Cambridge IGCSE · Chemistry 0620 · Notes

Reactivity series and corrosion

Read online at **pastopic.com/cambridge/chemistry-0620/notes/reactivity-and-corrosion**

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Read first: **Formulae and equations**, **Redox**

What you need to know

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

1. **Recite the reactivity series** from most to least reactive: potassium, sodium, calcium, magnesium, aluminium, **carbon**, zinc, iron, **hydrogen**, copper, silver, gold. Carbon and hydrogen are non-metals, but they are placed in the list because they help you predict reactions.

2. **Describe how metals react (or don't)** with water and dilute acid:

    - potassium, sodium and calcium with **cold water**;
    - magnesium with **steam**;
    - magnesium, zinc, iron, copper, silver and gold with **dilute hydrochloric acid**;

    and explain each result from the metal's position in the series.

3. **Work out an order of reactivity from experimental results** you are given, such as how fast bubbles form, how much the temperature rises, or whether a metal reacts at all.

4. **Extended only:** describe reactivity as a metal's **tendency to form positive ions**, and show it with **displacement reactions** between metals and the aqueous ions of magnesium, zinc, iron, copper and silver.

5. **Extended only:** explain why **aluminium seems less reactive** than its place in the series suggests: it is covered by a layer of aluminium oxide.

6. **State the conditions for rusting**: iron and steel rust when **both water and oxygen** are present, forming **hydrated iron(III) oxide**.

7. **Name common barrier methods**: painting, greasing (or oiling) and coating with plastic.

8. **Describe how barrier methods work**: they keep oxygen or water away from the iron.

9. **Extended only:** describe **galvanising** (coating iron or steel with zinc) as both a barrier method and **sacrificial protection**.

10. **Extended only:** explain sacrificial protection using the reactivity series and **electron loss**.

How metals are extracted from their ores, and why some need electrolysis, is in the topic Extraction of metals. What alloys are and why they are used is in Properties, uses and alloys.

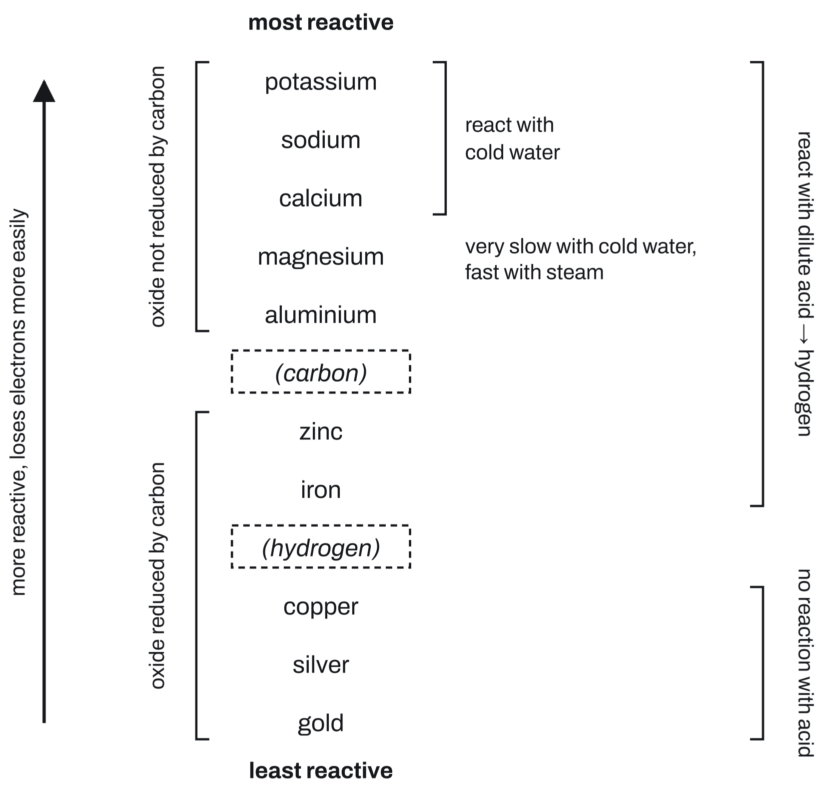
Understand it

What "reactive" means for a metal

When a metal reacts, its atoms **lose their outer electrons** and become **positive ions**: $\mathrm{Mg} \rightarrow \mathrm{Mg}^{2+} + 2e^{-}$. A **more reactive** metal gives up its electrons **more easily**. That one idea explains every reaction in this topic:

- with water or an acid, the metal pushes its electrons onto hydrogen, so hydrogen gas is given off;
- with another metal's ions, it pushes its electrons onto those ions, so the other metal comes out as a solid (displacement);
- when iron rusts, iron atoms lose electrons to oxygen; a more reactive metal touching the iron can lose electrons instead, and protect it.

The reactivity series



Learn the order by heart: **K, Na, Ca, Mg, Al, (C), Zn, Fe, (H), Cu, Ag, Au**. The two non-metals are markers:

- **Hydrogen** divides the metals that react with dilute acids (above it) from those that do not (below it).
- **Carbon** divides the metals whose oxides carbon can take the oxygen from when they are heated together (below it: zinc, iron, copper ...) from those it cannot (above it: aluminium, magnesium ...). A metal oxide that is "reduced by carbon" tells you the metal is below carbon.

