Chemical reactions

IGCSE Chemistry

Physical and chemical changes

Iron rusting is a chemical change —it forms a new substance.

A **physical change** 物理变化 does not make a new substance. The substance only changes its state or shape, and the change can usually be reversed. Melting ice and dissolving sugar are physical changes.

A **chemical change** 化学变化 (a chemical reaction) makes one or more new substances and is usually hard to reverse. Signs of a chemical change include a colour change, a gas being given off, an energy change, or a **precipitate** 沉淀 (a solid) forming.

Physical change	**Chemical change**
no new substance made	new substance(s) made
easy to reverse	usually hard to reverse
e.g. melting, boiling, dissolving	e.g. burning, rusting

Rate of reaction

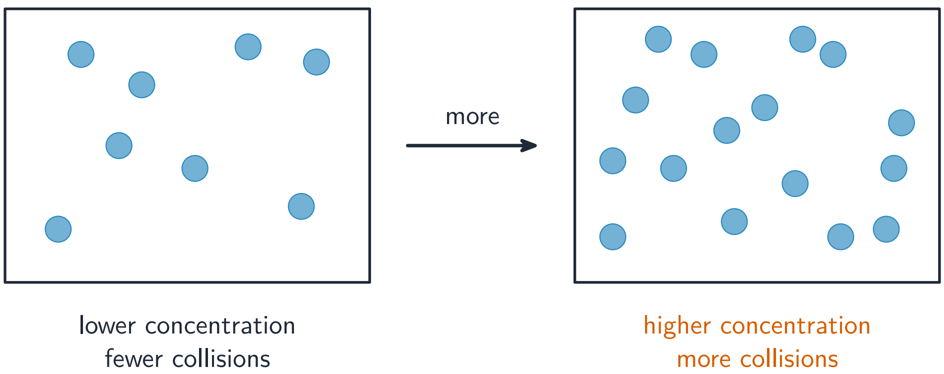
The **rate of reaction** 反应速率 tells you how fast the **reactants** 反应物 change into **products** 生成物.

Collision theory

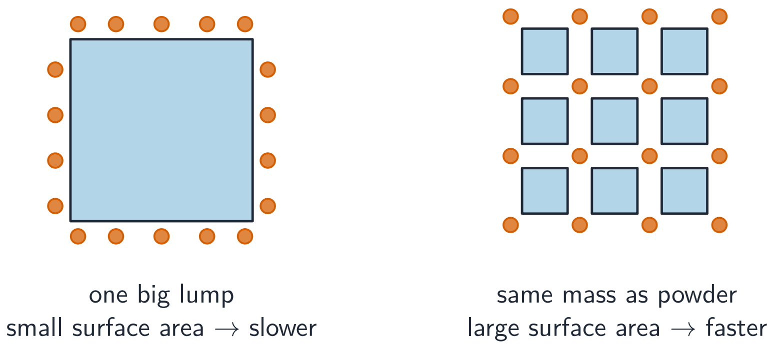
Collision theory 碰撞理论 explains what controls the rate. For a reaction to happen, the **particles** 粒子 must **collide** 碰撞, and they must collide with enough energy. The least energy they need is the **activation energy** 活化能 (E_a). A faster rate happens when the particles have successful collisions more often.

What changes the rate

Change	Effect	Reason (collision theory)
increase **concentration** 浓度 of a solution	faster	more particles in the same volume, so collisions happen more often
increase **pressure** 压强 of gases	faster	particles are pushed closer, so collisions happen more often
increase **surface area** 表面积 of a solid	faster	more particles are exposed, so collisions happen more often
increase temperature	faster	particles gain **kinetic energy** 动能 and move faster, so collisions are more frequent and more of them have enough energy
add a **catalyst** 催化剂	faster	the catalyst lowers the activation energy, so more collisions are successful



