

The Periodic Table: chemical periodicity

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What you need to know

By the end of this topic you should be able to:

9.1 Physical properties of the Period 3 elements

1. **Describe how four properties change from sodium to chlorine** (argon is left out), and point out the repeating pattern: atomic radius, ionic radius, melting point and electrical conductivity. You describe the changes in words; you are not asked to recall exact values.
2. **Explain the melting points and electrical conductivities** from the structure and bonding of each element: giant metallic, giant covalent or simple molecular.

9.2 Chemical properties of the Period 3 elements

1. **Describe the reactions of the elements, and write their equations**, with oxygen (giving Na_2O , MgO , Al_2O_3 , P_4O_{10} and SO_2), with chlorine (giving NaCl , MgCl_2 , AlCl_3 , SiCl_4 and PCl_5) and with water (sodium and magnesium only).
2. **State the oxidation number of the Period 3 element** in the oxides Na_2O , MgO , Al_2O_3 , P_4O_{10} , SO_2 , SO_3 and the chlorides NaCl , MgCl_2 , AlCl_3 , SiCl_4 , PCl_5 , and explain the pattern from the number of outer (valence) shell electrons.
3. **Describe what happens, if anything, when the oxides** Na_2O , MgO , Al_2O_3 , SiO_2 , P_4O_{10} , SO_2 and SO_3 **are added to water**, with equations and the likely pH of each solution.
4. **Describe and explain the acid–base behaviour** of the oxides Na_2O , MgO , Al_2O_3 , P_4O_{10} , SO_2 , SO_3 and the hydroxides NaOH , $\text{Mg}(\text{OH})_2$, $\text{Al}(\text{OH})_3$, with equations, including the amphoteric behaviour of aluminium's oxide and hydroxide with acids and with sodium hydroxide (the only base you need).
5. **Describe what happens when the chlorides** NaCl , MgCl_2 , AlCl_3 , SiCl_4 and PCl_5 **are added to water**, with equations and the likely pH of each solution.
6. **Explain all of these patterns** (points 2 to 5) using bonding and electronegativity.
7. **Suggest the type of bonding** in an oxide or chloride from what it does: its melting point, whether it conducts, and how it behaves with water.

9.3 Periodicity of other elements

1. **Predict how an element in a given group will behave**, using the patterns you know.
2. **Work out what an unknown element is**, where it probably sits in the Periodic Table and what it is like, from information about its physical and chemical properties.

Understand it

Period 3 at a glance

Period 3 runs from sodium to argon. Every element has its outer electrons in the third shell, and each step to the right adds one proton to the nucleus and one electron to that shell. The elements change from metals on the left, through silicon in the middle, to non-metals on the right, and their structures change with them:

Element	Na	Mg	Al	Si	P	S	Cl
Outer electrons	1	2	3	4	5	6	7
Structure	giant metallic	giant metallic	giant metallic	giant covalent	simple molecular, P ₄	simple molecular, S ₈	simple molecular, Cl ₂
Force broken on melting	metallic bonds	metallic bonds	metallic bonds	covalent bonds	id-id forces	id-id forces	id-id forces

"Giant covalent" is also called "giant molecular" in mark schemes. "id-id forces" are instantaneous dipole-induced dipole forces, which mark schemes also call van der Waals' forces. Argon exists as single atoms.

Atomic radius

Atomic radius **decreases** from sodium to chlorine: sodium's atom is almost twice as wide as chlorine's.

Two facts explain it, and exam answers need both:

- the **nuclear charge increases** by one proton at each step;
- the extra electron goes into the **same (third) shell**, so the shielding by the inner electrons (2, 8) stays **about the same**.

So each nucleus pulls the outer shell in more strongly, and the atom gets smaller.

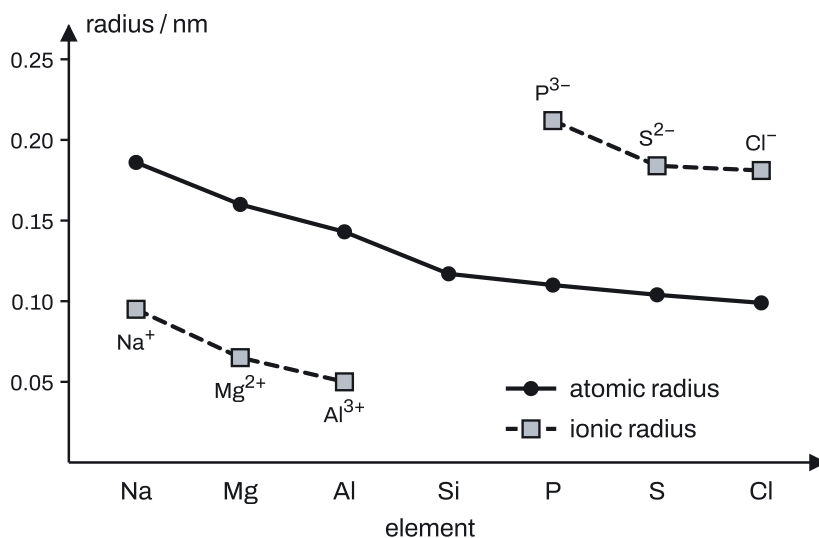
Ionic radius

Metals lose their outer electrons to form positive ions; non-metals gain electrons to form negative ions. This changes the number of shells, so ionic radius follows a different pattern from atomic radius.

- **Positive ions are much smaller than their atoms.** Na⁺, Mg²⁺ and Al³⁺ have lost the whole third shell and are left with the arrangement 2, 8.

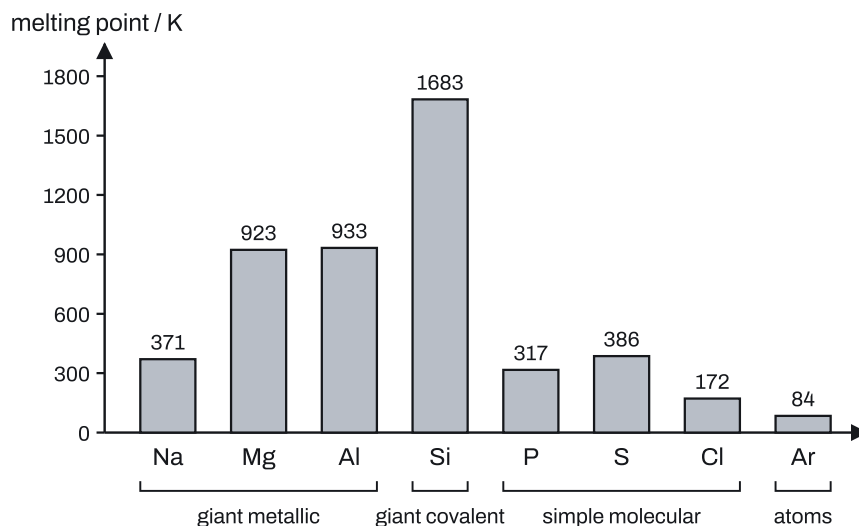
- **Negative ions are larger than their atoms.** P^{3-} , S^{2-} and Cl^- have gained electrons into the third shell (2, 8, 8): the same nuclear charge now holds more electrons, which repel each other more.
- **Within each set the radius falls.** Na^+ , Mg^{2+} , Al^{3+} all have 10 electrons, but 11, 12 and 13 protons, so the electrons are pulled in harder each time. The same happens for P^{3-} , S^{2-} , Cl^- (18 electrons, 15 to 17 protons).
- **There is a big jump between Al^{3+} and P^{3-} ,** because P^{3-} has **one more shell** of electrons.

