

How fast? The rate of chemical change

International Baccalaureate · IB Diploma · Chemistry · SL

Scope and prerequisites

This handout teaches Reactivity 2.2, How fast? The rate of chemical change, for the course first assessed in 2025.

Prerequisites: concentration and moles from Structure 1.4, enthalpy changes and energy profiles from Reactivity 1.1, and drawing tangents to curves. At Higher Level you will also use natural logarithms and the Arrhenius equation from the data booklet.

Measuring the rate of reaction

■ Why does food last longer in a fridge?

Milk goes sour in two days on a warm table but lasts a week in a fridge. A firework burns in a second, iron rusts over months. Chemists need to know not only what forms but how fast, and how to make a reaction faster or slower.

■ What rate means

The **rate of reaction** is the change in the amount or concentration of a reactant or product per unit time.

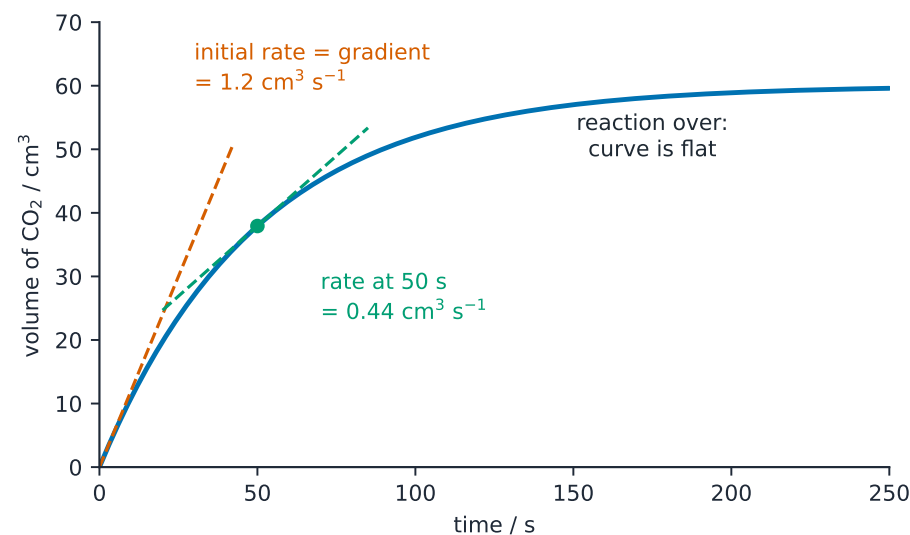
$$\text{rate} = \frac{\Delta[\text{product}]}{\Delta t} \quad \text{or} \quad - \frac{\Delta[\text{reactant}]}{\Delta t}$$

The unit is usually $\text{mol dm}^{-3} \text{s}^{-1}$. If you follow something else, such as a gas volume, the unit follows it: $\text{cm}^3 \text{s}^{-1}$ or g s^{-1} .

■ Ways to follow a reaction

What changes	Method	Example
gas is given off	collect the gas in a gas syringe; read the volume every 10 s	$\text{CaCO}_3 + \text{HCl}$
gas escapes	stand the flask on a balance; read the mass loss	$\text{CaCO}_3 + \text{HCl}$
colour	colorimeter: measure how much light passes through	bromine reacting with methanoic acid
ions form or are used	conductivity or pH meter	ester hydrolysis
a precipitate forms	time until a cross under the flask disappears	sodium thiosulfate + HCl

■ Reading a rate from a graph



The rate at any moment is the gradient of the tangent to the curve

- The rate at any time is the gradient of the curve at that time. Draw a **tangent** and find its gradient.
- The curve is steepest at the start, where reactant concentrations are highest. The **initial rate** is the gradient of the tangent at $t = 0$.
- The rate falls as reactants are used up. When the curve is flat, the reaction has stopped.

Collision theory

■ Three conditions for a reaction

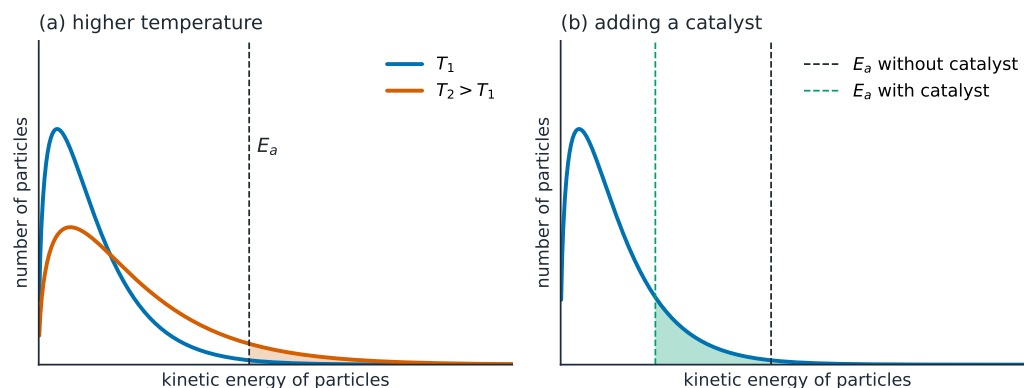
Collision theory says that particles react only when they collide, and only some collisions work. A successful collision needs:

1. A collision: the particles must meet.
2. Enough energy: the collision energy must be at least the **activation energy**, E_a , the minimum energy needed for a reaction.
3. The right orientation: the reacting parts of the particles must meet.

