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OCR GCSE Physics B

Twenty First Century Science J259

CHAPTER P5

Radioactive Materials

Higher Tier

Systematic lesson notebook

Teaching and worked examples, lesson practice, a chapter assessment, complete indicative answers and a knowledge organiser.

Read the explanation, try the practice independently, then use the answers to improve your reasoning and calculations.

Name _____ Class _____

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How to use this notebook

Follow the lesson sequence. Each assessed lesson includes an explanation, a worked example and practice. Keep your working and units visible. Check the numbered lesson answers after attempting the questions; equivalent correct scientific wording can receive credit.

Specification reference: Cambridge OCR J259, Version 5.0, July 2026. References identify the intended outcomes; this independent notebook does not replace the official specification.

Foundation and Higher

Higher contains shared outcomes and Higher-only requirements. Some additional questions simply increase demand within shared content; they do not imply that the entire lesson is Higher-only.

Separate Physics content belongs to J259 at both tiers unless the specification explicitly marks an outcome as Higher-only.

Working and marking

Use the maximum mark shown for each question. The answer sections are indicative classroom guidance, not official OCR mark schemes. Credit valid alternatives and avoid awarding the same idea twice. This assessment is diagnostic; no GCSE grade boundary is implied.

Numerical tariffs, example data and model situations are classroom examples, not current prices or real safety estimates.

Lesson map

Lesson	Focus	References
1	Atomic structure, scale and the nuclear model	P5.1.1-3
2	Nuclei, isotopes and nuclide notation	P5.1.4-6
3	Unstable nuclei and types of nuclear emission	P5.1.7-8
4	Balanced nuclear equations	P5.1.9
5	Random radioactive decay and half-life	P5.1.10
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Use lesson numbers to locate the matching practice and answers. Pagination differs between editions because the assessed scope differs.

Lesson map continued

Lesson	Focus	References
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15	Nuclear energy decisions: risks, benefits and evidence	P5.3 / IaS4

Use lesson numbers to locate the matching practice and answers. Pagination differs between editions because the assessed scope differs.

Lesson 1 Atomic structure, scale and the nuclear model

P5.1.1-3 | Higher

describe atomic structure, explain how the model changed, and recall the order of magnitude of atomic size.

An atom has a tiny positively charged nucleus surrounded by negatively charged electrons. Almost all the mass is concentrated in the nucleus.

The atomic model changed as new evidence appeared: Dalton's solid-particle model, Thomson's electron-containing model, Rutherford's nuclear model and Bohr's energy-level model.

Atoms are typically about 10^-10 m across; the nucleus is vastly smaller. Strong alpha-particle deflections were key evidence for a small, concentrated positive nucleus.

Worked example

In a scattering experiment most alpha particles pass through foil, but a small fraction turn through large angles. A spread-out positive charge cannot explain those rare large deflections; a compact positive nucleus can.

Lesson 1 practice

Atomic structure, scale and the nuclear model

Answer independently. Show a clear method, substitutions and units for calculations.

1. Describe the modern atom. [3]

2. State the typical order of magnitude of atomic size. [1]

3. Explain what alpha-scattering evidence showed. [4]

4. Put Dalton, Thomson, Rutherford and Bohr in order. [2]

5. Explain why scientific models can change. [2]

Practice total 12 marks

Self check Write one correction you made and why it matters.

Lesson 2 Nuclei, isotopes and nuclide notation

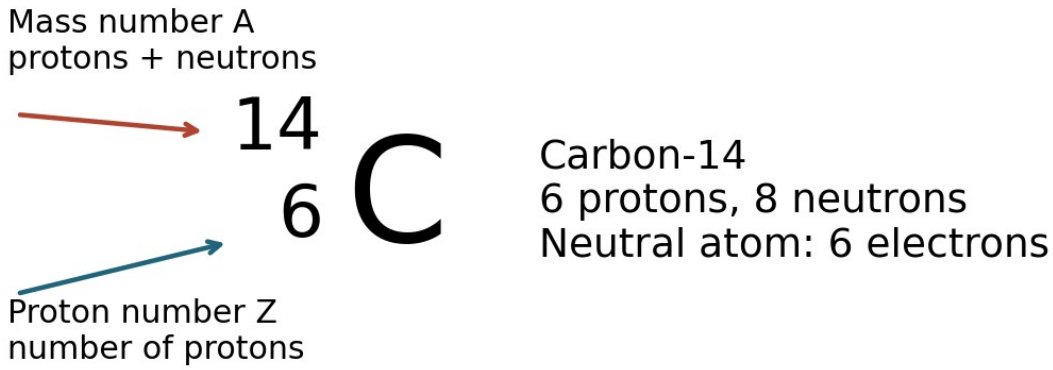
P5.1.4-6 | Higher

describe protons/neutrons, isotopes and conventional nuclear notation.

The nucleus contains protons and neutrons. The proton number identifies the element; isotopes of the same element have the same proton number but different neutron numbers.

In nuclide notation, the mass number A is protons + neutrons and the proton number Z is the number of protons.

Number of neutrons = A - Z. Isotopes have different mass numbers because their neutron counts differ.



Worked example

For $^{23}_{11}Na$: protons = 11; neutrons = 23 − 11 = 12; a neutral atom has 11 electrons. The mass number counts nucleons, not electrons.

Lesson 2 practice

Nuclei, isotopes and nuclide notation

Answer independently. Show a clear method, substitutions and units for calculations.

1. Define isotope. [2]

2. For carbon-14, state protons and neutrons. [2]

3. An isotope has A=23 and Z=11. Calculate neutrons. [1]

4. Explain why isotopes are the same element. [2]

5. Write conventional notation for an atom with 17 protons and 18 neutrons. [2]

Practice total 9 marks

Self check Write one correction you made and why it matters.

