Advanced Level

H2 Chemistry

(9476)

Exam Guide

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JAMES COLLINS (ASIA)

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How to use this Guide

Each chapter has the same plan. Page 1 is a concept map. Then: 1 Key definitions, 2 Explanation chains, 3 rules, data and diagrams, 4 Paper 1 multiple choice, 5 Paper 2 structured questions, 6 Paper 3 long question, 7 Quick Q&A.

Every Paper 2 and Paper 3 answer is taught in the same steps: 1 Read it, 2 Key words, then Model answer and Where students lose marks. Cover the model answer and write your own first.

Labels. POPULAR = asked often, must score. CHALLENGE = for an A grade. P2 / P3 = the paper the question comes from. → p N = turn to that page.

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1 Atomic Structure

Concept map

9476 Section 1 · JC1

The atom = tiny nucleus (protons + neutrons) surrounded by electrons in orbitals

Particles
proton +1, mass 1; neutron 0, mass 1; electron −1, mass 1/1840. The nucleus holds almost all the mass. In an electric field (same speed): angle ∝ **charge ÷ mass**; protons → negative plate, electrons → positive plate (much larger angle), neutrons undeflected.

Isotopes
Same proton number, **different numbers of neutrons**. Same electronic configuration, so the **same chemical properties**. Neutrons = $A - Z$; electrons = Z − charge.

Orbitals and subshells
s: 1 orbital (sphere); p: 3 (dumb-bell); d: 5. Each orbital holds **at most two** electrons. Filling order: 1s 2s 2p 3s 3p **4s 3d** 4p.

Electronic configuration
Fill the lowest energy first; fill orbitals singly, then pair. Ions lose **4s before 3d**. Exceptions: Cr [Ar] $3d^5\ 4s^1$, Cu [Ar] $3d^{10}\ 4s^1$.

First ionisation energy
Three factors: **nuclear charge**, **shielding**, **distance**. Increases across a period (dips at Group 13 and Group 16); decreases down a group (one more shell: more shielding, further away).

Successive ionisation energies
Always increase (fewer electrons, less shielding). A **big jump** = the first electron from an **inner shell**: electrons before the jump = outer electrons → the group (add 10 for Groups 13–18: the ten d-block groups lie in between).

Can you… define the first ionisation energy and write its equation? → P2 Q1, p 8 · predict and calculate the deflection of a beam? → P2 Q2, p 9 · sketch and explain the IE trend across Period 3? → P2 Q4, p 11 · find the group from successive ionisation energies? → P2 Q7, p 14

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1.1 Key definitions

Words in bold are the ones mark schemes look for.

Term	Definition / meaning
Proton number, *Z*	The number of **protons** in the nucleus of an atom.
Nucleon number, *A*	The **total number of protons and neutrons** in the nucleus of an atom.
Isotopes	Atoms of the **same element** with the **same number of protons** but **different numbers of neutrons**. Same electronic configuration, so the **same chemical properties**.
Orbital	A region of space around the nucleus where there is a **high probability of finding an electron**. Holds at most **two electrons**; two electrons in one orbital have opposite spins.
Shell and subshell	A **shell** is a main energy level, numbered by the principal quantum number *n*. Each shell is split into **subshells** (s, p, d) of slightly different energy.
Degenerate orbitals	Orbitals of the **same energy**, e.g. the three 2p orbitals.
First ionisation energy, IE_1	Energy **required** to remove **one mole of electrons** from **one mole of gaseous atoms** to form one mole of **singly charged gaseous cations**: $X(g) \rightarrow X^+(g) + e^-$.
Second ionisation energy, IE_2	Energy required to remove one mole of electrons from one mole of **gaseous 1+ ions** to form one mole of **gaseous 2+ ions**: $X^+(g) \rightarrow X^{2+}(g) + e^-$.
Shielding effect	The **repulsion** of an outer electron by the **inner electrons**, which reduces its attraction to the nucleus.
Effective nuclear charge	The nuclear charge **felt by an outer electron** after **shielding by the inner electrons**.
Isoelectronic species	Atoms or ions with the **same number of electrons**, e.g. Na^+, Mg^{2+} and Ne.

Rule An ionisation energy definition needs: **energy required**, **one mole of electrons**, **one mole of gaseous atoms (or ions)**, and the **cation formed**. An ionisation equation must have **(g)** on every atom and ion (not on e^-).

Symbols and words ***Z*** = proton number · ***A*** = nucleon number · ***n*** = shell number · **[Ar]** = the configuration of argon, $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$ · $\propto$ = is proportional to · **log** = $\log_{10}$, used to fit very large and small values on one graph · **outer (valence) electrons** = the electrons in the shell with the highest *n*.

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1.2 Explanation chains

Learn each chain in order; each numbered step is usually one marking point.

Particles and electric fields

How do beams of protons, neutrons and electrons behave in an electric field?

