope unstable?** It has too many neutrons (compare with a stable isotope of the same element with fewer neutrons), or the nucleus is too heavy.

2. Calculate with half-life (47 questions)

1. **Find the number of half-lives**: $n = \text{time} \div \text{half-life}$ (both in the same unit).
2. **Halve n times**, writing each step: $160 \to 80 \to 40 \to 20 \to 10$.
3. **Answer the question asked**: the amount left, the fraction left, or the fraction (or mass) that has **decayed**, which is start $-$ left.

Variations you will meet:

- **Time taken** to fall from one value to another: count the halvings, then time $= n\times$ half-life.
- **Find the half-life** from a start and an end value: count the halvings, then half-life $= \text{time} \div n$. For example, $2400 \to 300$ is 3 halvings.
- **Percentage left**: $50\%, 25\%, 12.5\%, 6.25\%$ after 1, 2, 3, 4 half-lives.
- **Working backwards**: double the final amount once for each half-life to find the starting amount.
- **Age of an object** (for example carbon-14 in old wood): count how many half-lives it takes for the amount to fall to the value measured, then multiply by the half-life.
- **Extended, with background**: see type 6.

3. State and compare properties of alpha, beta and gamma (40 questions)

1. **Nature**: alpha is a helium nucleus (2 protons, 2 neutrons); beta is a fast electron from the nucleus; gamma is an electromagnetic wave.
2. **Charge**: $+2$, -1, 0. Give the number **with its sign**, not just "positive".
3. **Ionising**: alpha most, gamma least. **Penetrating**: gamma most, alpha least.
4. **Stopped by**: paper (alpha), a few mm of aluminium (beta), thick lead only reduces gamma.

Variations you will meet:

- **Tick-tables and line-matching**: one tick per row unless told otherwise.
- **Extended: why alpha ionises more than beta.** Give two reasons: it has a larger charge ($+2$ against -1) and more kinetic energy (it also moves more slowly because of its large mass). Beta having less mass does **not** make it more ionising.
- **Extended: alpha's numbers**: proton number 2, nucleon number 4, charge $+3.2 \times 10^{-19}$ C (twice the size of the electron's charge).
- **Extended: how alpha ionises air** (for example in a smoke alarm): the alpha-particles collide with air molecules and knock electrons out of them, leaving positive ions and free electrons.

4. Find the half-life from a decay graph or table (39 questions)

1. **Choose two count rates in the ratio 2 : 1** (for example the value at time 0 and half of it). Use a value from the graph's axis, not the last time shown on the graph.
2. **Read the time for each** from the curve, and **draw the lines on the graph** to show your working.
3. **Half-life = the difference between the two times.** A check with a second pair should give the same answer.

With a **table**, find two times whose count rates are in the ratio 2 : 1, or estimate between rows.

Variations you will meet:

- **Extended, with background in the readings**: subtract the background first (see type 6). The background is the level the curve flattens out to at long times.
- **Which isotope has the longest half-life?** The curve that falls most slowly.
- **Predict a missing table value**: halve the (corrected) count rate one half-life earlier.
- **Growth of the product**: if a graph shows the amount of the **new** (stable) nucleus growing, half the parent has gone when the product reaches half its final value.

5. State safety precautions and effects of ionising radiation (31 questions)

1. **Effects**: cell death, mutation, cancer.
2. **Precautions**: give two **different** ones, each specific:
    - store in a lead-lined box, locked away and labelled;

- use tongs, keeping the source at arm's length and away from the body;
- keep the exposure time as short as possible;
- shield with lead or concrete; wear a radiation badge to monitor the dose.

3. **Extended, "explain"**: say what each precaution does: less time $\Rightarrow$ smaller dose; greater distance $\Rightarrow$ less radiation reaches you; lead $\Rightarrow$ absorbs the radiation.

Variations you will meet:

- **Which is not a precaution?** Cardboard boxes, goggles alone, a fire extinguisher, cooling the source, or getting closer.
- **Why lead?** It absorbs the radiation (it does not neutralise, repel or slow the decay).
- **Extended: is a thin plastic box safe for a source of alpha and gamma?** No: plastic would stop the alpha, but gamma passes straight through it, so lead is needed.
- **Extended: why is a very short half-life hazardous?** The nuclei decay very quickly, so the source gives out a lot of radiation in a short time.

6. Correct a count rate for background radiation (29 questions)

1. **Put everything in counts per minute (or per second)** first: $\text{count rate} = \text{counts} \div \text{time}$. If background is measured several times, take the mean.
2. **Subtract** the background: corrected $=$ measured $-$ background.
3. **If the source then decays**, halve the **corrected** rate once per half-life.
4. **Add the background back** if the question asks what the **detector** will read.

