IGCSE CHEMISTRY 0620 · CHAPTER 6 NOTES · ~17 MIN READ

Rates, equilibrium & redox

Why some reactions are fast and others slow, how to speed them up and read a rate graph, what equilibrium really means (with the Haber and Contact processes) and how to spot oxidation and reduction.

Physical vs chemical change | Rate factors | Collision theory | Catalysts | Reversible reactions | Haber & Contact processes | Redox

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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

- A **chemical change** makes a **new substance**. A **physical change** does not.
- **Rate** goes up with higher **concentration, pressure, temperature, surface area** or a **catalyst**. Particles must **collide with enough energy**. EXT
- In a **reversible** reaction (⇌) the products can turn back into reactants. At **equilibrium** the forward and backward rates are equal. EXT
- **Oxidation = gain of oxygen** (or loss of electrons). **Reduction = loss of oxygen** (or gain of electrons). EXT They always happen **together**.

BY THE END YOU CAN

- Tell physical and chemical changes apart.
- Describe and explain how concentration, pressure, temperature, surface area and catalysts affect rate, and interpret rate graphs.
- Use collision theory to explain rates. EXT
- Describe reversible reactions, including hydrated and anhydrous salts, and explain equilibrium and the Haber and Contact processes. EXT
- Identify oxidation, reduction, oxidising and reducing agents, and work out oxidation numbers. EXT

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1 Physical and chemical changes

Is a new substance made?

	Physical change	Chemical change
new substance?	no — the same particles, just rearranged	yes — new substances with new properties
reversible?	usually easily	usually difficult
energy change	small	often large (heat, light)
examples	melting, boiling, dissolving, crushing, magnetising	burning, rusting, cooking, photosynthesis, a metal reacting with acid

- Signs of a chemical change: **colour change**, **gas** produced (bubbles), **precipitate** formed, **temperature change**, **light** or heat given out.
- A physical change can sometimes look dramatic: boiling water gives a lot of steam, but it is still water. Dissolving sugar is physical — evaporate the water and the sugar is back.

COMMON MISTAKE

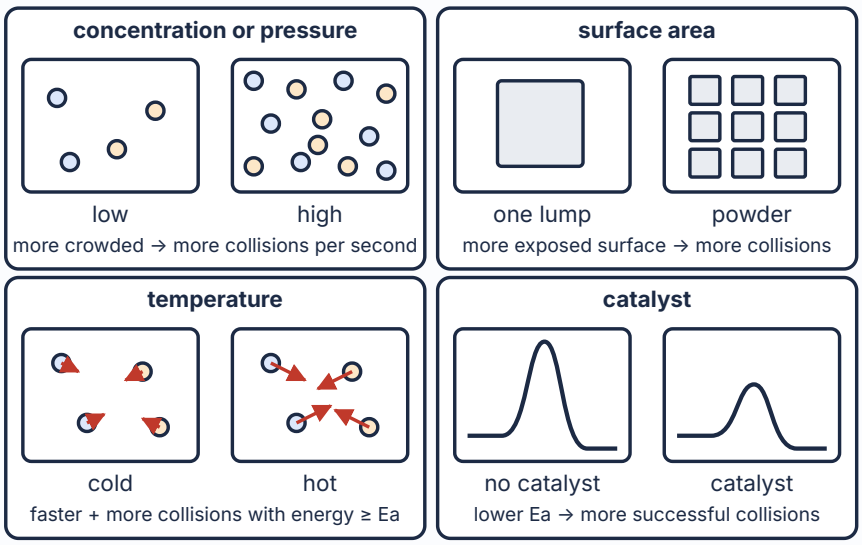
"Dissolving salt is a chemical change because the salt disappears." It is **physical**: it is still sodium chloride, and you get it back by evaporating the water.

2 Rate of reaction

What is rate?

Rate of reaction — how fast reactants are used up, or how fast products are made.

- Fast: explosions, burning magnesium. Slow: rusting, ripening. A **steeper** graph line = a **faster** reaction.