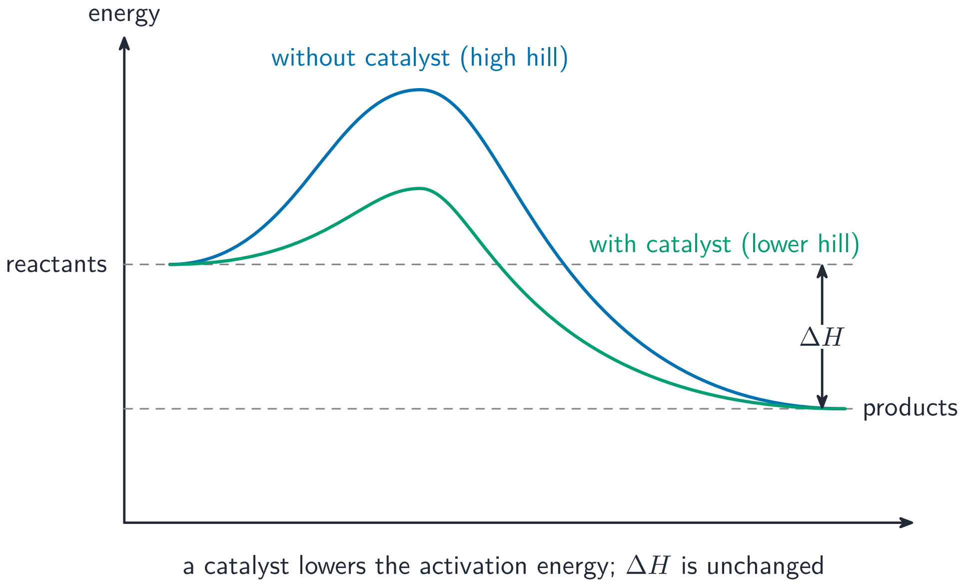
More particles in the same volume collide more often, so the rate is faster



Breaking a solid into a powder exposes much more surface, so the rate is faster

Catalysts

A catalyst speeds up a reaction but is not used up —it is unchanged at the end. It works by lowering the activation energy. **Enzymes** 酶 are biological catalysts (catalysts that work in living things).

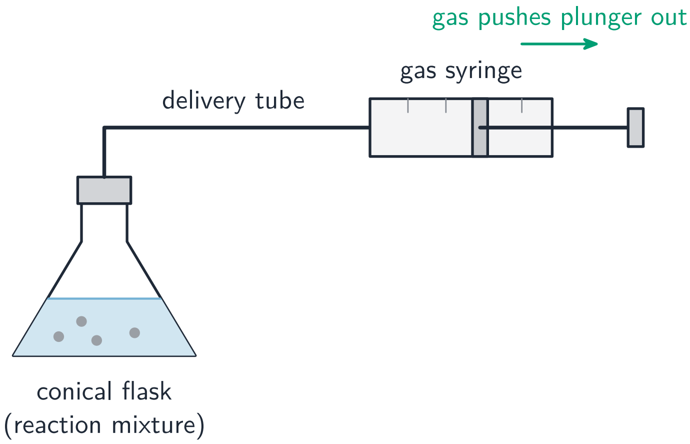


A catalyst gives a lower activation energy so more collisions succeed; ΔH is unchanged

Measuring the rate

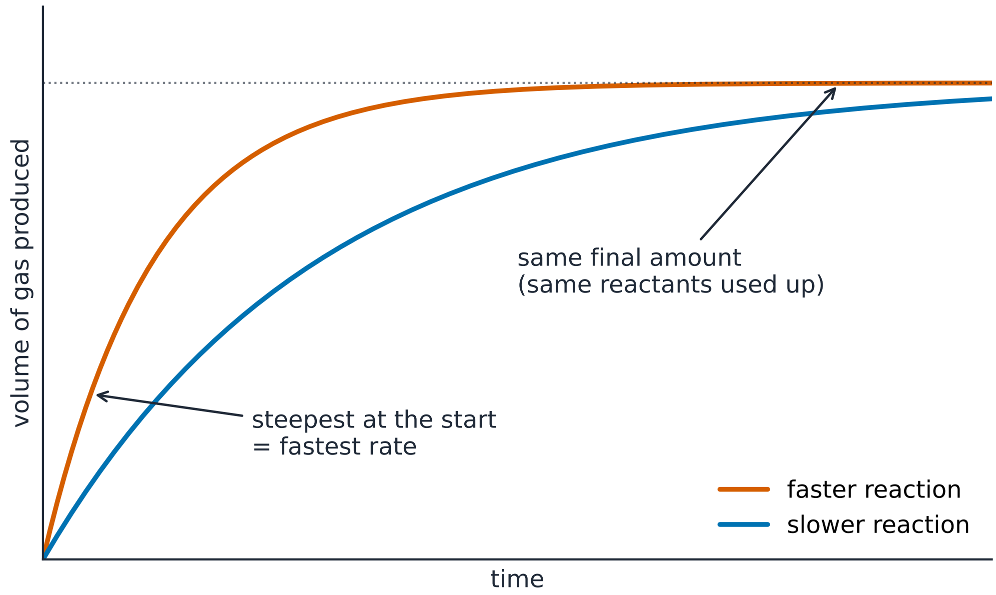
You can follow a reaction over time in these ways:

- **Change in mass**: stand the flask on a balance. If a gas escapes, the mass falls. Record the mass at regular times.
- **Volume of gas**: collect the gas in a gas **syringe** 注射器 and read its volume at regular times.
- **Formation of a precipitate**: in a reaction that turns cloudy, time how long it takes for a mark under the flask to disappear.