The Data Booklet also lists silicon ions: Si^{4-} at 0.271 nm, the largest of the anions, because it has the same 18 electrons as P^{3-} , S^{2-} and Cl^- but only 14 protons to hold them, and Si^{4+} at 0.041 nm. In practice silicon's compounds are covalent, so the graph leaves silicon's ionic radius out.



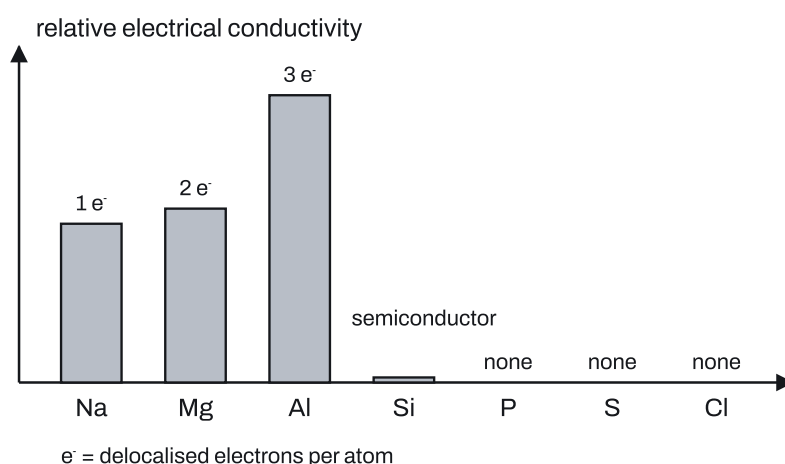
Melting point

The melting points rise from sodium to a peak at silicon, then drop sharply to phosphorus, sulfur and chlorine. The reason is the structure of each element.



- **Na, Mg, Al (giant metallic).** A lattice of positive ions in a "sea" of delocalised electrons. From Na to Al the ions have a larger charge (1+, 2+, 3+), are smaller, and each atom gives more delocalised electrons (1, 2, 3). The attraction between the ions and the delocalised electrons gets stronger, so more energy is needed to melt the metal.
- **Si (giant covalent).** Each silicon atom is joined to four others by strong covalent bonds, in a structure like diamond. Melting means breaking **many strong covalent bonds**, so silicon has the highest melting point in the period.
- **P, S, Cl (simple molecular).** Inside each molecule (P_4 , S_8 , Cl_2) the atoms are held by strong covalent bonds, but melting only separates the molecules. That breaks the **weak id-id forces between molecules**, not the covalent bonds, so the melting points are low. S_8 has the most electrons per molecule (128), then P_4 (60), then Cl_2 (34): more electrons give stronger id-id forces, so sulfur melts above phosphorus, and chlorine is lowest of the three.

Electrical conductivity



To conduct, a substance needs **charged particles that can move** (mobile charge carriers).

- **Na, Mg, Al** conduct well, because their **delocalised electrons move through the structure** when a voltage is applied. Conductivity rises from Na to Al as the number of delocalised electrons per atom rises (1, 2, 3).
- **Si** is a **semiconductor**: its electrons are held in covalent bonds, and only a very few are free to move.
- **P, S, Cl** do not conduct: every outer electron is held in a covalent bond or a lone pair, so there are **no delocalised electrons and no ions**.

Electronegativity and ionisation energy

Electronegativity rises steadily from sodium to chlorine, for the same reason the atoms shrink: more nuclear charge, similar shielding, and a smaller distance to the bonding electrons. Oxygen and chlorine are both more electronegative than every Period 3 element before them, so in the oxides and chlorides the Period 3 element always has the **positive** oxidation number.

The **difference in electronegativity** decides the bonding. Sodium and magnesium differ a lot from oxygen and chlorine, so their compounds are **ionic**. Silicon, phosphorus and sulfur are close to oxygen and chlorine, so their compounds are **covalent**. Aluminium sits in between, which is why its compounds are the ones "on the boundary".

First ionisation energy also rises across the period, but not smoothly: it dips at Al and at S. The reasons are in the Atomic structure note; here you only need to recognise the shape of the graph.

How the elements react with oxygen

Element	What you see	Equation
Sodium	burns with a bright yellow-orange flame; white solid	$4\text{Na} + \text{O}_2 \rightarrow 2\text{Na}_2\text{O}$
Magnesium	burns with a brilliant white flame; white powder	$2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$
Aluminium	burns (as a powder) with a bright white flame; white solid	$4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$
Phosphorus	white phosphorus catches fire; white flame and dense white smoke	$\text{P}_4 + 5\text{O}_2 \rightarrow \text{P}_4\text{O}_{10}$
Sulfur	burns with a blue flame; colourless, choking gas	$\text{S} + \text{O}_2 \rightarrow \text{SO}_2$

With a limited supply of oxygen phosphorus gives P_4O_6 , so P_4O_{10} needs **an excess** of oxygen. Sulfur burning in air gives SO_2 , not SO_3 ; SO_3 is made from SO_2 and more oxygen with a catalyst. Silicon forms SiO_2 only when heated strongly.

How the elements react with chlorine

All of them react when heated in chlorine, forming the chloride with the element's highest usual oxidation number:

- $2\text{Na} + \text{Cl}_2 \rightarrow 2\text{NaCl}$ and $\text{Mg} + \text{Cl}_2 \rightarrow \text{MgCl}_2$: white ionic solids;
- $2\text{Al} + 3\text{Cl}_2 \rightarrow 2\text{AlCl}_3$: a white or pale yellow solid;
- $\text{Si} + 2\text{Cl}_2 \rightarrow \text{SiCl}_4$: a colourless liquid;
- $2\text{P} + 5\text{Cl}_2 \rightarrow 2\text{PCl}_5$ (or $\text{P}_4 + 10\text{Cl}_2 \rightarrow 4\text{PCl}_5$) with an excess of chlorine: a pale yellow or off-white solid.

Sodium and magnesium with water

- **Sodium** reacts vigorously with cold water: it floats, melts into a ball, fizzes as hydrogen is given off, moves around and disappears, leaving a colourless solution of pH 13–14. $2\text{Na(s)} + 2\text{H}_2\text{O(l)} \rightarrow 2\text{NaOH(aq)} + \text{H}_2\text{(g)}$
- **Magnesium** reacts only very slowly with cold water, giving a few bubbles over many hours and a weakly alkaline mixture (about pH 9–10), because Mg(OH)_2 is only slightly soluble. $\text{Mg(s)} + 2\text{H}_2\text{O(l)} \rightarrow \text{Mg(OH)}_2\text{(s)} + \text{H}_2\text{(g)}$ Heated magnesium burns in **steam** with a white flame: $\text{Mg} + \text{H}_2\text{O} \rightarrow \text{MgO} + \text{H}_2$. Read which one the question asks for.

Aluminium does not react with water in practice: a thin layer of Al_2O_3 covers the metal, and that oxide is insoluble, so water never reaches the metal.

Oxidation numbers of the oxides and chlorides

Oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_3 (SO_2)
Oxidation number	+1	+2	+3	+4	+5	+6 (+4)

Chloride	NaCl	MgCl_2	AlCl_3	SiCl_4	PCl_5
Oxidation number	+1	+2	+3	+4	+5

The **highest oxidation number equals the number of outer (valence) shell electrons**, because in these compounds **all the outer electrons are used in bonding** to the more electronegative oxygen or chlorine. So it rises by one each step: Na has 1 outer electron and reaches +1; P has 5 and reaches +5; S has 6 and reaches +6 in SO_3 . In SO_2 sulfur uses only four of its six, so it is +4.

