OCR GATEWAY A GCSE PHYSICS J249 | P6

RADIOACTIVITY

Exam practice notebook

FOUNDATION TIER

12 diagnostic choices + 18 topic sets
2 extended responses + 5 timed sets
162 marks | Original questions | Detailed answers at the end

P6.1 Radioactive emissions

P6.2 Uses and hazards

Name: _____

Class: _____ Date: _____

Independent practice resource. Not an official OCR examination paper. Past-paper questions, mark schemes and logos are not reproduced.

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AI-assisted text and diagrams. Publisher: GCSE Online Tutoring x RS Remote Tutoring.

ROUTE AND TIER COVERAGE

How to use this notebook

Start with the diagnostic choices, then attempt the topic sets after studying each sub-topic. Allow around 8-10 minutes per six-mark set. Complete each extended response in about 10 minutes. The fresh timed check has 30 marks with a suggested 40 minutes.

> This is a P6 topic practice collection, not a complete GCSE paper. Its marks and timings are independent guidance. No GCSE grade boundaries are assigned.

Calculator allowed. Use the optional reference page if your teacher permits it. Show equations, substitutions and units. Read graph axes carefully and balance both rows of nuclear numbers. Unless stated otherwise, beta means beta-minus. No real radioactive source is needed to answer these questions.

Both tiers: nuclear composition and isotopes; emissions and balanced equations; electron levels; random decay, activity and background correction; half-life concept and graph reading; penetration, uses, contamination and irradiation; fission and fusion.

P6.1k is Higher-only: numerical net decline and ratios after whole numbers of half-lives. This book does not assess repeated-half-life ratio calculations. Its half-life tasks interpret the concept or read a half-life from supplied data.

Mark, correct and retry

All answers follow the final score record. Each worked answer includes credit points, the reasoning or calculation method, and a common-error note. Use the marking instructions at the start of that section.

Command	Answer approach
Calculate	Show a relationship, substitute, then give a result with units.
Explain	Connect a cause, interaction or observation to its physical consequence.
Draw	Use clear labels, appropriate directions and the stated scale.
Evaluate	Use evidence to judge a claim and recognise limitations.

OPTIONAL SUPPORT | NOT THE OFFICIAL EQUATION SHEET

Practice equation reference

Relationship / idea	Reference
Nuclear notation	A = protons + neutrons; Z = protons; neutrons = A - Z.
Charge of a neutral atom	Number of electrons equals number of protons.
Activity	Nuclear decays per second; unit Bq. Detector count rate is not automatically the activity.
Mean detector rate	Counts / collection time. Use consistent time units.
Background correction	Source-only rate = total rate - background rate.
Half-life concept	Time for a large population of undecayed nuclei, or its activity, to halve on average.
Nuclear equations	Conserve total A and total Z on the two sides.

Use 1 minute = 60 seconds when converting count rates. An electron’s A = 0 in a nuclear equation means it is not a nucleon; it does not mean its physical mass is zero. Gamma is an uncharged photon.

Source alignment: OCR J249 specification, version 5.0 (July 2026), P6 and relevant practical/mathematical skills. Checked 13 November 2026. AI-assisted preparation. Independent resource; not produced, endorsed or approved by OCR.

Official OCR J249 specification

2021-2025 | NEWLY WRITTEN QUESTIONS

Five-series reference review

P6-relevant tasks and marking guidance in J249/02 (Foundation) and J249/04 (Higher) were reviewed for November 2021 and June 2022, 2023, 2024 and 2025. These are the latest five public question-paper series linked in the assessment archive used for this edition.

The papers guide skill coverage, task formats and demand. These notebook questions use original contexts, data and wording; they are not one-to-one paraphrases of official items. No official paper or marking table is reproduced.

2021: Nuclear composition, alpha equations and context-dependent hazards; Higher half-life graphs and fission/fusion explanations.

2022: Isotope labels, beta changes and tracer choices; Higher repeated-half-life calculations and chain reactions.

2023: Fission/fusion representations, tracer half-life choices and radiation detection; Higher decay reasoning and nuclear-process comparisons.

2024: Counting methods, contamination and irradiation, half-life meaning and nuclear equations across both tiers.

2025: Beta-minus changes, containment and shielding; Higher identification from radiation/half-life data and fission/fusion energy questions.

Official archive: question papers and mark schemes

The companion reference record contains the direct official links. This collection practises P6 skills; it does not predict future questions. Tasks may combine outcomes within P6.

D1-D4 | 4 MARKS

Diagnostic multiple choice

D1. Two atoms have the same proton number but different neutron numbers. What are they? [1]

A Isotopes of one element B Two different elements in every case C Always oppositely charged ions D Both beta particles

Answer: _____

D2. What is an alpha particle? [1]

A An electron from an atomic shell B A helium nucleus with two protons and two neutrons C An electromagnetic wave D A single neutron

Answer: _____

D3. In beta-minus decay, how does the daughter proton number change? [1]

A It falls by two B It stays fixed in every case C It rises by one D It rises by four

Answer: _____

D4. What happens to nuclear A and Z during gamma emission? [1]

A Both fall B A rises and Z falls C Both rise D Both stay the same

Answer: _____

D5-D8 | 4 MARKS

Diagnostic multiple choice

D5. Which describes half-life? [1]

A The exact lifetime of every nucleus B The time for a large population of undecayed nuclei to halve on average C The time until no nuclei remain D The detector's collection time in every experiment

Answer: _____

D6. What does 1 Bq mean? [1]

A One detected count each minute B One coulomb each second C One nuclear decay each second D One joule each kilogram

Answer: _____

D7. Which particle has nuclear mass number 1 and charge 0? [1]

A Neutron B Proton C Alpha particle D Beta-minus electron

Answer: _____

D8. Which emission is most penetrating in the usual alpha/beta/gamma comparison? [1]

A Alpha B Beta in every material C They all have identical penetration D Gamma

Answer: _____

D9-D12 | 4 MARKS

Diagnostic multiple choice

D9. Which is evidence of contamination rather than irradiation alone? [1]

A Radiation passes through a region B A detector clicks near an external sealed source C Radioactive material is deposited on an object D A source is removed after exposure with no material transfer

Answer: _____

D10. An electron absorbs energy but remains bound at a higher allowed level. What is this? [1]

A Excitation B Fission C Fusion D Complete ionisation

Answer: _____

D11. Which process joins light nuclei into a heavier nucleus? [1]

A Ordinary evaporation B Nuclear fission C Electron emission from a metal D Nuclear fusion

Answer: _____

D12. A neutral atom loses an outer electron. What is left? [1]

A A new element automatically B A positive ion of the same element C A negative ion with an extra neutron D A gamma ray only

Answer: _____

TOPIC PRACTICE | Q1 | 6 MARKS

Nuclei and isotope labels

Two atoms are represented by $^{24}_{12}Mg$ and $^{26}_{12}Mg$. Both are initially neutral.

Q1(a) State the number of protons and neutrons in magnesium-24. [2]

Q1(b) State the number of neutrons and electrons in the neutral magnesium-26 atom. [2]

Q1(c) Explain why they are isotopes of the same element. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q2 | 6 MARKS

Identify the emitted radiation

Four emissions are labelled α, β^-, γ and n. In this notebook beta means beta-minus. Use the GCSE nuclear-equation convention for mass numbers.