Lesson 3 Unstable nuclei and types of nuclear emission

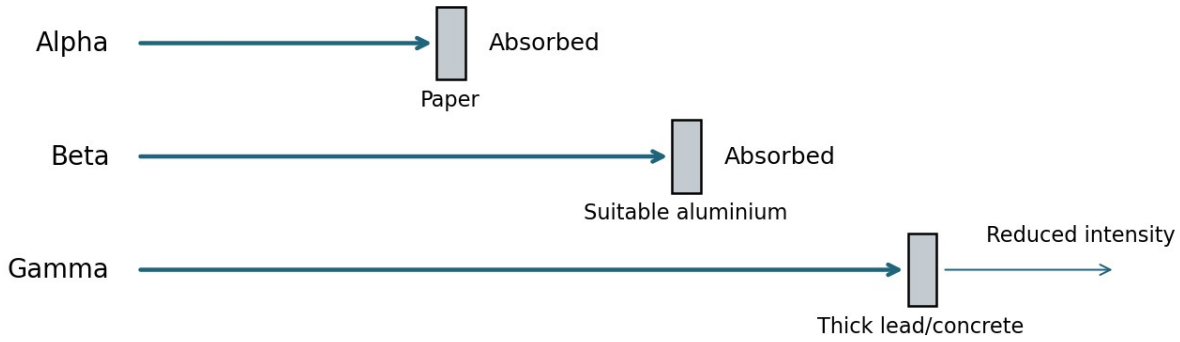
P5.1.7-8 | Higher

identify alpha, beta, gamma and neutron emission and relate each to changes in the nucleus.

An unstable nucleus can emit alpha particles, beta particles, neutrons or gamma radiation and become more stable.

Alpha emission removes two protons and two neutrons, so mass number decreases by 4 and proton number by 2.

Beta-minus emission converts a neutron to a proton and emits an electron, so mass number stays the same while proton number increases by 1. Gamma emission changes neither mass nor charge.



Worked example

After alpha decay, a nucleus with A = 210 and Z = 84 becomes one with A = 206 and Z = 82. The emitted alpha has A = 4 and Z = 2, so both totals balance.

Lesson 3 practice

Unstable nuclei and types of nuclear emission

Answer independently. Show a clear method, substitutions and units for calculations.

1. State the composition of an alpha particle. [2]

2. State what beta-minus radiation is. [1]

3. How does alpha emission change A and Z? [2]

4. How does beta-minus emission change A and Z? [2]

5. What changes in the nucleus during gamma emission? [1]

Practice total 8 marks

Self check Write one correction you made and why it matters.

Lesson 4 Balanced nuclear equations

P5.1.9 | Higher

write balanced nuclear equations for alpha, beta, gamma and neutron emissions.

Nuclear equations conserve total mass number and total proton/charge number.

For alpha decay include an alpha particle with mass number 4 and proton number 2. For beta-minus decay use an electron with mass number 0 and charge/proton number -1.

Gamma is written with no mass or charge change. A neutron has mass number 1 and charge number 0.

Worked example

Balance beta-minus decay: $^{3}H \rightarrow {}^{3}He + \beta^{-}$, with full lower numbers ${}^{3}_{1}H \rightarrow {}^{3}_{2}He + {}^{0}_{-1}e$. Mass: 3 = 3 + 0; charge number: 1 = 2 − 1. The electron is created in the nuclear process, not expelled from an atomic shell.

Lesson 4 practice

Balanced nuclear equations

Answer independently. Show a clear method, substitutions and units for calculations.

1. Complete the alpha-decay equation: $^{238}_{92}U \rightarrow$ Th (A=?, Z=?) + $^{4}_{2}He$. State the missing mass number A, proton number Z and the name of the emitted particle. [3]

2. Complete the beta-minus equation: $^{14}_{6}C \rightarrow$ N (A=?, Z=?) + $^{0}_{-1}e$. State A, Z and how the totals balance. [3]

3. Explain how you check a nuclear equation is balanced. [2]

4. State the mass and charge numbers for a neutron. [2]

5. Explain why gamma emission leaves A and Z unchanged. [2]

Practice total 12 marks

Self check Write one correction you made and why it matters.

Lesson 5 Random radioactive decay and half-life

P5.1.10 | Higher

explain half-life and connect it to the random nature of radioactive decay.

Radioactive decay is random for individual nuclei: you cannot predict when a particular nucleus will decay.

For a large sample, the probability of decay leads to a predictable overall pattern. Half-life is the time taken for activity or number of undecayed nuclei to fall to half its value.

Different isotopes have different half-lives, but the half-life of a given isotope is constant under normal physical conditions.

Worked example

A background-corrected count rate falls from 600 to 300 counts/min in 4 h. The rate has halved, so the measured half-life is 4 h. This does not identify when any particular nucleus will decay.

Lesson 5 practice

Random radioactive decay and half-life

Answer independently. Show a clear method, substitutions and units for calculations.

1. Define half-life. [2]

2. Explain why radioactive decay is described as random. [3]

3. A source falls from 800 counts/min to 400 counts/min in 6 h. State half-life. [1]

4. Explain why a large sample gives a predictable trend. [2]

5. Does temperature normally change nuclear half-life? State the expected answer. [1]

Practice total 9 marks

Self check Write one correction you made and why it matters.

Lesson 6 Higher net decline after integral half-lives

P5.1.11 | Higher

calculate the decline as a ratio after a whole number of half-lives.

After one half-life, 1/2 remains; after two, 1/4; after three, 1/8; after n half-lives, (1/2)^n remains.