For example, background 20 counts/minute, reading 500 counts/minute, half-life 2 hours: after 4 hours the source gives $480 \to 240 \to 120$, and the detector reads $120 + 20 = 140$ counts/minute.

Variations you will meet:

- **Half-life from readings that include background**: correct each reading first, then look for the ratio 2 : 1.
- **Find the background**: from a reading with no source, or from the level a decay curve flattens out to.
- **"Why do the readings vary / not lie on the curve?"** Decay is random, and background also varies.

7. Define background radiation and name its sources (21 questions)

1. **Definition**: ionising radiation that is present all the time from the surroundings, even when no radioactive source is being used.
2. **Sources**: radon gas in the air, rocks and buildings, food and drink, cosmic rays; from people: medical X-rays, nuclear power and waste, weapons tests.

Watch for distractors: mobile phones, microwaves, radio, infrared, visible light and seismic waves are not background radiation. Radon gas is the largest single part.

8. Choose a source (radiation and half-life) for a use and explain (19 questions)

1. **Choose the radiation** from what it must do: pass out of a body or through soil (gamma), be partly absorbed by a thin sheet (beta), ionise air strongly over a short range (alpha).
2. **Say why the others won't work**, if asked: alpha would be stopped completely, gamma would pass through unchanged, and so on.
3. **Choose the half-life**: long for a source that must last (smoke alarm, thickness gauge, sterilising, treatment beam); short (minutes to days) for anything put inside a body or the ground.
4. **Explain the half-life** both ways: not too short (it would decay before it could be used, or the count rate would fall during measurement); not too long (it would stay radioactive in the patient or the environment).

Link every property to the use: "alpha is absorbed by paper **so the alpha-particles are absorbed by the smoke**", not just "alpha is stopped by paper". The table in "Understand it" has the standard uses.

Variations you will meet:

- **An alpha source used to treat cancer** (for example an alpha-emitter injected or implanted into a patient): alpha has such a short range that it would be absorbed by the skin, so from outside the body it could not reach the tumour. It must be placed **inside** the body, next to the tumour, where it strongly ionises and kills only the nearby cells and hardly reaches healthy tissue further away.
- **Why a thickness-gauge source is replaced after some years**: work out how much is left, for example after two half-lives only 25% of the nuclei (and of the count rate) remain. The count rate becomes too low, too close to the background count, so changes in thickness no longer make a clear change in the reading.

9. Predict or draw deflection in electric and magnetic fields (18 questions)

1. **Gamma**: straight on, in both fields.
2. **Electric field**: alpha towards the negative plate, beta towards the positive plate.
3. **Magnetic field**: use the left-hand rule for alpha with the current in its direction of motion; beta curves the opposite way.
4. **Beta is deflected more** than alpha (much smaller mass). On a drawing, make the beta curve tighter, and start both curves where the particles enter the field.

Variations you will meet:

- **Poles either side** (field from N to S across the path): the left-hand rule gives deflection **into** or **out of** the page.
- **Why is beta deflected more?** Its mass is much smaller (even though its charge is smaller).
- **Core (Paper 1)**: only that gamma is not deflected because it has no charge.

10. Describe decay as random and spontaneous; define half-life (15 questions)

- **Half-life**: the time taken for **half the nuclei** of the isotope in a sample to **decay** (or for the count rate to halve). Not "half the neutrons", not "half the time for all of it to decay".

- **Random**: you can't predict which nucleus decays or when. **Spontaneous**: nothing triggers it, and it is not affected by temperature, pressure, lead or chemical changes.
- **Extended: why is the nucleus unstable?** Too many neutrons, or too heavy.

11. Identify emissions from absorption or range data (11 questions)

1. **Compare each reading with the one before**, and with the background.
2. **Paper**: a big drop means alpha is present; no change means no alpha.
3. **A few mm of aluminium**: a big drop means beta is present.
4. **Counts above background get through aluminium or lead**: gamma is present.
5. **Give the evidence**: quote the readings ("the count rate hardly changes when paper is added, so there is no alpha").

A count rate that falls to background within a few centimetres of air also means alpha.

12. Detect radiation (4 questions)

- A **detector connected to a counter** measures ionising nuclear radiation (not light, microwaves or heat). With no source, it measures background.
- Count rate is in **counts/s** or **counts/minute**.
- **Extended rarity, the cloud chamber**: particles leave tracks of droplets. Alpha tracks are short, thick and straight (heavily ionising, short range); beta tracks are longer, thin and wiggly.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

A sample contains 160 mg of a radioactive isotope. The half-life of the isotope is 7 days.