1. **Protons** (positive) are deflected **towards the negative plate**; **electrons** (negative) **towards the positive plate**. Name the plates: "opposite directions" alone is not enough.
2. **Neutrons** have no charge, so they are **not deflected**.
3. For beams at the **same speed** in the same field, angle of deflection ∝ **charge ÷ mass**. An electron has a **much smaller mass** (about 1/1840 of a proton), so it is deflected through a **much larger angle**.

Electrons in atoms and ions

Why is 4s filled before 3d, but 4s electrons are lost first?

1. In atoms up to calcium, the 4s orbital is **lower in energy** than 3d, so it **fills first**.
2. When ions form, the electrons are removed from the **outermost shell** ($n = 4$) first, so the **4s electrons are lost before the 3d** electrons: Fe [Ar] $3d^6\ 4s^2 \rightarrow Fe^{2+}$ [Ar] $3d^6$.

Why are chromium and copper exceptions?

1. Cr is [Ar] $3d^5\ 4s^1$ (not $3d^4\ 4s^2$); Cu is [Ar] $3d^{10}\ 4s^1$ (not $3d^9\ 4s^2$).
2. The 3d and 4s orbitals are **very close in energy**. A **half-filled** ($3d^5$) or **fully filled** ($3d^{10}$) d subshell has **less inter-electronic repulsion**, so this arrangement has a **lower energy** (is more stable).

First ionisation energy

Why does the first ionisation energy increase across a period?

1. The **number of protons increases**, so the **nuclear charge increases**.
2. Electrons are added to the **same outermost shell**, so the **shielding effect stays about the same**.
3. So the **effective nuclear charge increases**.
4. The **attraction** between the nucleus and the outermost electron is **stronger**, so **more energy is required** to remove it.

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Why does the first ionisation energy decrease down a group?

1. The nuclear charge increases, **but** there is **one more electron shell** each time.
2. The **shielding effect increases significantly** (examiners say leaving this out is the most common error).
3. The outermost electron is **further from the nucleus**, so the attraction is **weaker** and **less energy is required** to remove it.

Why is IE_1 of Al lower than Mg? (dip from Group 2 to Group 13)

1. Mg: [Ne] $3s^2$; Al: [Ne] $3s^2\ 3p^1$. The electron removed from Al is in the **3p subshell**.
2. 3p is **higher in energy** and **further from the nucleus** than 3s, and is **shielded by the filled 3s** electrons.
3. So **less energy is required** to remove the 3p electron of Al.

Why is IE_1 of S lower than P? (dip from Group 15 to Group 16)

1. P: $3p_x^{\ 1}\ 3p_y^{\ 1}\ 3p_z^{\ 1}$; S: $3p_x^{\ 2}\ 3p_y^{\ 1}\ 3p_z^{\ 1}$. The electron removed from S is a **paired electron in the $3p_x$ orbital**; in P all three 3p electrons are **unpaired**.
2. The two electrons in that orbital **repel each other** (**inter-electronic repulsion**).
3. So **less energy is required** to remove it. "S^+ has a stable half-filled subshell" alone does not earn the mark.

Successive ionisation energies

Why do successive ionisation energies always increase?

1. After each electron is removed, there are **fewer electrons than protons**.
2. There is **less shielding (repulsion)** among the remaining electrons.
3. The remaining electrons are **more strongly attracted** by the **same nuclear charge**, so more energy is required each time. (Not "the nuclear charge increases": it does not.)

Why is there a big jump between two successive ionisation energies?

1. The next electron is removed from an **inner shell** (lower n).
2. It is **closer to the nucleus** and has **much less shielding**.
3. So it is **much more strongly attracted**, and **much more energy** is required. The number of electrons removed **before** the jump = the number of outer electrons.

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1.3 Rules, data and diagrams

Write the rule first, then put the numbers in.

Particle	Relative charge	Relative mass	Where it is
proton	+1	1	nucleus
neutron	0	1	nucleus
electron	−1	1/1840 (negligible)	orbitals around the nucleus

The nucleus is **tiny** (about 10^{-15} m across, in an atom about 10^{-10} m across) but holds **almost all the mass** and all the positive charge.

To find	Use	Remember
protons, neutrons, electrons	protons = Z; neutrons = $A - Z$; electrons = Z − charge	for $^{37}Cl^-$: 17 p, 20 n, 18 e (a negative ion has **more** electrons)
a deflection angle	same speed, same field: angle ∝ charge ÷ mass (formula below the table)	keep the **sign**: a negative answer means the **opposite** plate; mass ≈ nucleon number A
orbitals in a subshell	s: 1, p: 3, d: 5 orbitals	electrons: s 2, p 6, d 10; shell n holds $2n^2$
electronic configuration	1s 2s 2p 3s 3p 4s 3d 4p (Figure 1.1)	fill orbitals singly first, then pair; ions lose 4s before 3d
an ionisation equation	nth IE: $X^{(n-1)+}(g) \rightarrow X^{n+}(g) + e^-$	one electron per step; (g) on every atom and ion
the group from successive IEs	count the electrons removed **before** the first big jump; a big jump is **several times larger** than the rises before it	outer electrons 1, 2 → Group 1, 2; 3 to 8 → Group 13 to 18 (add 10: the ten d-block groups lie in between)
ionisation energy values	**DATA BOOKLET** Section 2: 1st to 4th IE of selected elements (all of H to Zn, and some heavier ones)	higher IEs (5th onwards) are given in the question

