C1aD Atomic Structure and the History of the Atom: Exam Drill

AQA 8464 · Calculator allowed · about 90 minutes

Total Marks

Name: ________________________________ Date: ____ / ____ / ______

Answer ALL questions. Show all your working.

1 An atom is described by its proton number and mass number.

(a) State which particle determines the atomic (proton) number of an element. **(1)**

(b) State what the mass number of an atom represents. **(1)**

(c) An atom has 17 protons and 18 neutrons. Give its atomic number and mass number. **(1)**

(Total for Question 1 is 3 marks)

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2 Briefly outline three historical models or discoveries that led to our modern view of the atom.

(a) Name the scientist associated with the idea of indivisible particles called atoms in the early model. **(1)**

(b) Name the scientist who discovered the electron and proposed a model with electrons embedded in a positive sphere. **(1)**

(c) Name the experiment and lead scientist whose results supported a small, dense nucleus at the centre of the atom. **(1)**

(Total for Question 2 is 3 marks)

3 Write the electron arrangement (shell notation) for the following neutral atoms.

(a) Oxygen, atomic number 8. **(1)**

(b) Magnesium, atomic number 12. **(1)**

(c) Chlorine, atomic number 17. **(1)**

(Total for Question 3 is 3 marks)

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4 Ions form when atoms gain or lose electrons.

(a) Explain how a neutral sodium atom (11 electrons) becomes a sodium ion with charge +1. **(1)**

(b) State the electron configuration of Cl- ion (chloride). **(1)**

(Total for Question 4 is 2 marks)

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5 A sample contains two isotopes of element X. Isotope X-63 has mass 62.930 u and abundance 69.15%. Isotope X-65 has mass 64.928 u and abundance 30.85%. Calculate the relative atomic mass Ar of element X to three significant figures. Use Ar = sum(isotopic mass x abundance fraction).

(a) Substitute the values into the Ar formula. **(1)**

(b) Calculate the value and give the answer to three significant figures. **(2)**

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(Total for Question 5 is 3 marks)

6 A student uses a simple mass spectrometer model to measure relative isotopic masses. Their recorded peaks are at m/z 24 and 25 with peak heights proportional to signal 80 and 20 respectively. The instrument was correctly calibrated. The student claims (i) the sample contains two isotopes with relative abundances 80% and 20%, and (ii) the relative atomic mass Ar of the element is 24.2 u. Using the peak data, assess both parts of the student's claim and show your working.

(a) Use the peak heights to determine the percentage abundance of each isotope. Show the calculation. **(2)**

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(b) Calculate the relative atomic mass Ar from these abundances and the m/z values, to one decimal place. Show working. **(2)**

....

(c) Comment briefly on the student's overall claim that the sample contains two isotopes with abundances 80% and 20% and that Ar = 24.2 u. Include any assumptions made. **(2)**

(Total for Question 6 is 6 marks)

7 Complete the nuclear notation and calculate the number of protons, neutrons and electrons for the species shown.

(a) Write the nuclear notation for the isotope with 26 protons and 30 neutrons (use A over Z notation, e.g. A over Z X). **(2)**

(b) An ion is shown as 35 over 17 X with charge -1. Calculate the numbers of protons, neutrons and electrons. **(2)**

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(c) A neutral atom of element Y has mass number 23 and proton number 11. Give its symbol and electron configuration. **(2)**

(Total for Question 7 is 6 marks)

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8 A class practical investigates the scattering of α particles by thin metal foils. The student measures the number of α particles detected at various angles for a gold foil and a thin aluminium foil. The data collected (counts per minute) are: gold foil at 0 degrees 1200 cpm, at 10 degrees 180 cpm, at 30 degrees 24 cpm; aluminium foil at 0 degrees 1180 cpm, at 10 degrees 60 cpm, at 30 degrees 6 cpm. Use these data to answer the following.

(a) Calculate the percentage of detected α particles scattered at 30 degrees for each foil relative to counts at 0 degrees. Give answers to 2 significant figures. **(3)**

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(b) Explain, using the data, what these results show about the nuclear structure of gold compared with aluminium. Refer to scattering at large angles. **(3)**

(Total for Question 8 is 6 marks)

9 The relative atomic mass of an element Z is measured experimentally to be 40.08 u. Explain why the value on the periodic table is not necessarily a whole number and describe briefly how the existence of isotopes leads to the value 40.08 u.

(a) Explain why relative atomic mass values are not whole numbers. **(2)**

(b) Give a brief description of how two isotopes of element Z, with masses near 39 u and 41 u, could combine in natural abundance to produce Ar = 40.08 u. **(3)**

(Total for Question 9 is 5 marks)

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10 Explain how the sequence of atomic models from Thomson to Rutherford to Bohr improved our understanding of atomic structure. In your answer include experimental evidence and how each model solved a problem from the previous model.