Q2(a) Describe an alpha particle’s composition and charge. [2]

Q2(b) Describe beta-minus radiation and gamma radiation. [2]

Q2(c) State a neutron’s relative charge and its nuclear mass number. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q3 | 6 MARKS

Balance an alpha decay

Radium-226 undergoes alpha decay. The daughter is radon, symbol Rn. Use the pattern $^{226}_{88}\text{Ra} \rightarrow \text{Rn} + {}^{4}_{2}\text{He}$.

Q3(a) Calculate the daughter mass number. [2]

Q3(b) Calculate the daughter proton number. [2]

Q3(c) Write the completed nuclear equation. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q4 | 6 MARKS

Balance a beta-minus decay

Phosphorus-32 emits a beta-minus particle. Sulfur is the daughter element, symbol S. The electron may be written $^{0}_{-1}e$.

Q4(a) Complete the mass and proton numbers of the sulfur daughter. [2]

Q4(b) Write the balanced equation starting from $^{32}_{15}P$. [2]

Q4(c) Explain the nuclear change that accounts for these numbers. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q5 | 6 MARKS

Gamma and neutron bookkeeping

An asterisk marks an excited nucleus. One process is $^{99}_{43}\mathrm{Tc}^{*} \rightarrow {}^{99}_{43}\mathrm{Tc} + \gamma$. In a separate simplified model, a nucleus with A = 87 and Z = 35 emits one neutron.

Q5(a) State how A and Z change in the gamma process. [2]

Q5(b) Calculate A and Z for the daughter after the model neutron emission. [2]

Q5(c) Explain what changes in the gamma-emitting nucleus if its particle counts stay the same. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q6 | 6 MARKS

Electron excitation and ionisation

An electron in an atom absorbs energy and moves to a higher allowed energy level. Later an electron can either return to a lower level or escape from the atom.

Q6(a) Name the first process and state whether the electron is still bound. [2]

Q6(b) Describe what happens when an electron falls to a lower energy level. [2]

Q6(c) Explain how losing an outer electron changes the atom. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q7 | 6 MARKS

Random decay and activity

A sample contains many identical unstable nuclei. A detector records their emissions over equal time intervals.

Q7(a) Explain what random decay means for one chosen nucleus. [2]

Q7(b) Define activity and give its unit. [2]

Q7(c) Explain why successive detector readings need not be identical even under steady conditions. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q8 | 6 MARKS

Correct a detector reading for background

Over 120 s, a detector records 240 counts with a source present. A separate 120 s background measurement records 60 counts. Detector geometry is unchanged.

Q8(a) Calculate the mean background count rate in counts per second. [2]

Q8(b) Calculate the source-only count and source-only count rate. [2]

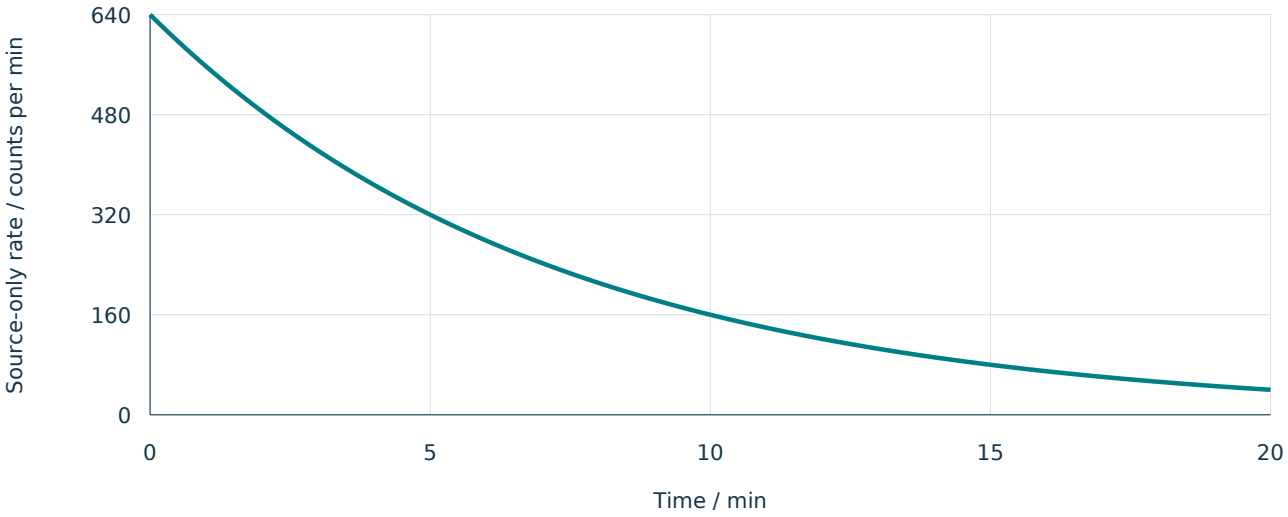
Q8(c) Explain why 1.5 counts/s is not necessarily the source’s activity of 1.5 Bq. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q9 | 6 MARKS

Read a half-life from a graph

The curve shows the expected source-only count rate of one isotope after background correction. The detector geometry is fixed.



Q9(a) Use the initial value and its half-value to read the half-life. [2]

Q9(b) Define half-life in terms of unstable nuclei. [2]

Q9(c) Explain why the curve becomes less steep with time. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q10 | 6 MARKS

Penetration and absorber evidence

The table gives long-run mean count rates at fixed detector geometry. Background is 30 counts/min; uncertainty is much smaller than 4 counts/min. Use the usual GCSE absorber model.

Absorber	Total counts/min
None	720
Paper	280
Thin aluminium	50
Thick lead	34

Q10(a) Calculate the source-only rates with aluminium and with thick lead. [2]

Q10(b) Identify the radiation mainly responsible for the large decrease when paper is inserted, and explain. [2]

Q10(c) Evaluate the claim that the lead has stopped every gamma ray. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q11 | 6 MARKS

Ionisation and location of a source

Compare an alpha-emitting material outside intact skin with the same material entering the body. Consider also gamma radiation incident on the body from outside.

Q11(a) Explain why external alpha radiation is relatively easy to shield. [2]

Q11(b) Explain why an internal alpha source can be hazardous. [2]

Q11(c) Explain one reason gamma can pose a significant external irradiation hazard. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q12 | 6 MARKS

Contamination or irradiation?

In situation A, a sealed external gamma source exposes an object and is then removed. In situation B, a droplet containing radioactive material remains on another object. Use the ordinary school model without nuclear activation.

Q12(a) Classify A and explain whether radioactive material was transferred. [2]

Q12(b) Classify B and explain why exposure can continue after the original bottle is removed. [2]

Q12(c) Explain how contamination can also cause irradiation. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q13 | 6 MARKS

Choose a tracer for a model test

A supervised model system needs a tracer detectable from outside a pipe during a two-hour test. Candidate X emits alpha and lasts many years; Y emits gamma and has a half-life of several hours; Z emits gamma but has a half-life of a fraction of a second.