OCR marks this calculation outcome as Higher-only. Foundation students should understand the qualitative halving pattern but are not assessed on the explicit net-decline ratio calculation.

Distinguish 'fraction remaining' from 'fraction decayed'. If 1/8 remains, then 7/8 has decayed.

Worked example

A source has 3 h half-life and initial activity 800 Bq. In 9 h there are 9/3 = 3 half-lives. Activity = 800/8 = 100 Bq; 1/8 remains and 7/8 has decayed. Higher-only ratio calculation.

Lesson 6 practice

Higher: net decline after integral half-lives

Answer independently. Show a clear method, substitutions and units for calculations.

1. After 3 half-lives, what fraction remains? [1]

2. After 4 half-lives, what fraction has decayed? [2]

3. A source starts at 640 Bq. Calculate activity after 5 half-lives. [2]

4. Write the remaining fraction after n half-lives. [2]

5. Distinguish fraction remaining from fraction decayed. [2]

Practice total 9 marks

Self check Write one correction you made and why it matters.

Lesson 7 Activity-time graphs and practical half-life models

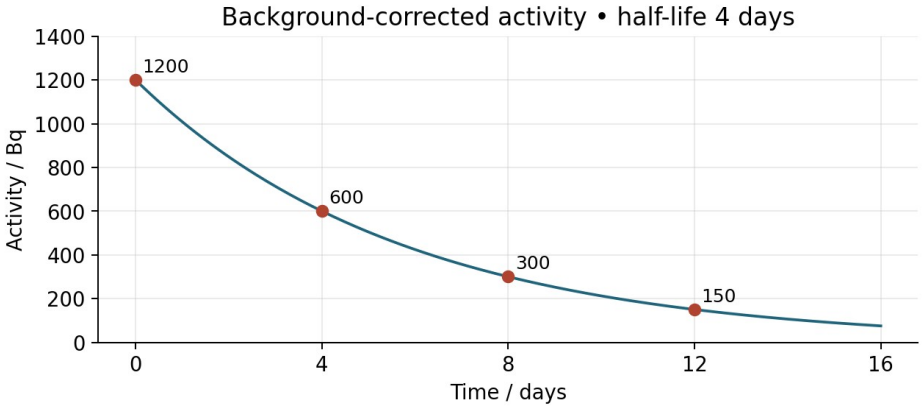
P5.1.12 | Higher

interpret decay graphs to determine half-life and evaluate random-event models.

To find half-life from a graph, choose an activity value, halve it, then measure the horizontal time interval between the two points.

A dice/coin model can represent random decay: each object has a fixed chance of removal each trial, yet the class total follows a smooth overall decline.

Real measurements include background radiation and counting uncertainty. Repeats and background correction improve interpretation.



Worked example

A detector records 210 counts/min with a source and 10 counts/min without it. Source rate = 200 counts/min. One half-life later its source rate should be about 100 counts/min, so the detector would read about 110 counts/min if background stays constant.

Lesson 7 practice

Activity-time graphs and practical half-life models

Answer independently. Show a clear method, substitutions and units for calculations.

1. Describe how to find half-life from an activity-time graph. [3]

2. Why should background count be measured? [2]

3. Explain why a dice model is useful for random decay. [3]

4. State one limitation of the dice model. [2]

5. A graph falls from 1200 Bq to 300 Bq in 8 days. Estimate half-life. [2]

6. A source has a 5 h half-life. Its activity is 960 Bq. Calculate activity after 20 h. [3]

Practice total 15 marks

Self check Write one correction you made and why it matters.

Lesson 8 Penetration and ionisation

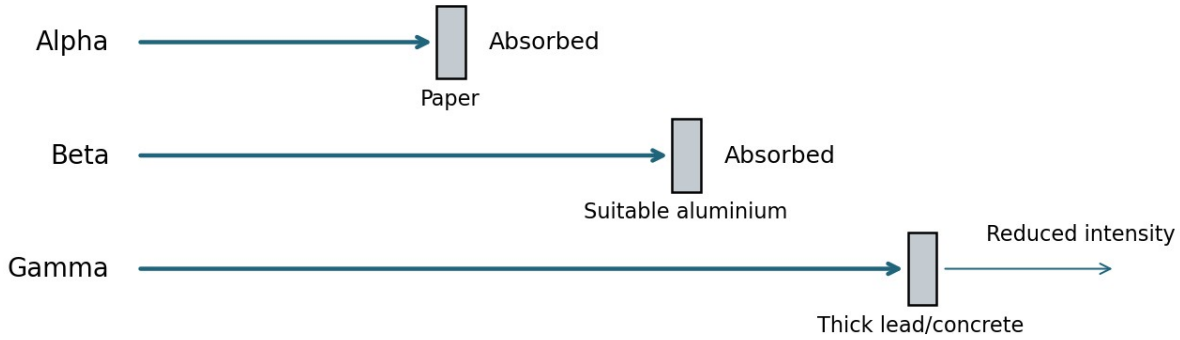
P5.2.1 | Higher

compare the penetration properties of alpha, beta and gamma radiation.

Alpha is strongly ionising and weakly penetrating: paper or skin can stop it. Beta penetrates further and is reduced by thin aluminium. Gamma is weakly ionising but highly penetrating and needs thick dense shielding.

Penetration and ionising ability are different properties. Strong ionisation often corresponds to rapid energy loss and shorter range.

Practical attenuation measurements should control source-detector distance and account for background count.



Worked example

A beta source gives 500 counts in 60 s. With an absorber it gives 80 counts; background is 20 counts in 60 s. Corrected counts are 480 and 60, so the absorber has greatly reduced the source radiation reaching the detector. Keep time and distance fixed.

