IGCSE CHEMISTRY 0620 · CHAPTER 9 NOTES · ~14 MIN READ

Metals

What makes a metal a metal, why alloys beat pure metals, how the reactivity series predicts everything, how to stop rusting — and how iron and aluminium are extracted.

Properties | Alloys | Reactivity series | Corrosion | Extraction of iron & aluminium

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No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

IN 30 SECONDS

- Metals are **shiny, good conductors, malleable** and ductile, with **high melting points**. They form **positive ions** and **basic oxides**.
- **Alloys** are mixtures of a metal with other elements. They are **harder and stronger** than the pure metal.
- The **reactivity series** (K Na Ca Mg Al C Zn Fe H Cu Ag Au) predicts reactions with water, acid and other metals — and how a metal is **extracted**.
- **Rusting** needs **oxygen and water**. **Galvanising** and **sacrificial protection** use zinc. EXT

BY THE END YOU CAN

- Compare metals and non-metals, and give uses of aluminium and copper.
- Define an alloy and explain why alloys are harder than pure metals.
- Order metals by reactivity using their reactions, and predict displacement reactions.
- Describe the conditions for rusting and the methods of preventing it.
- Describe the extraction of iron in the blast furnace and aluminium by electrolysis.

1 Properties and uses of metals

Metals and non-metals

Property	Metals	Non-metals
appearance	shiny	dull
electrical conductivity	good	poor (graphite is an exception)
thermal conductivity	good	poor
malleable and ductile	yes — can be hammered or drawn into wires	no — brittle if solid
melting and boiling points	usually high	usually low
density	usually high	usually low
sound	ring ("sonorous")	dull sound
oxides	basic	acidic

- **Exceptions:** mercury is a liquid at room temperature; Group I metals are soft with low melting points and low density; graphite is a non-metal that conducts.

Reactions of metals

- **With oxygen:** metal + oxygen → metal **oxide** (basic). $2Mg + O_2 \rightarrow 2MgO$ (burns with a bright white flame).
- **With water:** the very reactive metals give **hydroxide + hydrogen**; the moderately reactive give **oxide + hydrogen** with steam. $Mg + H_2O(g) \rightarrow MgO + H_2$.
- **With dilute acids:** metal + acid → **salt + hydrogen**.

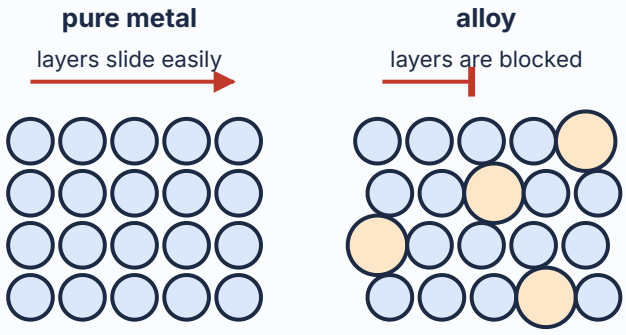
Uses

Metal	Uses	Property that explains the use
aluminium	aircraft	low density, and strong when made into an alloy
aluminium	electricity cables (overhead power lines)	good electrical conductor and low density
aluminium	food containers	resists corrosion, malleable and non-toxic
copper	electrical wiring	very good electrical conductor, ductile, does not corrode
copper	pans (base of cooking pans)	very good thermal conductor

2 Alloys

Stronger than pure metals

Alloy — a mixture of a metal with other elements (usually other metals).



all atoms the same size
→ soft, bends easily

different sized atoms
→ harder and stronger

brass:
copper + zinc
(door handles, taps)
stainless steel:
iron + chromium +
nickel (+ carbon)
(cutlery, sinks:
does not rust)

alloy = a mixture of a metal with other elements (usually other metals)

Left: in a pure metal all the atoms are the same size and the layers slide easily. Right: in an alloy, atoms of other sizes block the layers from sliding, so it is harder.

- **Pure metals** are often **too soft** for most uses because the layers of identical atoms slide over each other.

- EXT In an alloy, atoms of a **different size** disrupt the regular layers, so the layers **cannot slide** as easily. The alloy is **harder and stronger**.

Alloy	Made of	Uses
brass	copper + zinc	door handles, taps, musical instruments
stainless steel	iron + chromium + nickel (+ some carbon)	cutlery, kitchen sinks, surgical tools
mild steel	iron + a little carbon	car bodies, buildings

- **Stainless steel** is used for cutlery because it is hard **and does not rust**.