Deflection angle: $\text{angle}_2 = \text{angle}_1 \times (q_2/m_2) \div (q_1/m_1)$

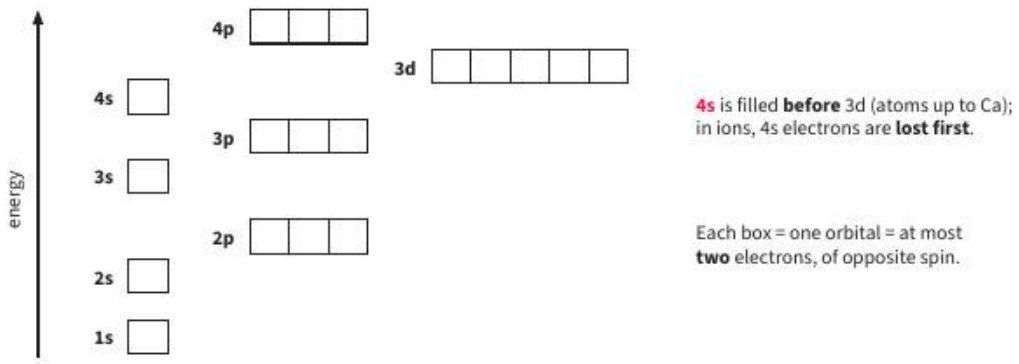
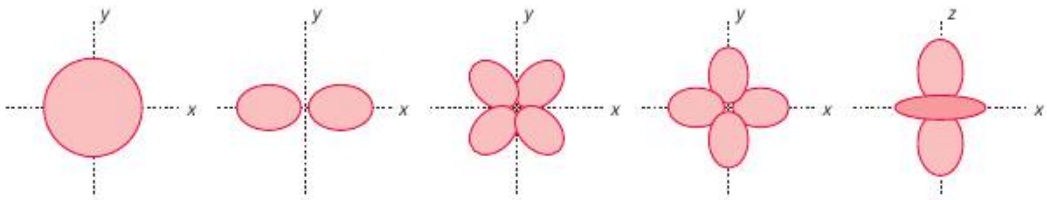


Figure 1.1 The order in which orbitals fill (n = 1 to 3, with 4s and 4p; not to scale). 4s is filled first up to Ca; in ions, 4s electrons are lost first because 4s is the outermost shell (n = 4).

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s: sphere around the nucleus | **p_x**: dumb-bell along *x* | **d_{xy}**: lobes between the axes | **$d_{x^2-y^2}$**: lobes along the axes | **d_{z^2}**: lobes along *z* + a ring around it

Figure 1.2 Shapes of orbitals. The 2p and 3p orbitals have the same shape; 3p is larger. There are three p orbitals (p_x, p_y, p_z: same shape, along different axes) and five d orbitals: d_{xz} and d_{yz} have the same shape as d_{xy}.

1.4 Paper 1: multiple choice

Read every option. Why each wrong option is wrong teaches as much as the right answer.

P1 **POPULAR** **Q1** Which species has 17 protons, 18 electrons and 20 neutrons? **[1]**

A $^{37}Cl^-$ **B** $^{35}Cl^-$
C ^{37}Cl **D** ^{38}Ar

ANSWER A

Why A is right: Cl has $Z = 17$; neutrons = 37 − 17 = **20**; the 1− charge adds one electron: 17 + 1 = **18**.

✗ **B** 35 − 17 = 18 neutrons, not 20.

✗ **C** a neutral atom has 17 electrons, not 18.

✗ **D** argon has **18** protons.

P1 **POPULAR** **Q2** Beams of the following ions pass through the same electric field at the same speed. Which is deflected through the largest angle? **[1]**

A $^{1}H^+$ **B** $^{2}H^+$
C $^{3}He^{2+}$ **D** $^{4}He^{2+}$

ANSWER A

Why A is right: angle ∝ charge ÷ mass: $^{1}H^+$ 1/1 = **1**; the others are smaller.

✗ **B** 1/2 = 0.5.

✗ **C** 2/3 = 0.67: a larger charge, but the mass is larger too.

✗ **D** 2/4 = 0.5.

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P1 **POPULAR** **Q3** What is the electronic configuration of Fe^{3+}? (Fe: $Z = 26$) **[1]**

A $[Ar]\ 3d^5$ **B** $[Ar]\ 3d^3\ 4s^2$

C $[Ar]\ 3d^4\ 4s^1$ **D** $[Ar]\ 3d^6$

ANSWER A

Why A is right: Fe is $[Ar]\ 3d^6\ 4s^2$. Remove the **two 4s electrons first**, then one 3d electron: $[Ar]\ 3d^5$.

✗ **B** removes 3d electrons before 4s.

✗ **C** removes one 4s and two 3d electrons: 4s must empty first.