Work any oxidation number from the formula: O is -2 and Cl is -1 , and the total is zero. In P_4O_{10} : $4x + 10(-2) = 0$, so $x = +5$.

The oxides: structure and bonding

Oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_3	SO_2
Bonding	ionic	ionic	ionic (some covalent character)	covalent	covalent	covalent	covalent
Structure	giant	giant	giant	giant	simple	simple	simple
State at room temperature	white solid	white solid	white solid	white solid	white solid	colourless volatile solid or liquid (m.p. 17°C)	colourless gas
Melting point	high	very high	very high	very high	low	very low	very low

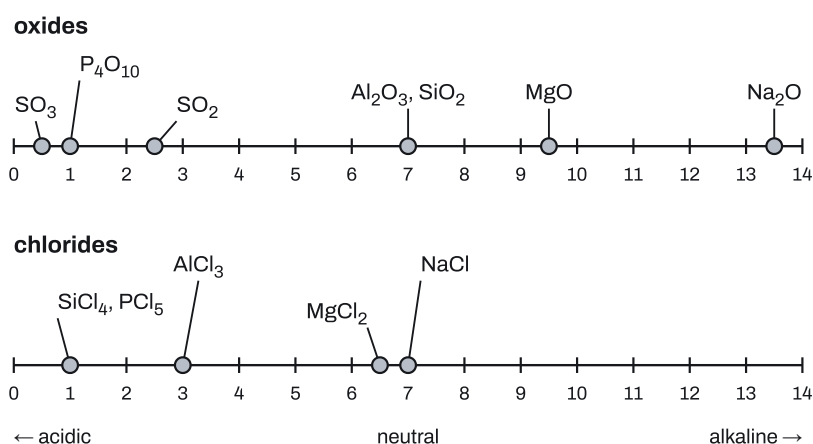
So the bonding changes from **giant ionic** (Na, Mg, Al) to **giant covalent** (Si) to **simple molecular** (P, S). The giant oxides melt at well over 1000°C because melting breaks strong ionic or covalent bonds throughout the lattice. The simple ones melt low because only intermolecular forces break. MgO , Al_2O_3 and SiO_2 are hard, heat-resistant solids used as ceramics.

Melting point does **not** simply follow charge: MgO (Mg^{2+}) melts higher than Al_2O_3 (Al^{3+}), because the very small, highly charged Al^{3+} ion pulls the oxide ions' electrons towards itself, giving Al_2O_3 some covalent character.

The oxides with water

Oxide	Equation	pH of the mixture
Na ₂ O	$\text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{NaOH}$	13–14 (strongly alkaline)
MgO	$\text{MgO} + \text{H}_2\text{O} \rightarrow \text{Mg}(\text{OH})_2$ (slightly soluble)	about 9–10 (weakly alkaline)
Al ₂ O ₃	no reaction: insoluble	7
SiO ₂	no reaction: insoluble	7
P ₄ O ₁₀	$\text{P}_4\text{O}_{10} + 6\text{H}_2\text{O} \rightarrow 4\text{H}_3\text{PO}_4$ (phosphoric(V) acid)	0–2 (strongly acidic)
SO ₂	$\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3$ (sulfurous acid)	about 2–3
SO ₃	$\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$ (sulfuric acid)	0–1

Why the change? The ionic oxides contain the oxide ion, O^{2-} , a strong base that takes a proton from water: $\text{O}^{2-} + \text{H}_2\text{O} \rightarrow 2\text{OH}^-$. The covalent oxides of the electronegative non-metals react with water to make acids. Al₂O₃ and SiO₂ are insoluble because their giant lattices are too strong, so the water stays neutral. When a question asks for "the pH of the solution" of these two, the answer is that there is no solution: they are insoluble.



Acidic, basic and amphoteric

- A **basic** oxide or hydroxide reacts with acids (to give a salt and water) but not with bases: Na₂O, MgO, NaOH, Mg(OH)₂.
- An **acidic** oxide reacts with bases but not with acids: P₄O₁₀, SO₂, SO₃ (and SiO₂, which reacts only with hot, concentrated sodium hydroxide).
- An **amphoteric** oxide or hydroxide reacts with **both** acids and bases: Al₂O₃ and Al(OH)₃.

So the oxides go **basic** → **amphoteric** → **acidic** across the period, following the change from ionic to covalent bonding.

Basic oxides and hydroxides with acid:

- $\text{Na}_2\text{O} + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O}$ and $\text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O}$
- $\text{MgO} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2\text{O}$ and $\text{Mg}(\text{OH})_2 + 2\text{HCl} \rightarrow \text{MgCl}_2 + 2\text{H}_2\text{O}$

Aluminium oxide and hydroxide, amphoteric:

- with acid: $\text{Al}_2\text{O}_3 + 6\text{HCl} \rightarrow 2\text{AlCl}_3 + 3\text{H}_2\text{O}$ and $\text{Al}(\text{OH})_3 + 3\text{HCl} \rightarrow \text{AlCl}_3 + 3\text{H}_2\text{O}$; with sulfuric acid the salt is $\text{Al}_2(\text{SO}_4)_3$: $\text{Al}_2\text{O}_3 + 3\text{H}_2\text{SO}_4 \rightarrow \text{Al}_2(\text{SO}_4)_3 + 3\text{H}_2\text{O}$
- with sodium hydroxide (aqueous): $\text{Al}_2\text{O}_3 + 2\text{NaOH} + 3\text{H}_2\text{O} \rightarrow 2\text{NaAl}(\text{OH})_4$ and $\text{Al}(\text{OH})_3 + \text{NaOH} \rightarrow \text{NaAl}(\text{OH})_4$
- mark schemes also accept the "aluminate" form: $\text{Al}_2\text{O}_3 + 2\text{NaOH} \rightarrow 2\text{NaAlO}_2 + \text{H}_2\text{O}$

Acidic oxides with sodium hydroxide:

- $\text{P}_4\text{O}_{10} + 12\text{NaOH} \rightarrow 4\text{Na}_3\text{PO}_4 + 6\text{H}_2\text{O}$
- $\text{SO}_2 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_3 + \text{H}_2\text{O}$ and $\text{SO}_3 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + \text{H}_2\text{O}$
- $\text{SiO}_2 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SiO}_3 + \text{H}_2\text{O}$ (hot, concentrated)

A useful test that follows: adding sodium hydroxide to a solution of Al^{3+} gives a white precipitate of $\text{Al}(\text{OH})_3$ that **dissolves in excess**; with Mg^{2+} the white $\text{Mg}(\text{OH})_2$ precipitate **does not** dissolve.

The chlorides: structure and bonding

Chloride	NaCl	MgCl ₂	AlCl ₃	SiCl ₄	PCl ₅
Bonding	ionic	ionic	on the boundary	covalent	covalent
Structure	giant	giant	giant solid; Al ₂ Cl ₆ molecules in the vapour	simple	simple
State at room temperature	white solid	white solid	white or pale yellow solid	colourless liquid	pale yellow or off-white solid
Melting point	801 °C	714 °C	turns to vapour at about 180 °C	−69 °C	turns to vapour at about 160 °C
Conducts when liquid?	yes (ions move)	yes (ions move)	poorly	no	no

NaCl and MgCl₂ conduct when molten because their **ions can move**; SiCl₄ does not conduct because it is made of neutral molecules, with no ions and no delocalised electrons. Aluminium chloride has a lot of covalent character: the small, highly charged Al^{3+} distorts the electron clouds of the chloride ions. Mark schemes have accepted ionic, giant for the solid in a table, but never describe it as a simple lattice of separate Al^{3+} and Cl^- ions. Its vapour is Al₂Cl₆ molecules, each with two dative (coordinate) bonds from Cl to Al.