Metals with cold water

Only the most reactive metals react with cold water. They make a **metal hydroxide** (which dissolves to give an alkaline solution) and **hydrogen**:

$$\text{metal} + \text{water} \rightarrow \text{metal hydroxide} + \text{hydrogen}$$

Metal	What you see with cold water	Equation
Potassium	floats, melts into a ball, rushes around, fizzes violently; the hydrogen catches fire with a lilac flame	$2K + 2H_2O \rightarrow 2KOH + H_2$
Sodium	floats, melts into a ball, moves about, fizzes quickly and disappears	$2Na + 2H_2O \rightarrow 2NaOH + H_2$
Calcium	sinks, fizzes steadily, the water turns cloudy and warms up	$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$

The further up the series, the more violent the reaction: potassium > sodium > calcium.

Magnesium with steam

Magnesium reacts only **very slowly** with cold water (a few bubbles over days). Heated in **steam**, it glows with a bright white light and makes a white solid, **magnesium oxide**, and hydrogen:

$$Mg(s) + H_2O(g) \rightarrow MgO(s) + H_2(g)$$

Notice the product: with steam a metal gives its **oxide**, not its hydroxide. Metals a little lower (zinc, iron) also react with hot steam, more slowly still. Metals below hydrogen (copper, silver, gold) react with neither water nor steam.

Metals with dilute hydrochloric acid

Metals **above hydrogen** react with dilute acids to give a **salt** and **hydrogen**:

$$\text{metal} + \text{acid} \rightarrow \text{salt} + \text{hydrogen}$$

Metal	With dilute hydrochloric acid	Equation
Magnesium	fizzes rapidly, gets warm, metal soon disappears	$Mg + 2HCl \rightarrow MgCl_2 + H_2$
Zinc	fizzes steadily	$Zn + 2HCl \rightarrow ZnCl_2 + H_2$
Iron	a few bubbles, slowly	$Fe + 2HCl \rightarrow FeCl_2 + H_2$
Copper, silver, gold	no reaction	none

Iron makes **iron(II) chloride**. Copper, silver and gold are **below hydrogen**, so they cannot push hydrogen out of the acid. (Potassium, sodium and calcium would react with acid far too violently to try safely.)

The salt's name comes from the acid: hydrochloric acid → **chloride**, sulfuric acid → **sulfate**, nitric acid → **nitrate**, ethanoic acid → **ethanoate**. So zinc and dilute sulfuric acid give zinc sulfate and hydrogen.

Deducing an order from results

Exams often use metals you have never met, then give you results. Reactivity shows up as:

- **how many tests the metal reacts in**: a metal that reacts with cold water is more reactive than one that needs steam, which is more reactive than one that only reacts with acid, which is more reactive than one that reacts with nothing;
- **how vigorous the reaction is** in the same test: faster bubbling, a faster temperature rise, burning rather than slowly forming an oxide layer;
- **whether carbon reduces its oxide**: if carbon does, the metal is below carbon, so less reactive than any metal whose oxide carbon cannot reduce.

For a fair comparison, everything except the metal must be the same: the same mass and size of metal pieces (same surface area), the same volume, concentration and starting temperature of acid or water.

Extended only: displacement reactions

A more reactive metal **displaces** a less reactive metal from a solution of its ions. Put magnesium into blue copper(II) sulfate solution: magnesium atoms lose electrons, copper(II) ions gain them, the blue colour fades and a pink-brown layer of copper forms.

$$\mathrm{Mg(s)} + \mathrm{Cu^{2+}(aq)} \rightarrow \mathrm{Mg^{2+}(aq)} + \mathrm{Cu(s)}$$

The sulfate ions do nothing (they are spectator ions), so the **ionic equation** leaves them out. The charges must balance on each side: here $+2$ and $+2$. When the metal ion has a different charge, balance the electrons, for example $\mathrm{Cu} + 2\mathrm{Ag^+} \rightarrow \mathrm{Cu^{2+}} + 2\mathrm{Ag}$.

If the added metal is **less** reactive, nothing happens: copper does not react with magnesium sulfate solution.

Testing each metal with the others' ions gives a grid. For the five syllabus metals ($\checkmark$ = the metal is displaced from solution; $\times$ = no reaction):

Metal added	$\mathrm{Mg^{2+}}$(aq)	$\mathrm{Zn^{2+}}$(aq)	$\mathrm{Fe^{2+}}$(aq)	$\mathrm{Cu^{2+}}$(aq)	$\mathrm{Ag^{+}}$(aq)	Reactions
Magnesium	—	✓	✓	✓	✓	4
Zinc	×	—	✓	✓	✓	3
Iron	×	×	—	✓	✓	2
Copper	×	×	×	—	✓	1
Silver	×	×	×	×	—	0

The more reactions a metal has, the higher it is: Mg > Zn > Fe > Cu > Ag. In words, the more reactive a metal, the **greater its tendency to form positive ions** (to lose electrons). Note it is the **atom** (Mg), not the ion (Mg^{2+}), that has the tendency to lose electrons.