Q13(a) Choose the most suitable candidate and justify the emission type. [2]

Q13(b) Explain why Y has a more suitable half-life than either extreme. [2]

Q13(c) Explain why the suitability judgement needs more than half-life alone. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q14 | 6 MARKS

A sheet-thickness gauge

A sheet passes between a sealed beta source and a detector. A thicker sheet absorbs more beta radiation. The source-detector geometry and source behaviour are stable over the observation interval.

Q14(a) State how the detector rate changes if the sheet becomes thicker and explain. [2]

Q14(b) Explain why alpha and gamma can be less suitable than beta for this particular thin-sheet gauge. [2]

Q14(c) Explain why a sealed source reduces contamination risk but does not remove irradiation risk. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q15 | 6 MARKS

Diagnosis and treatment: different aims

Consider two theoretical applications: locating an injected gamma-emitting tracer with an external detector, and delivering a controlled radiation dose to a tumour.

Q15(a) Explain why gamma emission can be useful for the tracer image. [2]

Q15(b) Explain why ionisation can be useful in radiotherapy despite being a hazard in other contexts. [2]

Q15(c) State two factors, apart from the radiation name alone, relevant to evaluating exposure. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q16 | 6 MARKS

Fission and a chain reaction

A simplified fission model is $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$. The products also receive released energy.

Q16(a) Check the total mass numbers and charge numbers on both sides. [2]

Q16(b) Describe how this process can lead to a chain reaction. [2]

Q16(c) State two forms in which released energy may appear initially. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q17 | 6 MARKS

Fusion and nuclear energy

Two light nuclei can join to make a heavier nucleus in a nuclear-fusion reaction. The total energy balance can include radiation and particle motion.

Q17(a) Describe fusion and distinguish it from fission. [2]

Q17(b) Explain why very high temperature helps fusion occur. [2]

Q17(c) Explain why released fusion energy is not ordinary chemical burning. [2]

Score: ____ / 6 Review: secure / developing / revisit

TOPIC PRACTICE | Q18 | 6 MARKS

A dice model of decay

A class rolls a large number of dice, removes every die showing a six and rerolls the survivors. Removed dice represent decayed nuclei. Different groups obtain slightly different totals.

Q18(a) Explain what the random roll represents. [2]

Q18(b) Explain why different groups do not remove exactly the same number each round. [2]

Q18(c) State one useful feature and one limitation of the model. [2]

Score: ____ / 6 Review: secure / developing / revisit

P6.1l; P6.2a-b | 6 MARKS

E1: Evaluate exposure claims

In the ordinary school model without activation, one person is exposed briefly to an external sealed gamma source. In a separate situation alpha-emitting dust remains inside a person. Evaluate these claims: (1) gamma exposure alone leaves the first person contaminated; (2) the dust is harmless because alpha has short range; (3) ordinary gloves block gamma as effectively as they contain radioactive dust.

Write a coherent response. Use calculations, evidence and cause-and-effect links as appropriate. Suggested time: 10 minutes.

P6.2d-e | 6 MARKS

E2: Correct a museum explanation

A museum label says: “Fission joins heavy nuclei, fusion is only chemical burning and needs no special temperature, and neutrons from one fission cannot cause another.” Write a corrected explanation of fission and fusion, including chain reactions and the origin of released energy.

Write a coherent response. Use calculations, evidence and cause-and-effect links as appropriate. Suggested time: 10 minutes.

FRESH QUESTIONS | 30 MARKS

Timed P6 check

Suggested time: 40 minutes. Attempt all 5 sets without consulting answers. Show method and units. The equation reference may be used only if your teacher chooses.

Start time: _____ Finish time: _____
Equation reference permitted? yes / no

Use this check to identify what to practise next. The score is not an official GCSE grade.

TIMED CHECK | T1 | 6 MARKS

T1: Isotopes and beta-minus

Two sodium isotopes are $^{23}_{11}Na$ and $^{24}_{11}Na$. Sodium-24 emits beta-minus radiation to form magnesium.

T1(a) State the neutron number in each isotope. [2]

T1(b) Complete the magnesium daughter’s mass and proton numbers. [2]

T1(c) Write the balanced decay equation. [2]

Score: ____ / 6 Review: secure / developing / revisit

TIMED CHECK | T2 | 6 MARKS

T2: Detector data

A detector records 350 counts in 100 s with a source present and 50 counts in 100 s with the source absent.

T2(a) Calculate the background rate. [2]

T2(b) Calculate the corrected source rate. [2]

T2(c) Give two reasons not to call 3.0 counts/s the exact nuclear activity. [2]

Score: ____ / 6 Review: secure / developing / revisit

TIMED CHECK | T3 | 6 MARKS

T3: Penetration and a source seal

A sealed source emits beta and gamma. A suitable aluminium sheet absorbs essentially all the beta in this idealised test but allows a substantial gamma signal to pass.

T3(a) State which component remains after the aluminium and explain. [2]

T3(b) Explain why the sealed source can still irradiate a detector. [2]

T3(c) Explain what additional event would create contamination of a nearby surface. [2]

Score: ____ / 6 Review: secure / developing / revisit

TIMED CHECK | T4 | 6 MARKS

T4: A half-life statement

For one isotope at fixed detector geometry, a source-only model predicts an expected rate falling from 500 to 250 counts/min over 8.0 min.

T4(a) State the half-life and explain the reading. [2]

T4(b) Explain why this does not mean each nucleus lives for exactly 8.0 min. [2]

T4(c) Explain why a fresh measured value can lie slightly above or below the smooth expected graph. [2]

Score: ____ / 6 Review: secure / developing / revisit

TIMED CHECK | T5 | 6 MARKS

T5: Nuclear processes

One process splits a heavy nucleus after it absorbs a neutron. Another joins two light nuclei.

T5(a) Name both processes. [2]

T5(b) Explain how the first process can become a chain reaction. [2]

T5(c) State the physical origin of released nuclear energy and one initial output form. [2]

Score: ____ / 6 Review: secure / developing / revisit

COMPLETE AFTER MARKING

Score and improvement record

Set	Specification focus	Score / 6
Q1	P6.1a-c	
Q2	P6.1c-e,l	
Q3	P6.1e-g	
Q4	P6.1e-g	
Q5	P6.1d-g	
Q6	P6.1h-i	
Q7	P6.1d,j	
Q8	P6.1d; working scientifically	
Q9	P6.1j	
Q10	P6.1l; practical evidence	

Diagnostic: ____ / 12 Extended responses: ____ / 12

Topic sets: ____ / 108 Timed check: ____ / 30

Whole notebook: ____ / 162

Question to retry: _____ Correct physics and method:

COMPLETE AFTER MARKING

Score and improvement record

Set	Specification focus	Score / 6
Q11	P6.1l; P6.2a-b	
Q12	P6.2a-b	
Q13	P6.2b-c	
Q14	P6.2c; P6.1l	
Q15	P6.2b-c	
Q16	P6.2d	
Q17	P6.2e	
Q18	P6.1d,j; working scientifically	
T1	P6.1a-c,e-g	
T2	P6.1d; practical skills	

Diagnostic: ____ / 12 Extended responses: ____ / 12

Topic sets: ____ / 108 Timed check: ____ / 30

Whole notebook: ____ / 162

Question to retry: _____ Correct physics and method:

COMPLETE AFTER MARKING

Score and improvement record

Set	Specification focus	Score / 6
T3	P6.1l; P6.2a-b	
T4	P6.1j	
T5	P6.2d-e	

Diagnostic: ____ / 12 Extended responses: ____ / 12

Topic sets: ____ / 108 Timed check: ____ / 30

Whole notebook: ____ / 162

Question to retry: _____ Correct physics and method:

DETAILED SOLUTIONS AND MARKING GUIDANCE

ANSWERS

Stop here until you have attempted the questions. All answers are grouped from this page to the end.