The chlorides with water

Chloride	What happens	pH
NaCl	dissolves; the ions are hydrated: $\text{NaCl(s)} \rightarrow \text{Na}^+(\text{aq}) + \text{Cl}^-(\text{aq})$	7
MgCl ₂	dissolves; a very slight reaction with water	about 6.5
AlCl ₃	hydrolysed: $\text{AlCl}_3 + 3\text{H}_2\text{O} \rightarrow \text{Al(OH)}_3 + 3\text{HCl}$; in a lot of water, hydrated Al^{3+} ions also release H^+	about 3
SiCl ₄	hydrolysed vigorously: $\text{SiCl}_4 + 2\text{H}_2\text{O} \rightarrow \text{SiO}_2 + 4\text{HCl}$	0–2
PCl ₅	hydrolysed vigorously: $\text{PCl}_5 + 4\text{H}_2\text{O} \rightarrow \text{H}_3\text{PO}_4 + 5\text{HCl}$	0–2

Hydrolysis means a reaction with water that splits a compound; AlCl₃, SiCl₄ and PCl₅ are all hydrolysed (mark schemes also accept "substitution"). It is **not redox**: every oxidation number stays the same (Al is +3 in AlCl₃ and in Al(OH)₃; Si is +4 in SiCl₄ and in SiO₂; P is +5 in PCl₅ and in H₃PO₄).

What you see:

- NaCl and MgCl₂ just dissolve to give colourless solutions. Nothing fizzes and no fumes form.
- SiCl₄ (a colourless liquid) reacts with a hiss, giving off heat and **steamy (white, misty) fumes of HCl**, and leaves a **white solid**, SiO₂, in a strongly acidic liquid.
- PCl₅ (a solid) reacts violently, giving **steamy fumes of HCl** and a **colourless solution** of phosphoric(V) and hydrochloric acids. With only a little water it gives phosphorus oxychloride instead: $\text{PCl}_5 + \text{H}_2\text{O} \rightarrow \text{POCl}_3 + 2\text{HCl}$.
- AlCl₃: in a lot of water it dissolves with heat to give an acidic solution. The small, highly charged Al^{3+} ion pulls electrons from the water molecules bonded to it, so they release H^+ :



With only a **little** water (or moist air), solid AlCl₃ gives **steamy fumes of HCl** and a **white solid**: $\text{AlCl}_3 + 3\text{H}_2\text{O} \rightarrow \text{Al(OH)}_3 + 3\text{HCl}$. The white solid dissolves in both acid and alkali, the amphoteric test for aluminium.

The acidic solutions (from AlCl₃, SiCl₄ and PCl₅) turn blue litmus red and fizz with sodium carbonate, giving carbon dioxide. NaCl solution does neither.

Why the patterns happen

Everything in this topic comes back to one change across the period: **electronegativity rises, so the bonding to oxygen and chlorine changes from ionic to covalent.**

- **Ionic** oxides and chlorides (Na, Mg): high melting points, conduct when molten. The oxides are basic; the chlorides simply dissolve to give neutral solutions.
- **Boundary** compounds (Al): the small, highly charged Al^{3+} polarises its neighbours. The oxide is amphoteric; the chloride is partly covalent and gives an acidic solution.
- **Covalent** oxides and chlorides (Si, P, S): the element is bonded to more electronegative atoms, and its bonds are polar, with a slightly positive Period 3 atom that water can attack. The oxides are acidic (or insoluble SiO_2); the chlorides are hydrolysed to acidic solutions and HCl fumes.

Deducing bonding from properties

Use the evidence like this:

Evidence	Points to
high melting point and conducts when molten or dissolved	giant ionic
very high melting point, does not conduct even when molten	giant covalent
low melting or boiling point, volatile	simple molecular
fumes in moist air, is hydrolysed by water to an acidic solution	covalent (chloride)
dissolves to a neutral solution, no fumes	ionic (chloride)

For example, a new chloride that is a liquid at room temperature and fumes in moist air, giving an acidic solution, is **simple molecular** (low melting point) and **covalent** (it is hydrolysed). Give each piece of evidence with the conclusion it supports.

Predicting other elements

Elements in the same group have the **same number of outer electrons**, so they form compounds with the same formulas and the same highest oxidation number. Down a group, atoms get bigger and electronegativity falls, so the elements become **more metallic** and their oxides **more basic**. That lets you predict:

- **Formulas.** Selenium, below sulfur in Group 16, has 6 outer electrons, so its highest oxide is SeO_3 and it also forms SeO_2 , which dissolves in water to give an acidic solution, like SO_2 .
- **Behaviour by analogy.** Gallium, below aluminium in Group 13, forms Ga_2O_3 and GaCl_3 ; Ga_2O_3 is amphoteric, so you would write its equations exactly like aluminium's: $\text{Ga}_2\text{O}_3 + 6\text{HCl} \rightarrow 2\text{GaCl}_3 + 3\text{H}_2\text{O}$.
- **Physical properties.** Values change steadily down a group, so a missing value lies between its neighbours: for example, an atomic radius between the elements above and below.

To **identify an unknown element**, match each clue to the pattern it belongs to. A high melting point with no conductivity means giant covalent; an oxide that dissolves in both acid and alkali means Group 13 behaviour like aluminium's; a chloride that fumes in water means a non-metal. Put the clues together to decide the group, then use the period or other data to pick the element.

Key facts and formulas

"Given" means it is printed in the 9701 Data Booklet or the paper's Periodic Table. "Learn it" means you must remember it. The Data Booklet does not print melting points, pH values or equations, so learn those.

Formula	Status
Atomic and ionic radii of the elements	Given
Relative atomic masses (Periodic Table); molar gas volume $24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions	Given
Across Period 3: atomic radius ↓, electronegativity ↑, cation radius ↓ Na^+ to Al^{3+} , anion radius ↓ P^{3-} to Cl^-	Learn it
Melting point: rises $\text{Na} \rightarrow \text{Al}$, peak at Si, low for P, S, Cl ($\text{S} > \text{P} > \text{Cl}$)	Learn it
Conductivity: rises $\text{Na} \rightarrow \text{Al}$, Si semiconductor, P, S, Cl none	Learn it
Highest oxidation number = number of outer electrons ($\text{Na} +1 \dots \text{S} +6$)	Learn it
Oxygen: $4\text{Na} + \text{O}_2 \rightarrow 2\text{Na}_2\text{O}$, $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$, $4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$, $\text{P}_4 + 5\text{O}_2 \rightarrow \text{P}_4\text{O}_{10}$, $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$	Learn it
Chlorine: $2\text{Na} + \text{Cl}_2 \rightarrow 2\text{NaCl}$, $\text{Mg} + \text{Cl}_2 \rightarrow \text{MgCl}_2$, $2\text{Al} + 3\text{Cl}_2 \rightarrow 2\text{AlCl}_3$, $\text{Si} + 2\text{Cl}_2 \rightarrow \text{SiCl}_4$, $2\text{P} + 5\text{Cl}_2 \rightarrow 2\text{PCl}_5$	Learn it
Water: $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$, $\text{Mg} + 2\text{H}_2\text{O} \rightarrow \text{Mg}(\text{OH})_2 + \text{H}_2$ (steam: $\text{Mg} + \text{H}_2\text{O} \rightarrow \text{MgO} + \text{H}_2$)	Learn it
Oxides + water: $\text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{NaOH}$, $\text{MgO} + \text{H}_2\text{O} \rightarrow \text{Mg}(\text{OH})_2$, $\text{P}_4\text{O}_{10} + 6\text{H}_2\text{O} \rightarrow 4\text{H}_3\text{PO}_4$, $\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3$, $\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$	Learn it
pH with water: Na_2O 13–14, MgO 9–10, Al_2O_3 and SiO_2 insoluble (7), P_4O_{10} / SO_3 0–2, SO_2 2–3	Learn it
Amphoteric: $\text{Al}_2\text{O}_3 + 6\text{HCl} \rightarrow 2\text{AlCl}_3 + 3\text{H}_2\text{O}$; $\text{Al}_2\text{O}_3 + 2\text{NaOH} + 3\text{H}_2\text{O} \rightarrow 2\text{NaAl}(\text{OH})_4$; $\text{Al}(\text{OH})_3 + \text{NaOH} \rightarrow \text{NaAl}(\text{OH})_4$	Learn it
$\text{P}_4\text{O}_{10} + 12\text{NaOH} \rightarrow 4\text{Na}_3\text{PO}_4 + 6\text{H}_2\text{O}$	Learn it
Chlorides + water: $\text{SiCl}_4 + 2\text{H}_2\text{O} \rightarrow \text{SiO}_2 + 4\text{HCl}$; $\text{PCl}_5 + 4\text{H}_2\text{O} \rightarrow \text{H}_3\text{PO}_4 + 5\text{HCl}$	Learn it
pH with water: NaCl 7, MgCl_2 6.5, AlCl_3 about 3, SiCl_4 and PCl_5 0–2	Learn it

