

Orbitals, configurations and ionisation energy patterns

Chemistry grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Each answer shows the method, the substitution and the result with its unit in bold. For explanation problems, check that you used the three factors: nuclear charge, distance and shielding, or electron pairing where it applies.

Level: Chemistry grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** A Level 3.1.1, IB S1.3

Problem 1 Counting orbitals

1. A p subshell has **3 orbitals**.
2. Five d orbitals $\times 2 =$ **10 electrons**.
3. $2n^2 = 2 \times 3^2 =$ **18 electrons**. Check: $3s\ 2 + 3p\ 6 + 3d\ 10 = 18$.

Problem 2 Spot the shapes

1. A is an **s orbital** (sphere); B is a **p orbital** (dumbbell).
2. A p subshell contains **3** such orbitals.
3. Each orbital holds two electrons at most, because only two spin states exist and no two electrons in an atom can share all the same quantum numbers (Pauli principle).

Problem 3 Sulfur and chloride

1. S: **$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$** .
2. Cl^- has 18 electrons: **$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$** .
3. The noble gas is **argon**.

Problem 4 Calcium and its ion

1. Ca: **$[Ar]\ 4s^2$** .
2. Ca^{2+} loses both 4s electrons: **$[Ar] = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$** .
3. The outer shell ($n = 4$) holds **2 electrons**.

Problem 5 Hund's rule error

1. Aarav has paired two electrons in one 2p orbital while another 2p orbital is empty.
2. He broke **Hund's rule**.
3. Correct diagram: one electron in each 2p box, all with parallel spins, so nitrogen has **3 unpaired electrons**.

Problem 6 Writing the equations

1. $\text{Na(g)} \rightarrow \text{Na}^{\text{+}}(\text{g}) + \text{e}^{-}$
2. $\text{Mg(g)} \rightarrow \text{Mg}^{2+}(\text{g}) + \text{e}^{-}$
3. The unit is **kJ mol⁻¹**. The sign is positive (endothermic) because energy must be supplied to overcome the attraction between the electron and the nucleus.

Problem 7 Energy per atom

1. Energy per atom = $496 \times 10^3 \text{ J mol}^{-1} \div 6.02 \times 10^{23} \text{ mol}^{-1} = \mathbf{8.24 \times 10^{-19} \text{ J}}$.
2. $0.250 \text{ mol} \times 496 \text{ kJ mol}^{-1} = \mathbf{124 \text{ kJ}}$.

Problem 8 Which block?

1. 15 electrons: **phosphorus, p block**.
2. 27 electrons: **cobalt, d block**.
3. 19 electrons: **potassium, s block**.
4. 35 electrons: **bromine, p block**.

Problem 9 Chromium and copper

1. Cr: **[Ar] 3d⁵ 4s¹**; Cu: **[Ar] 3d¹⁰ 4s¹**.
2. A half-full (3d⁵) or full (3d¹⁰) subshell lowers the repulsion and the energy enough that one 4s electron moves into 3d, because 3d and 4s are very close in energy.
3. Cr³⁺ loses the 4s electron and two 3d electrons: **[Ar] 3d³**.

Problem 10 Ions of iron and zinc

1. Fe²⁺: **[Ar] 3d⁶**; Fe³⁺: **[Ar] 3d⁵**; Zn²⁺: **[Ar] 3d¹⁰**.
2. Unpaired electrons: Fe²⁺ has **4** (3d⁶: one pair, four singles), Fe³⁺ has **5**, Zn²⁺ has **0**.
3. Once the 3d subshell is occupied it lies lower in energy than 4s, and the 4s electrons are outermost, so they are lost first.

Problem 11 Sodium versus magnesium

1. Both outer electrons are in the third shell (3s). Sodium has 11 protons and magnesium has 12, so the nuclear charge is larger in magnesium. Shielding by the 10 inner electrons is the same.
2. The outer electrons feel a stronger pull in magnesium, at a similar distance, so **more energy is needed**, 738 against 496 kJ mol⁻¹.

Problem 12 Down group 1

1. The first ionisation energy **decreases** down the group.
2. The outer electron is in a higher shell, further from the nucleus, and shielded by more

inner shells. These effects outweigh the increase in nuclear charge.

3. Caesium is **below 403 kJ mol⁻¹** because its outer electron is in the sixth shell, even further away.

Problem 13 Beryllium to boron

1. Be: $1s^2 2s^2$; B: $1s^2 2s^2 2p^1$.

2. The 2p electron of boron is in a higher-energy subshell, slightly further from the nucleus, and partly shielded by the 2s electrons. It is removed more easily, so **boron is lower**.

Problem 14 Nitrogen to oxygen

1. N: 2p has three boxes with one electron each. O: 2p has one full box and two boxes with one electron each.

2. In oxygen, two electrons share one 2p orbital and repel one another. Removing one relieves this repulsion, so **oxygen has the lower value**.

Problem 15 Group from data

1. The big jump comes after the third value ($2750 \rightarrow 11600$), so there are **3 outer electrons: group 13**.

2. The ion is X^{3+} , so the chloride is **XCl₃**.

3. The fourth electron comes from an inner shell, nearer the nucleus and less shielded, so it needs much more energy.

Problem 16 Reading the graph

1. The graph jumps after electron 4, so Q has **4 outer electrons: group 14**.

2. With 14 electrons Q is **silicon**: $1s^2 2s^2 2p^6 3s^2 3p^2$.

3. Silicon has 8 electrons in the second shell, so the next jump is between the 12th and 13th electrons, when the first electron is taken from the 1s shell.

Problem 17 Second ionisation of sodium

1. Na^+ : $1s^2 2s^2 2p^6$. Mg^+ : $1s^2 2s^2 2p^6 3s^1$.

2. Removing the second electron from sodium takes it from the full 2p subshell of the second shell, close to the nucleus and with less shielding. In magnesium it is the 3s electron, in the third shell. So sodium needs **much more energy**.

Problem 18 Energy to make Mg^{2+}

1. $738 + 1451 = \mathbf{2189 \text{ kJ mol}^{-1}}$.

2. $n = 3.6 \text{ g} \div 24.3 \text{ g/mol} = 0.1481 \text{ mol}$ (0.148 mol).

3. $E = 0.1481 \text{ mol} \times 2189 \text{ kJ/mol} = 324.3 \text{ kJ}$, which is **$3.2 \times 10^2 \text{ kJ}$** (2 significant figures).

Problem 19 Light that ionises hydrogen

1. $E = 1312 \times 10^3 \text{ J mol}^{-1} \div 6.022 \times 10^{23} \text{ mol}^{-1} = \mathbf{2.179 \times 10^{-18} \text{ J}}$.
2. $\lambda = hc/E = (6.626 \times 10^{-34} \times 3.00 \times 10^8) \div 2.179 \times 10^{-18} = 9.12 \times 10^{-8} \text{ m}$, so $\lambda = \mathbf{91.2 \text{ nm}}$.
3. This is **ultraviolet**, since it is shorter than 400 nm.

Problem 20 Zinc and gallium

1. Zn: [Ar] $3d^{10} 4s^2$; Ga: [Ar] $3d^{10} 4s^2 4p^1$.
2. The outer electron of gallium is in a 4p orbital, higher in energy than 4s and slightly shielded by the 4s electrons. Removing it is easier, so **gallium has the lower value** despite the extra proton.