Lesson 8 practice

Penetration and ionisation

Answer independently. Show a clear method, substitutions and units for calculations.

1. Rank alpha, beta, gamma by penetration. [3]

2. State a suitable absorber for beta. [1]

3. Explain why alpha has short range in matter. [2]

4. Describe a fair method to compare penetration of radiations. [4]

5. Why must background radiation be considered? [2]

6. Explain the link between ionisation strength, energy loss and penetration. [3]

Practice total 15 marks

Self check Write one correction you made and why it matters.

Lesson 9 Contamination versus irradiation

P5.2.2 | Higher

distinguish contamination from irradiation and compare their hazards.

Contamination means radioactive material is on or inside an object/person. Irradiation means radiation reaches the person from an external source without radioactive material being transferred.

Internal contamination can be especially hazardous for alpha emitters because alpha deposits energy strongly over a short range inside tissue.

External irradiation ends when the source is removed; contamination continues until the radioactive material is removed or leaves the body/decays.

Worked example

An X-ray passes through a patient: this is irradiation, and the exposure stops when the beam is switched off. Swallowing a radioactive tracer is controlled internal contamination: the material continues to emit until it leaves or decays.

Lesson 9 practice

Contamination versus irradiation

Answer independently. Show a clear method, substitutions and units for calculations.

1. Define contamination. [2]

2. Define irradiation. [2]

3. Explain why internal alpha contamination is hazardous. [3]

4. Why does external irradiation stop when source is removed? [2]

5. Give one way to reduce contamination risk. [1]

Practice total 10 marks

Self check Write one correction you made and why it matters.

Lesson 10 Medical uses and biological hazards

P5.2.3-4 | Higher

describe medical uses of ionising radiation and explain how it can damage tissue.

Ionising radiation can be used to trace processes inside the body, image organs and destroy unwanted tissue such as cancer cells.

Ionisation can damage DNA and cells. Cells may die or mutations may increase cancer risk.

Medical decisions compare benefit with risk: dose, target tissue, radiation type and exposure time matter.

Worked example

A gamma tracer can be detected outside the body because gamma radiation penetrates tissue. Choose a half-life long enough for the scan but short enough to limit unnecessary continuing exposure. The exact isotope depends on the clinical task.

Lesson 10 practice

Medical uses and biological hazards

Answer independently. Show a clear method, substitutions and units for calculations.

1. State one medical imaging use of radiation. [1]

2. State one treatment use. [1]

3. Explain how ionising radiation can increase cancer risk. [3]

4. Explain why dose should be minimised. [2]

5. Compare benefit and risk in one medical example. [3]

Practice total 10 marks

Self check Write one correction you made and why it matters.

Lesson 11 Hazard depends on radiation type and half-life

P5.2.5 | Higher

explain why hazard depends on both radiation emitted and isotope half-life.

Radiation type changes penetration and ionisation; therefore the same activity can present different external/internal hazards.

For the same initial number of radioactive nuclei, a shorter half-life gives a greater initial activity. A longer half-life means a more persistent source; overall hazard also depends on amount, radiation type, location and exposure.

The most suitable isotope depends on the use: long enough to perform the task, but not unnecessarily long-lived.

Worked example

Two equal-number samples emit the same radiation type but have different half-lives. The shorter-lived sample initially has greater activity per nucleus; the longer-lived one persists longer. Neither half-life alone determines the full hazard.

Lesson 11 practice

Hazard depends on radiation type and half-life

Answer independently. Show a clear method, substitutions and units for calculations.

1. Explain why alpha may be low external risk but high internal risk. [3]

2. Why can long half-life increase long-term contamination concern? [2]

3. Why might a tracer isotope need a short half-life? [2]

4. Why might an extremely short half-life be impractical? [2]

5. Explain how radiation type and half-life jointly affect hazard. [4]

Practice total 13 marks

Self check Write one correction you made and why it matters.

Lesson 12 Separate Physics nuclear fission and energy release

P5.3.1-2 | Higher

describe nuclear fission and relate released energy to particle kinetic energy and ionising radiation.

In fission, a neutron can be absorbed by a large unstable nucleus, which splits into two smaller nuclei.

Energy is released mainly as kinetic energy of the fission fragments and neutrons, with gamma radiation also emitted.

Nuclear fuels such as suitable uranium/plutonium isotopes release far more energy per kilogram than chemical fuels because the change involves the nuclear energy store.

Worked example

A uranium-235 nucleus absorbs a neutron, forming an excited uranium-236 nucleus that splits. Fast fragments and neutrons carry much of the released energy, warming material as they interact. Gamma radiation carries some energy too.

Lesson 12 practice

Separate Physics: nuclear fission and energy release

Answer independently. Show a clear method, substitutions and units for calculations.

1. Define nuclear fission. [2]

2. Describe what initiates a typical fission event. [2]

3. State two forms in which energy leaves a fission event. [2]

4. Explain why nuclear fuel releases much more energy per kg than chemical fuel. [2]

5. State one example of a fissile fuel isotope family. [1]

Practice total 9 marks

Self check Write one correction you made and why it matters.

Lesson 13 Separate Physics chain reactions

P5.3.3 | Higher

explain how fission can lead to a chain reaction.

A fission event can release several neutrons. If one or more of these are absorbed by other fissile nuclei, further fissions occur.

A controlled chain reaction maintains an approximately steady rate of fission. If too many neutrons continue the process, the reaction rate rises.

In reactors, control systems absorb excess neutrons; moderators can slow neutrons so fission is more likely in certain fuels.