Order: diagnostic answers; topic-practice worked answers; extended-response models; timed-check worked answers; nuclear-number, electron-level, decay-graph, penetration and nuclear-process reference answers.

Awarding credit

Each part shows its maximum mark. Award independent points once; accept equivalent scientific language and valid alternative methods. A correct calculation with suitable units earns full credit unless a specific drawing, explanation or method is required.

When an arithmetic error is carried into a later part, credit valid later methods that use it consistently. Do not award accuracy marks for incorrect values. Avoid penalising the same arithmetic error repeatedly. For nuclear equations check A and Z totals separately. Accept conventional particle symbols, including alpha as a helium nucleus and beta-minus as an electron.

The extended responses use six original independent credit points. Model paragraphs show one coherent full-credit response, not the only acceptable wording. They do not reproduce an official OCR level-of-response scheme.

For each diagnostic item award one mark for the single correct option and zero for another choice or multiple selections. Do not subtract marks. For graph reading, allow sensible reading precision from the supplied scale. Keep detector count rates distinct from actual nuclear activity.

No GCSE grade boundaries are assigned. Use the score record to identify calculation, explanation, graph or evaluation skills to revisit.

D1-D4 | REASONS INCLUDED

Diagnostic answers

D1: A [1]

Proton number identifies the element; neutron-number differences produce isotopes.

D2: B [1]

Alpha is a helium nucleus, with A = 4 and relative charge +2.

D3: C [1]

A neutron becomes a proton while a negative electron is emitted, so Z rises by one and A is unchanged.

D4: D [1]

Gamma removes excitation energy without removing protons or neutrons.

D5-D8 | REASONS INCLUDED

Diagnostic answers

D5: B [1]

Half-life is a statistical population property, not an individual decay timetable.

D6: C [1]

Becquerel is the activity unit: one decay per second.

D7: A [1]

A neutron is an uncharged nucleon with A = 1.

D8: D [1]

Gamma generally needs much thicker shielding for substantial attenuation than alpha or beta.

D9-D12 | REASONS INCLUDED

Diagnostic answers

D9: C [1]

Contamination means unwanted radioactive material is on or inside the object.

D10: A [1]

Excitation raises a bound electron’s energy; ionisation removes an electron from the atom.

D11: D [1]

Fusion joins light nuclei; fission splits a heavy one.

D12: B [1]

Proton number is unchanged, but the remaining atom has an electron deficit and net positive charge.

WORKED ANSWER | TOTAL 6 MARKS

Q1: Nuclei and isotope labels

Part (a) / 2

12 protons (1); 24 - 12 = 12 neutrons (1).

Part (b) / 2

26 - 12 = 14 neutrons (1); 12 electrons (1).

Part (c) / 2

They have the same proton number (1); they have different neutron numbers/mass numbers (1).

Reasoning and worked method

The lower number Z counts protons and identifies the element. The upper number A counts protons plus neutrons. Neutron number is A - Z. A neutral atom has as many electrons as protons, but the electrons are outside the nucleus and do not contribute to A.

Common error to avoid: Do not read the mass number as the neutron number. Changing proton number changes the element.

WORKED ANSWER | TOTAL 6 MARKS

Q2: Identify the emitted radiation

Part (a) / 2

Two protons and two neutrons/a helium nucleus (1); charge +2 in relative units (1).

Part (b) / 2

Beta-minus is a high-speed electron emitted in a nuclear change (1); gamma is electromagnetic radiation/a photon from the nucleus (1).

Part (c) / 2

Charge 0 (1); mass number 1 (1).

Reasoning and worked method

An alpha particle is not a neutral helium atom because it has no bound electrons. A beta-minus electron has charge -1 and is not a pre-existing atomic electron simply falling out of its shell. In nuclear bookkeeping beta has A = 0 because it is not a nucleon; its physical rest mass is small but not zero. Gamma is uncharged and has no rest mass.

Common error to avoid: Do not describe gamma as a neutron or alpha as an electromagnetic wave.

WORKED ANSWER | TOTAL 6 MARKS

Q3: Balance an alpha decay

Part (a) / 2

Mass numbers balance: 226 = Adaughter + 4 (1); Adaughter = 222 (1).

Part (b) / 2

Charge numbers balance: 88 = Zdaughter + 2 (1); Zdaughter = 86 (1).

Part (c) / 2

$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$ (2). Award 1 for correct symbols and emission with only one number error; do not penalise a consistent earlier arithmetic error twice.

Reasoning and worked method

Alpha emission removes two protons and two neutrons from the parent nucleus. A therefore falls by four and Z by two. Check the upper and lower number totals independently. The lower number changes, so the daughter is a different element.

Common error to avoid: Do not subtract four from the proton number. Alpha carries mass number 4 but charge number 2.

WORKED ANSWER | TOTAL 6 MARKS

Q4: Balance a beta-minus decay

Part (a) / 2

Daughter A = 32 (1); daughter Z = 16 (1).

Part (b) / 2

$^{32}_{15}P \rightarrow {}^{32}_{16}S + {}^{0}_{-1}e$ (2). Award 1 for correct parent/emission symbols with one daughter-number error; allow consistent earlier values for later method credit.

Part (c) / 2

A neutron changes into a proton while an electron is emitted (1); nucleon number stays fixed but proton number increases by one (1).

Reasoning and worked method

Upper-number balance is 32 = 32 + 0. Lower-number balance is 15 = 16 + (-1). The negative emitted charge explains why the daughter's positive charge number rises. Additional particles beyond the GCSE number-balancing model are not required in this equation.

Common error to avoid: The beta electron is produced in the nuclear change; do not say a proton leaves the nucleus or that an orbital electron becomes gamma.

WORKED ANSWER | TOTAL 6 MARKS

Q5: Gamma and neutron bookkeeping

Part (a) / 2

A is unchanged (1); Z is unchanged (1).

Part (b) / 2

A = 87 - 1 = 86 (1); Z = 35 because a neutron has no charge (1).

Part (c) / 2

Its energy decreases/the nucleus loses excitation energy (1); energy leaves as electromagnetic radiation/a gamma photon (1).

Reasoning and worked method

Gamma emission changes nuclear energy without removing protons or neutrons. Neutron emission removes one nucleon but no positive charge. The second process is explicitly a number-bookkeeping model, not a claim about the observed dominant decay channel of a named isotope.