How to do it

In the questions we have tagged for this topic (135 questions, 2021–2025), the types came up this often. 42 of the 135 questions mix more than one type, so the counts add up to 223.

Question type	Questions
Chlorides with water: observations, equations, pH	40
Structure and bonding of oxides and chlorides from their properties	29
Identify unknown elements or compounds from clues	24
Oxides with water: equations, pH, insolubility	23
Acid–base and amphoteric behaviour of oxides and hydroxides	19
Reactions of the elements with oxygen, chlorine and water	15
Melting point and conductivity of the elements	15
Oxidation numbers in the oxides and chlorides	15
Judge statements or table rows about Period 3	15
Atomic and ionic radius	14
Match a property to its trend graph	7
Predict the properties of other elements	4
Evaluate a hypothesis about melting points	3

1. Chlorides with water: observations, equations, pH (40 questions)

1. **Decide which group the chloride is in:** ionic and just dissolves (NaCl , MgCl_2), or hydrolysed to HCl and an acidic solution (AlCl_3 , SiCl_4 , PCl_5). AlCl_3 's reaction with water is hydrolysis too.
2. **Write the equation** from the table in "Understand it". For the hydrolysed ones: the element ends up in its oxide or oxoacid with the same oxidation number, and all the chlorine ends up as HCl . Balance Cl first, then H , then O .
3. **Give the pH** as a number or a small range: 7, 6.5, about 3, 0–2.
4. **Explain** the acidity: HCl forms and dissolves in the water to make hydrochloric acid (SiCl_4 , PCl_5 , and AlCl_3 : $\text{AlCl}_3 + 3\text{H}_2\text{O} \rightarrow \text{Al}(\text{OH})_3 + 3\text{HCl}$). For AlCl_3 you can also say the small, highly charged Al^{3+} ion polarises its water molecules, which release H^+ . Either answer is accepted.

Variations you will meet:

- **Observations.** Steamy (misty) fumes, a white solid left (SiO_2 from SiCl_4 ; $\text{Al}(\text{OH})_3$ from AlCl_3 with a little water), a colourless solution (PCl_5), heat given out. Say what the fumes are (HCl) if asked, and that they turn moist blue litmus red.
- **Physical state first:** SiCl_4 is a colourless liquid, PCl_5 a pale yellow or white solid, AlCl_3 a white solid, NaCl and MgCl_2 white crystalline solids.

- **Name the reaction:** hydrolysis. Not displacement, not redox.
- **Tests on the solutions:** which ones give CO_2 with sodium carbonate (the acidic ones: Al, Si, P); which give a white precipitate with a little aqueous alkali (Mg^{2+} and Al^{3+} , or SiCl_4 , which makes SiO_2 with the water in the alkali); which precipitate dissolves in excess NaOH ($\text{Al}(\text{OH})_3$ only).
- **An impossible record.** A Period 3 chloride never gives an alkaline solution, so a "chloride solution of pH 12" means an observation is wrong.
- **Moles with the chlorides.** If x mol of a chloride gives $4x$ mol of HCl , the formula has 4 Cl (for example SiCl_4). With silver nitrate every chloride ion gives one AgCl , so moles of $\text{AgCl} \div$ moles of chloride = the number of Cl in the formula. To precipitate all the aluminium from AlCl_3 as $\text{Al}(\text{OH})_3$ you need 3 mol NaOH per mol of AlCl_3 (6 per Al_2Cl_6); any more starts to dissolve it.

2. Structure and bonding of oxides and chlorides from their properties (29 questions)

1. **Classify each compound:** giant ionic (Na, Mg, and Al's oxide), giant covalent (SiO_2), simple molecular (SiCl_4 , PCl_5 , P_4O_{10} , SO_2 , SO_3).
2. **Explain a melting point** by naming what is broken: "ionic bonds between oppositely charged ions" (many, strong), "covalent bonds throughout the giant structure" (many, strong), or "weak intermolecular forces" (id-id, or permanent dipole–permanent dipole for polar molecules such as SO_2). Then compare: more energy is needed to break the stronger one.
3. **Explain conductivity** by the particles: ions that move in the molten ionic compound; no ions and no delocalised electrons in a molecular one.

Variations you will meet:

- **Complete a table** of bonding (I, C) and structure (G, S) for a row of chlorides or oxides; AlCl_3 is accepted as ionic and giant in the solid.
- **An unfamiliar compound** (a new chloride or oxide): low melting point $\rightarrow$ simple molecular; reacts with water to give an acidic solution and fumes $\rightarrow$ covalent. Give the reason for each, not just the words from the question.
- **Room-temperature states** of the oxides: only SO_2 is a gas; SO_3 melts at about 17°C ; the rest are white solids.
- **Ceramics:** MgO , Al_2O_3 and SiO_2 , because of their very high melting points.

3. Identify unknown elements or compounds from clues (24 questions)

1. **Translate each clue** into what it tells you, using the "map" of Period 3:
 - highest melting point, semiconductor $\rightarrow$ Si; best conductor $\rightarrow$ Al; lowest melting point (not Ar) $\rightarrow$ Cl;
 - largest atom $\rightarrow$ Na; smallest atom $\rightarrow$ Cl; largest simple ion $\rightarrow \text{P}^{3-}$;
 - oxide dissolves in both acid and alkali $\rightarrow$ Al; oxide insoluble in water and not attacked by acid $\rightarrow$ Si;
 - chloride gives pH 7 $\rightarrow$ Na only; chloride gives a white solid and fumes with water $\rightarrow$ Si (or Al with little water);

- electron clues: a single full (paired) orbital in the outer sub-shell → Mg ($3s^2$) or S ($3p^4$); three unpaired 3p electrons → P.

2. **Cross off options** that break any clue. A single clue rarely settles it; two or three do.

3. **Check your answer against every clue**, including the ones you did not use.