✗ **D** this is Fe^{2+}: only two electrons removed.

P1 **CHALLENGE** **Q4** The first eight ionisation energies of element Y, in kJ mol^{-1}, are 1000, 2260, 3390, 4540, 7000, 8500, 27 100, 31 700. In which group is Y? **[1]**

A Group 2 **B** Group 14

C Group 16 **D** Group 17

ANSWER C

Why C is right: The big jump is between the **6th** (8500) and **7th** (27 100) IE: six electrons are in the outer shell, so Group 16 (Y is sulfur).

✗ **A** there is no big jump after the 2nd IE (2260 → 3390 is a small rise).

✗ **B** 4540 → 7000 is not a big jump: 8500 → 27 100 is a rise of 18 600: about 8 times the largest rise before it (4540 → 7000 = 2460).

✗ **D** counts the 7th electron as an outer electron: it is the first one removed from the **inner** shell.

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1.5 Paper 2: structured questions

Every answer is taught in the same steps: 1 Read it, 2 Key words, 3 Model answer (in the words you should write), 4 Where students lose marks. Calculations add Working as step 3, so the later steps move down one number. POPULAR = asked often, must score. CHALLENGE = for an A grade. P2 / P3 = the paper the question comes from.

Rule The marks tell you how many points to write. Examiners often give [1] per point; for a 2-mark trend explanation, four correct points earn [2] and two earn [1] (see the four numbered points in Q6).

P2 **POPULAR** **Q1**

(a) Define the first ionisation energy of magnesium, and write an equation for it.

(b) Explain why the second ionisation energy of magnesium is larger than the first. **[3]**

1 READ IT

Define + Write + Explain → the definition needs all four key ideas; the equation needs (g); then the fewer-electrons reason.

2 KEY WORDS THE EXAMINER LOOKS FOR

energy required · one mole of electrons · one mole of gaseous atoms · singly charged gaseous cations · (g) on atom and ion · fewer electrons than protons · less shielding

3 MODEL ANSWER (write it like this; one [1] = one marking point)

(a) The energy **required** to remove **one mole of electrons** from **one mole of gaseous** magnesium atoms to form one mole of **singly charged gaseous** Mg^+ ions. **[1]**

$Mg(g) \rightarrow Mg^+(g) + e^-$ **[1]**

(b) Mg^+ has **fewer electrons than protons**, so there is **less shielding**; the remaining electrons are **more strongly attracted** by the same nuclear charge, so more energy is required. **[1]**

✓ **Also works:** "energy needed" for "energy required" (from school answer keys; no SEAB mark scheme seen).

✗ **Not accepted:** $Mg(s) \rightarrow Mg^+(g) + e^-$ (the atom must be gaseous).

4 WHERE STUDENTS LOSE MARKS

- ✗ Writing "energy released", or forming negative ions.
- ✗ Leaving out "gaseous", or the (g) state symbols in the equation.
- ✗ Saying the nuclear charge increases after an electron is removed: it does not change.

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P2 **POPULAR** **Q2** A beam of protons is deflected through an angle of +12.0° (towards the negative plate). Under the same conditions:

(a) describe how beams of electrons and of neutrons behave;

(b) calculate the angle of deflection of a beam of $^{2}H^{+}$;

(c) calculate the angle of deflection of a beam of $^{16}O^{2-}$. **[4]**

1 READ IT

Describe + Calculate → name the plate for each particle; then angle ∝ charge ÷ mass, keeping the sign.

2 KEY WORDS THE EXAMINER LOOKS FOR

towards the positive plate · much larger angle · much smaller mass · not deflected · angle ∝ charge ÷ mass · sign = direction

3 WORKING (show every line)

angle ∝ charge ÷ mass; proton: +1 ÷ 1 = 1 → +12.0°, so angle = 12.0 × (charge ÷ mass)

$^{2}H^{+}$: charge ÷ mass = +1 ÷ 2 = 0.5 → 12.0 × 0.5 = **+6.00°**

$^{16}O^{2-}$: charge ÷ mass = −2 ÷ 16 = −0.125 → 12.0 × (−0.125) = **−1.50°**

4 MODEL ANSWER (write it like this; one [1] = one marking point)

(a) Electrons are deflected **towards the positive plate** through a **much larger angle**, because their mass is **much smaller**. **[1]**

Neutrons are **not deflected**: they have no charge. **[1]**

(b) 12.0 × (1/2) = **+6.00°** (towards the negative plate) **[1]**

(c) 12.0 × (−2/16) = **−1.50°**: 1.50° **towards the positive plate** **[1]**

5 WHERE STUDENTS LOSE MARKS

✗ Writing "opposite direction" without naming the positive plate.

✗ Saying electrons and protons are deflected by the same angle.

✗ Losing the minus sign in **(c)**, or using 8 (the proton number) as the mass of O^{2-}.

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P2 **POPULAR** **Q3** Write the full electronic configurations of

(a) Cr;

(b) Cu^{2+};

(c) Fe^{3+}.