Displacement works with oxides too, when they are heated together: aluminium takes the oxygen from iron(III) oxide, $2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$, which shows aluminium forms ions more readily than iron. A metal can never take oxygen from the oxide of a **more** reactive metal: iron and sodium oxide do not react.

Colour clues: copper(II) solutions are **blue** (fading as copper is displaced); iron(II) solutions are pale **green**; magnesium, zinc and silver solutions are **colourless**. So iron in copper(II) sulfate turns the solution from blue to pale green, with copper forming on the iron.

Extended only: why aluminium seems unreactive

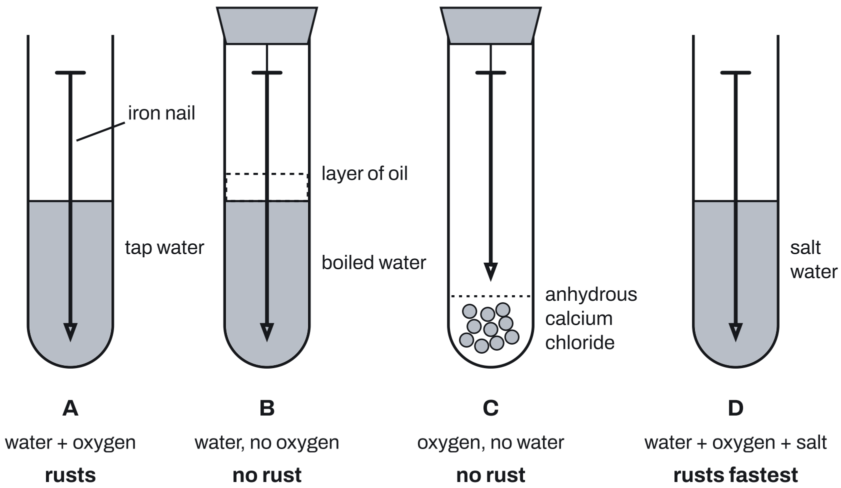
Aluminium is high in the series, above zinc and iron, yet a piece of aluminium foil dropped into dilute acid or copper(II) sulfate solution often shows **no reaction at first**, and aluminium objects barely corrode. The reason: aluminium reacts with oxygen in the air straight away to form a **thin, tough layer of aluminium oxide** on its surface. This layer is unreactive and sticks firmly, so it stops water, acid and ions reaching the metal underneath. Once the layer is broken down (for example after some minutes in acid, or if the surface is scratched), the aluminium beneath reacts as fast as its position suggests.

Rusting

Rust is **hydrated iron(III) oxide**, $Fe_2O_3 \cdot xH_2O$. "Hydrated" means it contains water; "iron(III)" means the iron ions are Fe^{3+}. Iron and steel (which is mostly iron) rust only when **both water and oxygen** are present:

$$\text{iron} + \text{oxygen} + \text{water} \rightarrow \text{hydrated iron(III) oxide}$$

Rusting is the name for the corrosion of iron and steel only; other metals corrode, but they do not "rust". Iron atoms lose electrons as they rust, so rusting is an oxidation.



The classic experiment compares nails in tubes like these:

- **Boiled water** has had its dissolved air driven out, and the **layer of oil** stops air dissolving again: water but no oxygen, so no rust.

- **Anhydrous calcium chloride** is a drying agent that removes water vapour from the air: oxygen but no water, so no rust.
- **Salt water** speeds rusting up, so that nail rusts most.
- A nail in a sealed tube of **nitrogen or argon** with water does not rust either: there is no oxygen.

If iron rusts in a closed tube of air standing over water, the oxygen is used up and **the water rises** to take its place. Air is about **21% oxygen**, so the gas volume falls by about a fifth and then stops (the nitrogen is left). A tube with painted or greased iron, which cannot rust, shows **no change** in the water level.

Preventing rusting: barrier methods

A **barrier method** covers the iron so that **oxygen and water cannot reach it**:

- **painting**: cars, bridges, railings;
- **greasing or oiling**: moving parts such as bicycle chains and machine tools, where paint would rub off;
- **coating with plastic**: garden wire, dish racks, fences.

A barrier only works while it is unbroken. Once it is scratched or chipped, air and water reach the iron and it rusts there. Alloying (making stainless steel) is **not** a barrier method: it changes the metal itself instead of covering it.