Five ways to speed up a reaction, and why. In each, the particles collide more often, or a bigger fraction of collisions succeed.

Factor	Effect on rate	Why EXT
higher concentration (solutions)	faster	more particles in the same volume, so **more frequent** collisions
higher pressure (gases)	faster	gas particles are closer together, so **more frequent** collisions
higher temperature	**much** faster	particles move faster → **more collisions**, and a **larger fraction have energy ≥ Ea**
larger surface area (smaller pieces, powder)	faster	more particles on the surface exposed to the other reactant, so **more frequent** collisions
catalyst	faster	provides a different pathway with a **lower Ea**, so more collisions are successful

- A **catalyst** speeds up a reaction and is **not used up** — it is chemically the same at the end. It does not change the amount of product.
- Examples: manganese(IV) oxide for hydrogen peroxide decomposition; iron in the Haber process; vanadium(V) oxide in the Contact process; **enzymes** (biological catalysts) in living things.

PICTURE IT

Imagine trying to bump into a friend in a crowded room, rather than an empty one. More people packed in = more bumps per second. A powder is like a lump broken into dust — many more faces get exposed.

COMMON MISTAKE

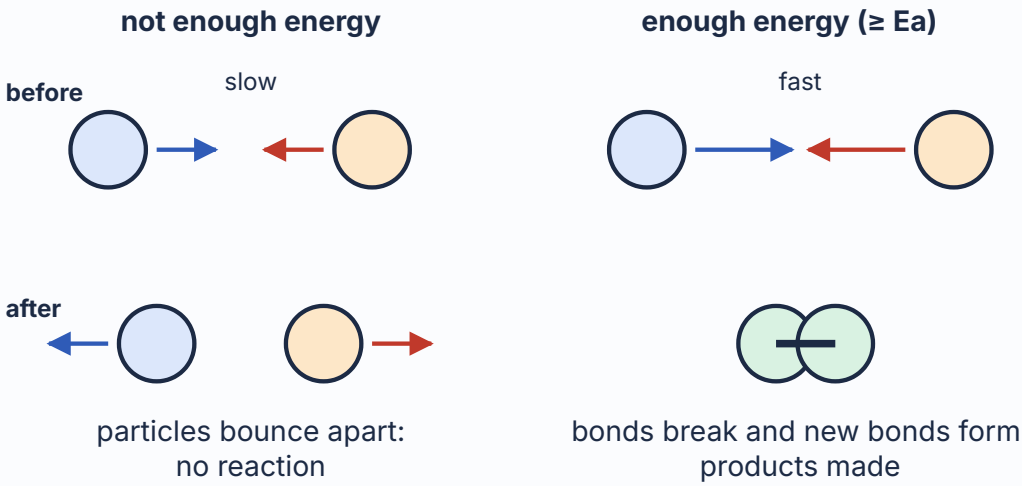
"At a higher temperature, particles collide more often, so the rate rises." That is only half the answer. The most important reason is that **more of the collisions have enough energy** to react.

COMMON MISTAKE

"A catalyst gives the particles more energy." It does not — it **lowers the energy needed** (Ea).

Collision theory

EXTENDED



only collisions with energy ≥ Ea are successful

Only collisions with energy of at least the activation energy are successful. Left: not enough energy, the particles bounce apart. Right: enough energy, a reaction occurs.

- A reaction can only happen when particles **collide** with energy **greater than or equal to the activation energy (Ea)**.
- Rate depends on (1) the **frequency** of collisions and (2) the **energy** of the collisions.

- Not every collision is successful: most particles just bounce apart.