A gas syringe collects the gas given off; read its volume at regular times to follow the rate

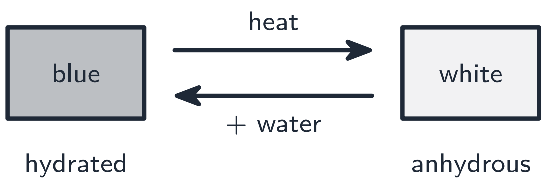
On a graph of product against time, the line is **steepest at the start** (fastest rate), becomes less steep as reactants are used up, and goes **flat** when the reaction has finished.



The rate is fastest at the start (steepest) and the line levels off when the reaction finishes

Reversible reactions and equilibrium

Some reactions are **reversible** 可逆反应: the products can react to form the reactants again. We show this with the symbol $\rightleftharpoons$.



Heating blue copper sulfate drives off water; adding water turns it blue again

Changing the direction

A clear example uses **hydrated** 水合 and **anhydrous** 无水 compounds:

- Blue hydrated copper(II) sulfate, when heated, loses its water to become white anhydrous copper(II) sulfate. Adding water turns it blue again.
- Pink hydrated cobalt(II) chloride loses water when heated to become blue anhydrous cobalt(II) chloride. Adding water turns it pink again.

Adding water to the anhydrous solid (and seeing the colour return) is used as a test for water.

Equilibrium

In a **closed system** 密闭系统 (where nothing enters or leaves), a reversible reaction reaches **equilibrium** 平衡 when:

- the rate of the **forward reaction** 正反应 equals the rate of the **reverse reaction** 逆反应, and
- the concentrations of the reactants and products are no longer changing.

Changing the position of equilibrium

The **position of equilibrium** 平衡位置 tells you whether there are more reactants or more products. You can move it:

- **Temperature**: heating moves the equilibrium in the direction that takes in heat (the **endothermic** 吸热反应 direction); cooling moves it in the direction that gives out heat (the **exothermic** 放热反应 direction).
- **Pressure** (gases): more pressure moves the equilibrium to the side with fewer gas molecules.
- **Concentration**: adding more of a substance moves the equilibrium to the other side, to use it up.
- A **catalyst** does **not** move the position of equilibrium. It only helps the reaction reach equilibrium faster.

The Haber process

The **Haber process** 哈伯法 makes ammonia:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

- The **hydrogen** 氢气 comes from **methane** 甲烷 (natural gas); the **nitrogen** 氮气 comes from the air.
- Typical conditions: a temperature of 450 °C, a pressure of about 200 atm (20 000 kPa), and an **iron** 铁 catalyst.

The Contact process

The **Contact process** 接触法 turns sulfur dioxide into sulfur trioxide:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

- The sulfur dioxide comes from burning **sulfur** 硫 (or roasting sulfide ores); the **oxygen** 氧气 comes from the air.
- Typical conditions: a temperature of 450 °C, a pressure of about 2 atm (200 kPa), and a **vanadium(V) oxide** 五氧化二钒 catalyst.

Why these conditions are chosen

The conditions are a **compromise** 折中:

- A higher pressure would give more product, but very high pressure is dangerous and expensive, so a medium pressure is used.
- A lower temperature would give more product (both forward reactions are exothermic), but the reaction would be too slow, so a fairly high temperature is used to keep a good rate.
- The catalyst speeds up the reaction without changing the position of equilibrium, which lowers cost.

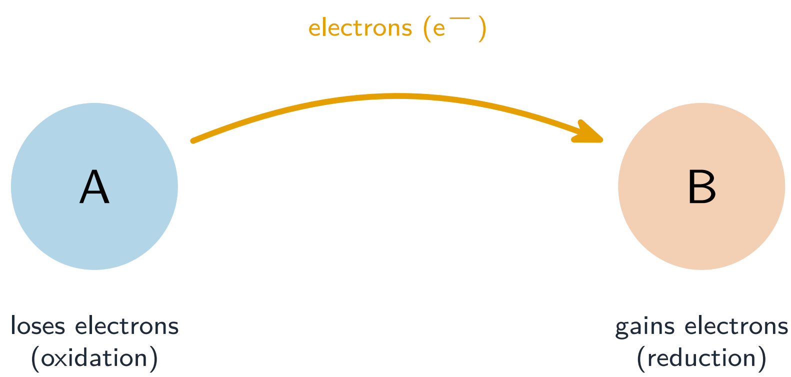
Redox

Oxidation 氧化 and **reduction** 还原 always happen at the same time, in what is called a **redox reaction** 氧化还原反应. ('Redox' is short for reduction–oxidation.)