Variations you will meet:

- **Two elements then a compound**: identify both, then decide their compound's formula and bonding (for example, a Group 1 metal and a Group 16 non-metal give an ionic compound X_2Y).
- **Radius data**: an element whose ion is much smaller than its atom is a metal (lost a shell); one whose ion is larger is a non-metal. A metal and a non-metal form an ionic compound.
- **Indicator colours**: an indicator's colour tells you whether a solution is strongly acidic, weakly acidic or alkaline; match it to the chloride or oxide.

4. Oxides with water: equations, pH, insolubility (23 questions)

1. **Write the equation** (table in "Understand it"): metal oxides give hydroxides; non-metal oxides give acids with the same oxidation number ($SO_2 \rightarrow H_2SO_3$, $SO_3 \rightarrow H_2SO_4$, $P_4O_{10} \rightarrow H_3PO_4$).
2. **Give the pH**: 13–14, 9–10, 7 (insoluble), 0–2 or 2–3.
3. For Al_2O_3 and SiO_2 , write "no reaction" and give the reason: **insoluble**.

Variations you will meet:

- **Pick the oxide** from a description: a white solid that gives an acidic solution is P_4O_{10} (SO_2 is a gas; SiO_2 and Al_2O_3 don't dissolve).
- **Name the acid**: phosphoric(V) acid, sulfuric(VI) acid (sulfuric acid), sulfurous acid. If asked for a name, write a name.
- **Mixtures**: two oxides together in water. An alkaline oxide and an acidic oxide neutralise each other; the one in excess (in moles of OH^- or H^+ they make) sets the pH.
- **Why aluminium does not react with water**: its insoluble oxide layer.

5. Acid–base and amphoteric behaviour of oxides and hydroxides (19 questions)

1. **Classify**: basic (Na, Mg), amphoteric (Al), acidic (Si, P, S).
2. **Define amphoteric** when asked: reacts with both acids and bases.
3. **Write the equation** the question wants (lists in "Understand it"). With sodium hydroxide the aluminium product is $NaAl(OH)_4$ (or $NaAlO_2 + H_2O$); with sulfuric acid it is $Al_2(SO_4)_3$.

Variations you will meet:

- **Which oxide does not dissolve in sodium hydroxide?** The basic one, MgO (and Na_2O just reacts with the water).
- **Ratios**: P_4O_{10} needs 12 NaOH (it makes 4 H_3PO_4 , each with 3 acidic H); SO_3 and SO_2 need 2 each; Al_2O_3 needs 2.

- **A new oxide by analogy**, such as Ga_2O_3 with NaOH : copy aluminium's equation with the new symbol.
- **Brønsted–Lowry language**: a basic oxide accepts protons from an acid.

6. Reactions of the elements with oxygen, chlorine and water (15 questions)

1. Write the formula of the product first (Na_2O , MgO , Al_2O_3 , P_4O_{10} , SO_2 ; NaCl , MgCl_2 , AlCl_3 , SiCl_4 , PCl_5), then balance.
2. Add observations if asked: flame colours (Na yellow-orange, Mg brilliant white, S blue), sodium fizzing and moving on water, magnesium barely reacting with cold water.

Variations you will meet:

- **Balancing with given numbers**: for $4\text{Na} + \text{O}_2 \rightarrow 2\text{Na}_2\text{O}$ and $4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$ the metal's number is 4 and the oxide's 2; $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$ has 2 and 2.
- **Moles of O_2 per mole of element**: Na $\frac{1}{4}$, Mg $\frac{1}{2}$, Al $\frac{3}{4}$, Si 1, P $\frac{5}{4}$ (for P_4O_{10}), S 1 (for SO_2).
- **Sodium versus sodium oxide in water**: both give colourless NaOH solutions and the solids disappear; only sodium fizzes (hydrogen).

7. Melting point and conductivity of the elements (15 questions)

1. **Name the structure**: giant metallic (Na, Mg, Al), giant covalent (Si), simple molecular (P, S, Cl).
2. **Melting point**: say which bonds or forces break, and how strong they are ("many strong covalent bonds" for Si; "weak id–id forces between molecules" for P, S, Cl; "stronger metallic bonding: greater ion charge and more delocalised electrons" from Na to Al).
3. **Conductivity**: "delocalised electrons that can move through the structure" for metals, more of them from Na to Al; "no mobile charge carriers: no delocalised electrons and no ions" for P, S, Cl.

Variations you will meet:

- **Sketch the melting-point graph**: rising Na $\rightarrow$ Al, highest at Si, a big drop to P, S above P, Cl below P (as in the bar chart above).
- **Draw metallic bonding**: a regular lattice of labelled positive ions (for example Na^+) with labelled delocalised electrons between them.
- **Allotropes** (for example white phosphorus, P_4 molecules, versus a giant form): simple molecular melts low; giant melts high.

8. Oxidation numbers in the oxides and chlorides (15 questions)

1. Work each from the formula (O -2 , Cl -1 , total 0).
2. **Explain the maximum**: it equals the number of outer (valence) electrons, because all of them are used in bonding. Name numbers: "Na has one outer electron, P has five."

Variations you will meet:

- **Pick the oxide with the highest oxidation number:** SO_3 (+6).
- **Why Al and P differ** (+3 and +5): they have different numbers of outer electrons. Don't explain it with nuclear charge.
- **Two chlorides or oxides of one element** ($\text{PCl}_3/\text{PCl}_5$, SO_2/SO_3): the one with more O or Cl uses more of its outer electrons.

9. Judge statements or table rows about Period 3 (15 questions)

1. **Test each statement or row on its own** against the facts in this note. Look for the one wrong word: "increases" versus "decreases", "every element", "giant" versus "simple".
2. For a **statement plus reason**, both must be true **and** the reason must explain the statement.

Traps that come up often:

- The highest oxidation number rises **all the way** from Na (+1) to S (+6); it does not stop at P.
- Na_2O and MgO **react** with water; Al_2O_3 and SiO_2 are insoluble.
- The oxides go giant ionic $\rightarrow$ giant covalent $\rightarrow$ simple molecular.
- Melting point does **not** rise steadily: it peaks at Si.
- SiO_2 is giant covalent, and SiCl_4 is simple molecular.
- Aluminium chloride is not made of separate Al^{3+} and Cl^- ions; AlCl_3 vapour is Al_2Cl_6 with dative bonds.

10. Atomic and ionic radius (14 questions)

1. **Atomic radius falls** across the period: nuclear charge increases **and** shielding stays about the same, so the outer electrons are attracted more strongly.
2. **Ions**: cations have lost a whole shell (smaller than the atom); anions have gained electrons (larger than the atom). Compare shells first, then protons.

Variations you will meet:

- Al^{3+} **versus** P^{3-} : P^{3-} has one more shell.
- **Two ions with the same electrons** (Na^+ and Al^{3+} , or S^{2-} and Cl^-): the one with more protons is smaller.
- **The anions from silicon to chlorine** (Si^{4-} 0.271 nm down to Cl^- 0.181 nm, from the Data Booklet): all have 18 electrons in the same three shells, while the proton number rises from 14 to 17, so each pulls its electrons in harder and the radius falls.
- **An element and its ion** in a compound such as sodium sulfide: sodium's atom is larger than sulfur's, but the sulfide ion is larger than the sodium ion.

11. Match a property to its trend graph (7 questions)

Know the shape of each graph across $\text{Na} \rightarrow \text{Cl}$:

- **atomic radius**: falls steadily;

- **electronegativity**: rises steadily;
- **melting point**: rises to a peak at Si, then very low for P, S, Cl;
- **conductivity**: rises Na → Al, then almost zero at Si and zero after;
- **first ionisation energy**: rises overall, with dips at Al and S.