Worked example

Imagine each fission leads on average to two further fissions. Successive generations grow 1, 2, 4, 8, so power rises rapidly. A controlled steady reaction instead has about one continuing fission per previous fission on average.

Lesson 13 practice

Separate Physics: chain reactions

Answer independently. Show a clear method, substitutions and units for calculations.

1. Explain how one fission can trigger more fissions. [3]

2. What is meant by a controlled chain reaction? [2]

3. State the role of control rods. [2]

4. Why can slowing neutrons be useful in some reactors? [2]

5. Explain why an uncontrolled reaction rate is dangerous. [2]

Practice total 11 marks

Self check Write one correction you made and why it matters.

Lesson 14 Separate Physics nuclear fusion

P5.3.4 | Higher

describe nuclear fusion and relate mass change to released energy.

Fusion joins light nuclei to form a heavier nucleus and releases energy.

Very high temperature is required so nuclei have enough kinetic energy to approach despite electrostatic repulsion.

Some mass is converted into energy of radiation/particles. Fusion powers stars; controlled fusion on Earth is technologically difficult.

Worked example

In a suitable fusion reaction the final products have slightly less total rest mass than the initial particles. The difference corresponds to released energy. Fusion does not mean creating energy from nothing; mass and energy are accounted for together.

Lesson 14 practice

Separate Physics: nuclear fusion

Answer independently. Show a clear method, substitutions and units for calculations.

1. Define nuclear fusion. [2]

2. Why are very high temperatures required? [3]

3. State where fusion occurs naturally. [1]

4. Explain how mass can be related to released energy in fusion. [2]

5. Give one reason controlled fusion is difficult. [2]

Practice total 10 marks

Self check Write one correction you made and why it matters.

Lesson 15 Nuclear energy decisions risks, benefits and evidence

P5.3 / IaS4 | Higher

evaluate nuclear fission as an electricity source using scientific and societal evidence.

Nuclear fission can provide reliable low-carbon electricity during operation, but produces radioactive waste and involves high construction, decommissioning and safety costs.

Risk decisions depend on probability and consequence. Scientific evidence informs decisions, but economic, social and ethical priorities also affect conclusions.

A strong evaluation uses data where available, considers both benefits and disadvantages, and explains why different communities may reasonably reach different decisions.

Worked example

A decision compares reliable low-carbon output with construction cost, waste and accident consequences. State the alternatives and whose needs matter. Without cost/output/risk data, a confident numerical ranking is not justified.

Lesson 15 practice

Nuclear energy decisions: risks, benefits and evidence

Answer independently. Show a clear method, substitutions and units for calculations.

1. Give two benefits of nuclear electricity generation. [2]

2. Give two disadvantages. [2]

3. Explain why risk includes both probability and consequence. [3]

4. Why might two countries make different nuclear-energy decisions? [3]

5. State one type of data useful in a nuclear-energy evaluation. [1]

6. Evaluate nuclear fission against a fossil-fuel alternative using reliability, emissions, waste, cost and risk. [6]

Practice total 17 marks

Self check Write one correction you made and why it matters.

End of chapter assessment

Higher | Total 62 marks across all assessment parts

Answer every question. Use additional paper for diagrams or longer explanations when needed.

1. Explain how alpha-scattering evidence changed the atomic model. [5]

2. For an isotope with A=37 and Z=17, determine protons, neutrons and electrons in a neutral atom. [3]

3. Complete $^{238}_{92}U$ → Th (A=?, Z=?) + $^{4}_{2}He$. State the missing daughter mass number A, proton number Z and the name of the emitted particle. [3]

4. Complete $^{14}_{6}C$ → N (A=?, Z=?) + $^{0}_{-1}e$ by stating A and Z and the beta-particle numbers. Explain the change inside the nucleus. [4]

5. Explain why radioactive decay is random but half-life is useful for large samples. [4]

End of chapter assessment continued

Higher | Total 62 marks across all assessment parts

Answer every question. Use additional paper for diagrams or longer explanations when needed.

6. A source has a half-life of 6 h and starts at 1600 Bq. Calculate activity after 24 h and state the fraction remaining. [4]

7. Describe how to determine half-life from an activity-time graph and why background count matters. [4]

8. Compare penetration and ionisation of alpha, beta and gamma. [5]

9. Distinguish contamination from irradiation and explain why internal alpha contamination is hazardous. [5]

10. Explain one medical imaging use and one treatment use of ionising radiation. [4]

End of chapter assessment continued

Higher | Total 62 marks across all assessment parts

Answer every question. Use additional paper for diagrams or longer explanations when needed.

11. Explain why isotope choice depends on radiation type and half-life. [4]

12. Describe nuclear fission and where released energy appears. [4]

13. Explain how a chain reaction develops and how it can be controlled. [4]

14. Describe nuclear fusion and why high temperature is required. [4]

15. Evaluate nuclear fission as an electricity source using scientific and societal factors. [5]

Lesson practice answers

Indicative answers. Credit equivalent correct wording, up to the maximum in the question.

Lesson 1 Atomic structure, scale and the nuclear model

1. A tiny, dense, positively charged nucleus contains protons and neutrons. Electrons occupy regions/energy levels around it. Most of the atom's volume is empty space. [maximum 3]

2. About 10^{-10} m across. [maximum 1]

3. Most alpha particles passed through, showing the atom is mostly empty space. A few were strongly deflected or reflected, showing positive charge and most mass are concentrated in a very small, dense nucleus. [maximum 4]

4. Dalton → Thomson → Rutherford → Bohr. [maximum 2]

5. New experimental evidence can contradict a model's predictions. Scientists revise or replace models to explain the evidence more successfully. [maximum 2]

Lesson 2 Nuclei, isotopes and nuclide notation

1. Atoms of the same element with the same proton number but different neutron numbers. [maximum 2]

2. 6 protons; 14 − 6 = 8 neutrons. [maximum 2]

3. N = A − Z = 23 − 11 = 12. [maximum 1]

4. An element is defined by proton number. Isotopes have the same proton number even though their neutron numbers differ. [maximum 2]

5. $^{35}_{17}Cl$: mass number 35 at upper left, proton number 17 at lower left, symbol Cl. [maximum 2]

Lesson practice answers

Indicative answers. Credit equivalent correct wording, up to the maximum in the question.