(d) State the number of unpaired electrons in Fe^{3+}. (Cr $Z = 24$, Fe $Z = 26$, Cu $Z = 29$) **[4]**

1 READ IT

Write + State → "full" means every subshell written out, no [Ar]; ions lose 4s first. Write the subshells in order of shell (3d before 4s); writing 4s before 3d is also accepted.

2 KEY WORDS THE EXAMINER LOOKS FOR

full configuration · Cr $3d^5\ 4s^1$ · Cu $3d^{10}\ 4s^1$ · lose 4s first · orbitals filled singly

3 MODEL ANSWER (write it like this; one [1] = one marking point)

(a) Cr: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^1$ **[1]**

(b) Cu^{2+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9$ **[1]**

(c) Fe^{3+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$ **[1]**

(d) **Five**: the five 3d electrons are in five different 3d orbitals, one in each. **[1]**

4 WHERE STUDENTS LOSE MARKS

✗ Cr as $3d^4\ 4s^2$, or Cu^{2+} as $3d^8\ 4s^1$ (3d electrons removed before 4s).

✗ Using [Ar] when the question says "full".

✗ Counting unpaired electrons without drawing (or picturing) the five 3d boxes.

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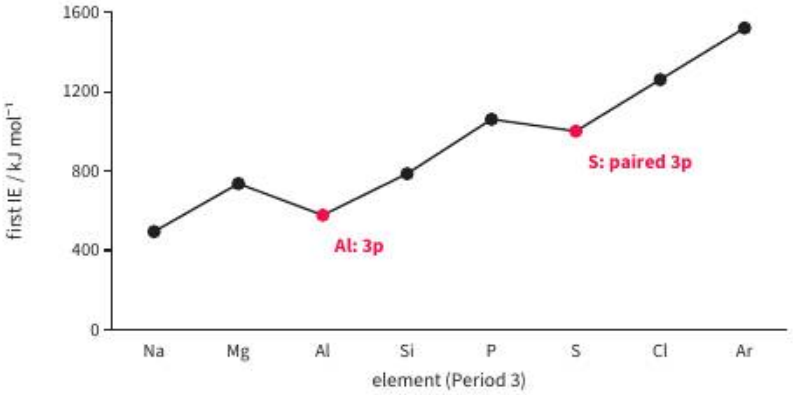
P2 **POPULAR** **Q4** Use the Data Booklet to sketch a graph of the first ionisation energies of the Period 3 elements, Na to Ar. Explain the general increase across the period. **[4]**

1 READ IT

Sketch + Explain → plot the eight values in order, with the two dips; then the four-point chain. **DATA BOOKLET** Section 2: Na 494, Mg 736, Al 577, Si 786, P 1060, S 1000, Cl 1260, Ar 1520 kJ mol^{-1}.

2 KEY WORDS THE EXAMINER LOOKS FOR

general increase · dips at Al and S · nuclear charge increases · same outermost shell · shielding about the same · stronger attraction · more energy required



Model sketch for Q4: values from the Data Booklet, Section 2. The two crimson points are the dips.

3 MODEL ANSWER (write it like this; one [1] = one marking point)

Sketch: increase from Na (lowest) to Ar (highest), with **dips at Al and S** (shown above); **label both axes, with units.** **[1]**

Across the period the **number of protons increases**, so the **nuclear charge increases.** **[1]**

Electrons are added to the **same outermost shell**, so **shielding stays about the same**: the effective nuclear charge increases. **[1]**

The outermost electron is **more strongly attracted** to the nucleus, so **more energy is required** to remove it. **[1]**

The dips at Al and S are explained in Q5, p 12.

4 WHERE STUDENTS LOSE MARKS

- ✗ Leaving out the dips, or putting the dip at Si or Cl. Check the Data Booklet values: Al (577) is below Mg (736).
- ✗ Leaving out the attraction step: examiners say this is often missed.
- ✗ Saying "atoms get smaller" with no link to nuclear charge and shielding.

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P2 POPULAR **Q5** Explain why

(a) the first ionisation energy of aluminium is lower than that of magnesium;

(b) the first ionisation energy of sulfur is lower than that of phosphorus. **[4]**

1 READ IT

Explain → write the configurations, name the subshell or orbital the electron comes from, then the reason.

2 KEY WORDS THE EXAMINER LOOKS FOR

3p subshell · higher in energy · shielded by the filled 3s · paired electron · $3p_x$ orbital · inter-electronic repulsion · less energy required

3 MODEL ANSWER (write it like this; one [1] = one marking point)

(a) Al is [Ne] $3s^2\ 3p^1$: the electron removed is in the **3p subshell**, which is **higher in energy** and **further from the nucleus** than the 3s subshell of Mg. **[1]**

The 3p electron is also **shielded by the filled 3s** electrons, so **less energy is required** to remove it. **[1]**

(b) S is [Ne] $3s^2\ 3p_x^2\ 3p_y^1\ 3p_z^1$: the electron removed is a **paired electron in the $3p_x$ orbital.** **[1]**

There is **inter-electronic repulsion** between the two electrons in that orbital (in P the three 3p electrons are **unpaired**, one in each orbital), so **less energy is required** to remove one. **[1]**

4 WHERE STUDENTS LOSE MARKS

✗ Saying "repulsion between orbitals": the repulsion is between two electrons **in the same orbital**.