WORKED EXAMPLE

EXT **Explain why powdered calcium carbonate reacts faster with acid than lumps of the same mass.**

1. Powder has a much larger surface area
2. more particles of calcium carbonate are exposed to the acid
3. **so there are more frequent collisions between the particles, and the rate is faster**

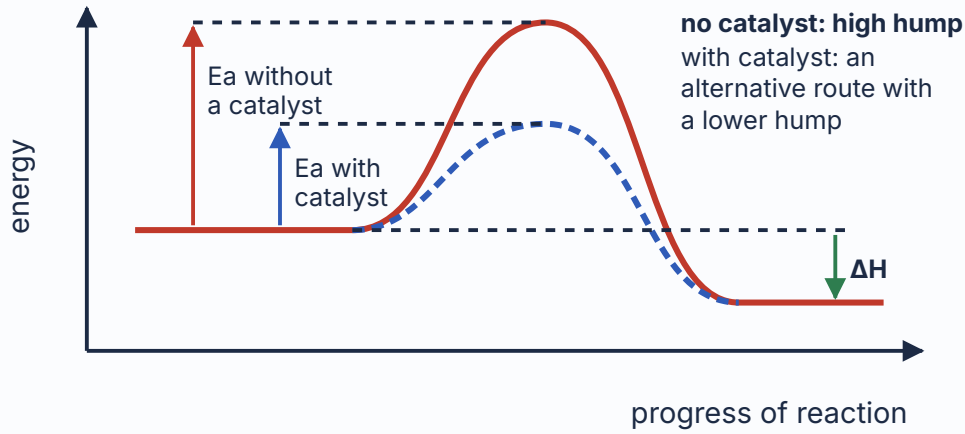
WORKED EXAMPLE

EXT **Explain why increasing the temperature increases the rate of reaction.**

1. The particles move faster
2. so they collide more frequently
3. and a greater proportion of the collisions have energy ≥ the activation energy
4. **so more of the collisions are successful and the rate increases**

Catalysts and the energy profile

EXTENDED

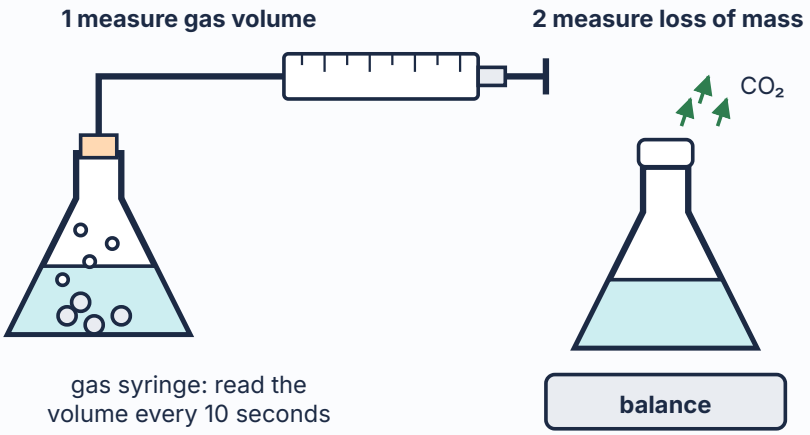


ΔH is unchanged · the catalyst is not used up · the products are the same

A catalyst offers a different route with a lower hump (Ea). ΔH is unchanged and the catalyst is not used up.

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Measuring the rate



drawn for marble chips + acid: $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$

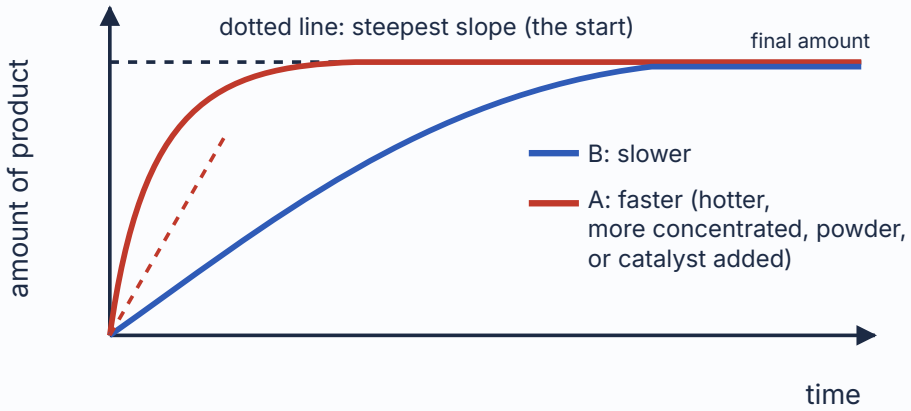
Two ways to follow a reaction that gives off a gas: collect the gas in a gas syringe, or measure the loss of mass on a balance.