(Total for Question 10 is 6 marks)

11 A student is given an unknown sample of a metal they are told may contain two stable isotopes, A and B. They use mass spectrometry and obtain relative peak areas of isotope A = 600 and isotope B = 400. They calculate a relative atomic mass Ar = 56.4 u when the m/z values are 56 for A and 57 for B. Critically evaluate the student's calculation and suggest one experimental improvement to increase accuracy.

(a) Show the calculation for Ar using the given peak areas and m/z values. **(2)**

(b) Give two brief comments that evaluate the reliability of this result and state one experimental improvement to increase accuracy. **(4)**

(Total for Question 11 is 6 marks)

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12 Describe and explain one real-world application that depends on knowledge of isotopes and atomic structure. Give an explicit link between the isotope property used and how it enables the application.

(Total for Question 12 is 6 marks)

Mark scheme · C1aD Atomic Structure and the History of the Atom: Exam Drill

Question 1

- (a) **B1** proton cao
- **(a) Answer: Proton**
- (b) **B1** the total number of protons and neutrons in the nucleus, oe
- **(b) Answer: The total number of protons and neutrons in the nucleus.**
- (c) **B1** atomic number 17 and mass number 35 cao
- **(c) Answer: Atomic number 17, mass number 35.**

Question 2

- (a) **B1** John Dalton or Dalton cao
- **(a) Answer: John Dalton**
- (b) **B1** J J Thomson or Thomson cao
- **(b) Answer: J J Thomson**
- (c) **B1** Rutherford gold foil experiment or Rutherford cao
- **(c) Answer: Rutherford gold foil experiment (Rutherford)**

Question 3

- (a) **B1** 2,6 cao
- **(a) Answer: 2,6**
- (b) **B1** 2,8,2 cao
- **(b) Answer: 2,8,2**
- (c) **B1** 2,8,7 cao
- **(c) Answer: 2,8,7**

Question 4

- (a) **B1** loses one electron from outer shell to form Na^+ (gives 10 electrons total), oe
- **(a) Answer: It loses one electron from its outer shell, giving Na^+ with one more proton than electrons.**
- (b) **B1** 2,8,8 cao
- **(b) Answer: 2,8,8**

Question 5

- (a) **M1** substitutes: $A_r = 62.930 \times 0.6915 + 64.928 \times 0.3085$
- (b) **A1** $A_r = 63.546...$ correctly calculated to at least 4 dp and rounded to 3 s.f., cao
- (b) **A1** correct final answer: 63.5 u cao
- **(b) Answer: 63.5 u**

Question 6

- (a) **M1** calculates fractions from peak heights: fraction 24 = 80/(80+20), fraction 25 = 20/(80+20)
- (a) **A1** gives percentages: 24 is 80% and 25 is 20% cao
- **(a) Answer: Isotope m/z 24: 80%; m/z 25: 20%.**
- (b) **M1** substitutes: Ar = 24 x 0.80 + 25 x 0.20
- (b) **A1** Ar = 24.2 u cao
- **(b) Answer: 24.2 u**
- (c) **M1** states that the peak heights give relative abundances so claim (i) is supported, assuming detector response is equal for both isotopes and no overlapping peaks, oe
- (c) **A1** states that Ar = 24.2 u is correct given those abundances and m/z values, and notes possible sources of error such as fractionation or incomplete ion detection, oe
- **(c) Answer: Both parts are supported by the data: abundances 80% and 20% and Ar = 24.2 u, assuming equal detector response and no other isotopes or overlapping peaks; instrument fractionation would change results.**

Question 7

- (a) **M1** writes mass number A = protons + neutrons = 56
- (a) **A1** full notation: 56 over 26 Fe (or Fe-56) cao
- **(a) Answer: 56 over 26 Fe (Fe-56)**
- (b) **M1** states protons = 17 and neutrons = 35 - 17 = 18
- (b) **A1** states electrons = 18 (17 + 1) cao
- **(b) Answer: Protons 17; Neutrons 18; Electrons 18.**
- (c) **M1** identifies element with Z = 11 as sodium (Na)
- (c) **A1** gives correct electron configuration 2,8,1 cao
- **(c) Answer: Symbol Na (sodium); electron configuration 2,8,1.**

