

Atomic structure and nuclear radiation

AQA GCSE Physics 8463 and Combined Science Trilogy 8464 | Paper 1 | Foundation and Higher

Worked solutions and teaching prompts | Shared Foundation and Higher content

Specification points covered

Atoms and isotope notation: 8463 4.4.1.1–4.4.1.2 / 8464 6.4.1.1–6.4.1.2 (selected content)

Evidence for the nuclear model: 8463 4.4.1.3 / 8464 6.4.1.3 (selected content)

Radioactive decay and radiation properties: 8463 4.4.2.1 / 8464 6.4.2.1

Single alpha and beta-minus nuclear equations: 8463 4.4.2.2 / 8464 6.4.2.2

Contamination, irradiation and precautions: 8463 4.4.2.4 / 8464 6.4.2.4 (selected content)

A materials-testing laboratory checks isotope records and compares how materials absorb radiation. You will audit the records, interpret supplied measurements and explain the precautions used by its trained staff. This is a paper-based investigation, not an activity involving radioactive sources.

Shared content for both routes and tiers. Accept equivalent scientific wording, e or β for a beta-minus particle with mass number 0 and charge number -1 , and consistent follow-through. GCSE equations show the nucleus and emitted alpha or beta particle. Timing is suggested, not classroom-tested. Original PhysicsUK questions, not an official AQA paper or mark scheme.

1 Auditing the isotope records

The laboratory records the isotope of each material, not just the element name.

1(a) State what the atomic number of an atom tells you. **[1 mark]**

Answer / mark points: The number of protons in its nucleus. [1]

1(b) State what the mass number of an atom tells you. **[1 mark]**

Answer / mark points: The total number of protons and neutrons in its nucleus. [1]

Teacher prompt: Electrons are not included in mass number.

1(c) A neutral atom on a record is $^{22}_{10}\text{Ne}$. Determine its number of neutrons and its number of electrons. **[2 marks]**

Answer / mark points: Neutrons = $22 - 10 = 12$. [1] Electrons = protons = 10. [1]

1(d) A second record shows a neutral $^{24}_{12}\text{Mg}$ atom. Determine its number of neutrons and its number of electrons. **[2 marks]**

Answer / mark points: Neutrons = $24 - 12 = 12$. [1] Electrons = protons = 12. [1]



1 Auditing the isotope records continued

1(e) The records contain $^{24}_{12}\text{Mg}$ and $^{26}_{12}\text{Mg}$. Explain why they are isotopes of the same element. [2 marks]

Answer / mark points: Both nuclei have 12 protons, so they are the same element. [1]
They have different neutron numbers: 12 and 14, respectively. [1]

1(f) An atom of $^{24}_{12}\text{Mg}$ loses two outer electrons. State how many electrons remain and explain whether its nucleus has changed. [2 marks]

Answer / mark points: 10 electrons remain. [1] The nucleus is unchanged: only outer electrons were removed, so it still has 12 protons and 12 neutrons. [1]

Teacher prompt: Ionisation is not radioactive decay; it does not change the element or mass number.

2 Using evidence to test an atomic model

For staff training, Table 1 gives an illustrative pattern for 10 000 positively charged alpha particles directed at very thin metal foil. It is not a record of a new laboratory experiment. The older plum pudding model spread positive charge through the atom.

Table 1

Observation	Number of alpha particles
Pass straight through	9900
Deflected, but not backwards	99
Turn back towards source	1

2(a) Use the observation for most alpha particles in Table 1 to state a conclusion about the space inside an atom. [1 mark]

Answer / mark points: Most alpha particles pass straight through, so most of an atom is empty space. [1]

2(b) A very small number of positive alpha particles turn back. What does this suggest about the charge and mass concentrated inside the atom? [2 marks]

Answer / mark points: There is a concentrated positive charge that repels positive alpha particles. [1]
Most mass is concentrated in a small, dense nucleus, allowing a few alpha particles to turn back. [1]

2(c) Explain why these observations led scientists to replace the plum pudding model rather than keep its spread-out positive charge. [2 marks]

Answer / mark points: A spread-out positive charge could not account for the rare, very large deflections or backwards scattering. [1]
A small concentrated positive nucleus explains those events while also allowing most alpha particles to pass through empty space. [1]

Teacher prompt: Link evidence to the changed model. The scattering experiment did not directly discover neutrons.

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3 Balancing the decay records

Balance the upper and lower numbers separately. Worked alpha example: ${}_{90}^{228}\text{Th} \rightarrow {}_{88}^{224}\text{Ra} + {}_2^4\text{He}$. Upper numbers: $228 = 224 + 4$; lower numbers: $90 = 88 + 2$. Worked beta-minus example: ${}_{16}^{35}\text{S} \rightarrow {}_{17}^{35}\text{Cl} + {}_{-1}^0\text{e}$. Upper numbers: $35 = 35 + 0$; lower numbers: $16 = 17 - 1$. In each task, the named daughter element is already identified.