- **Gas volume:** use a gas syringe or an upturned measuring cylinder and read the volume at regular times.
- **Mass loss:** put the flask on a balance. As gas escapes, the mass goes down. Cotton wool in the neck lets the gas out but stops spray escaping.
- **Time for something to happen:** for example, the time for a cross to disappear when a precipitate forms.
- EXT Compare methods: mass loss works well for a heavy gas such as CO_2 but poorly for hydrogen (too light to measure); a gas syringe is accurate but may stick, and some gas can escape while the bung is put in.

$$\text{average rate} = \frac{\text{amount of product formed (or reactant used)}}{\text{time taken}}$$

for example, cm^3 per second, or g per second

Reading a rate graph



steeper line = faster rate · a line goes flat when a reactant has been used up
both reach the same final amount if they start with the same amount of reactant

Curve A is steeper, so the reaction is faster. Both curves flatten when a reactant has run out, and both reach the same final amount.

- The **gradient** of the line is the rate. It is **steepest at the start** (the most reactant, the most collisions), and it falls as reactants are used up.
- When the line becomes **flat**, the reaction has **stopped** — one reactant has been used up.
- Faster conditions give a steeper curve that reaches the **same final amount** (if the amount of the limiting reactant is the same).

Time (s)	0	10	20	30	40	50	60
Volume of gas (cm^3)	0	24	38	46	50	50	50

WORKED EXAMPLE

Use the table to find (a) when the reaction stops, (b) the mean rate in the first 10 s, (c) the mean rate from 20 s to 30 s, and explain why they differ.

1. (a) the volume stops rising at 40 s, so the reaction finished at **40 s**
2. (b) 24 ÷ 10 = **2.4 cm^3/s**
3. (c) (46 − 38) ÷ 10 = **0.8 cm^3/s**
4. **The rate is lower later because the reactant concentration has fallen, so there are fewer collisions per second**

WORKED EXAMPLE

EXT **In a mass-loss experiment, 0.44 g of CO_2 escapes from a flask. What volume of gas is this at r.t.p.?**

1. $n(CO_2)$ = 0.44 ÷ 44 = 0.010 mol
2. **V = 0.010 × 24 = 0.24 dm^3 (240 cm^3)**

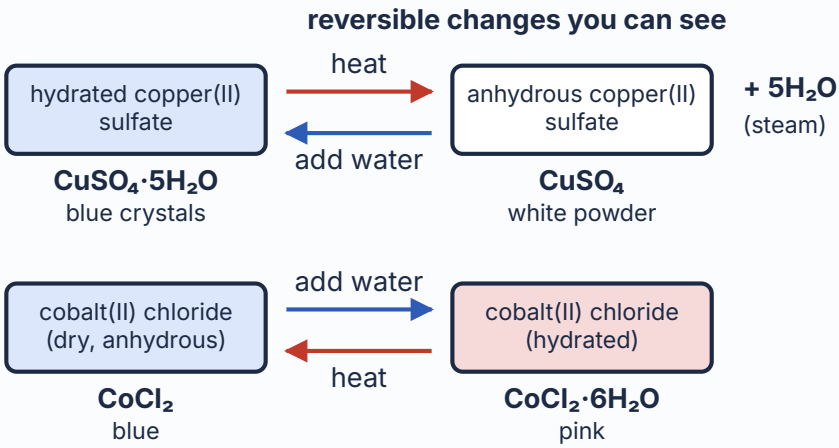
EXAM TIP

To compare two experiments say **what is the same** (fair test) and **what is different**. A curve that ends at a **higher** level means more reactant was used; the same final level means only the **rate** changed.