EXAM TIP

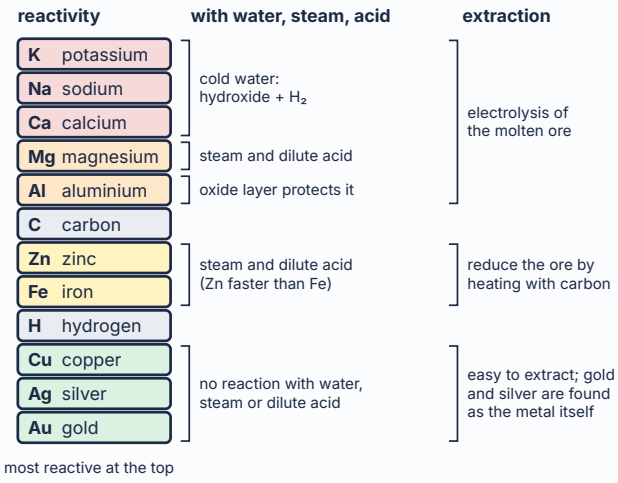
To spot an alloy in a diagram, look for atoms of **different sizes** mixed in the lattice. A pure metal has all the atoms the same size.

COMMON MISTAKE

"An alloy is a compound." It is a **mixture**. The elements are not chemically bonded in fixed amounts.

3 The reactivity series

The order



The reactivity series. The most reactive metals are at the top. Carbon and hydrogen are non-metals shown for comparison. The mnemonic gives the order.

MEMORY TRICK

Please Stop Calling Me A Careless Zebra; I Hate Copper, Silver & Gold = **P**otassium **S**odium **C**alcium **M**agnesium **A**luminium **C**arbon **Z**inc **I**ron **H**ydrogen **C**opper **S**ilver **G**old.

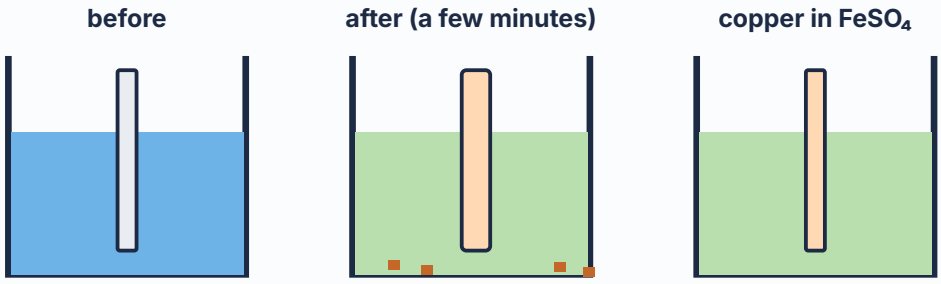
Reactions with water and acid

Metal	Cold water	Steam	Dilute acid
potassium, sodium	violent → hydroxide + H_2	—	explosive
calcium	steady fizzing → hydroxide + H_2	—	vigorous
magnesium	very slow	burns brightly → MgO + H_2	fast fizzing
aluminium	no reaction (oxide layer)	reacts only if the oxide layer is removed	slow at first, then faster
zinc	no reaction	reacts → ZnO + H_2	steady fizzing
iron	no reaction	reacts slowly	slow fizzing
copper, silver, gold	no reaction	no reaction	no reaction

- **Ordering metals by experiment:** use the **same-size pieces** of each metal in the **same acid**. The more vigorous the fizzing (and the greater the temperature rise), the more reactive the metal.

Displacement reactions

EXTENDED



iron nail in blue copper(II) sulfate

copper coats the nail solution: blue → pale green

no reaction: copper is less reactive than iron

iron + copper(II) sulfate → iron(II) sulfate + copper
$Fe + Cu^{2+} \rightarrow Fe^{2+} + Cu$ (iron is more reactive, so it displaces copper)

Iron nail in copper(II) sulfate. Iron is more reactive than copper, so it displaces copper. Copper cannot displace iron from iron(II) sulfate.

- A **more reactive metal displaces a less reactive metal** from a solution of its salt.
- Iron + copper(II) sulfate → iron(II) sulfate + copper. Ionic equation: **$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$**. The blue solution turns pale green.
- Copper + iron(II) sulfate → **no reaction** (copper is less reactive).
- Displacement is a **redox** reaction: iron loses electrons (oxidised) and copper ions gain them (reduced).