3(a) A radium-224 nucleus undergoes alpha decay to radon, Rn. Complete the daughter's mass and atomic numbers: ${}_{88}^{224}\text{Ra} \rightarrow {}_Z^A\text{Rn} + {}_2^4\text{He}$. **[2 marks]**

Answer / mark points: ${}_{88}^{224}\text{Ra} \rightarrow {}_{86}^{220}\text{Rn} + {}_2^4\text{He}$.

A = $224 - 4 = 220$. [1] Z = $88 - 2 = 86$. [1]

3(b) Americium-241 undergoes alpha decay to neptunium, Np. Complete: ${}_{95}^{241}\text{Am} \rightarrow {}_Z^A\text{Np} + {}_2^4\text{He}$. **[2 marks]**

Answer / mark points: ${}_{95}^{241}\text{Am} \rightarrow {}_{93}^{237}\text{Np} + {}_2^4\text{He}$.

A = $241 - 4 = 237$. [1] Z = $95 - 2 = 93$. [1]

3(c) An archived alpha-decay record is ${}_{87}^{221}\text{Fr} \rightarrow {}_{85}^{217}\text{At} + {}_Z^A\text{He}$. Determine A and Z for the emitted particle. **[2 marks]**

Answer / mark points: A = $221 - 217 = 4$. [1] Z = $87 - 85 = 2$. [1]

The emitted particle is ${}_2^4\text{He}$, a helium nucleus.

3(d) Carbon-14 undergoes beta-minus decay to nitrogen, N. Complete: ${}_6^{14}\text{C} \rightarrow {}_Z^A\text{N} + {}_{-1}^0\text{e}$. **[2 marks]**

Answer / mark points: ${}_6^{14}\text{C} \rightarrow {}_7^{14}\text{N} + {}_{-1}^0\text{e}$.

A = 14. [1] Z = 7 because $6 = 7 - 1$. [1]



3 Balancing the decay records continued

3(e) A strontium nucleus ${}^{90}_{38}\text{Sr}$ emits a beta-minus particle and becomes yttrium, Y. Write the balanced nuclear equation. **[2 marks]**

Answer / mark points: ${}^{90}_{38}\text{Sr} \rightarrow {}^{90}_{39}\text{Y} + {}^0_{-1}\text{e}$.

Mass numbers: $90 = 90 + 0$. [1] Atomic numbers: $38 = 39 - 1$. [1]

3(f) A tritium nucleus ${}^3_1\text{H}$ emits a beta-minus particle and becomes helium, He. Write the balanced nuclear equation. **[2 marks]**

Answer / mark points: ${}^3_1\text{H} \rightarrow {}^3_2\text{He} + {}^0_{-1}\text{e}$.

Mass numbers: $3 = 3 + 0$. [1] Atomic numbers: $1 = 2 - 1$. [1]

3(g) A trainee says beta-minus decay is just the loss of an outer electron, so the nucleus stays unchanged. Explain why this is wrong. **[2 marks]**

Answer / mark points: In beta-minus decay a neutron in the nucleus changes into a proton and an electron is emitted from the nucleus. [1]

The atomic number increases by 1 while the mass number stays the same; losing an outer electron would not do this. [1]

3(h) An excited nickel-60 nucleus emits a gamma ray. State what happens to its mass number and atomic number, and explain why it remains nickel. **[2 marks]**

Answer / mark points: Both mass number and atomic number stay the same. [1]

Gamma is electromagnetic radiation; no proton is removed or changed, so the element remains nickel. [1]

3(i) A trainee writes this alpha decay: ${}^{241}_{95}\text{Am} \rightarrow {}^{237}_{94}\text{Np} + {}^4_2\text{He}$. Correct the daughter's atomic number and show the balance that proves your correction. **[2 marks]**

Answer / mark points: The daughter atomic number should be 93. [1]

$95 = 93 + 2$; the proposed 94 would give $94 + 2 = 96$, not 95. [1]

Teacher prompt: The wrong equation is intentional. Check lower numbers as well as upper numbers.



4 Interpreting the absorption tests

Figure 1 shows the laboratory arrangement. Each sealed test source emits only one of alpha, beta-minus or gamma radiation for this comparison. The source–detector air gap is short enough for alpha particles to reach the detector without an absorber. Table 2 gives mean net count-rates after the laboratory has subtracted its no-source reading. Treat a zero as no detected source contribution.