3 Reversible reactions and equilibrium

Reactions that go both ways

Reversible reaction — a reaction in which the products can react to form the reactants again. It is shown by the symbol ⇌.



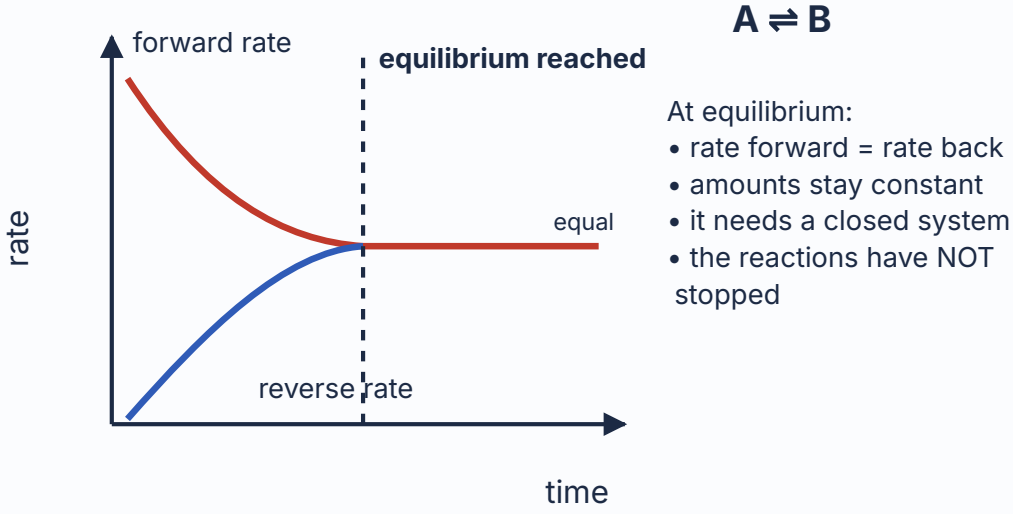
tests for water: white anhydrous copper(II) sulfate turns blue;
blue cobalt chloride paper turns pink

Hydrated copper(II) sulfate (blue) loses its water on heating to become white anhydrous copper(II) sulfate. Add water and it turns blue again. Cobalt(II) chloride paper is blue when dry and pink with water.

- **Hydrated copper(II) sulfate (blue) ⇌ anhydrous copper(II) sulfate (white) + water:** $CuSO_4 \cdot 5H_2O \rightleftharpoons CuSO_4 + 5H_2O$
- **Anhydrous** means "without water". **Hydrated** means "with water of crystallisation".
- Heat blue crystals → white powder and steam. Add water to the white powder → it turns blue and gets **hot**.
- **Test for water:** anhydrous copper(II) sulfate turns **white → blue**; blue cobalt(II) chloride paper turns **blue → pink**. These tests show that water is **present**, but not that it is pure (use boiling point for that).

Equilibrium

EXTENDED



In a closed system, the forward and reverse rates become equal. The amounts of reactants and products then stay constant.

Dynamic equilibrium — the state of a reversible reaction in a **closed system** where the forward and reverse reactions happen at the **same rate**, so the concentrations stay constant.

- It is called **dynamic** because both reactions are **still happening** — it does not stop.
- A **closed system** is needed so that nothing can escape.
- At equilibrium the amounts of reactants and products are **constant** but **not necessarily equal**.

Changing the conditions

EXTENDED

- If you change the conditions, the **position of equilibrium shifts** to oppose the change:

Change	Position shifts towards
increase temperature	the **endothermic** direction (absorbs the extra heat)
decrease temperature	the **exothermic** direction
increase pressure	the side with **fewer gas molecules**
decrease pressure	the side with **more gas molecules**
increase concentration of a reactant	the **products** (uses up the extra reactant)
add a catalyst	**no change** — it speeds up both directions equally, so equilibrium is reached faster

WORKED EXAMPLE

EXT **The reaction N_2O_4 (colourless) ⇌ $2NO_2$ (brown) is endothermic in the forward direction. What is seen when the mixture is heated?**