WORKED EXAMPLE

EXT **Metal P is added to a solution of Q^{2+} and a reaction occurs. Metal Q reacts with R^{2+}. Metal R does not react with P^{2+}. Put P, Q and R in order of reactivity.**

1. P displaces Q^{2+}, so P is more reactive than Q
2. Q displaces R^{2+}, so Q is more reactive than R
3. R does not displace P^{2+}, which fits
4. **order: P > Q > R (most reactive first)**

Aluminium — the odd one out

EXTENDED

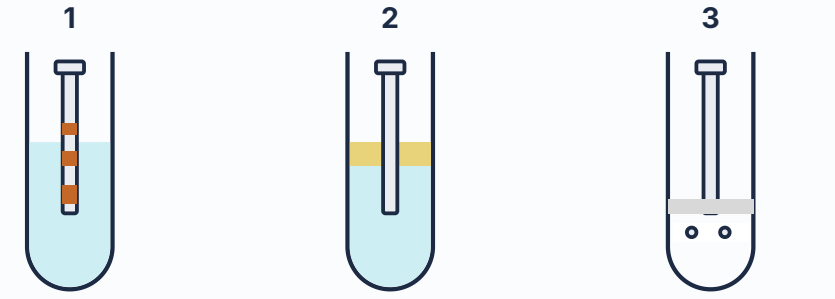
- Aluminium is high in the series but seems unreactive. Its surface is covered with a **thin, tough layer of aluminium oxide (Al_2O_3)** that stops water and acid reaching the metal. That is why aluminium is used for aircraft and food containers.

COMMON MISTAKE

Believing that aluminium is unreactive because it is low in the reactivity series. It is **high** in the series — the oxide layer is protecting it.

4 Corrosion

Rusting

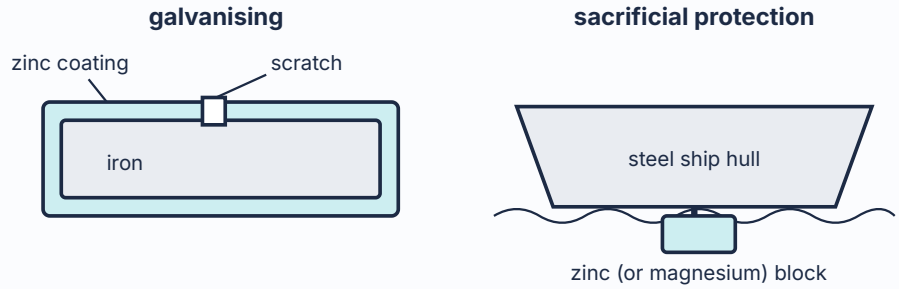


rust = hydrated iron(III) oxide: iron + oxygen + water
both oxygen AND water must be present

Three test tubes. Rust forms only where iron has both air (oxygen) and water.

- **Rusting** needs **both oxygen and water**. Rust is **hydrated iron(III) oxide**.
- **Test tube 1:** iron nail in air and water → **rusts**. **Tube 2:** boiled water (no dissolved air) with a layer of oil → no rust. **Tube 3:** dry air (calcium chloride absorbs the water) → no rust.
- Rust is **flaky**, so it falls off and exposes fresh iron to rust further. **Salt** and **acid** speed up rusting.
- **Corrosion** is the slow destruction of a metal by reaction with substances in the environment. Only iron "rusts" — other metals corrode in other ways.

Preventing rust



zinc is more reactive than iron:
it loses electrons first
$Zn \rightarrow Zn^{2+} + 2e^-$
so the iron is protected,
even where it is scratched

the block is more reactive than steel, so it corrodes instead and is replaced regularly

barrier methods: paint · oil or grease · plastic coating · galvanising
they keep oxygen and water away from the iron

Left: galvanising. A zinc coating protects iron even when it is scratched. Right: sacrificial protection with a zinc or magnesium block on a ship's hull.

- **Barrier methods** keep oxygen and water away from the iron: **paint**, **oil or grease**, **plastic coating**, and a coating of another metal (zinc, tin or chromium).
- EXT **Galvanising** = coating iron with **zinc**. Zinc is a barrier **and** more reactive than iron. If scratched, zinc corrodes **first**: $Zn \rightarrow Zn^{2+} + 2e^-$. The electrons flow to the iron and protect it.
- EXT **Sacrificial protection:** a block of a more reactive metal (zinc or magnesium) is attached to steel (ship hulls, pipelines). The block **loses electrons** and corrodes instead of the steel. It is replaced regularly.
- EXT **Tin plating** is only a barrier. If it is scratched, the iron (more reactive than tin) rusts **faster**.