For a graph of **one property against another** (for example electronegativity against atomic radius for Na, Mg, Al, Si), work out where each element lies on each axis, then plot the points in that order: here Na has the largest radius and lowest electronegativity, Si the smallest radius and highest electronegativity. For **melting points of consecutive elements**, sodium is the one straight after the very low value of a noble gas, at the start of a rise.

12. Predict the properties of other elements (4 questions)

1. Use the **group** to set the formulas and the highest oxidation number.
2. Use the **trend down the group** to decide more metallic or less, larger or smaller, and more basic or more acidic.
3. **Write equations by analogy** with the Period 3 element in the same group, changing only the symbol.
4. For a missing number in a table, use the trend: it lies between the values above and below.

13. Evaluate a hypothesis about melting points (3 questions)

1. Find the data that test the hypothesis, and **quote them** (two compounds and their melting points).
2. **Give a verdict**: true, false, or "not enough information".
3. **Explain it**: a counter-example makes it false; if the melting points depend on something the hypothesis ignores (for example, a simple molecular oxide melts by breaking intermolecular forces, not its covalent bonds), there is not enough information.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

The table gives the melting points of four Period 3 elements.

Element	chlorine	magnesium	phosphorus	silicon
Melting point / K	172	923	317	1683

(a) List the four elements in order of increasing melting point. **[1]**

(b) Explain this order in terms of the structure and bonding of each element. **[4]**

(c) Predict whether the melting point of sodium is higher or lower than that of magnesium. Explain your prediction. **[2]**

(a) chlorine < phosphorus < magnesium < silicon **B1**.

(b) Chlorine and phosphorus are simple molecular (Cl_2 and P_4): melting only overcomes weak id-id forces between molecules, so both melt low **B1**. P_4 has more electrons per molecule (60) than Cl_2 (34), so its id-id forces are stronger and it melts higher **B1**. Magnesium is giant metallic: strong attraction between Mg^{2+} ions and the delocalised electrons must be overcome **B1**. Silicon is giant covalent: melting breaks many strong covalent bonds throughout the lattice, which needs the most energy **B1**.

(c) Lower **B1**. Na^+ has a smaller charge than Mg^{2+} and is larger, and each sodium atom gives only one delocalised electron (magnesium gives two), so the metallic bonding is weaker **B1**. (The chart in "Understand it" shows 371 K.)

Example 2

Three bottles, **P**, **Q** and **R**, each hold one anhydrous chloride: magnesium chloride, aluminium chloride or silicon(IV) chloride.

- **P** is a colourless liquid that fumes in moist air.
- **Q** is a white solid that dissolves in water to give a solution of pH 6.5.
- **R** is a white solid that reacts with water, giving off steamy fumes and forming a solution of pH 3.

(a) Identify **P**, **Q** and **R**. **[2]**

(b) Write an equation for the reaction of **P** with water, and describe what you would see. **[3]**

(c) Explain why the solution formed from **R** is acidic. **[2]**

(d) 2.55 g of **P** is added to an excess of water. The solid formed is filtered off and the filtrate is made up to 250 cm^3 . Calculate the volume of 0.200 mol dm^{-3} sodium hydroxide needed to neutralise 25.0 cm^3 of this solution. **[3]**

(a) **P** is SiCl_4 , **Q** is MgCl_2 , **R** is AlCl_3 . All three correct **B2**; two correct **B1**.

(b) $\text{SiCl}_4 + 2\text{H}_2\text{O} \rightarrow \text{SiO}_2 + 4\text{HCl}$ **B1**. Steamy (misty) white fumes **B1**; a white solid forms (and the mixture gets hot) **B1**.

(c) In water, Al^{3+} is surrounded by six water molecules. The small, highly charged Al^{3+} ion polarises (pulls electron density from) these water molecules **M1**, so they release H^+ ions: $[\text{Al}(\text{H}_2\text{O})_6]^{3+} \rightleftharpoons [\text{Al}(\text{H}_2\text{O})_5(\text{OH})]^{2+} + \text{H}^+$ **A1**. (Also accepted: AlCl_3 is hydrolysed, $\text{AlCl}_3 + 3\text{H}_2\text{O} \rightarrow \text{Al}(\text{OH})_3 + 3\text{HCl}$, and the HCl dissolves to make hydrochloric acid.)

(d) $M_r(\text{SiCl}_4) = 28.1 + 4(35.5) = 170.1$, so moles of $\text{SiCl}_4 = \frac{2.55}{170.1} = 0.01499$ mol **M1**.

Each SiCl_4 gives 4 HCl : $4 \times 0.01499 = 0.05996$ mol in 250 cm^3 , so 25.0 cm^3 holds 0.005996 mol **M1**.

$\text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O}$ is 1 : 1, so volume = $\frac{0.005996}{0.200} = 0.02998 \text{ dm}^3 = 30.0 \text{ cm}^3$ **A1**.

Example 3

A student has samples of magnesium oxide, aluminium oxide and sulfur trioxide.

(a) Each oxide is added to water. For each one, write an equation for any reaction and suggest the pH of the mixture. **[4]**

(b) Only one of the three oxides reacts with both hydrochloric acid and aqueous sodium hydroxide. Name this behaviour and write an equation for each reaction. **[3]**

(c) Explain, in terms of bonding, why magnesium oxide is basic but sulfur trioxide is acidic. **[2]**

(d) 0.710 g of phosphorus(V) oxide is dissolved in water and the solution is neutralised exactly by $0.500 \text{ mol dm}^{-3}$ sodium hydroxide, forming Na_3PO_4 . Write the overall equation and calculate the volume of sodium hydroxide used. **[3]**

(a) $\text{MgO} + \text{H}_2\text{O} \rightarrow \text{Mg}(\text{OH})_2$, pH 9–10 **B1 B1** (it is only slightly soluble). Al_2O_3 : no reaction, it is insoluble, pH 7 **B1**. $\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$, pH 0–1 **B1**.

(b) Amphoteric **B1**. $\text{Al}_2\text{O}_3 + 6\text{HCl} \rightarrow 2\text{AlCl}_3 + 3\text{H}_2\text{O}$ **B1**. $\text{Al}_2\text{O}_3 + 2\text{NaOH} + 3\text{H}_2\text{O} \rightarrow 2\text{NaAl}(\text{OH})_4$ (or $\text{Al}_2\text{O}_3 + 2\text{NaOH} \rightarrow 2\text{NaAlO}_2 + \text{H}_2\text{O}$) **B1**.

(c) MgO is ionic: its oxide ions, O^{2-} , accept protons (from water or an acid), so it is basic **B1**. SO_3 is covalent: the S atom, bonded to more electronegative O atoms, reacts with water to form an acid, H_2SO_4 **B1**.

(d) $\text{P}_4\text{O}_{10} + 12\text{NaOH} \rightarrow 4\text{Na}_3\text{PO}_4 + 6\text{H}_2\text{O}$ **B1**.

$M_r(\text{P}_4\text{O}_{10}) = 4(31.0) + 10(16.0) = 284.0$, so moles = $\frac{0.710}{284.0} = 0.00250$ mol **M1**.

Moles of $\text{NaOH} = 12 \times 0.00250 = 0.0300$ mol; volume = $\frac{0.0300}{0.500} = 0.0600 \text{ dm}^3 = 60.0 \text{ cm}^3$ **A1**.

Example 4

Arsenic, As, is in Group 15, directly below phosphorus.