Extended only: sacrificial protection and galvanising

In **sacrificial protection**, a **more reactive metal**, usually **zinc** or **magnesium**, is in contact with the iron. The more reactive metal **loses electrons more readily** than iron, so it is oxidised (it corrodes) instead of the iron:

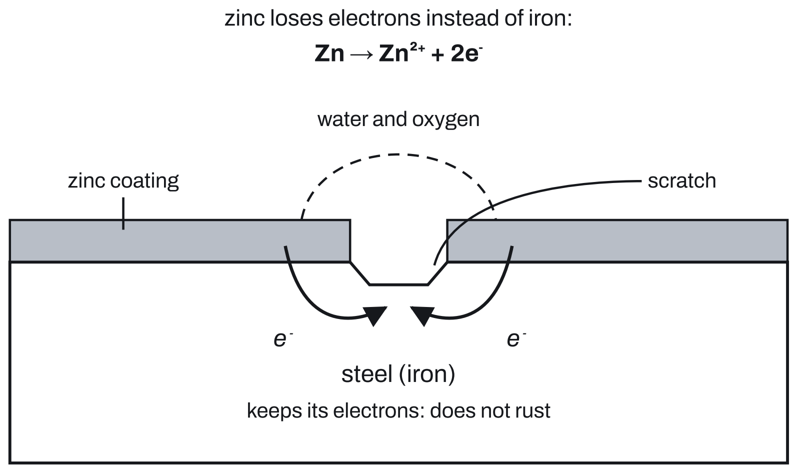
$$\mathrm{Zn} \rightarrow \mathrm{Zn}^{2+} + 2e^- \qquad \text{or} \qquad \mathrm{Mg} \rightarrow \mathrm{Mg}^{2+} + 2e^-$$

The electrons it releases flow into the iron, so the iron does not lose electrons and does not rust. The protecting metal is "sacrificed": it is used up and has to be replaced. Ships' hulls, oil rigs and buried pipes have zinc or magnesium blocks bolted to them.

Any metal used must be **above iron** in the series. Copper, tin, silver or lead **cannot** protect iron this way: they are less reactive, so iron loses electrons to them more readily, and the iron corrodes even faster where they touch. Very reactive metals such as potassium or sodium are no good either, because they would react with water straight away.

Galvanising is coating iron or steel with a layer of **zinc**. It protects in **two** ways:

1. **Barrier**: while the zinc coating is complete, it keeps water and oxygen away from the iron.
2. **Sacrificial**: if the coating is scratched and the iron is exposed, zinc is still more reactive than iron, so zinc loses electrons instead of iron and the iron still does not rust.



Zinc is above iron in the reactivity series, so zinc is oxidised first.

Compare a coating of a **less** reactive metal, such as tin or paint: it is a barrier only, so once scratched, the iron underneath rusts.

Key facts and formulas

"Given" means the exam paper prints it. "Learn it" means you must remember it. Chemistry 0620 has no formula sheet, so everything here must be learned.

Formula	Status
Order: K, Na, Ca, Mg, Al, (C), Zn, Fe, (H), Cu, Ag, Au	Learn it
Metal + cold water → metal hydroxide + hydrogen (K, Na, Ca), for example $\mathrm{Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2}$	Learn it
Metal + steam → metal oxide + hydrogen: $\mathrm{Mg + H_2O \rightarrow MgO + H_2}$	Learn it
Metal + dilute acid → salt + hydrogen (metals above hydrogen only), for example $\mathrm{Zn + 2HCl \rightarrow ZnCl_2 + H_2}$	Learn it
Oxide reduced by carbon $\Longleftrightarrow$ metal is below carbon	Learn it
Extended: more reactive metal + ions of a less reactive metal → displacement, for example $\mathrm{Mg + Cu^{2+} \rightarrow Mg^{2+} + Cu}$	Learn it
Extended: more reactive = greater tendency to form positive ions (lose electrons)	Learn it
Rusting needs water **and** oxygen; rust is hydrated iron(III) oxide, $\mathrm{Fe_2O_3 \cdot x H_2O}$	Learn it

Formula	Status
iron + oxygen + water → hydrated iron(III) oxide	Learn it
Barrier methods (painting, greasing, plastic coating) exclude oxygen and/or water	Learn it
Extended: sacrificial metal is more reactive than iron: $\mathrm{Zn} \to \mathrm{Zn}^{2+} + 2e^{-}$	Learn it
Extended: galvanising = zinc coating = barrier + sacrificial protection	Learn it
Extended: aluminium's apparent unreactivity = protective aluminium oxide layer	Learn it
Air is about 21% oxygen (for rusting-tube volumes)	Learn it

How to do it

In the questions we have tagged for this topic (162 questions, 2021–2025, from all four papers), the types came up this often. 19 of the 162 questions mix types, so the counts add up to 189.

Question type	Questions
Put metals in order of reactivity from experimental results	43
Recall the series and use a metal's position	36
Conditions for rusting, the name of rust, rusting experiments	29
Sacrificial protection and galvanising (Extended)	23
Displacement reactions and tendency to form positive ions (Extended)	18
Products and equations for metals with water, steam, acid or oxygen	17
Why aluminium seems unreactive (Extended)	13
Barrier methods of rust prevention	10

1. Put metals in order of reactivity from experimental results (43 questions)

1. **Read the question's direction first**: "least reactive first" or "most reactive first". Many lose the mark by writing the right order backwards.
2. **Rank each metal on the evidence**:
   - no reaction in any test → least reactive;
   - more tests reacted in → more reactive (cold water beats steam only, which beats acid only);
   - in the same test, faster bubbles, faster or bigger temperature rise, or burning → more reactive;

- oxide reduced by carbon → below carbon, so less reactive than a metal whose oxide is not reduced.