1. Heating favours the **endothermic** direction
2. so the position shifts to the right
3. **more NO_2 forms, and the mixture becomes darker brown**

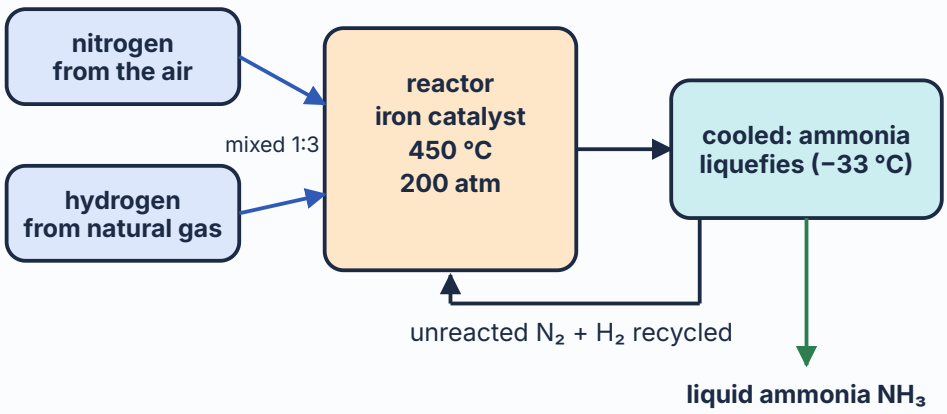
WORKED EXAMPLE

EXT **How does pressure affect $2SO_2 + O_2 ⇌ 2SO_3$?**

1. Left side: 2 + 1 = 3 gas molecules. Right side: 2 gas molecules
2. higher pressure favours the side with **fewer molecules** (the right)
3. **so more SO_3 is made at high pressure**

The Haber process

EXTENDED



$N_2 + 3H_2 ⇌ 2NH_3$ (forward reaction is exothermic)

The Haber process. Nitrogen and hydrogen are mixed 1 : 3, passed over an iron catalyst, and the ammonia is liquefied. Unreacted gases are recycled.

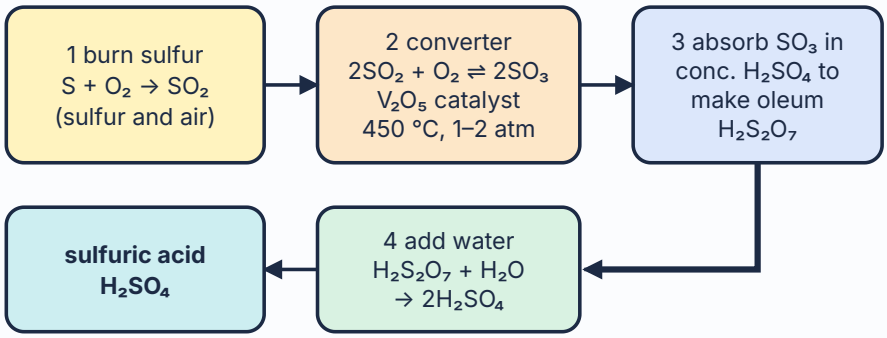
$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

forward reaction is exothermic

- **Nitrogen** comes from the **air** (fractional distillation of liquid air). **Hydrogen** comes from **natural gas** (methane) reacting with steam.
- Conditions: **450 °C, 200 atm, iron catalyst**.
- Only a fraction of the nitrogen and hydrogen turns into ammonia on each pass. The **unreacted gases are recycled** and the ammonia is cooled until it liquefies and is removed.

The Contact process

EXTENDED



SO_3 is not added straight to water: the reaction gives off so much heat it makes a mist of acid. Oleum is diluted instead.