Lesson 3 Unstable nuclei and types of nuclear emission

1. Two protons and two neutrons (a helium-4 nucleus). [maximum 2]

2. A high-speed electron emitted from the nucleus when a neutron changes into a proton. [maximum 1]

3. Mass number A decreases by 4; proton number Z decreases by 2. [maximum 2]

4. A is unchanged; Z increases by 1. [maximum 2]

5. The nucleus loses energy. A and Z do not change. [maximum 1]

Lesson 4 Balanced nuclear equations

1. ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$. Missing daughter numbers: A = 234 and Z = 90; emitted particle is alpha (helium nucleus). [maximum 3]

2. ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$ (plus an antineutrino, not required here). A stays 14; daughter Z = 7 and beta-minus has A = 0, charge number −1. [maximum 3]

3. Add the mass numbers on each side; they must match. Separately add the proton/charge numbers on each side; they must also match. [maximum 2]

4. A = 1; charge number Z = 0 for a neutron, ${}^{1}_{0}n$. [maximum 2]

5. Gamma is electromagnetic radiation carrying energy but no nucleons or charge. It therefore changes nuclear energy without changing A or Z. [maximum 2]

Lesson practice answers

Indicative answers. Credit equivalent correct wording, up to the maximum in the question.

Lesson 5 Random radioactive decay and half-life

1. The time for the number of undecayed nuclei, or the activity of a large sample, to fall to half its initial value. [maximum 2]

2. An individual nucleus's decay time cannot be predicted. Each undecayed nucleus has a probability of decay in a given interval. Only the overall statistical behaviour of many nuclei is predictable. [maximum 3]

3. 6 h, assuming the stated count rates are background-corrected and measured under the same conditions. [maximum 1]

4. Random variation averages out across very many nuclei. A roughly constant fraction decays per unit time, giving a predictable exponential trend. [maximum 2]

5. No: ordinary changes in temperature do not significantly alter a radioactive isotope's nuclear half-life. [maximum 1]

Lesson 6 Higher net decline after integral half-lives

1. After three half-lives, $(½)^3 = 1/8$ remains. [maximum 1]

2. After four half-lives, 1/16 remains. Fraction decayed = 1 − 1/16 = 15/16. [maximum 2]

3. Activity = $640/2^5 = 640/32 = 20$ Bq. [maximum 2]

4. Fraction remaining = $(½)^n = 2^{-n}$. [maximum 2]

5. Remaining fraction is undecayed/original. Decayed fraction = 1 − remaining fraction; they add to 1. [maximum 2]

Lesson practice answers

Indicative answers. Credit equivalent correct wording, up to the maximum in the question.

Lesson 7 Activity-time graphs and practical half-life models

1. Choose a starting activity, locate half that value, and read the times for the two values. Their difference is the half-life. Repeat for other starting points to check the estimate. [maximum 3]

2. The detector also records background events unrelated to the source. Subtract background rate to estimate the source rate and avoid biasing the half-life. [maximum 2]

3. Each die has a fixed chance of removal on each throw. Which dice are removed is random. Many dice show a predictable declining population, analogous to undecayed nuclei. [maximum 3]

4. Time occurs in discrete throws rather than continuously; a small number of dice gives large fluctuations. The model does not reproduce the nuclear mechanism. [maximum 2]

5. 1200 → 600 → 300 is two half-lives in 8 days, so half-life = 4 days. [maximum 2]

6. 20/5 = 4 half-lives. Activity = 960/16 = 60 Bq. [maximum 3]

Lesson 8 Penetration and ionisation

1. Increasing penetration: alpha < beta < gamma. Alpha is stopped by paper/skin, beta by suitable thin metal/plastic, while gamma needs thick shielding for substantial attenuation. [maximum 3]

2. A suitable thickness of aluminium (or appropriate plastic shielding). [maximum 1]

3. Alpha is strongly ionising, transferring energy in many interactions over a short path. It quickly loses its kinetic energy and stops. [maximum 2]

4. Use an approved sealed source and detector at a fixed distance. Measure background, then counts over equal times with different absorber materials/thicknesses. Keep geometry fixed, subtract background and repeat, following the approved handling procedure. [maximum 4]

5. Background contributes counts without the tested source. Subtracting it avoids attributing those counts to transmitted source radiation. [maximum 2]

6. For comparable energies, strongly ionising radiation transfers energy rapidly along its path and has a short range. Weakly ionising gamma is more penetrating; its intensity falls with shielding thickness rather than all photons stopping at a fixed distance. [maximum 3]

Lesson practice answers

Indicative answers. Credit equivalent correct wording, up to the maximum in the question.