There are three ways to describe oxidation and reduction:

- **Oxygen**: oxidation is the gain of oxygen; reduction is the loss of oxygen.
- **Electrons** 电子: oxidation is the loss of electrons; reduction is the gain of electrons.
- **Oxidation number** 氧化数: in oxidation the oxidation number goes up; in reduction it goes down.

A useful memory aid is **OIL RIG**: *Oxidation Is Loss, Reduction Is Gain* —of electrons.



Electrons pass from the substance that is oxidised (loses them) to the one that is reduced (gains them) —the two always happen together

Oxidation number rules

The oxidation number is shown by a Roman numeral, as in iron(II) and iron(III). The rules are:

- An element that is not combined has an oxidation number of 0.

- A single-atom ion has an oxidation number equal to its charge (so Na^+ is +1).
- The oxidation numbers in a compound add up to 0.
- The oxidation numbers in an ion add up to the charge on the ion.

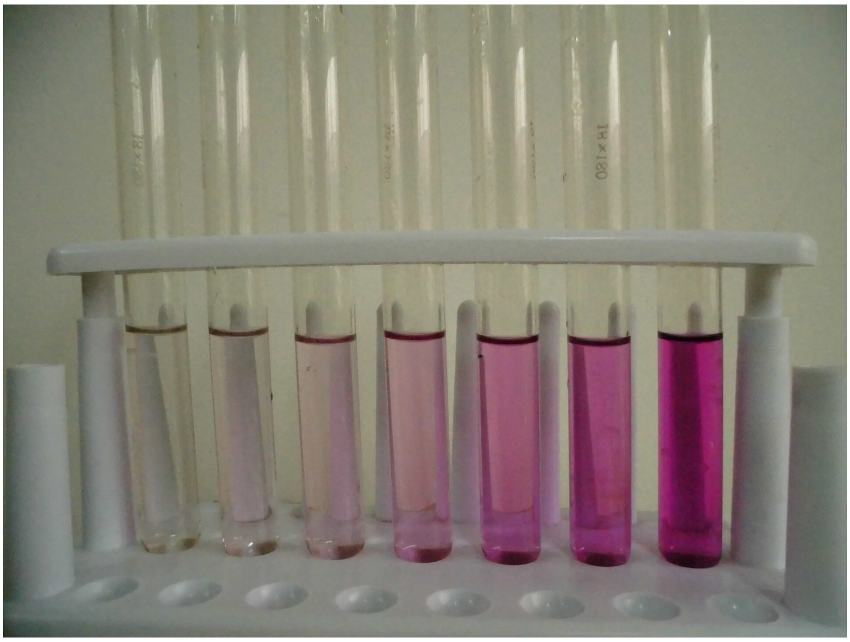
Worked example. Find the oxidation number of manganese in the manganate(VII) ion, MnO_4^-. Each oxygen is -2, and there are four of them, giving $4 \times (-2) = -8$. The oxidation numbers in an **ion** must add up to the charge on the ion, which here is -1. So if manganese is x, then $x + (-8) = -1$, giving $x = +7$ - exactly what the (VII) in the name tells you. Set the total to the **ion's charge**, not to zero: zero is only for a neutral compound.

Oxidising and reducing agents

- An **oxidising agent** 氧化剂 oxidises another substance, and is itself reduced.
- A **reducing agent** 还原剂 reduces another substance, and is itself oxidised.

Some redox reactions show clear colour changes:

- Acidified **potassium manganate(VII)** 高锰酸钾 is purple. When it acts as an oxidising agent it is reduced, and the purple colour fades to colourless.
- **Potassium iodide** 碘化钾 is colourless. When it is oxidised, red-brown **iodine** 碘 is formed.



Potassium manganate(VII) is deep purple; as it is reduced (or diluted) the purple fades to colourless

Exam tips

- Explain a faster rate with **collision theory**: successful collisions happen more often. Concentration, pressure and surface area all raise how often particles collide; a higher temperature does that *and* gives more particles enough energy.

- A **catalyst** lowers the activation energy and speeds the reaction up, but is not used up and does *not* change ΔH or the position of equilibrium.
- At **equilibrium** the forward and reverse rates are equal and the concentrations stop changing —it does *not* mean the amounts of reactant and product are equal.
- Use Le Chatelier's principle: raising temperature favours the endothermic direction; raising pressure favours the side with fewer gas molecules; adding a substance shifts the equilibrium away from it.
- **Redox** —OIL RIG: Oxidation Is Loss, Reduction Is Gain of electrons. They always happen together, and an oxidising agent is itself reduced.