(a) State what is meant by the half-life of a radioactive isotope. **[1]**

(b) Calculate the mass of the isotope left after 28 days. **[3]**

(c) Calculate the mass of the isotope that has decayed in these 28 days. **[1]**

(a) The time taken for half the nuclei of the isotope in a sample to decay. **B1**

(b) Number of half-lives $= 28 \div 7 = 4$. **C1**

$160 \rightarrow 80 \rightarrow 40 \rightarrow 20 \rightarrow 10$, or $160 \times \left(\frac{1}{2}\right)^4$. **C1**

Mass left $= 10$ mg. **A1**

(c) $160 - 10 = 150$ mg. **B1** (Only $\frac{1}{16}$ is left, so $\frac{15}{16}$ has decayed.)

Example 2 (Extended)

A detector in a laboratory measures a background count rate of 24 counts/minute. A radioactive source is placed in front of the detector, and the reading is 824 counts/minute. The half-life of the source is 45 minutes.

Calculate the expected reading on the detector 3.0 hours later. **[4]**

Corrected count rate $= 824 - 24 = 800$ counts/minute. **C1**

3.0 hours $= 180$ minutes $= 180 \div 45 = 4$ half-lives. **C1**

$800 \rightarrow 400 \rightarrow 200 \rightarrow 100 \rightarrow 50$ counts/minute from the source. **C1**

Reading $= 50 + 24 = 74$ counts/minute. **A1**

Stopping at 50 (forgetting the background) or halving 824 (not subtracting it first) loses marks.

Example 3 (Extended)

Polonium-210 has proton number 84. It decays by emitting an α-particle and forms an isotope of lead, symbol Pb.

(a) Write the nuclide equation for this decay. **[3]**

(b) Determine the number of neutrons in the lead nucleus. **[1]**

(c) Give two reasons why α-particles are more strongly ionising than β-particles. **[2]**

(a)

$$^{210}_{84}\mathrm{Po} \;\rightarrow\; ^{206}_{82}\mathrm{Pb} + ^{4}_{2}\alpha$$

B1 for $^{210}_{84}\mathrm{Po}$, **B1** for $^{4}_{2}\alpha$, **B1** for $^{206}_{82}\mathrm{Pb}$ (the numbers balance: $210 = 206 + 4$ and $84 = 82 + 2$).

(b) $206 - 82 = 124$. **B1**

(c) Any two of: an α-particle has a larger charge ($+2$ compared with -1); it has more kinetic energy; it has a larger mass, so it moves more slowly and spends longer near each atom. **B1 B1**

Example 4 (Extended)

A hospital tests an isotope that emits γ-radiation. A detector is placed near a sample, and the readings in the table include a background count rate of 15 counts/minute.

Time / minutes	0	10	20	30	40
Reading / counts per minute	415	298	215	156	115

(a) Use the table to determine the half-life of the isotope. **[3]**

(b) Calculate the reading on the detector at 60 minutes. **[2]**

(c) The isotope is to be injected into patients as a tracer, to find a tumour. Explain why its type of radiation and its half-life make it suitable. **[3]**

(a) Corrected count rate at time 0: $415 - 15 = 400$ counts/minute. **C1**

Half of this is 200, which means a reading of $200 + 15 = 215$ counts/minute. **C1**

That reading is at 20 minutes, so the half-life is 20 minutes. **A1**

Check: the corrected rate at 40 minutes is $115 - 15 = 100$, half of 200, again 20 minutes later.

(b) 60 minutes is 3 half-lives: $400 \to 200 \to 100 \to 50$. **C1**

Reading $= 50 + 15 = 65$ counts/minute. **A1**

(c) Gamma passes out of the body, so it can be detected outside the patient. **B1** It is only weakly ionising, so it does little damage to cells. **B1** A half-life of 20 minutes is long enough to carry out the scan, but the activity falls quickly, so the patient is not left radioactive for long. **B1**

Common mistakes

- **Forgetting background.** Examiners see it every year: candidates halve the measured reading instead of the corrected one, or forget to add the background back when asked for the detector's reading. Subtract, halve, then add back.
- **Mixing up time units in background.** "180 counts in 10 minutes" is 18 counts/minute. Convert counts to a rate before subtracting.
- **Taking half-life as half the time on the graph.** Many weaker candidates halve the last time shown on the axis. The half-life is the time for the **count rate** to halve; read it from the curve.
- **Half-life definitions that are nearly right.** "The time for half the neutrons to decay" or "half the time for the source to decay" score nothing. Say "half the **nuclei** ... to decay".
- **Giving alpha's charge as just "positive".** The charge is $+2$ (or $+3.2 \times 10^{-19}$ C). A beta-particle's charge is -1, and it is an electron: many candidates don't know this.
- **Not knowing what happens in beta decay.** A neutron turns into a proton and an electron; the electron comes out of the nucleus, not the electron shells.