✗ Only saying "S^+ has a stable half-filled 3p subshell": not credited on its own.

✗ Not saying which subshell or orbital the electron is removed from.

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P2 **POPULAR** **Q6** Use the Data Booklet to find the first ionisation energies of magnesium and calcium. Explain why calcium has the lower value. **[2]**

1 READ IT

Explain → the down-a-group chain: shells, shielding, distance, attraction. Four points earn [2]. **DATA BOOKLET** Section 2: Mg 736, Ca 590 kJ mol^{-1}.

2 KEY WORDS THE EXAMINER LOOKS FOR

one more electron shell · shielding increases significantly · further from the nucleus · weaker attraction · less energy required

3 MODEL ANSWER (write it like this; one [1] = one marking point)

(1) Ca has **one more electron shell**: although its nuclear charge is larger, **(2)** the **shielding effect increases significantly**. **[1]**

(3) The outer 4s electron is **further from the nucleus**, **(4)** so it is **less strongly attracted** and **less energy is required** to remove it. **[1]**

4 WHERE STUDENTS LOSE MARKS

✗ Leaving out shielding: the most common error in this answer.

✗ Saying "Ca has more protons, so its IE is higher": the extra shell and shielding outweigh the extra protons.

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P2 CHALLENGE **Q7** The first six ionisation energies of element X, in kJ mol^{-1}, are 786, 1580, 3230, 4360, 16 100, 19 800.

(a) State and explain the group of X.

(b) Explain why the 5th ionisation energy is so much larger than the 4th. **[4]**

1 READ IT

State + Explain → find the big jump; count the electrons before it; then the inner-shell reason.

2 KEY WORDS THE EXAMINER LOOKS FOR

big jump between the 4th and 5th · four outer electrons · Group 14 · inner shell · closer to the nucleus · much less shielding

3 MODEL ANSWER (write it like this; one [1] = one marking point)

(a) **Group 14**: the big jump is between the **4th and 5th** ionisation energies (4360 → 16 100). **[1]**

So X has **four electrons in its outer shell**. **[1]**

(b) The 5th electron is removed from an **inner shell**, which is **closer to the nucleus** and has **much less shielding**. **[1]**

It is **much more strongly attracted**, so **much more energy is required** to remove it. **[1]**

4 WHERE STUDENTS LOSE MARKS

✗ Counting the 5th electron (after the jump) and giving Group 15. X has 4 outer electrons: Group 14.

✗ Explaining the jump with "the nuclear charge increases".

✗ Stating the group with no reason: "State and explain" needs the jump and the electron count.

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P2 **CHALLENGE** **Q8** Use the Data Booklet to explain why the second ionisation energy of oxygen is **larger** than that of fluorine, although fluorine has more protons. **[3]**

1 READ IT

Explain → write the configurations of O^+ and F^+; find the paired electron. **DATA BOOKLET** Section 2: IE_2 of O 3390, F 3370 kJ mol^{-1}.

2 KEY WORDS THE EXAMINER LOOKS FOR

O^+ $2p^3$ · F^+ $2p^4$ · paired electron in the same 2p orbital · inter-electronic repulsion · outweighs the higher nuclear charge

3 MODEL ANSWER (write it like this; one [1] = one marking point)

O^+ is $1s^2\ 2s^2\ 2p^3$ (one electron in each 2p orbital); F^+ is $1s^2\ 2s^2\ 2p_x^{\ 2}\ 2p_y^{\ 1}\ 2p_z^{\ 1}$. **[1]**

The electron removed from F^+ is a **paired electron in the $2p_x$ orbital**, so there is **inter-electronic repulsion**. **[1]**

This **outweighs the higher nuclear charge** of F, so **less energy is required**: $IE_2(F)$ 3370 < $IE_2(O)$ 3390 kJ mol^{-1}. **[1]**

4 WHERE STUDENTS LOSE MARKS

✗ Writing the configurations of the atoms (O, F) instead of the 1+ ions.

✗ Not quoting the Data Booklet values when the question says "use the Data Booklet".

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1.6 Paper 3: long question

Work part by part. Each part has 1 Read it, then 2 Model answer (calculations: 2 Working, 3 Model answer). Where students lose marks comes at the end.

P3 **CHALLENGE** **Q9** This question is about aluminium, $Z = 13$, and its ion $^{27}Al^{3+}$.

(a) State the numbers of protons, neutrons and electrons in $^{27}Al^{3+}$. **[1]**

1 READ IT

State [1] → protons = Z; neutrons = $A - Z$; electrons = $Z - 3$.

