Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Spot the error

ANSWER U · 3

Her configuration is wrong: a transition metal loses its **4s** electrons first, not the 3d electrons that went in last, because once 3d holds electrons it drops below 4s in energy. So Fe^{2+} is **[Ar] $3d^6$**.
Her answer of 4 unpaired comes out right only by luck: in $3d^6$ the boxes are ↑↓ ↑ ↑ ↑ ↑, the sixth electron pairing with the first, which leaves **4 unpaired**. (Her own [Ar] $4s^2$ $3d^4$ would also give 4, so the count can't tell the two apart.)

MARKING SCHEME

- ✓ The 4s electrons are lost first, so her order of removal is wrong.
- ✓ Fe^{2+} is [Ar] $3d^6$.
- ✓ By Hund's rule $3d^6$ is ↑↓ ↑ ↑ ↑ ↑, so 4 unpaired.

2 Whose fingerprints?

ANSWER A · 5

i. X: 11,577 ÷ 2,745 = **4.2 times**, at the 4th electron. Y: 4,562 ÷ 496 = **9.2 times**, at the 2nd. Z: 7,733 ÷ 1,451 = **5.3 times**, at the 3rd.
ii. The jump comes when an electron must come out of the full inner shell, so the electrons before it are the valence electrons. X has 3: **aluminium**, valency 3. Y has 1: **sodium**, valency 1. Z has 2: **magnesium**, valency 2.
iii. **$AlCl_3$, NaCl, $MgCl_2$.**
iv. To remove two electrons from each atom: 738 + 1,451 = 2,189 kJ/mol. Moles of Z = 1.2 ÷ 24 = 0.05 mol. Energy = 0.05 × 2,189 = **109 kJ** (109.45 kJ).

MARKING SCHEME

- ✓ The three ratios 4.2, 9.2 and 5.3.
- ✓ The jump marks where the valence electrons end: valencies 3, 1 and 2.
- ✓ X is aluminium, Y sodium, Z magnesium, with their chlorides.
- ✓ Energy for two electrons: 738 + 1,451 = 2,189 kJ/mol.
- ✓ 0.05 mol × 2,189 = 109 kJ.

3 Which explanation fits the evidence?

ANSWER HA · 3

Yasmin's. Mijash's reason starts from something false: sulphur's atom, at 105 pm, is smaller than phosphorus's, at 107 pm, and sulphur has one more proton, so by size and nuclear charge alone its ionization potential should be higher. Something else must make that one electron easier to remove, and it is the pairing: phosphorus's half-filled 3p (↑ ↑ ↑) has no shared orbital, while sulphur's has (↑↓ ↑ ↑), and the two electrons sharing it repel each other.
The dip is evidence that electrons really do go into separate orbitals first, as Hund's rule says.

MARKING SCHEME

- ✓ Yasmin's explanation; sulphur is smaller (105 pm against 107 pm), so Mijash's is ruled out.
- ✓ Size and nuclear charge alone would make sulphur's ionization potential higher, so the pairing must be the cause.
- ✓ The dip supports Hund's rule: separate orbitals first, and a pair repels.

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4 Three bottles

ANSWER A · 4

i. Take a sample of each in a test tube and add chlorine water to each. The one that stays colorless is **potassium chloride**; the one that turns orange is **potassium bromide**; the one that turns brown is **potassium iodide**. One round of three tubes is enough. (Bromine water can confirm: added to fresh samples, it sets iodine free only from the potassium iodide.)

ii. $Cl_2 + 2KBr \rightarrow 2KCl + Br_2$ and $Cl_2 + 2KI \rightarrow 2KCl + I_2$.

iii. **Nothing.** Iodine is the least reactive of the three, so it can't displace chlorine or bromine from their salts, and it has no effect on potassium iodide.

MARKING SCHEME

- ✓ Add chlorine water to a sample of each.
- ✓ No change: KCl; orange: KBr; brown: KI.
- ✓ Both equations.
- ✓ Iodine shows nothing, because it can't displace the more reactive halogens.

5 Pushing past the table

ANSWER HA · 4

i. Element 118 ends period 7 with a full 7p, so a new shell must begin: **8s**, as $8s^1$.

ii. **Period 8, s block, group 1.**

iii. Valency **1**; oxide **M_2O**, chloride **MCl**.

iv. **Below** 376 kJ/mol: down group 1 the outer electron is farther out and better shielded, so the first ionization potential keeps falling. It would react even more violently than cesium, which already explodes: the reactivity of the alkali metals rises as the ionization potential falls.

(This is a prediction from the trends only, for a next element that has not been made.)

MARKING SCHEME

- ✓ Last electron in a new shell, 8s.
- ✓ Period 8, s block, group 1.
- ✓ Valency 1; M_2O and MCl.
- ✓ Ionization potential below 376 kJ/mol, and more violent than cesium with water, because the outer electron is farther out and better shielded.