Common error to avoid: Do not make every type of decay change the element. Gamma and neutron emission leave Z unchanged.

WORKED ANSWER | TOTAL 6 MARKS

Q6: Electron excitation and ionisation

Part (a) / 2

Excitation (1); it is still bound to the atom (1).

Part (b) / 2

The atom/electron loses energy (1); electromagnetic radiation is emitted with energy corresponding to the level difference (1).

Part (c) / 2

It becomes ionised/a positive ion (1); there are now more protons than bound electrons while the nucleus itself is unchanged (1).

Reasoning and worked method

Atomic electron transitions and nuclear transitions are different. Excitation rearranges bound electrons; ionisation removes an electron. Neither process by itself changes the element because proton number remains fixed. Atomic and nuclear changes can involve different electromagnetic frequencies; not every emitted photon is gamma.

Common error to avoid: Do not confuse a higher electron energy level with an increased nuclear mass number.

WORKED ANSWER | TOTAL 6 MARKS

Q7: Random decay and activity

Part (a) / 2

Its exact decay time cannot be predicted (1); only a probability of decay in a time interval can be assigned (1).

Part (b) / 2

Activity is the number of nuclear decays per second (1); becquerel/Bq (1).

Part (c) / 2

Individual decay events occur randomly (1); the finite number detected in each equal interval therefore fluctuates statistically (1).

Reasoning and worked method

A smooth activity model describes a large population’s expected behaviour, not an exact timetable for individual nuclei. A detector count rate may be smaller than actual activity because not every emission reaches it or is detected. One becquerel means one decay per second, not one detected count per minute.

Common error to avoid: Do not assign every nucleus an identical fixed lifetime or assume a fluctuating count automatically proves equipment failure.

WORKED ANSWER | TOTAL 6 MARKS

Q8: Correct a detector reading for background

Part (a) / 2

Rate = 60/120 (1); 0.50 counts/s (1).

Part (b) / 2

Net source count = 240 - 60 = 180 (1); source-only rate = 180/120 = 1.5 counts/s (1).

Part (c) / 2

The detector may register only some emitted radiation (1); actual activity counts all nuclear decays, whereas detector rate depends on geometry/efficiency and emission details (1).

Reasoning and worked method

Use equal collection times or convert both measurements to rates before subtraction. The 240-count total includes background. Removing the 60 background counts leaves 180 attributed to the source during the same two minutes. Detector counts and nuclear decays must not be treated as interchangeable without an efficiency model.

Common error to avoid: Do not subtract counts measured over different durations without first putting them on a common time basis.

WORKED ANSWER | TOTAL 6 MARKS

Q9: Read a half-life from a graph

Part (a) / 2

Half of 640 is 320 counts/min (1); the graph reaches that at 5.0 min, so half-life = 5.0 min (1).

Part (b) / 2

The time for the number of undecayed nuclei in a large sample (1) to fall to half its previous value on average (1).

Part (c) / 2

Fewer unstable nuclei remain (1); fewer decays per interval occur on average, so the count rate falls more slowly in absolute terms (1).

Reasoning and worked method

The graph is a statistical expectation for source count rate, not a claim that every measured point lies exactly on the curve. Half-life describes a population, not the lifetime of each nucleus. The first halving takes five minutes.

Common error to avoid: Do not say all nuclei decay exactly at five minutes or that the half-life grows as the curve becomes shallower.

WORKED ANSWER | TOTAL 6 MARKS

Q10: Penetration and absorber evidence

Part (a) / 2

Aluminium: 50 - 30 = 20 counts/min (1); lead: 34 - 30 = 4 counts/min (1).

Part (b) / 2

Alpha (1); it is readily absorbed by paper/has low penetration (1).

Part (c) / 2

The non-zero 4 counts/min source signal contradicts complete stopping (1); thick lead attenuates gamma strongly but does not necessarily absorb all of it (1).

Reasoning and worked method

The large paper decrease is consistent with alpha, the further aluminium decrease with beta, and the remaining penetrating component with gamma. Correct for background before interpreting small residual rates. The stated long-run precision makes the residual above background meaningful in this idealised evidence set.

Common error to avoid: Do not call a raw rate equal to background a surviving source signal, or say a thin paper barrier blocks gamma.

WORKED ANSWER | TOTAL 6 MARKS

Q11: Ionisation and location of a source

Part (a) / 2

Alpha has short range/low penetration (1); paper or the outer skin layer can absorb it (1).

Part (b) / 2

The source may remain close to living cells (1); alpha is strongly ionising and can deposit energy/damage cells over its short path (1).

Part (c) / 2

Gamma is highly penetrating (1); it can reach and transfer energy to tissues inside the body (1).

Reasoning and worked method

Hazard cannot be ranked by penetration alone. Location matters: a short-range strongly ionising emission may be a serious problem if emitted next to sensitive cells. Gamma can irradiate internal tissues from an external source. Dose, time, activity and biological location also affect risk.

Common error to avoid: Do not state that alpha is always harmless or that the most penetrating radiation must always be the most hazardous in every situation.

WORKED ANSWER | TOTAL 6 MARKS

Q12: Contamination or irradiation?

Part (a) / 2

Irradiation (1); radiation reaches the object but the radioactive source material is not transferred (1).

Part (b) / 2

Contamination (1); radioactive material remains on the object and continues to emit (1).

Part (c) / 2

The contaminating material itself emits radiation (1); this irradiates the object or nearby tissues/people (1).

Reasoning and worked method

Irradiation is exposure to radiation; contamination is unwanted radioactive material on or in something. They can occur together. Removing an external source ends that source’s ongoing irradiation, while contamination can keep emitting until it is removed or decays. In the specified school model exposure alone does not make the object a new radioactive source.

Common error to avoid: Do not describe every irradiated object as contaminated. Identify whether radioactive material, rather than only radiation, was transferred.

WORKED ANSWER | TOTAL 6 MARKS

Q13: Choose a tracer for a model test

Part (a) / 2

Y (1); gamma is penetrating enough to be detected outside the pipe in this model (1).

Part (b) / 2

It lasts long enough to obtain observations during the test (1); it does not remain strongly radioactive for years afterwards (1).

Part (c) / 2

Emission type/activity and detector sensitivity must permit detection (1); chemical behaviour, containment and exposure constraints also matter (1).

Reasoning and worked method

The task asks for a qualitative balance, not a repeated-halving calculation. A tracer must remain observable during use but should not persist unnecessarily. Alpha’s low penetration makes it unsuitable for detection through the pipe wall in this stated model. Actual tracer selection is made under authorised procedures.

Common error to avoid: Do not select the shortest half-life automatically. A tracer that decays before measurement cannot perform its intended function.

WORKED ANSWER | TOTAL 6 MARKS

Q14: A sheet-thickness gauge

Part (a) / 2

It decreases (1); more beta radiation is absorbed before reaching the detector (1).

Part (b) / 2

Alpha may be absorbed almost completely even by a thin sheet (1); gamma may penetrate with too little change to give good sensitivity for these thicknesses (1).

Part (c) / 2

The enclosure helps prevent radioactive material escaping (1); some emitted radiation still leaves the enclosure and can irradiate nearby objects (1).