3. **Write the metal names (or letters)**, each once, in the boxes. Don't copy the table heading "metal" into a box.
4. Check the order makes sense against anything you know, such as familiar metals in the list (iron below magnesium, copper below iron).

Variants you will meet:

- **Core structured (Paper 3):** a table of four metals, often unfamiliar ones, with one test (dilute acid, steam, oxygen, air or even concentrated nitric acid). One or two marks for the whole order.
- **Several tests in one table** (multiple choice): combine them. For example, a metal that gives a few bubbles with water but whose oxide is **also** reduced by carbon is less reactive than one that gives a few bubbles with water but whose oxide is not reduced.
- **"Which conclusion can be made?"** Only choose a statement the results actually support. If two metals both show no reaction, you cannot tell which is more reactive.
- **Reacting with oxygen or air**: burns > forms an oxide layer rapidly > slowly > only when heated > not at all.
- **Plan an investigation** (practical papers): add the same mass of each metal, as similar-sized pieces or powder, to the same volume and concentration of the same acid at the same starting temperature; measure the temperature rise (or the volume of gas in a set time). The biggest rise (or most gas) = most reactive. Say "volume", not "amount", of acid.

2. Recall the series and use a metal's position (36 questions)

1. **Write the series down** at the start of the question: K Na Ca Mg Al (C) Zn Fe (H) Cu Ag Au.
2. **Place the metal** you are asked about and read off what follows:
   - calcium and above (K, Na, Ca): reacts with cold water;
   - magnesium: very slowly with cold water, quickly with steam;
   - above hydrogen: reacts with dilute acid to give hydrogen; below hydrogen: no reaction with dilute acid (and none with water or steam);
   - above carbon: oxide not reduced by carbon; below carbon: oxide reduced by carbon when heated.
3. **Answer each statement or row separately**, then pick the option that matches every part.

Variants you will meet:

- **"Metal M is between X and Y in the series."** For example, a metal between iron and hydrogen reacts slowly with dilute acid, does not react with cold water, and carbon reduces its oxide.
- **Identify metals from clues**: "reacts with acid and steam but only very slowly with cold water" is magnesium; "reacts rapidly with cold water" is sodium, potassium or calcium; "no reaction with dilute acid" is copper, silver or gold.
- **Order familiar metals from memory** (Core Paper 3): copper and zinc, and magnesium and potassium, are the pairs most often swapped.
- **Which reaction happens?** A word equation where a metal takes oxygen from a more reactive metal's oxide cannot happen; nor can carbon reduce the oxide of a metal above carbon.

- **Why is a metal stored under oil?** Potassium and sodium react with water and oxygen in the air.
- **Why is aluminium not extracted by heating with carbon?** It is above carbon in the series (more reactive than carbon).
- **Why blow an unreactive gas (argon) over hot magnesium?** Magnesium is reactive and would react with oxygen in the air.

3. Conditions for rusting, the name of rust, rusting experiments (29 questions)

1. **Conditions:** water **and** oxygen (one mark each). Not "air and moisture"; name oxygen. Not hydrogen, carbon dioxide or nitrogen.
2. **Name of rust: hydrated iron(III) oxide**. Mark schemes give separate marks for "hydrated" and "iron(III) oxide", so write both. Wrong options: anhydrous, iron(II), hydroxide.
3. **Test-tube set-ups:** for each tube, ask "is there water? is there oxygen?" Rust needs a yes to both.
   - boiled water + oil layer → no oxygen → no rust;
   - drying agent + stopper → no water → no rust;
   - painted, greased or plastic-coated nail → barrier → no rust;
   - salt water → rusts fastest;
   - stainless steel → does not rust.
4. **Water-level questions:** unprotected iron uses up oxygen, so the water **rises** (by about a fifth of the air volume). Protected iron: **no change**.

Variants you will meet:

- **Word equation:** iron + oxygen + water → hydrated iron(III) oxide.
- **How to stop nails rusting in a sealed box:** replace the air with argon or nitrogen (no oxygen), or keep them dry.
- **Statements to judge**, such as "rusting forms iron(II) oxide" (false), "iron loses electrons when it rusts" (true), "iron covered in grease rusts faster" (false).

4. Sacrificial protection and galvanising (23 questions)

Extended only (Papers 2 and 4).

1. **Say it is more reactive than iron.** Zinc or magnesium is **above iron** in the series.
2. **Say what it does with electrons.** It **loses electrons more readily** than iron: $\mathrm{Zn} \rightarrow \mathrm{Zn}^{2+} + 2e^-$. So zinc is oxidised (corrodes) **instead of** iron.
3. **Say the result.** The iron does not lose electrons, so it does not rust.

Variants you will meet:

- **Galvanising** = coating with **zinc**. It is a barrier method **and** sacrificial protection; the second is why it still works when scratched.