The rate depends on how many successful collisions happen each second.

■ The Maxwell–Boltzmann distribution

The particles in a gas or solution do not all have the same energy. The **Maxwell–Boltzmann distribution** shows how many particles have each energy.



The shaded areas are the particles with at least enough energy to react

- The curve starts at the origin: no particle has zero energy.
- It has no maximum energy: the curve never meets the x-axis.
- The area under the curve is the total number of particles. At a higher temperature the area stays the same, so the peak moves right and falls.
- Only particles in the shaded area beyond E_a can react.

Factors that affect the rate

■ Concentration, pressure and surface area

Change	Effect on collisions	Effect on rate
higher concentration of a solution	more particles per dm^3 , so more frequent collisions	faster
higher pressure of a gas	particles closer together, so more frequent collisions	faster
smaller pieces of a solid (larger surface area)	more particles exposed, so more frequent collisions	faster

These three change only the **frequency** of collisions. The fraction of collisions with enough energy stays the same.

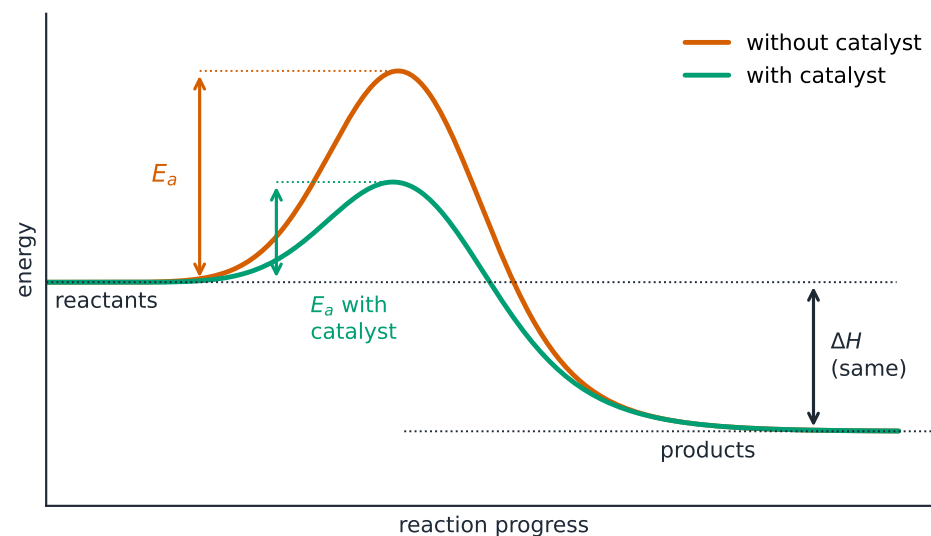
■ Temperature

A temperature rise of 10 K often roughly doubles the rate. Two effects add together:

1. Particles move faster, so collisions are a little more frequent.
2. Much more important: more particles have energy at least E_a (panel (a) above), so a much larger fraction of collisions succeeds.

■ Catalysts

A **catalyst** increases the rate of a reaction without being used up. It gives an **alternative reaction pathway** with a lower activation energy.



A catalyst lowers E_a but does not change ΔH

- With a lower E_a , more particles have enough energy (panel (b) above), so more collisions succeed.
- A catalyst does not change ΔH , and it does not change the position of an equilibrium.
- Examples: iron in the Haber process, MnO_2 for the decomposition of hydrogen peroxide, enzymes in living cells.

Practice

1. In an experiment, $0.050 \text{ mol dm}^{-3}$ of a reactant is used up in 25 s. Calculate the mean rate in $\text{mol dm}^{-3} \text{ s}^{-1}$.
2. Describe how to follow the rate of the reaction between magnesium ribbon and hydrochloric acid.
3. State the three conditions for a successful collision.
4. Use collision theory to explain why powdered calcium carbonate reacts faster with acid than the same mass of lumps.
5. Sketch Maxwell–Boltzmann curves at two temperatures and use them to explain why a small rise in temperature gives a large rise in rate.
6. Explain how a catalyst increases the rate, with reference to an energy profile and a Maxwell–Boltzmann curve.
7. From the gas–time graph in this handout, explain why the rate at 50 s is lower than the initial rate.

Answers.

1. $0.050/25 = 2.0 \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}$.
2. Collect the hydrogen in a gas syringe and read the volume every 10 s (or measure the mass loss on a balance); keep the temperature, acid concentration and volume the same.
3. The particles collide, with energy at least equal to E_a , and with the correct orientation.
4. Powder has a larger surface area, so more particles are exposed and collisions with acid particles are more frequent.
5. At the higher temperature the curve is lower and broader with the same area; the area beyond E_a is much larger, so a much larger fraction of collisions has enough energy.
6. It gives an alternative pathway with a lower E_a (a lower peak on the profile, the same ΔH). On the Maxwell–Boltzmann curve the lower E_a line has more particles beyond it, so more collisions succeed.
7. Reactants have been used up, so their concentration is lower and collisions are less frequent; the tangent is less steep.

Exam tips

- Rate is measured from the gradient of a tangent; draw the tangent long and read two far-apart points.
- Concentration, pressure and surface area change the collision frequency; temperature and catalysts change the fraction of collisions with enough energy.
- On a Maxwell–Boltzmann curve: start at the origin, never touch the x-axis, keep the same area at the higher temperature.
- A catalyst does not change ΔH or the equilibrium position.