Reasoning and worked method

The gauge uses a change in detected transmission to infer thickness. Its useful range depends on how much radiation is absorbed by the material. Stable geometry is essential: moving the detector could mimic a thickness change. “Sealed” refers to containment of source material, not complete prevention of emitted radiation.

Common error to avoid: Do not say a thicker sheet creates more beta radiation. It changes the fraction reaching the detector.

WORKED ANSWER | TOTAL 6 MARKS

Q15: Diagnosis and treatment: different aims

Part (a) / 2

Some gamma radiation escapes the body model (1); an external detector can locate its distribution (1).

Part (b) / 2

Radiation can damage or kill targeted tumour cells (1); treatment aims to deliver the required effect while limiting damage to surrounding healthy tissue (1).

Part (c) / 2

Any two distinct factors (1 each): activity; exposure time; absorbed dose; source location; distance; shielding; tissue/biological distribution.

Reasoning and worked method

The desired signal and energy deposition differ between diagnosis and treatment. A tracer must be detected; therapy intentionally deposits energy in a target. These are physical principles for examination study, not instructions for choosing an individual’s investigation or treatment.

Common error to avoid: Do not assume that usefulness means zero hazard or that the highest activity is automatically the best choice.

WORKED ANSWER | TOTAL 6 MARKS

Q16: Fission and a chain reaction

Part (a) / 2

Mass numbers: 235 + 1 = 141 + 92 + 3 = 236 (1); charge numbers: 92 = 56 + 36 = 92 (1).

Part (b) / 2

Released neutrons can be absorbed by other suitable heavy nuclei (1); these undergo further fission, releasing more neutrons (1).

Part (c) / 2

Kinetic energy of fission fragments/neutrons (1); electromagnetic radiation/gamma radiation (1).

Reasoning and worked method

A heavy nucleus commonly absorbs a neutron before splitting. The daughter nuclei and neutrons share the conserved nucleon and charge totals in the simplified equation. Whether a chain reaction continues depends on how many released neutrons cause further fissions rather than escaping or being absorbed elsewhere.

Common error to avoid: Do not call splitting a nucleus fusion. A chain reaction involves subsequent nuclear events, not just one nucleus breaking.

WORKED ANSWER | TOTAL 6 MARKS

Q17: Fusion and nuclear energy

Part (a) / 2

Fusion joins light nuclei into a heavier nucleus (1); fission splits a heavy nucleus into smaller nuclei (1).

Part (b) / 2

Positive nuclei repel electrostatically (1); higher kinetic energy helps them approach closely enough for nuclear interactions/fusion (1).

Part (c) / 2

Fusion changes nuclei rather than only rearranging atomic electrons/bonds (1); a small decrease in total rest mass can be transferred into energy of radiation and particles (1).

Reasoning and worked method

The final nucleus is heavier than either individual starting nucleus, but its rest mass plus that of any emitted products can be slightly less than the initial total. The difference appears as released energy. “Heavier product nucleus” therefore does not contradict mass-energy conversion in an energy-releasing reaction.

Common error to avoid: Do not say fusion must make a nucleus lighter than each individual starting nucleus, or that high temperature changes positive charges into negative ones.

WORKED ANSWER | TOTAL 6 MARKS

Q18: A dice model of decay

Part (a) / 2

The exact round in which a particular die is removed is unpredictable (1); each surviving die has the same probability of removal on each roll (1).

Part (b) / 2

Removal is random (1); finite samples give statistical variation even under the same rules (1).

Part (c) / 2

Useful: random individual events with a predictable large-population trend (1); limitation: real nuclei do not wait for discrete rolls/use dice, and removal probability is a model choice (1).

Reasoning and worked method

For ordinary dice the removal probability is one sixth per roll, not one half. A round is not automatically a half-life. The simulation illustrates constant decay probability for survivors and decreasing expected event numbers as fewer remain.

Common error to avoid: Do not state that a die becomes “due” to show six because it survived previous rolls; independent rolls have no such memory.

EXTENDED RESPONSE | 6 MARKS

E1: Evaluate exposure claims: model answer

Claim 1 is incorrect: the first person is irradiated, but no radioactive source material is transferred by radiation exposure alone in this model. Claim 2 is incorrect because the internal dust is contamination and can keep emitting close to living cells; alpha's strong ionisation over a short path can damage nearby tissue. Claim 3 confuses containment with shielding: suitable gloves can help prevent material transfer but are not substantial gamma shielding. Gamma exposure is reduced using appropriate time, distance and shielding controls under authorised arrangements.

Credit points: one mark each

1. Classify the first exposure as irradiation.

2. Explain that contamination requires radioactive material transfer, absent in that first scenario.

3. Identify the dust as internal contamination that can continue emitting.

4. Explain alpha's local strong ionisation/cell-damage hazard inside the body.

5. Distinguish glove containment from penetrating-gamma shielding.

6. Give a relevant gamma-exposure control principle: time, distance or suitable shielding, with a link to reduced exposure.

Improvement note: The type of radiation and the source's location both matter. Do not turn a penetration ranking into an unconditional hazard ranking.

EXTENDED RESPONSE | 6 MARKS

E2: Correct a museum explanation: model answer

Fission splits a heavy nucleus, commonly after neutron absorption, into smaller nuclei and emitted particles. Some released neutrons can cause further fissions, allowing a chain reaction. Fusion instead joins light nuclei to form a heavier nucleus. High temperature provides large kinetic energies so positive nuclei can approach despite electrostatic repulsion. Both are nuclear changes rather than simply electron or chemical-bond rearrangements. In energy-releasing reactions a small decrease in the initial-to-final total rest mass is transferred into energy, including particle motion and radiation.

Credit points: one mark each

1. Correct fission to splitting of a heavy nucleus, often after neutron absorption.

2. Explain that released neutrons can trigger further fissions in a chain.

3. Correct fusion to joining light nuclei.

4. Link high temperature/kinetic energy to overcoming positive-nucleus repulsion.

5. Distinguish nuclear changes from chemical electron/bond rearrangement.

6. Account for released energy through total rest-mass decrease, with radiation or particle kinetic energy as an output.

Improvement note: When comparing masses, compare the complete initial and final systems, not a fusion product with only one of its starting nuclei.

WORKED ANSWER | TOTAL 6 MARKS

T1: Isotopes and beta-minus

Part (a) / 2

Sodium-23: 23 - 11 = 12 (1); sodium-24: 24 - 11 = 13 (1).

Part (b) / 2

A = 24 (1); Z = 12 (1).

Part (c) / 2

$^{24}_{11}Na \rightarrow {}^{24}_{12}Mg + {}^{0}_{-1}e$ (2). Award 1 for correct emission with one numerical error; allow consistent earlier daughter values for later method credit.

Reasoning and worked method

Isotopes have the same Z but different A. In beta-minus emission the mass number is unchanged while the daughter proton number rises by one. Lower-row balance is 11 = 12 - 1; upper-row balance is 24 = 24 + 0.

Common error to avoid: Do not reduce the mass number by one just because an electron has left.

WORKED ANSWER | TOTAL 6 MARKS

T2: Detector data

Part (a) / 2

50/100 (1); 0.50 counts/s (1).