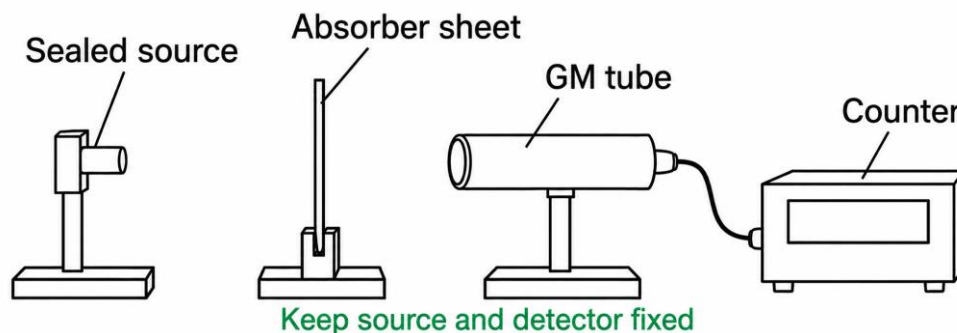


Figure 1

Table 2

Absorber	A / counts s ⁻¹	B / counts s ⁻¹	C / counts s ⁻¹
None	240	240	240
Paper	0	230	238
3 mm aluminium	0	0	210
20 mm lead	0	0	72

4(a) In a separate calibration test, the detector records 3600 counts in 30 s. Calculate its mean count-rate. **[1 mark]**

Answer / mark points: Count-rate = counts / time = 3600 / 30 = 120 counts s⁻¹. [1]

4(b) Identify the radiation from source A in Table 2. Justify your answer using the paper result. **[2 marks]**

Answer / mark points: Alpha. [1] Paper reduces the detected source contribution from 240 counts s⁻¹ to zero, showing that the radiation is absorbed by paper. [1]

4(c) Identify the radiation from source B. Use both its paper result and its aluminium result to justify your answer. **[2 marks]**

Answer / mark points: Beta-minus. [1] It passes through paper but is stopped by the 3 mm aluminium sheet. [1]



4 Interpreting the absorption tests continued

4(d) Identify the radiation from source C. Use the aluminium and lead measurements as evidence. **[2 marks]**

Answer / mark points: Gamma. [1] A substantial count-rate remains through aluminium, and the thick lead reduces it without making it zero. [1]

4(e) A trainee says that the lead makes source C less radioactive because the count-rate falls. Explain why this conclusion is wrong. **[2 marks]**

Answer / mark points: The lead absorbs some emitted radiation before it reaches the detector, reducing the detector's count-rate. [1]
It does not change the rate at which the source's unstable nuclei decay, so it does not change the source's activity. [1]

Teacher prompt: Specify count-rate, not just fewer counts. The absorber does not prevent gamma rays being emitted by the source.

4(f) Explain why the source and detector in Figure 1 should stay in the same positions while the absorber is changed. **[2 marks]**

Answer / mark points: This keeps the source–detector distance and alignment constant. [1]
Moving them could change how much radiation reaches the detector, so a change in count-rate could not be attributed to the absorber alone. [1]

4(g) Source C has activity 60 000 Bq but gives an unshielded detector reading of 240 counts s^{-1} . Explain why these values do not have to be equal. **[2 marks]**

Answer / mark points: Activity counts all nuclear decays per second in the source; count-rate is the number detected per second. [1]
Not every decay produces radiation recorded by this detector, for example because some radiation travels in other directions or is absorbed. [1]

4(h) The laboratory needs radiation still detectable after passing through a 3 mm aluminium test piece. Choose source A, B or C and justify the choice from Table 2. **[2 marks]**

Answer / mark points: Choose C: it still gives 210 counts s^{-1} after the aluminium. [1]
A and B both give zero detected source contribution through aluminium, so they would not meet the requirement. [1]



5 Distinguishing the radiation hazards

The laboratory compares an intact sealed source with a damaged source that has released radioactive dust. Use the presence or absence of radioactive material to explain each case.

5(a) A metal sample is exposed to an intact sealed source. No source material transfers to it, and the source is then removed. Explain why this is irradiation, not contamination. **[2 marks]**

Answer / mark points: The sample was exposed to nuclear radiation, which is irradiation. [1]
No radioactive material was transferred to it, so it is not contaminated or made radioactive by this exposure. [1]

5(b) Radioactive dust from the damaged source settles on a workbench. Explain why the bench can remain a radiation hazard after the original source is taken away. **[2 marks]**

Answer / mark points: Radioactive material remains on the bench: it is contaminated. [1]
The unstable nuclei in that material continue to decay and emit radiation there. [1]

5(c) An alpha emitter outside the body is compared with dust from the same emitter inhaled into the body. Explain why the inhaled material can be much more hazardous. **[2 marks]**

Answer / mark points: Outside the body, alpha particles have low penetration and are usually stopped by the outer skin. [1]
Inside, their strong ionising effect can damage nearby living cells as the contaminating material continues to emit radiation. [1]

5(d) The laboratory uses a remote handling arm rather than holding a sealed source close to the body. Explain how this reduces the irradiation hazard. **[2 marks]**

Answer / mark points: The arm increases the distance between the source and the person. [1]
Less radiation reaches the person, reducing their exposure. [1]

Teacher prompt: Do not say radiation travels along the arm, or that the source is dangerous because it is hot or gives electric shocks.

Review and improve

Mass number counts nucleons, not all particles in an atom. In beta-minus decay a neutron changes into a proton; the electron is emitted from the nucleus, not an electron shell. Absorbers affect detected radiation, not the source's activity. Irradiation is exposure; contamination means radioactive material is present where it is unwanted.

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