- **Why not copper, tin or silver?** They are **less** reactive than iron, so they cannot lose electrons in place of iron; once a tin coating is scratched, the iron rusts.
- **Why not potassium?** It reacts with water.
- **A metal that protects iron but not aluminium**: it must be between aluminium and iron, so zinc.
- **Distractors to reject:** "zinc gains (accepts) electrons", "zinc is reduced", "zinc is less reactive", "magnesium forms a barrier", "zinc forms an alloy with iron", and an equation for the reduction of rust. The change that protects the iron is the metal losing electrons, $\mathrm{Mg} \rightarrow \mathrm{Mg}^{2+} + 2e^{-}$.

5. Displacement reactions and tendency to form positive ions (18 questions)

Extended only.

1. **Decide whether it reacts:** the metal added must be **above** the metal in the solution (or oxide). If not, write "no reaction".
2. **Write the ionic equation:** metal atom + metal ion → metal ion + metal atom, leaving out spectator ions. Balance the charges, for example $\mathrm{Fe} + 2\mathrm{Ag}^{+} \rightarrow \mathrm{Fe}^{2+} + 2\mathrm{Ag}$.
3. **For a grid:** count the displacements for each metal; most displacements = most reactive.

Variants you will meet:

- **Tendency to form positive ions** = reactivity: the more reactive metal **atom** has the greater tendency to lose electrons. If metal X does not displace metal Y from a solution of Y ions, then Y atoms have the greater tendency to lose electrons. Choose the atom (such as Fe), not the ion (Fe^{2+}).
- **Which extra result completes an order?** Look for the pair of metals the given results never compare.
- **Why use nitrates** for the solutions: all nitrates are soluble.
- **Observations:** blue copper(II) solution fades and a pink-brown solid forms; green iron(II) solution turns colourless when magnesium or zinc displaces the iron.
- **Oxides:** a metal displaces a less reactive metal from its **oxide** on heating (aluminium with iron(III) oxide), showing it forms ions more readily.
- **Name the products** of a displacement in words, for example zinc + copper(II) sulfate → zinc sulfate + copper.

6. Products and equations for metals with water, steam, acid or oxygen (17 questions)

1. **Pick the pattern:** cold water → hydroxide + hydrogen; steam → oxide + hydrogen; acid → salt + hydrogen; oxygen → oxide.
2. **Name the salt from the acid:** chloride, sulfate, nitrate, ethanoate.
3. **For a symbol equation**, write the formulae, then balance, then add state symbols if asked: $\mathrm{Zn(s)} + 2\mathrm{HCl(aq)} \rightarrow \mathrm{ZnCl_2(aq)} + \mathrm{H_2(g)}$.

Variants you will meet:

- **Unfamiliar metals** follow the same pattern, using the charge from the Group: barium (Group II) + hydrochloric acid → barium chloride + hydrogen, $\mathrm{Ba + 2HCl \rightarrow BaCl_2 + H_2}$; barium + water → barium hydroxide + hydrogen.
- **Which pairs make hydrogen?** Only metals above hydrogen with acid, and very reactive metals with water or steam. Silver and dilute acid do not.
- **Wrong products to reject:** chlorine, oxygen, carbon dioxide or sulfur dioxide from a metal and a dilute acid; an acidic solution from a metal and water (it is **alkaline**).
- **Iron with steam or oxygen** can make $\mathrm{Fe_3O_4}$: balance it by counting atoms, for example $\mathrm{3Fe + 2O_2 \rightarrow Fe_3O_4}$.
- **A very reactive metal added to an acid solution also reacts with the water**, making the hydroxide as well as the salt.

7. Why aluminium seems unreactive (13 questions)

Extended only.

1. **Give the reason in full:** aluminium is covered by a **thin, unreactive (protective) layer of aluminium oxide**.
2. **Say what it does:** the layer stops the acid, water or ions reaching the aluminium.

Variants you will meet: aluminium foil with no immediate reaction in acid or in a salt solution; aluminium not corroding in air; aluminium heated in air not reacting while copper blackens. Reject "aluminium is below hydrogen/iron/copper", "it is an alloy" and "it does not react with acids". Once the layer has gone, the expected displacement happens, for example $\mathrm{2Al + 3Cu^{2+} \rightarrow 2Al^{3+} + 3Cu}$ (charge $+6$ on each side).

8. Barrier methods of rust prevention (10 questions)

1. **Name one:** painting, greasing (oiling) or coating with plastic. Galvanising counts too, but "sacrificial protection" is **not** a barrier method.
2. **Explain it:** it **stops oxygen and water reaching the iron**.
3. **Pick barrier methods from a list:** painting, greasing, oiling and plastic coating are; alloying, washing with distilled water and attaching a more reactive metal are not.

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

A student compares four metals by adding 0.50 g of each, as powder, to 25.0 cm³ of dilute hydrochloric acid. The table shows the temperatures.

Metal	Starting temperature / °C	Highest temperature / °C
cadmium	21.0	22.5
europium	21.0	35.5
neodymium	21.0	30.0
palladium	21.0	21.0

(a) Calculate the temperature rise for each metal and put the metals in order of reactivity, most reactive first. **[2]**

(b) State **two** conditions, other than the mass of metal and the volume of acid, that must be kept the same to make this a fair test. **[2]**

(c) No bubbles form with palladium. State what this shows about the position of palladium in the reactivity series compared with hydrogen. **[1]**

(a) Rises: cadmium 1.5 °C, europium 14.5 °C, neodymium 9.0 °C, palladium 0.0 °C. **M1** for the rises (highest temperature minus starting temperature).