(a) Predict the highest oxidation number of arsenic in its oxides. Explain your answer. **[2]**

(b) Arsenic(III) chloride, AsCl_3 , is a colourless liquid that melts at -16°C and fumes in moist air. Suggest its structure and bonding, giving a reason for each. [2]

(c) AsCl_3 reacts with water to form H_3AsO_3 and one other product. Write the equation and suggest the pH of the solution. [2]

(d) Arsenic(V) oxide, As_2O_5 , dissolves in water to form H_3AsO_4 . Write equations for this reaction and for the reaction of H_3AsO_4 with an excess of aqueous sodium hydroxide. State whether As_2O_5 is acidic, basic or amphoteric. [3]

(a) +5 **B1**: like phosphorus, arsenic has five outer (valence) electrons, and all of them can be used in bonding to oxygen **B1**.

(b) Simple molecular, because its melting point is low **B1**. Covalent, because it is hydrolysed by water (it fumes, giving HCl) **B1**.

(c) $\text{AsCl}_3 + 3\text{H}_2\text{O} \rightarrow \text{H}_3\text{AsO}_3 + 3\text{HCl}$ **B1**; pH 0–2 **B1** (strongly acidic from the HCl).

(d) $\text{As}_2\text{O}_5 + 3\text{H}_2\text{O} \rightarrow 2\text{H}_3\text{AsO}_4$ **B1**. $\text{H}_3\text{AsO}_4 + 3\text{NaOH} \rightarrow \text{Na}_3\text{AsO}_4 + 3\text{H}_2\text{O}$ **B1**. Acidic, like P_4O_{10} **B1**.

Common mistakes

- **Saying sodium chloride gives an acidic solution or reacts with water.** It only dissolves: pH 7, no fumes. Examiners see this often, alongside giving PCl_5 the wrong state. Learn the states: SiCl_4 is a colourless **liquid**, PCl_5 a pale yellow or white **solid**.
- **Calling SiCl_4 giant covalent.** That is SiO_2 . SiCl_4 is simple molecular, which is why it is a liquid.
- **Writing hydrolysis as redox.** In the chloride and oxide reactions with water nothing is oxidised or reduced; check that each oxidation number is the same on both sides. Don't put Cl_2 or H_2 in these equations.
- **Giving a formula when a name is asked** (or the other way round). "Name the acid formed from P_4O_{10} " needs "phosphoric(V) acid".
- **"Free electrons" and electrons that don't move.** Say "delocalised electrons", and say they **move through the structure**. Having delocalised electrons is not enough on its own to explain conduction.
- **Using the steam reaction when cold water is asked.** Magnesium and cold water give $\text{Mg}(\text{OH})_2$ and H_2 ; MgO comes only from steam.
- **Explaining oxidation numbers with nuclear charge.** The highest oxidation number comes from the number of outer electrons, all used in bonding.
- **Repeating the question as an explanation.** "It is simple molecular because it is a liquid that fumes" needs splitting: low melting point $\rightarrow$ simple; hydrolysed $\rightarrow$ covalent.
- **Half an explanation of radius.** "More protons" alone does not earn the mark; add "same shell, similar shielding". For ions, count the shells before anything else.
- **Naming only the strongest force.** When comparing melting points of molecular substances, remember that all molecules have id–id forces, and polar ones have permanent dipole forces as well.

- **Forgetting SiO_2 in ceramic and insoluble-oxide answers.** MgO , Al_2O_3 and SiO_2 all have very high melting points; Al_2O_3 and SiO_2 are both insoluble in water.

How to get the marks

- **Equations:** balanced, with the right formulas (P_4O_{10} , not P_2O_5 ; $\text{NaAl}(\text{OH})_4$ or NaAlO_2 ; $\text{Al}_2(\text{SO}_4)_3$). Add state symbols only when asked, and then every species needs one.
- **"Describe"** a reaction with water means observations: fumes, fizzing, a white solid, a colourless solution. **"Suggest the pH"** wants a number or a narrow range, such as 7, 6.5 or 0–2, not just "acidic".
- **"Explain" the physical properties** in three steps: name the structure; name the bond or force broken (or the particle that moves); compare its strength or say whether it is there.
- **Radius:** "nuclear charge increases **and** shielding is similar" earns the first mark; "so a stronger attraction for the outer electrons" earns the second.
- **Oxidation numbers:** give the sign (+5, not 5), and link the maximum to the number of outer electrons.
- **Tables to complete:** use exactly the abbreviations given (I, C, M; G, S; i.d., p.d., H), and fill every cell.
- **"Suggest" and "predict"** questions accept a sensible answer based on a pattern, so always say which pattern you used ("like aluminium", "like phosphorus").
- **Hypotheses:** a verdict alone scores nothing. Give the verdict, quote the data you compared, and link them.
- **Paper 1:** in "which statements are correct" questions, judge every statement separately; one wrong word makes a statement false.

Quick check

1. Put these in order of increasing pH of the mixture formed when each is added to water: Na_2O , PCl_5 , Al_2O_3 , MgCl_2 .
2. Explain why the S^{2-} ion is much larger than the Mg^{2+} ion, and why the Cl^- ion is slightly smaller than the S^{2-} ion.
3. 0.230 g of sodium is added to an excess of cold water. Write the equation and calculate the volume of hydrogen formed at room conditions.
4. Element **W** is in Period 3. Its chloride dissolves in water to give a solution of pH 6.5, and adding aqueous sodium hydroxide gives a white precipitate that does not dissolve in excess. Identify **W** and write an equation for the formation of the precipitate from **W**'s chloride.
5. Which statement is correct?
 - A: Magnesium oxide dissolves in aqueous sodium hydroxide because it is amphoteric.
 - B: The highest oxidation number of phosphorus in its chlorides is +5 because a phosphorus atom has five outer electrons.
 - C: When phosphorus(V) chloride is hydrolysed, phosphorus is reduced to the +3 oxidation state.
 - D: Atomic radius increases from sodium to chlorine because more electrons are added.

Answers

1. PCl_5 (0–2) < MgCl_2 (6.5) < Al_2O_3 (7: insoluble, the water stays neutral) < Na_2O (13–14).
2. S^{2-} has three shells (2, 8, 8) and Mg^{2+} only two (2, 8), so S^{2-} is much larger. S^{2-} and Cl^- both have 18 electrons in the same shells, but Cl has 17 protons to sulfur's 16, so its electrons are pulled in a little more.
3. $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$. Moles of Na = $\frac{0.230}{23.0} = 0.0100$ mol, so moles of $\text{H}_2 = 0.00500$ mol, and volume = $0.00500 \times 24.0 = 0.120 \text{ dm}^3 = 120 \text{ cm}^3$.
4. **W** is magnesium: pH 6.5 fits MgCl_2 (NaCl gives 7, AlCl_3 about 3), and $\text{Mg}(\text{OH})_2$ is basic, so it does not dissolve in excess alkali. $\text{MgCl}_2 + 2\text{NaOH} \rightarrow \text{Mg}(\text{OH})_2 + 2\text{NaCl}$.
5. **B**. A is wrong because MgO is basic: it reacts with acids but not with sodium hydroxide. C is wrong because hydrolysis is not redox: phosphorus stays +5 in H_3PO_4 . D is wrong because atomic radius decreases.

Past questions to try

- [9701/22/O/N/25 Q2](#): conductivity and melting points of the elements, then a full table for the chlorides.
- [9701/22/M/J/25 Q1](#): PCl_5 and SiCl_4 with water, amphoteric oxides and a melting-point hypothesis.
- [9701/23/O/N/25 Q2](#): atomic and ionic radii, oxidation numbers and pH of the oxides, and amphoteric Al_2O_3 .
- [9701/12/M/J/25 Q18](#): identify a chloride from a set of test results.