EXAM TIP

A barrier stops working when scratched. **Sacrificial protection still works** when scratched, because the zinc is more reactive than iron and is oxidised first.

5 Extraction of metals

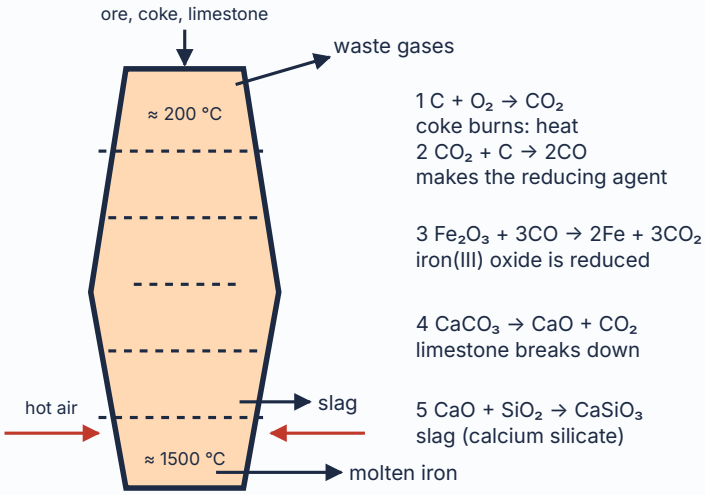
How reactivity decides the method

Ore — a rock that contains enough of a metal compound to make it worth extracting the metal.

Metals	Method	Why
K, Na, Ca, Mg, Al	**electrolysis** of the molten ore	too reactive to be reduced by carbon
Zn, Fe (and Cu)	**heat with carbon** (reduction)	less reactive than carbon, so carbon can remove the oxygen
Au, Ag	found **native** (as the metal itself)	very unreactive

- **Rule:** carbon can reduce the oxides of metals **below it** in the series (zinc, iron, copper). It cannot reduce those above it.

Iron — the blast furnace



The blast furnace. Iron ore, coke and limestone go in at the top; hot air is blown in at the bottom. Molten iron and slag are tapped off from the base.

- **Raw materials:** iron ore (**haematite**, Fe_2O_3), **coke** (carbon), **limestone** ($CaCO_3$) and **hot air**.
- **1.** Coke burns: **$C + O_2 \rightarrow CO_2$** (releases heat).
- **2.** CO_2 is reduced by coke: **$CO_2 + C \rightarrow 2CO$**. Carbon monoxide is the **reducing agent**.
- **3.** CO reduces the ore: **$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$**. The iron(III) oxide is **reduced** to molten iron.
- **4.** Limestone breaks down: **$CaCO_3 \rightarrow CaO + CO_2$**.
- **5.** CaO reacts with the silica (SiO_2) impurity: **$CaO + SiO_2 \rightarrow CaSiO_3$** — this is the molten **slag**, which floats on the iron. Both are tapped off at the bottom.

WORKED EXAMPLE

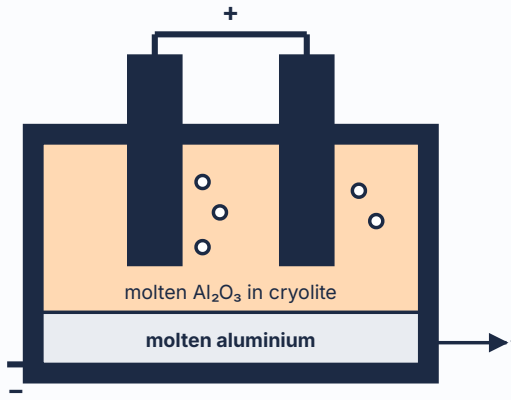
EXT **What mass of iron can be made from 800 kg of pure iron(III) oxide? (Ar: Fe = 56, O = 16)**

1. $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
2. $Mr(Fe_2O_3) = 2 \times 56 + 3 \times 16 = 160$
3. 160 g of Fe_2O_3 gives $2 \times 56 = 112$ g of iron
4. **800 kg × 112 ÷ 160 = 560 kg**

COMMON MISTAKE

Saying coke is "just a fuel". It is **both** the fuel and the source of the reducing agent, carbon monoxide.