6 Which bond pulls hardest?

ANSWER A · 4

i. C–H: 2.55 − 2.20 = **0.35**. N–H: 3.04 − 2.20 = **0.84**. O–H: 3.44 − 2.20 = **1.24**. H–Cl: 3.16 − 2.20 = **0.96**.

ii. **C–H, N–H, H–Cl, O–H.**

iii. **O–H**: oxygen pulls the shared pair hardest, away from hydrogen.

iv. **Fluorine**: H–F, 3.98 − 2.20 = **1.78**.

MARKING SCHEME

- ✓ The four differences 0.35, 0.84, 0.96 and 1.24.
- ✓ The order C–H, N–H, H–Cl, O–H.
- ✓ O–H has the most positive hydrogen end.
- ✓ Fluorine, with a difference of 1.78.

7 Same number of electrons

MARKING SCHEME U · 3

- ✓ The order $O^{2-} > F^- > Na^+ > Mg^{2+}$.
- ✓ The same 10 electrons held by 8, 9, 11 and 12 protons: more protons, a smaller ion.
- ✓ Mg^{2+} is about 29% smaller than Na^+ (30 ÷ 102).

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8 Correct the misconceptions

ANSWER U · 3

1. "More reactive from sodium to aluminium" is wrong: their reactivity **falls**, because the ionization potentials rise and they must lose more electrons.
2. "Chlorine has the highest electronegativity" is wrong: **fluorine** has (3.98, against chlorine's 3.16). Chlorine has the highest electron affinity, but electron affinity is for a lone atom gaining an electron, and electronegativity for an atom pulling on a shared pair.
3. "Better at taking electrons" is wrong: when phosphorus burns, **oxygen** takes electrons from it. It burns easily because its strained P_4 molecules fall apart easily; sulphur is the stronger oxidizing agent.

MARKING SCHEME

- ✓ Reactivity falls from sodium to aluminium, as ionization potentials rise and more electrons must be lost.
- ✓ Fluorine has the highest electronegativity; chlorine's record is in electron affinity, a different property.
- ✓ White phosphorus burns easily because P_4 is strained, not because it takes electrons; oxygen takes them.

9 Predict, then explain

ANSWER HA · 4

A transition metal ion loses its 4s electrons first, then 3d electrons.

Ion	Configuration	d subshell	Prediction
Sc^{3+}	[Ar] $3d^0$	empty	colorless or white
Ti^{4+}	[Ar] $3d^0$	empty	colorless or white
V^{3+}	[Ar] $3d^2$	partly filled	colored
Mn^{2+}	[Ar] $3d^5$	partly filled	colored
Fe^{3+}	[Ar] $3d^5$	partly filled	colored
Zn^{2+}	[Ar] $3d^{10}$	full	colorless or white

Color comes from electrons jumping between d orbitals of slightly different energy, absorbing part of the light. With an empty d subshell there is no electron to jump, and with a full one no orbital to jump to.

MARKING SCHEME

- ✓ The configurations, with 4s lost first.
- ✓ V^{3+}, Mn^{2+} and Fe^{3+} colored (partly filled d).
- ✓ Sc^{3+}, Ti^{4+} and Zn^{2+} colorless or white (empty or full d).
- ✓ Color comes from electrons jumping between d orbitals: an empty or full subshell can't do it.

10 Estimate it

ANSWER A · 3

i. $13.6 \times 96.5 = \mathbf{1{,}312\ kJ/mol}$.

ii. $1{,}312\ kJ \div 1\ kJ/s = 1{,}312\ s$, about **22 minutes**.

iii. Volume goes as the cube of the radius: $(244 \div 57)^3 = 4.28^3 \approx$ **78 times**.

MARKING SCHEME

- ✓ $13.6 \times 96.5 = 1{,}312$ kJ/mol.
- ✓ 1,312 s, about 22 minutes.
- ✓ $(244 \div 57)^3 \approx 78$ times.

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11 Think

ANSWER HA · 3

i. **No.** Moving one electron per atom takes in 496 kJ/mol and gives back only 349 kJ/mol: a net **147 kJ/mol taken in**, not given out.

ii. He stopped at the separate ions. Once formed, Na^+ and Cl^- attract each other strongly because of their opposite charges and come together into a crystal, and since the whole reaction goes, that step must release more than the 147 kJ/mol spent. Ionization potential and electron affinity are only single steps of a real reaction, as the unit says of fluorine.

MARKING SCHEME

✓ 496 taken in and 349 released, so a net 147 kJ/mol is taken in; he is wrong.

✓ He left out the attraction between the oppositely charged ions.

✓ The ions coming together must release more than the 147 kJ/mol.

12 Make your own

ANSWER HA · 2

For example: "I am in period 4. I am in the d block. I have 6 unpaired electrons." Answer: **chromium**, [Ar] $4s^1$ $3d^5$. Only the 3d metals, Sc to Zn, are in period 4's d block; their unpaired electrons, from the unit's table, are 1, 2, 3, 6, 5, 4, 3, 2, 1 and 0, so only chromium has 6.

MARKING SCHEME

✓ Three clues that fit the chosen element.

✓ A check that no other element up to 30 fits.

See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **The Giant Periodic Table** (exhibit): The elements stand in order of atomic number: elements in one column, a group, behave alike, and each row is a period.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	9	16	16	**41**

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