Lesson 9 Contamination versus irradiation

1. Radioactive material is present on or inside a person/object, so it remains a local source of radiation. [maximum 2]

2. Exposure to radiation from a source. In this context radioactive material is not transferred to the exposed person/object. [maximum 2]

3. Alpha is strongly ionising and deposits energy over a short range. Inside the body it can directly expose nearby cells/DNA without the protection of the outer skin. [maximum 3]

4. Without the external source, radiation from it no longer reaches the person. No radioactive material has been left behind by irradiation itself in this context. [maximum 2]

5. Use sealed sources, prevent ingestion/inhalation, or use approved handling/containment and contamination monitoring. [maximum 1]

Lesson 10 Medical uses and biological hazards

1. A gamma-emitting tracer imaged with an external gamma camera; also accept diagnostic X-ray imaging. [maximum 1]

2. Radiotherapy uses ionising radiation to kill cancer cells. [maximum 1]

3. Radiation ionises molecules and can damage DNA. A surviving cell may acquire mutations. Some mutations can lead to uncontrolled division/cancer. [maximum 3]

4. Dose carries a risk of tissue damage or future cancer. Use the lowest exposure that still achieves the medical purpose. [maximum 2]

5. Example: an X-ray may reveal a fracture and guide treatment, but carries a small radiation risk. Justify it only when the clinical benefit outweighs that risk, using a suitably limited dose. [maximum 3]

Lesson practice answers

Indicative answers. Credit equivalent correct wording, up to the maximum in the question.

Lesson 11 Hazard depends on radiation type and half-life

1. External alpha is usually stopped by the outer skin, but internal alpha deposits substantial energy in nearby tissue. Risk therefore depends on whether the source is outside or inside and on activity/exposure. [maximum 3]

2. A long-lived contaminant can remain radioactive for a long time, extending potential exposure. Persistence does not by itself establish a high instantaneous activity. [maximum 2]

3. It limits how long the patient remains exposed after the measurement, provided sufficient activity remains during the test. [maximum 2]

4. Too much may decay before preparation, transport or imaging is complete. The signal could become too weak during the procedure. [maximum 2]

5. Type determines penetration and ionisation, changing where dose is deposited. Half-life affects how activity changes and how long exposure persists. Assess activity, amount, location and duration together; short half-life is not automatically always safer. [maximum 4]

Lesson 12 Separate Physics nuclear fission and energy release

1. Splitting a heavy nucleus into two smaller nuclei, releasing energy and usually neutrons. [maximum 2]

2. A suitable heavy nucleus absorbs a neutron. It becomes unstable and can split. [maximum 2]

3. Kinetic energy of fission fragments/neutrons and energy carried by gamma radiation. [maximum 2]

4. Nuclear changes release much larger energy per reacting particle than chemical rearrangements of electrons/bonds. Hence suitable nuclear fuel has a much greater energy release per kilogram. [maximum 2]

5. Uranium-235 or plutonium-239 (not every isotope of either element is fissile). [maximum 1]

Lesson practice answers

Indicative answers. Credit equivalent correct wording, up to the maximum in the question.

Lesson 13 Separate Physics chain reactions

1. One fission releases neutrons. Some are absorbed by other fissile nuclei and cause more fissions. Those release more neutrons, sustaining a chain reaction. [maximum 3]

2. On average, one neutron from each fission causes one further fission. The overall fission rate is maintained approximately steady. [maximum 2]

3. Control rods absorb neutrons. Inserting them further reduces the number available to sustain fission, reducing the reaction rate. [maximum 2]

4. In some fuels slow neutrons have a greater chance of inducing fission. A moderator slows neutrons to improve the chain reaction's probability. [maximum 2]

5. The fission rate can increase rapidly, producing energy faster than it can be removed. Overheating and loss of control can damage the reactor. [maximum 2]

Lesson 14 Separate Physics nuclear fusion

1. Two light nuclei join to form a heavier nucleus, with energy released for suitable light-nucleus reactions. [maximum 2]

2. Both nuclei are positively charged and repel. A very high temperature gives them sufficient kinetic energy to approach closely enough for fusion. [maximum 3]

3. In the cores of stars, including the Sun. [maximum 1]

4. The total rest mass of products is smaller than that of the reactants. The mass difference corresponds to released energy carried by particles/radiation. [maximum 2]

5. Examples: achieving and sustaining high temperature, confining the plasma or maintaining enough collisions for a useful energy output. [maximum 2]

Lesson practice answers

Indicative answers. Credit equivalent correct wording, up to the maximum in the question.

Lesson 15 Nuclear energy decisions risks, benefits and evidence

1. Reliable high-output electricity and low operational CO_2 emissions. Accept two relevant benefits. [maximum 2]

2. Long-lived radioactive waste and high construction/decommissioning costs; also accept a developed accident/security concern. [maximum 2]

3. Risk involves how likely harm is and how severe it would be. A rare event can still have serious consequences; frequency alone is insufficient. [maximum 3]

4. Resource access, costs, existing infrastructure, waste arrangements and social priorities differ. These change the balance of benefits and burdens. [maximum 3]

5. Examples: lifetime cost, annual output/availability, lifecycle emissions, waste quantity/activity, or incident frequency and severity. [maximum 1]

6. Fission offers reliable output and low operational carbon emissions compared with fossil combustion. It requires costly construction/decommissioning, waste management and safeguards against accidents. Fossil generation can be flexible but emits CO_2 and pollutants and uses finite fuel. Give a conditional conclusion using the evidence and relevant local priorities, not just a list. [maximum 6]

Assessment answers

Indicative marking guidance. Award distinct valid points and correct method, up to the stated maximum.