Aluminium — electrolysis



pure aluminium oxide (from bauxite) dissolved in molten cryolite at about 950 °C (cryolite lowers the melting point: it saves energy)

cathode (−): $Al^{3+} + 3e^- \rightarrow Al$
anode (+): $2O^{2-} \rightarrow O_2 + 4e^-$

hot oxygen burns the carbon anodes (→ CO_2), so they are replaced regularly

aluminium is more reactive than carbon, so it cannot be extracted by heating with carbon

Extraction of aluminium. Pure aluminium oxide from bauxite is dissolved in molten cryolite and electrolysed. Aluminium forms at the cathode and oxygen at the anode.

- **Ore: bauxite**, which is impure **aluminium oxide (Al_2O_3)**. It is purified first.
- Aluminium is **above carbon** in the series, so carbon cannot reduce it. It is extracted by **electrolysis**.
- Al_2O_3 has a very high melting point (over 2000 °C). It is **dissolved in molten cryolite** (about 950 °C), which **lowers the melting point** and so saves energy.
- EXT **Cathode (−)** (the graphite lining of the tank): **$Al^{3+} + 3e^- \rightarrow Al$**. Molten aluminium collects at the bottom and is **tapped off**.
- EXT **Anode (+)** (graphite blocks): **$2O^{2-} \rightarrow O_2 + 4e^-$**.
- The hot oxygen **burns the carbon anodes** to CO_2, so the anodes must be **replaced regularly**.
- The process needs **a lot of electricity**, so smelters are often built near cheap hydroelectric power. Recycling aluminium saves most of this energy.

WORKED EXAMPLE

EXT **What mass of aluminium can be made from 102 kg of pure aluminium oxide? (Ar: Al = 27, O = 16)**

1. $2Al_2O_3 \rightarrow 4Al + 3O_2$, so 1 Al_2O_3 gives 2 Al
2. $Mr(Al_2O_3) = 2 \times 27 + 3 \times 16 = 102$
3. 102 g of Al_2O_3 gives $2 \times 27 = 54$ g of Al
4. **54 kg**

EXAM TIP

In an extraction question, give the **ore**, the **reaction type** (reduction or electrolysis), and **why that method** (position in the reactivity series).

6 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. Give two physical properties of metals that non-metals usually lack.
2. Give one use of aluminium and the property that explains it.
3. What is an alloy?
4. Name the alloys of copper + zinc, and of iron + chromium + nickel.
5. Which metal is more reactive: zinc or copper?
6. What two things are needed for iron to rust?
7. Name the ore of aluminium.
8. EXT Why are alloys harder than pure metals?

EXAM-STYLE

9. A student adds three metals to dilute hydrochloric acid. X fizzes quickly, Y fizzes slowly, Z does not fizz. Put them in order of reactivity and name the gas. [3]
10. Describe how rusting can be prevented using a barrier. Explain why a scratched barrier stops working. [3]
11. EXT Explain why a galvanised bucket does not rust even if it is scratched. [3]
12. Describe the extraction of iron in the blast furnace. Include the raw materials and the main reactions. [6]
13. EXT Explain why aluminium is extracted by electrolysis, and why cryolite is used. [3]

Show answers

1. shiny, good conductors, malleable, ductile, sonorous (any two)
2. aircraft/cables/food containers — low density/conducts/resists corrosion
3. a mixture of a metal with other elements
4. brass; stainless steel
5. zinc
6. oxygen and water
7. bauxite
8. atoms of different sizes stop the layers sliding
9. X > Y > Z
   hydrogen
   test: squeaky pop with a lit splint
10. paint / oil / plastic coating (or another metal coating)
    keeps out oxygen and water
    if scratched, air and water reach the iron again
11. zinc is more reactive than iron
    so it loses electrons / corrodes first ($Zn \rightarrow Zn^{2+} + 2e^-$)
    so the iron is protected (sacrificial protection)
12. haematite (Fe_2O_3), coke, limestone and hot air
    coke burns in the air to make CO_2: $C + O_2 \rightarrow CO_2$
    CO_2 reacts with coke to make carbon monoxide: $CO_2 + C \rightarrow 2CO$
    carbon monoxide reduces the iron oxide: $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
    limestone decomposes to CaO, which reacts with silica to form slag
    molten iron and slag are tapped off at the bottom
13. aluminium is more reactive than carbon, so carbon cannot reduce it
    Al_2O_3 has a very high melting point
    dissolving it in molten cryolite lowers the temperature needed, saving energy

Stuck on a question?

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