Part (b) / 2

Net count = 350 - 50 = 300 (1); 300/100 = 3.0 counts/s (1).

Part (c) / 2

The detector may register only a fraction of emissions (1); random decay/counting fluctuations mean a finite measurement has uncertainty (1).

Reasoning and worked method

Both measurements last the same time, so count subtraction is straightforward. A longer acquisition generally reduces relative random counting uncertainty, but it does not automatically correct detector efficiency or geometry. Activity refers to nuclear decays rather than detector pulses.

Common error to avoid: Use consistent timing and distinguish counts/s from Bq.

WORKED ANSWER | TOTAL 6 MARKS

T3: Penetration and a source seal

Part (a) / 2

Gamma (1); it is more penetrating than beta in this absorber setup (1).

Part (b) / 2

Sealing contains the radioactive material (1); some radiation leaves the enclosure and reaches the detector (1).

Part (c) / 2

Radioactive material must escape/transfer (1); it then remains on or enters the surface/object rather than only radiation passing through (1).

Reasoning and worked method

The absorber changes the detected radiation mix without changing the isotope’s underlying decay process. A source enclosure and an absorber serve different purposes. Containment prevents material transfer; shielding reduces transmitted radiation.

Common error to avoid: Do not equate a source being sealed with all its radiation being stopped.

WORKED ANSWER | TOTAL 6 MARKS

T4: A half-life statement

Part (a) / 2

8.0 min (1); the expected source-only rate has fallen to half its earlier value (1).

Part (b) / 2

Decay time of an individual nucleus is random (1); half-life describes a statistical change in a large population (1).

Part (c) / 2

Finite detected event numbers fluctuate randomly (1); the smooth graph describes expected/average behaviour, not an exact count timetable (1).

Reasoning and worked method

The question gives a single halving to interpret, without requiring a repeated-decay calculation. The isotope has a characteristic half-life under ordinary conditions, but the time of a particular event remains unpredictable.

Common error to avoid: Do not say a nucleus that survives one half-life must decay during the next.

WORKED ANSWER | TOTAL 6 MARKS

T5: Nuclear processes

Part (a) / 2

Splitting: fission (1); joining: fusion (1).

Part (b) / 2

Fission can release neutrons (1); they can trigger further fissions in other suitable nuclei (1).

Part (c) / 2

A small total rest-mass decrease is transferred into energy (1); kinetic energy of particles/fragments or electromagnetic radiation (1).

Reasoning and worked method

Both processes involve nuclear changes rather than only chemical rearrangement of electrons. A continuing fission chain needs enough of the emitted neutrons to cause further events. Energy release does not mean charge or nucleon number can be ignored in a balancing equation.

Common error to avoid: Do not confuse the name of a process with the type of radiation emitted afterwards.

Q3-Q5 | NUMBER BALANCE

Nuclear-equation reference

Upper numbers A count nucleons. Lower numbers Z count positive nuclear charge in proton-charge units. Check both rows independently.

Emission	Daughter change	Example
Alpha	A - 4; Z - 2	$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$
Beta-minus	A unchanged; Z + 1	$^{32}_{15}\mathrm{P} \rightarrow {}^{32}_{16}\mathrm{S} + {}^{0}_{-1}\mathrm{e}$
Gamma	A and Z unchanged	$^{99}_{43}\mathrm{Tc}^{*} \rightarrow {}^{99}_{43}\mathrm{Tc} + \gamma$
Neutron	A - 1; Z unchanged	One $^{1}_{0}\mathrm{n}$ leaves the nucleus.

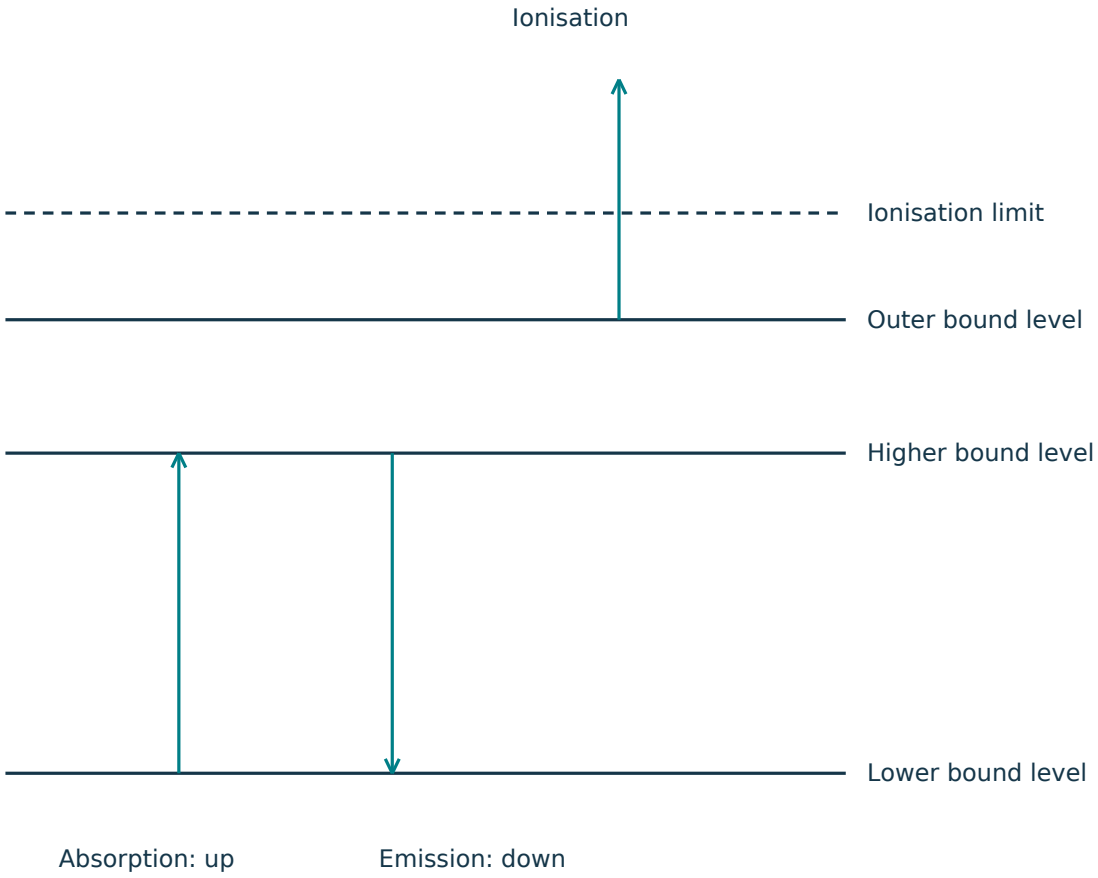
For beta-minus, A = 0 on the electron means it is not a nucleon in this bookkeeping. It does not mean the electron has zero rest mass. Gamma removes nuclear excitation energy without changing A or Z.

Symbols: Ra radium; Rn radon; P phosphorus; S sulfur; Tc technetium; He helium. The asterisk marks nuclear excitation. Additional particles beyond this GCSE balancing model are not required here.