1. Most alpha particles passed through foil (1), supporting mostly empty space (1). A few were strongly deflected/backscattered (1), requiring a very small concentrated positive region (1) containing most of the mass: the nucleus, replacing the spread-out positive-charge model (1). [maximum 5]

2. Protons = Z = 17 (1); neutrons = A − Z = 20 (1); neutral electrons = 17 (1). [maximum 3]

3. ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$. Missing daughter numbers: A = 234 and Z = 90; emitted particle is alpha (helium nucleus). [maximum 3]

4. ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$. Daughter A = 14 (1), Z = 7 (1), beta numbers 0 and −1 (1). In beta-minus decay a neutron changes into a proton, increasing Z by one while A stays fixed (1). Antineutrino not required. [maximum 4]

5. Individual decay time is unpredictable (1). Each undecayed nucleus has a probability of decay per interval (1). Many nuclei produce a predictable statistical decline (1), so half-life describes population/activity halving, not one nucleus's lifetime (1). [maximum 4]

6. 24/6 = 4 half-lives (1). Remaining fraction = $(½)^4$ = 1/16 (1). Activity = 1600/16 (1) = 100 Bq (1). [maximum 4]

7. Subtract measured background from observed count rates (1). Choose an activity and half that value on the corrected graph (1), read the corresponding time difference (1), and check at other pairs of values (1). [maximum 4]

Assessment answers continued

Indicative marking guidance. Award distinct valid points and correct method, up to the stated maximum.

8. Alpha is least penetrating and most strongly ionising (2); beta is intermediate (1); gamma is most penetrating and least strongly ionising of the three (2). Compare appropriate shielding: paper, suitable aluminium/plastic and substantial lead/concrete attenuation. [maximum 5]

9. Contamination is radioactive material on/in the body (1); irradiation is radiation reaching it without material transfer in this context (1). Internal alpha is strongly ionising (1), deposits energy close to the source (1) and can damage nearby cells/DNA without skin shielding (1). [maximum 5]

10. Imaging: gamma tracer emits radiation detected outside the body to show organ/process information (2). Treatment: targeted radiotherapy deposits dose in a tumour to kill cancer cells (2). Credit equivalent valid uses. [maximum 4]

11. Radiation type determines penetration/dose location (1), so tracer radiation must escape for detection or treatment radiation must reach its target (1). Half-life must allow the procedure (1) while limiting unnecessary continuing exposure (1). [maximum 4]

12. A suitable heavy nucleus absorbs a neutron and splits (2). Released energy appears mainly in kinetic energy of fragments/neutrons (1), with gamma radiation also emitted (1). [maximum 4]

13. Fission releases neutrons (1) that can induce further fissions (1). Control rods absorb some neutrons (1), maintaining about one continuing fission per previous fission on average for a steady chain reaction (1). [maximum 4]

14. Light nuclei join to form a heavier nucleus (1), releasing energy for suitable reactions (1). Positive nuclei repel (1), so very high temperature is needed to give sufficient kinetic energy for close approach (1). [maximum 4]

Assessment answers continued

Indicative marking guidance. Award distinct valid points and correct method, up to the stated maximum.

15. Reliable low-operational-carbon output is a benefit (1). Waste and decommissioning require long-term management/cost (1). Construction cost/time and accident likelihood/consequences must be assessed (1). Compare with alternatives and affected groups (1), then give a conditional conclusion based on evidence and stated priorities (1). [maximum 5]

Knowledge organiser

Lesson 1 Atomic structure, scale and the nuclear model

An atom has a tiny positively charged nucleus surrounded by negatively charged electrons. Almost all the mass is concentrated in the nucleus.

Lesson 2 Nuclei, isotopes and nuclide notation

The nucleus contains protons and neutrons. The proton number identifies the element; isotopes of the same element have the same proton number but different neutron numbers.

Lesson 3 Unstable nuclei and types of nuclear emission

An unstable nucleus can emit alpha particles, beta particles, neutrons or gamma radiation and become more stable.

Lesson 4 Balanced nuclear equations

Nuclear equations conserve total mass number and total proton/charge number.

Lesson 5 Random radioactive decay and half-life

Radioactive decay is random for individual nuclei: you cannot predict when a particular nucleus will decay.

Lesson 6 Higher net decline after integral half-lives

After one half-life, 1/2 remains; after two, 1/4; after three, 1/8; after n half-lives, (1/2)^n remains.

Lesson 7 Activity-time graphs and practical half-life models

To find half-life from a graph, choose an activity value, halve it, then measure the horizontal time interval between the two points.

Lesson 8 Penetration and ionisation

Alpha is strongly ionising and weakly penetrating: paper or skin can stop it. Beta penetrates further and is reduced by thin aluminium. Gamma is weakly ionising but highly penetrating and needs thick dense shielding.

Retrieval task Explain each idea without notes, then check it. For calculations, state the equation and SI units.

Knowledge organiser continued

Lesson 9 Contamination versus irradiation

Contamination means radioactive material is on or inside an object/person. Irradiation means radiation reaches the person from an external source without radioactive material being transferred.

Lesson 10 Medical uses and biological hazards

Ionising radiation can be used to trace processes inside the body, image organs and destroy unwanted tissue such as cancer cells.

Lesson 11 Hazard depends on radiation type and half-life

Radiation type changes penetration and ionisation; therefore the same activity can present different external/internal hazards.

Lesson 12 Separate Physics nuclear fission and energy release

In fission, a neutron can be absorbed by a large unstable nucleus, which splits into two smaller nuclei.

Lesson 13 Separate Physics chain reactions

A fission event can release several neutrons. If one or more of these are absorbed by other fissile nuclei, further fissions occur.

Lesson 14 Separate Physics nuclear fusion

Fusion joins light nuclei to form a heavier nucleus and releases energy.

Lesson 15 Nuclear energy decisions risks, benefits and evidence

Nuclear fission can provide reliable low-carbon electricity during operation, but produces radioactive waste and involves high construction, decommissioning and safety costs.

Retrieval task Explain each idea without notes, then check it. For calculations, state the equation and SI units.

Publication notes and references

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