Question 8

- (a) **M1** works out ratio 30 deg count / 0 deg count for each foil
- (a) **A1** gold: 24/1200 = 0.02 -> 2.0% cao
- (a) **A1** aluminium: 6/1180 = 0.00508 -> 0.51% -> 0.51% rounded to 2 s.f. = 0.51% cao
- **(a) Answer: Gold: 2.0%; Aluminium: 0.51%.**
- (b) **M1** states that gold shows a higher proportion of large-angle scattering than aluminium (2.0% vs 0.51%)
- (b) **M1** links large-angle scattering to encounter with a small, dense, positively charged nucleus
- (b) **A1** concludes that gold nuclei cause more large-angle deflections, consistent with higher nuclear charge or larger nucleus, oe
- **(b) Answer: Gold produces more large-angle scattering than aluminium, showing more α particles are deflected by close encounters with a small, dense, positively charged nucleus; this suggests gold nuclei produce stronger repulsion (higher nuclear charge or larger nucleus) than aluminium.**

Question 9

- (a) **M1** states that Ar is a weighted average of isotopic masses, not a mass of a single isotope
- (a) **A1** explains that differing masses and abundances of isotopes give a non-integer average cao
- **(a) Answer: Ar is a weighted average of the masses of the naturally occurring isotopes, so differing isotope masses and abundances produce a non-integer average.**
- (b) **M1** states approximate abundances such that the weighted mean lies near 40.08 (for example about 46% 39 u and 54% 41 u) or gives another plausible pair of abundances
- (b) **M1** shows calculation or reasoning to demonstrate weighted mean near 40.08 (example 39 x 0.46 + 41 x 0.54 = 40.08) oe
- (b) **A1** concludes that having a slightly greater proportion of the heavier isotope shifts the mean above 40, producing 40.08 u cao
- **(b) Answer: If about 46% is 39 u and 54% is 41 u then Ar = 39 x 0.46 + 41 x 0.54 = 17.94 + 22.14 = 40.08 u (illustrating how having a slightly greater proportion of the heavier isotope raises the mean just above 40 to match the measured value); other abundance pairs consistent with the given isotope masses could also work.**

Question 10

- **Level 3** (5-6): Detailed explanation linking models and evidence, clear reasoning and several correct comparisons.
- **Level 2** (3-4): Some linked statements about models and evidence with partial explanation.
- **Level 1** (0-2): Basic statements about one or two models with little or no linking to evidence.
- **Indicative content:**
  - Thomson proposed the plum-pudding model after discovery of the electron; explained atom had electrons but did not explain how positive charge distributed or scattering.
  - Rutherford alpha scattering experiment showed most alpha particles passed straight through but some were strongly deflected, indicating a small, dense, positively charged nucleus; this disproved the plum-pudding model.
  - Rutherford model introduced nucleus and mostly empty space around it but could not explain electron stability or discrete emission spectra.
  - Bohr proposed quantised electron orbits to explain stability of atoms and discrete spectral lines, matching observed hydrogen emission lines.
  - Each model solved a problem from the previous: Thomson explained electrons; Rutherford explained why some particles deflect strongly; Bohr explained atomic stability and spectra.
  - Limitations: Bohr worked for hydrogen-like atoms but was later refined by quantum mechanics.

Question 11

- (a) **M1** calculates fractions: A fraction = 600/(600+400) = 0.60, B fraction = 0.40
- (a) **A1** calculates Ar = 56 x 0.60 + 57 x 0.40 = 56.4 u cao
- **(a) Answer: Ar = 56 x 0.60 + 57 x 0.40 = 33.6 + 22.8 = 56.4 u.**
- (b) **M1** comments that acknowledge instrument assumptions such as equal ionisation efficiency and detector response for both isotopes, oe
- (b) **M1** notes possible sources of error such as peak overlap, background noise, or calibration drift, oe
- (b) **M1** states an appropriate improvement: calibrate with standard of known composition, or run replicate measurements and average, or improve vacuum to reduce collisions, oe
- (b) **A1** links the suggested improvement to increased accuracy (e.g. calibration reduces systematic bias; replicates reduce random error) cao
- **(b) Answer: The calculation is arithmetically correct but assumes equal ionisation and detector response; any preferential ionisation would bias abundances. Peak overlap or calibration drift could also affect peak areas. Improvement: run a calibration with a standard of known isotope ratio or take replicate runs and average results to reduce random and systematic error; this will improve accuracy.**

Question 12

- **M1** states a relevant application (examples: radiocarbon dating using C-14; medical tracer using technetium-99m; isotope separation for nuclear fuel using U-235)
- **M1** states the isotope property used (radioactive decay rate, γ emission energy, mass difference, oe)
- **M1** explains how this property is used in the application (e.g. C-14 half-life gives age estimate; Tc-99m emits γ rays detected for imaging)
- **M1** gives a specific, accurate link between property and practical outcome (e.g. known half-life allows calculation of sample age; short half-life of Tc-99m reduces patient dose)
- **M1** identifies one limitation or safety/accuracy consideration (e.g. contamination, need for calibration, shielding for radiation) oe
- **M1** concludes why understanding isotopes is essential to the application, oe