

AQA AS Atomic Structure, Specific Charge and Nuclear Stability solutions

Matching solutions and teaching prompts for the class review

Specification points covered

- 3.2.1.1(a-e) Describe atoms and nuclei; use particle charge and mass, nuclide notation, isotopes and specific charge.
- 3.2.1.2(a-b) Describe the strong nuclear force, including attraction to about 3 fm and repulsion below about 0.5 fm.
- 3.2.1.2(c-d) Describe unstable nuclei and write alpha and beta-minus decay equations.
- 3.2.1.2(e) Explain why a neutrino is needed in beta decay to conserve energy.

Teaching focus

Require complete working, correct SI units and precision justified by the data.

Use the common-error prompt to make pupils correct the method or language, not only the final number.

1. Constituents and nuclides

1. State the relative charge and relative mass of a proton, neutron and electron. [4 marks]

Answer / mark points: Proton: relative charge +1, relative mass 1. Neutron: charge 0, relative mass 1. Electron: charge -1, relative mass about 1/1836. Award across the complete set.

Teacher prompt / common error: Do not give electron mass as zero; its relative mass is small but non-zero.

2. An aluminium-27 ion has proton number 13 and contains 10 electrons. State its numbers of protons, neutrons and electrons and its charge in units of e. [4 marks]

Answer / mark points: Protons = 13. Neutrons = $27 - 13 = 14$. Electrons = 10. Net charge = $+3e$, so it is an Al^{3+} ion.

Teacher prompt / common error: Ion charge follows from protons minus electrons; nucleon number gives protons plus neutrons.

3. Define isotopes and explain which feature of their nuclei is the same and which is different. [2 marks]

Answer / mark points: Isotopes are nuclei or atoms of the same element with the same proton number but different numbers of neutrons, and therefore different nucleon numbers.

Teacher prompt / common error: Same element means the same proton number, not the same neutron number.



2. Specific charge

4. Calculate the specific charge of a hydrogen-3 nucleus. Use $e = 1.60 \times 10^{-19} \text{ C}$ and nucleon mass $= 1.67 \times 10^{-27} \text{ kg}$. [2 marks]

Answer / mark points: Specific charge = charge/mass $= 1.60 \times 10^{-19} / (3 \times 1.67 \times 10^{-27}) = 3.19 \times 10^7 \text{ C kg}^{-1}$.

Teacher prompt / common error: Specific charge is total charge divided by total mass, not charge divided by proton number.

5. An oxygen-18 ion has gained two electrons. Calculate its specific charge, including the sign. Neglect electron mass. [3 marks]

Answer / mark points: Charge $= -2e = -3.20 \times 10^{-19} \text{ C}$. Mass $\approx 18 \times 1.67 \times 10^{-27} = 3.01 \times 10^{-26} \text{ kg}$. Specific charge $= -3.20 \times 10^{-19} / 3.01 \times 10^{-26} = -1.06 \times 10^7 \text{ C kg}^{-1}$.

Teacher prompt / common error: A gained electron makes the ion negative. Electron mass may be neglected but electron charge may not.

6. The nuclei of hydrogen-1, hydrogen-2 and hydrogen-3 all have charge $+e$. State the ratio of their specific charges and explain the trend. [2 marks]

Answer / mark points: Specific-charge ratio H-1:H-2:H-3 $= 1:1/2:1/3$, or 6:3:2. The charge is the same but the mass increases with nucleon number, so charge divided by mass decreases.

Teacher prompt / common error: All three nuclei have the same charge; the denominator changes.

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3. Nuclear equations

7. Write complete nuclear equations for: (a) alpha decay of polonium-210 to lead; (b) beta-minus decay of carbon-14 to nitrogen. Include every emitted particle needed at AS level. [4 marks]

Answer / mark points: (a) ${}^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + {}^4_2\text{He}$. (b) ${}^{14}_6\text{C} \rightarrow {}^{14}_7\text{N} + {}^0_{-1}\text{e} + \bar{\nu}_e$. Nucleon number and charge are balanced in each equation.

Teacher prompt / common error: Beta-minus decay requires an electron antineutrino as well as the electron.

8. A thorium-234 nucleus, proton number 90, undergoes one alpha decay followed by two beta-minus decays. Determine the nucleon number and proton number of the final nucleus and identify its element. [3 marks]

Answer / mark points: After alpha decay: $A = 230$ and $Z = 88$. Two beta-minus decays leave A unchanged and increase Z by 2, giving $A = 230$ and $Z = 90$. The final nucleus is thorium-230.

Teacher prompt / common error: Alpha changes both A and Z ; beta-minus changes Z but leaves A constant.

9. Explain why the electron antineutrino is required in beta-minus decay. [2 marks]

Answer / mark points: In beta-minus decay the electron alone does not account for the continuously shared decay energy and momentum. The electron antineutrino carries the missing energy and momentum; it also makes lepton number conservation consistent.

Teacher prompt / common error: The expected language is conservation of energy and momentum, not that the neutrino provides energy.

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4. Nuclear stability

10. Describe how the strong nuclear force varies with nucleon separation and explain how this behaviour contributes to nuclear stability. [4 marks]

Answer / mark points: The strong nuclear force acts between nucleons. It is attractive over separations up to about 3 fm and is much stronger than electrostatic repulsion at nuclear separations. Below about 0.5 fm it becomes repulsive, preventing nucleons collapsing together. The balance provides a stable separation.

Teacher prompt / common error: Include both distance regimes: attractive to about 3 fm and repulsive below about 0.5 fm.

11. Stable heavy nuclei contain more neutrons than protons. Explain this imbalance by comparing the strong nuclear interaction with electrostatic repulsion. [4 marks]

Answer / mark points: Electrostatic repulsion acts between every pair of protons and is relatively long range. The strong interaction is short range and acts only between nearby nucleons. Extra neutrons increase strong attraction without adding electrostatic repulsion, helping bind a large nucleus; too many or too few neutrons can still make it unstable.

Teacher prompt / common error: Strong attraction is short range and acts between nucleons; electrostatic repulsion acts only between protons.

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5. Unfamiliar application

12. A space probe carries two calibration sources. Source X is polonium-210 and source Y is carbon-14. Deduce the daughter nucleus from each decay and explain, using nuclear forces and conservation, why the two decay processes change nucleon and proton numbers differently. [5 marks]

Answer / mark points: Source X: polonium-210 emits an alpha particle, so the daughter is lead-206; A decreases by 4 and Z by 2 because two protons and two neutrons leave together. Source Y: carbon-14 undergoes beta-minus decay to nitrogen-14; A is unchanged and Z increases by 1 because a neutron changes to a proton while an electron and electron antineutrino are emitted. In both cases charge and nucleon number are conserved across the complete equation. Instability arises when the balance of short-range strong attraction and proton-proton electrostatic repulsion is unfavourable; decay moves the nucleus toward a more stable arrangement.

Teacher prompt / common error: A strong response combines correct daughter nuclei, conservation and the force-balance explanation rather than treating decay as random particle loss.

Language and method check

Award marks for independent, creditworthy physics steps rather than the amount of working shown.

Where an equivalent method is valid, accept it only when the reasoning, units and final precision remain consistent.

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