450 °C: a compromise between rate (hotter is faster) and yield (colder is better)
1–2 atm: the yield is already high, so high pressure would waste money

The Contact process makes sulfuric acid in four steps. Sulfur dioxide is oxidised to sulfur trioxide over a vanadium(V) oxide catalyst.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

forward reaction is exothermic

- **Sulfur dioxide** comes from burning **sulfur** ($S + O_2 \rightarrow SO_2$) or from roasting **sulfide ores**. **Oxygen** comes from the **air**.
- Conditions: **450 °C, 1–2 atm, vanadium(V) oxide (V_2O_5) catalyst**.
- SO_3 is absorbed in concentrated sulfuric acid to make **oleum** ($H_2S_2O_7$), then **diluted with water** to give H_2SO_4. SO_3 is not added directly to water because the reaction is so violent it makes a mist of acid.

Why those conditions?

EXTENDED

	Haber process	Contact process
exothermic?	yes	yes
temperature	450 °C	450 °C
pressure	200 atm	1–2 atm
catalyst	iron	vanadium(V) oxide

- **Temperature — a compromise.** Exothermic reactions give more product at **low** temperature, but the rate is too slow when it is cold. So a **moderate** temperature (450 °C) is chosen to get an acceptable rate and yield.
- **Pressure — Haber:** 4 molecules → 2 molecules, so **high pressure** gives more ammonia and a faster rate. But very high pressure costs more (strong equipment, energy) and is dangerous, so 200 atm is a compromise.
- **Pressure — Contact:** 3 molecules → 2, but the yield is **already high** at 1–2 atm, so high pressure would waste money.

- **Catalyst:** speeds up the reaction so equilibrium is reached quickly at a lower temperature. It has **no effect on the yield**.

EXAM TIP

When explaining industrial conditions always mention **rate**, **yield** (position of equilibrium), **safety** and **cost**. "A compromise" is the key idea.

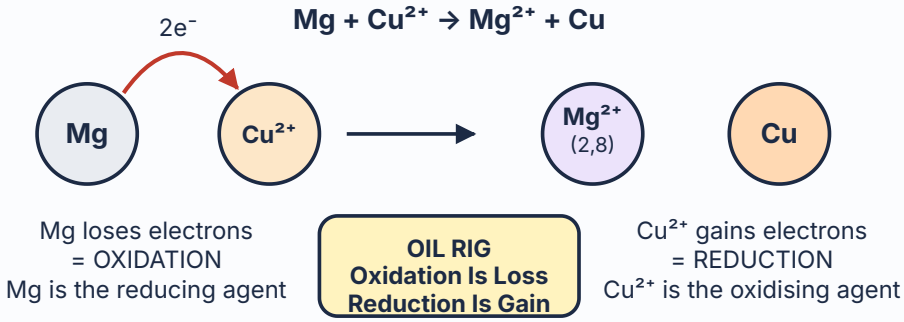
4 Redox

Oxidation and reduction

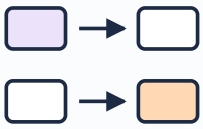
Oxidation — gain of oxygen. EXT Also **loss of electrons**, or an increase in oxidation number.

Reduction — loss of oxygen. EXT Also **gain of electrons**, or a decrease in oxidation number.

Redox reaction — a reaction in which **oxidation and reduction happen at the same time**.



colour-change tests (for oxidising and reducing agents)



acidified $KMnO_4$ turns purple → colourless: MnO_4^- is reduced, so it is an oxidising agent

potassium iodide turns colourless → brown: I^- is oxidised to I_2, so it is a reducing agent

Magnesium + copper(II) ions. Magnesium loses two electrons (oxidation); the copper ion gains them (reduction).

- Example: $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$. Fe_2O_3 **loses** oxygen (reduced). CO **gains** oxygen (oxidised).
- Example: $2Mg + O_2 \rightarrow 2MgO$. Magnesium **gains** oxygen: it is oxidised.

MEMORY TRICK

OIL RIG — **O**xidation **I**s **L**oss (of electrons); **R**eduction **I**s **G**ain.

- EXT $Mg + Cu^{2+} \rightarrow Mg^{2+} + Cu$: Mg loses 2 electrons → oxidised. Cu^{2+} gains 2 electrons → reduced.
- EXT An **oxidising agent** oxidises another substance and is **itself reduced**. A **reducing agent** reduces another substance and is **itself oxidised**.