2 MODEL ANSWER (write it like this)

13 protons, **14** neutrons, **10** electrons **[1]**

(b) Under the same conditions as a beam of protons deflected through +12.0°, calculate the angle of deflection of a beam of $^{27}Al^{3+}$ ions. **[2]**

1 READ IT

Calculate [2] → angle ∝ charge ÷ mass; mass ≈ 27 (the nucleon number), charge = +3.

2 WORKING (show every line)

proton: 1 ÷ 1 = 1 → 12.0°; $^{27}Al^{3+}$: 3 ÷ 27

angle = 12.0 × 3 ÷ 27 = **+1.33°** (keep 3 ÷ 27 to the end; do not round to 0.11 first)

3 MODEL ANSWER (write it like this)

charge ÷ mass = 3 ÷ 27 (= 1/9) **[1]**

angle = 12.0 × 3 ÷ 27 = **+1.33°** (towards the negative plate) **[1]**

(c) Write the full electronic configurations of Al and Al^{3+}. Name the orbital from which the first electron is removed when aluminium is ionised, and describe its shape. **[3]**

1 READ IT

Write + Name + Describe [3] → full = no [Ar] or [Ne]; the first electron comes from the highest-energy occupied orbital.

2 MODEL ANSWER (write it like this)

Al: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$ **[1]**

Al^{3+}: $1s^2\ 2s^2\ 2p^6$ **[1]**

A **3p** orbital: **dumb-bell** shaped, two lobes on opposite sides of the nucleus along one axis (Figure 1.2). **[1]**

✗ **Not accepted:** "3s orbital": the first electron comes from 3p (Al is $3s^2\ 3p^1$). "Figure-of-eight" for the shape: write "dumb-bell" (examiner's comment, GCE 2018).

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(d) Write an equation, with state symbols, for the third ionisation energy of aluminium. **[1]**

1 READ IT

Write [1] → third IE: the ion that already has a 2+ charge loses one electron.

2 MODEL ANSWER (write it like this)

$Al^{2+}(g) \rightarrow Al^{3+}(g) + e^-$ **[1]**

✗ **Not accepted:** $Al(g) \rightarrow Al^{3+}(g) + 3e^-$ (that is the sum of three IEs).

(e) The 5th to 13th ionisation energies of aluminium are given below. **(i)** Look up the 1st to 4th in the Data Booklet, calculate $\log_{10}$ of each value, then sketch a graph of $\log_{10}$(IE / kJ mol^{-1}) against the number of electrons removed, and explain how the graph shows that aluminium is in Group 13 and Period 3. **(ii)** Use the graph to deduce the number of electrons in each shell, then write the full electronic configuration of aluminium. **[4]**

IE number	1	2	3	4	5	6	7
IE / kJ mol^{-1}	DB	DB	DB	DB	14 800	18 400	23 300
IE number	**8**	**9**	**10**	**11**	**12**	**13**	
IE / kJ mol^{-1}	27 500	31 900	38 500	42 600	201 300	222 300	

DB = look up in the Data Booklet, Section 2.

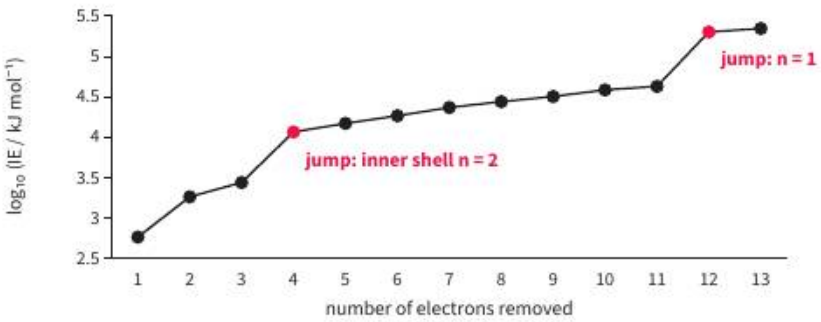
1 READ IT

Sketch + Explain + Deduce [4] → plot log IE (values from 2.76 to 5.35); find the two big jumps; count the electrons in each group of points. **DATA BOOKLET** Section 2: Al 577, 1820, 2740, 11 600 kJ mol^{-1}.

2 WORKING (show every line)

$\log_{10}$: 2.76, 3.26, 3.44 | 4.06, 4.17, 4.26, 4.37, 4.44, 4.50, 4.59, 4.63 | 5.30, 5.35

big jumps: 3rd → 4th (3.44 → 4.06) and 11th → 12th (4.63 → 5.30)



Model sketch for **(e)**: crimson points start each new (inner) shell.

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3 MODEL ANSWER (write it like this)

(i) Sketch: a gradual rise with **big jumps after the 3rd and after the 11th** electron (shown above); **label both axes**. **[1]**

Three electrons are removed before the first big jump, so there are **three outer electrons**: Group 13. **[1]**

The points form **three groups** (3, 8 and 2 electrons): **three occupied shells**, so Period 3. **[1]**

(ii) The groups on the graph hold 3, 8, 2 electrons → shells **2, 8, 3** (innermost first: reverse the order on the graph). Fill 1s 2s 2p 3s 3p in order: Al is **$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$**. **[1]**

(f) Use the Data Booklet to compare the first ionisation energies of aluminium and silicon. Explain why that of aluminium is lower. **[3]**

1 READ IT

Explain [3] → both outer electrons are in 3p; compare nuclear charge and shielding. **DATA BOOKLET** Section 2: Al 577, Si 786 kJ mol^{-1}.

