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ANSWER BOOK

Ionisation energies and the evidence for subshells

Atomic structure · Unit C01

AQA 3.1.1.3 · OCR A 3.1.1

15 questions · 46 marks

NAVY EDITION

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SECTION A · Short, 1 to 2 marks

A1 IE-Q17

B1 each electron is removed from an ion that is more positive than the one before. **B1** the same nuclear charge holds fewer electrons, which repel each other less and are pulled closer, so more energy is needed. [2]

A2 IE-Q18

B1 potassium has a lower first ionisation energy, 419 against 496 kJ mol^{-1}, because its outer electron is in 4s, further out and more shielded. **B1** the reaction begins with the loss of the outer electron, which therefore happens more readily for potassium. [2]

SECTION B · Standard, 3 to 5 marks

B1 IE-Q1

B1 the energy required to remove one electron from each atom in one mole of atoms. **B1** the atoms are gaseous, and one mole of gaseous 1+ ions is formed. **B1** $Ca(g) \rightarrow Ca^{+}(g) + e^{-}$. **B1** $Ca^{+}(g) \rightarrow Ca^{2+}(g) + e^{-}$; reject $Ca(g) \rightarrow Ca^{2+}(g) + 2e^{-}$. [4]

B2 IE-Q14

B1 gallium's value is lower than calcium's, although gallium has eleven more protons. **B1** calcium's electron is removed from 4s, gallium's from 4p. **B1** 4p is higher in energy than 4s, so its electron is on average further out and partly shielded by the 4s and 3d electrons. **B1** the extra protons are almost cancelled by the ten 3d electrons added between them, so less energy removes the 4p electron. [4]

B3 IE-Q16

B1 if the third shell were a single level, the values would rise smoothly with nuclear charge from sodium to argon. **B1** aluminium is lower than magnesium because its electron is removed from 3p, a subshell of higher energy than 3s. **B1** sulfur is lower than phosphorus because of pairing in a 3p orbital, consistent with orbitals each holding two electrons. **B1** the same dips appear in Period 2 at boron and oxygen, so the data support the claim. [4]

B4 IE-Q4

B1 the outer electron is in a shell further from the nucleus, so the atomic radius is larger. **B1** there are more inner shells of electrons, so there is more shielding. **B1** these outweigh the increase in nuclear charge, so the outer electron is attracted less strongly and less energy removes it. [3]

B5 IE-Q5

B1 the electron removed from aluminium is in a 3p orbital, while magnesium's is in 3s. **B1** 3p is higher in energy than 3s, so its electron is further from the nucleus on average and partly shielded by the 3s electrons. **B1** less energy is needed to remove it, so the first ionisation energy falls despite the greater nuclear charge. [3]

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B6 IE-Q6

B1 phosphorus, $3p^3$, has one electron in each 3p orbital. **B1** sulfur, $3p^4$, has two electrons paired in one 3p orbital. **B1** the paired electrons repel each other, so one of them is easier to remove, which outweighs sulfur's extra proton; reject a stable half-filled subshell argument. [3]

B7 IE-Q8

B1 the first electron is removed from 3s, and the second from 2p. **B1** the 2p electron is in a shell closer to the nucleus and is shielded only by the 1s electrons. **B1** it is also removed from a positive ion, so it is attracted far more strongly and much more energy is needed. [3]

B8 IE-Q9

M1 amount of sodium = 1.00 ÷ 23.0 = 0.0435 mol. **M1** energy = 0.0435 mol × 496 kJ mol^{-1}. **A1** 21.6 kJ, to three significant figures. [3]

B9 IE-Q10

M1 the change $Ca(g) \rightarrow Ca^{2+}(g) + 2e^-$ is the first ionisation followed by the second. **M1** energy = 590 + 1145. **A1** +1735 kJ mol^{-1}, to four significant figures. [3]

B10 IE-Q11

M1 convert to joules: 738 kJ mol^{-1} = 7.38×10^5 J mol^{-1}. **M1** energy per atom = $7.38 \times 10^5 \div 6.022 \times 10^{23}$. **A1** 1.23×10^{-18} J, to three significant figures. [3]

B11 IE-Q13

B1 Na^+ and Ne are isoelectronic, with the same arrangement of ten electrons. **B1** Na^+ has 11 protons against neon's 10, so the same electrons are attracted more strongly. **B1** the electron is removed from an ion that is already positive, so more energy is needed. [3]

B12 IE-Q19

M1 $Sc(g) \rightarrow Sc^{3+}(g) + 3e^-$ is the first three ionisations in turn, so their energies add. **M1** energy = 633 + 1235 + 2389. **A1** +4257 kJ mol^{-1}, to four significant figures. [3]

B13 IE-Q20

B1 the fourth electron is removed from 3s, and the fifth from 2p. **B1** the 2p electron is in a shell closer to the nucleus, shielded only by the 1s electrons. **B1** it is also removed from a 4+ ion, so it is attracted far more strongly and much more energy is needed. [3]

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