Oxidation numbers

- Roman numerals in names show the **oxidation number** of a metal: **iron(II)** chloride $FeCl_2$ has Fe^{2+}; **iron(III)** chloride $FeCl_3$ has Fe^{3+}; copper(II) oxide CuO has Cu^{2+}.
- EXT **Rules:** (1) uncombined elements = **0**; (2) a simple ion = its **charge**; (3) in compounds, hydrogen is usually **+1** and oxygen is usually **−2**; (4) the oxidation numbers in a compound add up to **0**, and in an ion add to its **charge**.
- EXT **Oxidation** = the oxidation number **increases**. **Reduction** = the oxidation number **decreases**.

WORKED EXAMPLE

EXT **Find the oxidation number of (a) S in H_2SO_4, (b) Mn in $KMnO_4$, (c) Cr in $Cr_2O_7^{2-}$.**

1. (a) 2(+1) + S + 4(−2) = 0 → S = **+6**
2. (b) (+1) + Mn + 4(−2) = 0 → Mn = **+7**
3. **(c) 2 × Cr + 7(−2) = −2 → 2 × Cr = +12 → Cr = +6**

WORKED EXAMPLE

EXT **In $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$, identify what is oxidised and reduced, and the oxidising and reducing agents.**

1. Fe: +3 → 0, the number decreases, so Fe_2O_3 is **reduced**
2. C: +2 → +4, the number increases, so CO is **oxidised**
3. **Fe_2O_3 is the oxidising agent; CO is the reducing agent**

Colour tests for oxidising and reducing agents

EXTENDED

- **Acidified potassium manganate(VII) ($KMnO_4$):** purple → **colourless** when it is **reduced**. So it shows a **reducing agent** is present.
- **Potassium iodide (KI):** colourless → **brown** (iodine) when I^- is **oxidised**. So it shows an **oxidising agent** is present.
- It looks backwards at first: the **test chemical** changes colour, and the thing it detects does the opposite job.

COMMON MISTAKE

"Oxidation is gain of electrons." No — **O**xidation **I**s **L**oss.

COMMON MISTAKE

Forgetting that redox needs **both** processes. Something that is oxidised must be balanced by something that is reduced.

Riyaz Sir

5 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. Give two signs of a chemical change.
2. Name five factors that change the rate of a reaction.
3. What does the symbol ⇌ mean?
4. What colour change shows that water is present using anhydrous copper(II) sulfate?
5. What is oxidation, in terms of oxygen?
6. What is the oxidation number of iron in iron(III) oxide?
7. EXT What does a catalyst do to the activation energy?
8. EXT Why does a higher pressure increase the yield of ammonia?

EXAM-STYLE

9. Explain, using particles, why increasing concentration increases the rate of reaction. [2]
10. EXT Explain why the Contact process uses a pressure of only 1–2 atm. [2]
11. EXT State the conditions used in the Haber process and explain why 450 °C is used. [4]
12. EXT Use oxidation numbers to show that the reaction Mg + $CuSO_4$ → $MgSO_4$ + Cu is redox. [3]

Show answers

1. any two from: colour change, gas given off, precipitate, temperature change, light
2. concentration, pressure (gases), temperature, surface area, catalyst
3. the reaction is reversible
4. white → blue
5. gain of oxygen
6. +3
7. lowers it
8. there are 4 gas molecules on the left but 2 on the right, so the position shifts right
9. more particles per unit volume
   so more frequent collisions and so a higher rate
10. the yield of SO_3 is already high at this pressure
    high pressure would increase costs and safety risks without much more product
11. 450 °C, 200 atm, iron catalyst
    low temperature gives a better yield (the reaction is exothermic)
    but the rate is too slow
    450 °C is a compromise between rate and yield
12. Mg: 0 → +2, oxidised (increase)
    Cu: +2 → 0, reduced (decrease)
    oxidation and reduction occur together, so it is redox

Stuck on a question?

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