Order: europium, neodymium, cadmium, palladium. **A1**

(b) Any two of: the same **concentration** of acid **(B1)**; the same **starting temperature** of the acid **(B1)**. (The mass and the particle size are already fixed: 0.50 g of powder each.)

(c) Palladium is **below hydrogen** in the series (it cannot displace hydrogen from the acid). **B1**

Example 2

Five iron nails are set up in test-tubes and left for a week.

Tube	Conditions
1	half covered by tap water, open to the air
2	in air, with anhydrous calcium chloride, stoppered
3	in boiled water with a layer of oil on top, stoppered
4	half covered by salty water, open to the air
5	coated in grease, half covered by tap water, open to the air

(a) State which nails rust, and which nail rusts most. **[2]**

(b) Explain why the nail in tube 3 does not rust. **[2]**

(c) In a second experiment, damp iron wool is pushed to the top of a measuring tube that holds 80.0 cm³ of air. The tube stands upside down in a beaker of water. Air contains about 21% oxygen. Calculate the volume of gas left in the tube when rusting stops, and describe what happens to the water level. **[3]**

(a) Tubes 1 and 4 rust **(B1)**; tube 4 (salty water) rusts most **(B1)**.

(b) Boiling removes the dissolved oxygen (air) from the water **(B1)**; the oil stops oxygen from the air dissolving in the water again, so there is no oxygen for rusting **(B1)**.

(c) Oxygen used $= \dfrac{21}{100} \times 80.0 = 16.8$ cm³. **M1**

Gas left $= 80.0 - 16.8 = 63.2$ cm³. **A1**

The water **rises** up the tube to take the place of the oxygen used, then stops. **B1**

Example 3

Extended. Nickel is a metal that forms Ni^{2+} ions.

- Nickel displaces copper from aqueous copper(II) sulfate.
- Iron displaces nickel from aqueous nickel sulfate.

(a) Write the ionic equation for the reaction of nickel with aqueous copper(II) ions. **[1]**

(b) Put nickel, copper and iron in order of their tendency to form positive ions, greatest first. **[1]**

(c) A steel water tank is joined by a wire to a block of zinc buried in the ground. Explain, in terms of electrons and the reactivity series, how the zinc stops the tank rusting. **[3]**

(d) An engineer suggests using a nickel block instead of zinc. Use the information above to explain why this would not protect the tank. **[2]**

(a) $\mathrm{Ni} + \mathrm{Cu}^{2+} \rightarrow \mathrm{Ni}^{2+} + \mathrm{Cu}$ **B1** (charges balance: $+2$ each side).

(b) iron > nickel > copper. **B1** (iron displaces nickel, so iron is higher; nickel displaces copper, so nickel is higher than copper.)

(c) Zinc is **more reactive than iron (B1)**. Zinc **loses electrons more readily** than iron, $\mathrm{Zn} \rightarrow \mathrm{Zn}^{2+} + 2e^-$ **(B1)**. So the zinc is oxidised (corrodes) **instead of the iron**, and the iron does not lose electrons **(B1)**.

(d) Iron displaces nickel, so nickel is **less reactive than iron (B1)**; iron would lose electrons more readily than nickel, so the iron would still corrode **(B1)**.

Example 4

Extended. A sheet of aluminium and some freshly made aluminium powder are put into separate beakers of dilute hydrochloric acid. The powder fizzes at once; the sheet shows no reaction for several minutes, then starts to fizz.

(a) Explain why the sheet shows no reaction at first. **[2]**

(b) Write the balanced symbol equation for the reaction of aluminium with hydrochloric acid. **[2]**

(a) The sheet is covered by a thin **layer of aluminium oxide (B1)**, which is unreactive and stops the acid reaching the aluminium until the acid has worn it away **(B1)**. (The fresh powder has had little time to form a layer.)

(b) $2\mathrm{Al} + 6\mathrm{HCl} \rightarrow 2\mathrm{AlCl_3} + 3\mathrm{H_2}$. **M1** for the correct formulae ($\mathrm{AlCl_3}$ and $\mathrm{H_2}$), **A1** for balancing: 2 Al, 6 H and 6 Cl on each side.

