FREE SAMPLE: THE FIRST QUESTION

Question One (16 marks)

(a) (i) Write the full electron configuration (using s, p, d notation) of the oxygen ion, O^{2-}.

(ii) State the number of unpaired electrons in the oxygen ion, and whether it is paramagnetic or diamagnetic.

(iii) Explain how the electrons are arranged in the oxygen ion, referring to the order in which sub-shells are filled and to Hund's rule.

[6 marks]

(b) The first ionisation energy of phosphorus is 1012 kJ mol^{-1} but that of sulfur is 1000 kJ mol^{-1}. Although the general trend across a period is for ionisation energy to increase, sulfur has a lower value than phosphorus.

Explain this exception, referring to electron configurations.

[5 marks]

(c) The first 3 ionisation energies of element Q (kJ mol^{-1}) are: 419, 3052, 4420.

(i) State the number of electrons in the outer energy level of Q and its group in the periodic table.

(ii) Explain how the ionisation energy data support your answer.

[5 marks]

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THE WORKED ANSWER TO THAT QUESTION

Question 1 (16 marks) [Atoms, electron configurations and periodic trends]

(a) (i) Write the full electron configuration (using s, p, d notation) of the oxygen ion, O^{2-}. (ii) State the number of unpaired electrons in the oxygen ion, and whether it is paramagnetic or diamagnetic. (iii) Explain how the electrons are arranged in the oxygen ion, referring to the order in which sub-shells are filled and to Hund's rule.

(a) Answer: (i) $1s^2\ 2s^2\ 2p^6$; (ii) 0 unpaired, diamagnetic

- Evidence level: Excellence (fill the sub-shells in order of increasing energy, apply Hund's rule, and adjust for ions and for half-full and full d sub-shells).
- (i) $1s^2\ 2s^2\ 2p^6$.
- (ii) The oxygen ion has 0 unpaired electron(s) (electrons occupy separate orbitals of a sub-shell with parallel spins before pairing, Hund's rule), so it is diamagnetic.
- Achievement: (iii) States the order of filling.
- Merit: Links to energy: electrons enter the lowest-energy sub-shell available first (1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p).
- Excellence: Full explanation: the 10 electrons are placed in sub-shells in order of increasing energy, each holding at most 2 (s), 6 (p) or 10 (d) electrons; where a sub-shell has several orbitals, electrons occupy them singly with parallel spins before pairing (Hund's rule); the anion gains electrons into the next available sub-shell, reaching a stable full outer shell.

> **KEY TAKEAWAY**
> Electron configurations: fill 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p; Cr and Cu are $4s^1\ 3d^5$ and $4s^1\ 3d^{10}$; remove 4s before 3d from cations; count unpaired electrons using Hund's rule.

(b) The first ionisation energy of phosphorus is 1012 kJ mol^{-1} but that of sulfur is 1000 kJ mol^{-1}. Although the general trend across a period is for ionisation energy to increase, sulfur has a lower value than phosphorus. Explain this exception, referring to electron configurations.

(b) Answer: Exception explained by the electron configurations: sulfur's $3p^4$ configuration has a pair of electrons in one 3p orbital; the repulsion between the paired electrons makes it easier to remove an electron than from phosphorus's $3p^3$ half-filled sub-shell

- Evidence level: Excellence (use the electron configurations to explain the exception).
- Achievement: Writes the electron configurations of both atoms.
- Merit: Links the configuration to the energy of the electron removed.
- Excellence: Full explanation: sulfur's $3p^4$ configuration has a pair of electrons in one 3p orbital; the repulsion between the paired electrons makes it easier to remove an electron than from phosphorus's $3p^3$ half-filled sub-shell.

> **KEY TAKEAWAY**
> Exceptions to the trend: Be→B and Mg→Al (the p electron is higher in energy than the s electron) and N→O and P→S (electron–electron repulsion in a paired p orbital).

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(c) The first 3 ionisation energies of element Q (kJ mol^{-1}) are: 419, 3052, 4420. (i) State the number of electrons in the outer energy level of Q and its group in the periodic table. (ii) Explain how the ionisation energy data support your answer.

(c) Answer: (i) 1 outer electrons, group 1; (ii) a large jump after the 1st ionisation energy as an inner-shell electron is removed

- Evidence level: Excellence (find the large jump in successive ionisation energies, which marks the start of a closer, inner energy level).
- (i) The ratios of successive values are 7.28, 1.45; the biggest jump is after the 1st ionisation energy (419 → 3052 kJ mol^{-1}), so Q has 1 outer electrons and is in group 1.
- Achievement: (ii) States that there is a big increase after the 1st ionisation energy.
- Merit: Links to shells: the next electron is removed from an inner energy level.
- Excellence: Full explanation: the first 1 electrons come from the outer energy level, which is shielded and far from the nucleus, so successive values rise gradually; the next electron comes from a full inner energy level that is closer to the nucleus and not shielded by the outer electrons, so the ionisation energy rises sharply, showing there are 1 outer electrons.

KEY TAKEAWAY

Successive ionisation energies: a big jump marks the move to a new, inner energy level; the number of electrons removed before the jump equals the number of outer electrons.

LOS: Atoms, electron configurations and periodic trends (91390)

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