- **Unbalanced equations.** Writing the beta-particle's nucleon number as 1, giving alpha the wrong numbers, or writing the parent's symbol again on the right. Check both rows add up.
- **Confusing alpha and gamma** when comparing ionising and penetrating ability. Alpha: most ionising, least penetrating. Gamma: the opposite.
- **Saying lead "stops" gamma.** Thick lead greatly **reduces** gamma; nothing stops all of it.
- **Deflection drawn the wrong way.** Use the left-hand rule for alpha; draw beta curving the opposite way and more sharply, both starting where the beam enters the field. Some candidates draw the beta curve starting later, rather than bending more.
- **Wrong reason for alpha's ionisation.** Alpha ionises more because it has more charge and more kinetic energy, not because it is "bigger" or because beta is "faster".
- **Uses without links.** "Alpha is stopped by paper" earns little on its own in a smoke-alarm question; say what that means for the alarm.
- **Calling non-ionising waves radiation hazards.** Microwaves and mobile phone signals are not ionising nuclear radiation.

How to get the marks

- **"State"** needs a short fact, such as "beta" or "lead-lined box". **"Explain"** needs the reason too, often with "so" or "because" linking the property to the situation.
- **Half-life calculations** earn method marks (**C1**) for the number of half-lives and for the halving steps, even if the final answer slips. Write the chain $160 \to 80 \to 40 \to \ldots$ in full.
- **Half-life from a graph**: draw the lines on the graph. The marks are for a pair of count rates in the ratio 2 : 1, the matching pair of times, and the answer.
- **Background**: show the subtraction as a separate line, then the halving, then the addition. Give units: counts/minute or counts/s.
- **Nuclide equations**: each correct nuclide usually earns a mark, so write every symbol with both numbers, including the particle's.
- **Deflection drawings**: label each path (α, β, γ) as asked. Marks go for the direction of each and for beta being more curved (smaller radius).
- **"Two precautions"** must be different ideas (time, distance, shielding, storage), not the same one twice.
- **Choosing a source**: give the radiation, the half-life, and reasons for **both**; if asked why the others are unsuitable, deal with each.
- **Multiple choice**: in "which is **not** ..." questions, look for the one false statement.
- Give answers to the accuracy of the data, usually 2 or 3 significant figures.

Quick check

1. The background count in a laboratory is 90 counts in 5.0 minutes. With a source in front of the detector, the reading is 618 counts/minute. Calculate the count rate due to the source.

2. Cobalt-60, ${}^{60}_{27}\mathrm{Co}$, decays by β-emission to nickel, Ni. Write the nuclide equation and state the change inside the nucleus.
3. Thorium-232, ${}^{232}_{90}\mathrm{Th}$, decays by α-emission to an isotope of radium. State the nucleon number and proton number of the radium nucleus and find how many neutrons it has.
4. The corrected count rate from a sample falls from 2400 counts/minute to 300 counts/minute in 27 hours. Calculate the half-life.
5. A detector near a source reads 362 counts/minute. With a sheet of paper between them it reads 361 counts/minute, and with 5 mm of aluminium it reads 12 counts/minute. The background count rate is 12 counts/minute. Which radiation does the source emit? Give your evidence.
6. A beam of α-particles and β-particles passes between two horizontal plates: the top plate is positive and the bottom plate is negative. Describe the path of each type of particle.

Answers

1. Background $= 90 \div 5.0 = 18$ counts/minute. Count rate due to the source $= 618 - 18 = 600$ counts/minute.
2. ${}^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni} + {}^{0}_{-1}\beta$ (top: $60 = 60 + 0$; bottom: $27 = 28 - 1$). A neutron changes into a proton and an electron, and the electron is emitted.
3. Nucleon number $232 - 4 = 228$; proton number $90 - 2 = 88$: ${}^{228}_{88}\mathrm{Ra}$. Neutrons $= 228 - 88 = 140$.
4. $2400 \rightarrow 1200 \rightarrow 600 \rightarrow 300$ is 3 half-lives, so the half-life is $27 \div 3 = 9$ hours.
5. Beta only. The paper makes almost no difference $(362 \rightarrow 361)$, so there is no alpha. The aluminium brings the reading down to 12, which is just background, so the source emits beta and nothing gets through the aluminium, so there is no gamma.
6. The α-particles curve down, towards the negative plate. The β-particles curve up, towards the positive plate, and are deflected much more because their mass is much smaller.

Past questions to try

- **0625/42/M/J/23 Q9**: properties of the three emissions, beta decay, a half-life with background, and safety.
- **0625/31/M/J/22 Q11**: deciding which emissions a source gives from absorber readings.
- **0625/41/M/J/24 Q8**: a beta-decay equation, why gamma changes nothing, and deflection in a magnetic field.
- **0625/43/M/J/24 Q10**: background radiation, and choosing the radiation and half-life for finding a leak.