Common mistakes

- **Getting the series wrong.** Examiners see copper and zinc swapped, and magnesium and potassium swapped, every year. Learn it in order, including carbon and hydrogen.
- **Writing the order backwards.** Check "least reactive first" or "most reactive first" before you fill in the boxes.
- **Writing "metal" in a box.** It is the table's heading, not an answer; write the metal's name.
- **Thinking a high metal's oxide is reduced by carbon.** Metals high in the series react readily with acids, but their oxides are **not** reduced by carbon. Carbon reduces only the oxides of metals below it.
- **Saying rusting needs hydrogen** (or air "and moisture" without naming oxygen). It needs **oxygen** and **water**.
- **Leaving out "hydrated" or "(III)"** when naming rust.
- **Giving "sacrificial protection" as a barrier method.** It works differently: a more reactive metal loses electrons instead of iron.
- **Saying "magnesium rusts instead of iron".** Only iron and steel rust. Say magnesium **corrodes** or is **oxidised** instead, because it **loses electrons more readily**.
- **Using the phrase "sacrificial protection" as if it were an explanation.** Say what happens: the more reactive metal loses electrons in place of iron.
- **Comparing with the wrong metal.** "Copper is less reactive than magnesium" does not explain why copper can't protect iron; compare copper **with iron**.
- **Saying the zinc "gains electrons"** or "is reduced". It loses electrons; it is oxidised.
- **Saying aluminium is "below hydrogen"** or "unreactive" to explain no reaction. It is high in the series; the **oxide layer** is the reason.
- **Writing spectator ions** (sulfate, nitrate) in an ionic equation, or leaving charges unbalanced.
- **In a plan, writing "amount" of acid** instead of volume, or forgetting to control concentration and temperature, or not saying how the results give the order.

How to get the marks

- **"Put in order"**: usually one mark for the whole order correct, sometimes two. Every metal must appear exactly once, at the end the question asks for.
- **"State"** needs only the fact: "water and oxygen", "hydrated iron(III) oxide", "painting". No explanation is needed, but each word counts: "hydrated" and "iron(III) oxide" can be separate marks.
- **"Explain" sacrificial protection** needs **both** halves: the comparison ("more reactive **than iron**") and the electrons ("**loses electrons** more readily **than iron**" or "is oxidised instead of iron").
- **"Explain" galvanising when scratched**: zinc is still more reactive than iron and loses electrons instead of the iron. "The zinc is a barrier" is only true while it is unbroken.
- **"Explain" why aluminium does not react**: name the **aluminium oxide** layer and say it is **unreactive/protective**. "A layer" alone is not enough.
- **"Explain" why a metal is not extracted with carbon** or whether carbon reduces its oxide: refer to the metal's position **relative to carbon**.
- **"Describe" how a barrier works**: it **stops oxygen and water** reaching the iron.
- **Word equations**: one mark per product, usually. Name the salt from the acid (chloride, sulfate, nitrate, ethanoate) and don't forget **hydrogen**.
- **Symbol and ionic equations**: correct formulae first (often **M1**), then balancing (**A1**). In an ionic equation, the total charge must be the same on both sides.
- **"Deduce"** means use the results given; "**Suggest**" means apply what you know to an unfamiliar metal or set-up.
- **"Predict"** reactions of a metal between two others by taking the behaviour of its neighbours: above hydrogen reacts with acid, below carbon has an oxide carbon can reduce.

Quick check

1. A metal lies between iron and hydrogen in the reactivity series. Predict whether it (a) reacts with cold water, (b) reacts with dilute hydrochloric acid, and (c) can be obtained by heating its oxide with carbon.
2. Write the balanced symbol equation, with state symbols, for the reaction of sodium with water.
3. Extended. An iron nail is put into aqueous silver nitrate. Write the ionic equation for the reaction, and name the species that loses electrons.
4. Extended. A steel gate is galvanised and a second gate is painted. Both are scratched. Explain why only the painted gate rusts at the scratch.
5. A measuring tube contains 60.0 cm³ of air trapped over water with damp iron wool. After a week the gas volume is 48.0 cm³ and no longer changes. Calculate the percentage of the air that was used up, and name the gas that was used up.

Answers

1. (a) No: only potassium, sodium and calcium react with cold water. (b) Yes, slowly, giving hydrogen, because it is above hydrogen. (c) Yes, because it is below carbon.
2. $2\mathrm{Na(s)} + 2\mathrm{H_2O(l)} \rightarrow 2\mathrm{NaOH(aq)} + \mathrm{H_2(g)}$. Check: 2 Na, 4 H and 2 O on each side.
3. $\mathrm{Fe} + 2\mathrm{Ag}^{+} \rightarrow \mathrm{Fe}^{2+} + 2\mathrm{Ag}$ (charge $+2$ on each side). The iron **atoms** lose electrons: iron is above silver, so it has the greater tendency to form positive ions.
4. On the galvanised gate, the zinc around the scratch is more reactive than iron, so zinc loses electrons ($\mathrm{Zn} \rightarrow \mathrm{Zn}^{2+} + 2e^{-}$) instead of the iron, and the exposed iron does not rust (sacrificial protection). Paint is only a barrier: at the scratch, water and oxygen reach the iron, and it rusts.
5. Volume used $= 60.0 - 48.0 = 12.0$ cm³; percentage $= \dfrac{12.0}{60.0} \times 100 = 20\%$. The gas used up is oxygen.

Past questions to try

- **0620/22/O/N/25 Q26**: an order from reactions with water and whether carbon reduces the oxide.
- **0620/11/M/J/25 Q29**: water levels in rusting tubes with bare and greased iron.
- **0620/41/O/N/23 Q3**: a displacement grid, the order it gives, and a symbol equation (Extended).
- **0620/41/M/J/24 Q6**: galvanising, and why the iron under a scratched zinc coating does not rust (Extended).