Q6 | EXCITATION AND IONISATION

Atomic-electron reference

The arrows show separate possible events, not one simultaneous history. The nucleus is unchanged in these electron-level processes. Vertical height represents energy qualitatively.

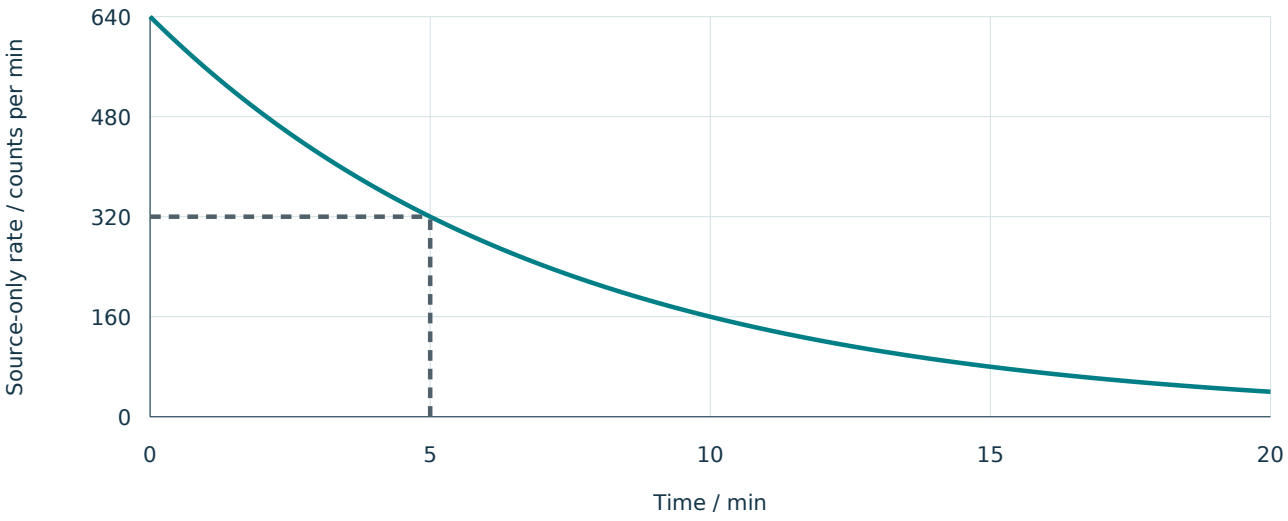


Excitation: an electron gains energy but stays bound. Emission: it loses energy as radiation on moving down. Ionisation: an electron escapes, leaving a positive ion if the atom began neutral. The dashed line marks the ionisation limit, not another bound level. No proton-number change is required.

Q9 | COMMON CONCEPT

Half-life graph reference

Use background-corrected source-only data. Half of the initial 640 counts/min is 320 counts/min.



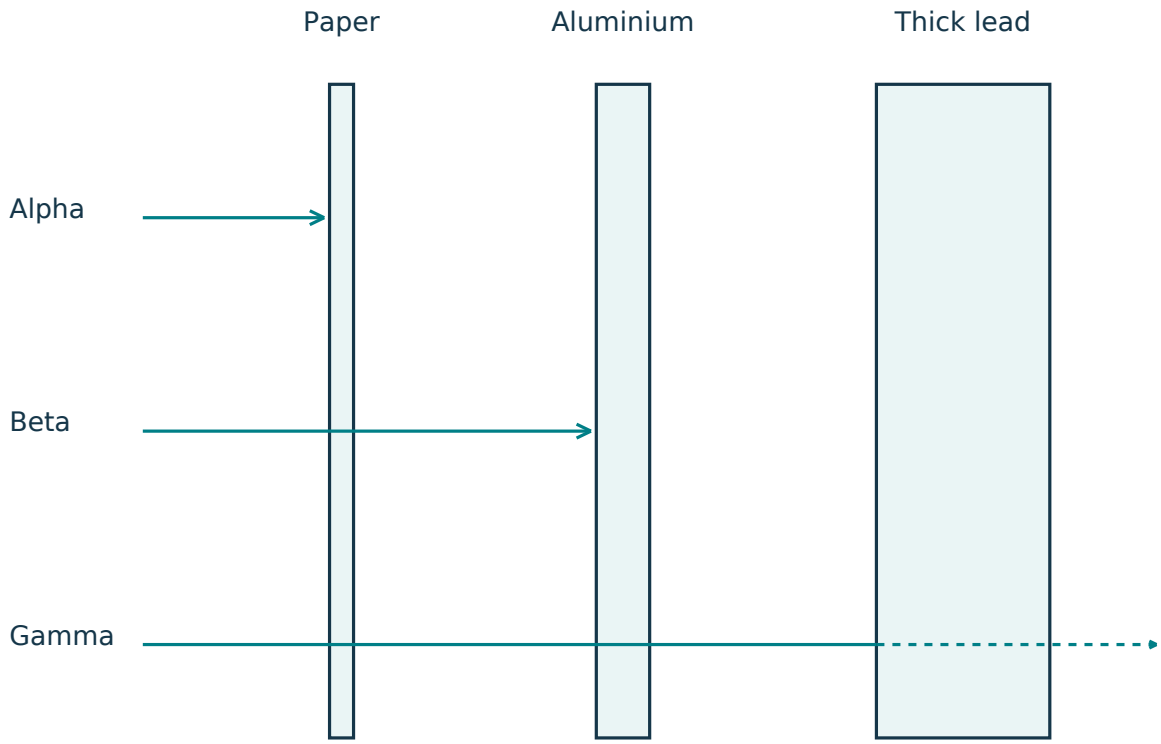
The 320 counts/min level meets the curve at 5.0 min, so the half-life is 5.0 min. It describes a large population’s expected decline. Individual nuclei do not all have that same lifetime.

The curve becomes shallower because fewer unstable nuclei remain. Random finite measurements can fluctuate around the expected curve. Background should be measured separately and detector geometry held fixed.

Q10-Q11 | QUALITATIVE MODEL

Penetration reference

The sketch summarises the usual comparison. Exact penetration depends on radiation energy, material and thickness. Gamma is attenuated, not guaranteed to be completely stopped.



Alpha: short range and strong ionisation, particularly hazardous near living cells if the source is internal. Beta: intermediate penetration. Gamma: penetrating electromagnetic radiation that can irradiate internal tissue from outside. Location and exposure conditions matter.

Q16-Q17 | NUCLEAR PROCESSES

Fission and fusion reference

These example equations conserve total mass number and charge number. Energy release is shared between radiation and particle motion.

Fission model

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

Upper numbers: 236 = 141 + 92 + 3. Lower numbers: 92 = 56 + 36. Released neutrons can cause further fissions when absorbed by suitable nuclei, creating a chain reaction.

Fusion example

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

Upper numbers: 2 + 3 = 4 + 1. Lower numbers: 1 + 1 = 2 + 0. The light nuclei join; very high temperature helps them approach against electrostatic repulsion.

Total rest mass can decrease slightly in an energy-releasing nuclear reaction. The difference is transferred to energy of particles and radiation; nucleon and charge bookkeeping are still respected.