2 MODEL ANSWER (write it like this)

Si has **one more proton**, so a **higher nuclear charge**. **[1]**

The electron removed from each is in the **same 3p subshell** with the **same [Ne] core**, and the $3s^2$ electrons are in the same shell, so the **shielding is about the same**. **[1]**

The 3p electron of Al is **less strongly attracted** to its nucleus, so **less energy is required** to remove it. **[1]**

(g) Use the Data Booklet to compare the second ionisation energies of sodium and aluminium. Explain why that of sodium is much larger. **[3]**

1 READ IT

Explain [3] → write Na^+ and Al^+; say which shell the 2nd electron comes from in each. **DATA BOOKLET** Section 2: IE_2 of Na 4560, Al 1820 kJ mol^{-1}.

2 MODEL ANSWER (write it like this)

Na^+ is $1s^2\ 2s^2\ 2p^6$: the 2nd electron of Na is removed from **2p** ($n = 2$), an **inner shell** of the Na atom. **[1]**

Al^+ is [Ne] $3s^2$: the 2nd electron of Al is removed from **3s** ($n = 3$), the **outer shell**. **[1]**

The 2p electron of Na^+ is **closer to the nucleus** with **much less shielding**; this **outweighs the smaller nuclear charge** of Na, so much more energy is required. **[1]**

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(h) Use the Data Booklet to explain why the first ionisation energy of argon is lower than that of neon. **[3]**

1 READ IT

Explain [3] → down-a-group chain: shell, shielding, distance, attraction. **DATA BOOKLET** Section 2: Ar 1520, Ne 2080 kJ mol^{-1}.

2 MODEL ANSWER (write it like this)

Ar has **one more electron shell**; its outer electron is in $n = 3$, **further from the nucleus**. **[1]**

The **shielding effect increases significantly**; with the greater distance, this outweighs the higher nuclear charge of Ar. **[1]**

The outer electron of Ar is **less strongly attracted**, so **less energy is required** to remove it. **[1]**

Total: 20 marks

WHERE STUDENTS LOSE MARKS (Paper 3)

- ✗ **(a)** Giving 13 electrons: the 3+ ion has lost three.
- ✗ **(b)** Using 13 (the proton number) as the mass.
- ✗ **(e)** Taking logs without looking up the 1st to 4th IEs; putting a jump after the 4th electron instead of the 3rd; writing the configuration as 2, 8, 3 only (the question says full).
- ✗ **(g)** Saying "Na has a smaller nuclear charge" with no mention of the inner shell.

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1.7 Quick Q&A

Cover the right side and test yourself. Most of these are the traps examiners set.

Q	A (cover this side)
Electrons and protons: "deflected in opposite directions"?	Not enough. Protons **towards the negative plate**, electrons **towards the positive plate**, through a much larger angle. → **P2 Q2, p 9**
Are neutrons deflected?	No: no charge.
Do isotopes have different chemical properties?	No. Same number of electrons and the same configuration, so the **same chemical properties**; only the mass and mass-dependent physical properties (e.g. density) differ.
Which electrons does Fe lose first to form Fe^{2+}?	The **4s** electrons: Fe^{2+} is [Ar] $3d^6$. → **§1.2, p 3**
Cr: [Ar] $3d^4\ 4s^2$?	No. **[Ar] $3d^5\ 4s^1$**; Cu is [Ar] $3d^{10}\ 4s^1$. → **P2 Q3, p 10**
How many electrons can one orbital hold?	At most **two**, of opposite spin.
Shape of a p orbital?	**Dumb-bell**: two lobes along one axis. → **P3 (c), p 16**
First IE: "energy released"?	No. Energy **required** to remove one mole of electrons from one mole of **gaseous** atoms, forming gaseous 1+ ions. → **P2 Q1, p 8**
Why is IE_1 of Al lower than Mg?	Al loses a **3p** electron, Mg a 3s electron: 3p is higher in energy, further away and shielded by the filled 3s. → **P2 Q5, p 12**
Why is IE_1 of S lower than P?	S: **paired electron** in $3p_x$, **inter-electronic repulsion**; in P all three 3p electrons are unpaired. → **P2 Q5, p 12**
IE down a group: the key word most often missed?	**Shielding** increases significantly (one more shell, further from the nucleus). → **P2 Q6, p 13**
Why do successive IEs rise: "the nuclear charge increases"?	No. The nuclear charge is the same; there are **fewer electrons, less shielding**.
Big jump after the 4th IE: which group?	**Group 14**: four outer electrons. → **P2 Q7, p 14**
Which IEs are in the Data Booklet?	1st to 4th of selected elements: all of H to Zn and some heavier ones (Section 2). Higher ones are given in the question.

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