Cambridge (CIE) A Level Chemistry

Your notes

Rate of Reaction

Contents

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Rate of Reaction & Collision Theory

Reaction rate

- The **rate of a reaction** is the speed at which a chemical reaction takes place and has units **mol dm^{-3} s^{-1}**
- The rate of a reaction can be calculated by:

Rate of reaction = $\frac{\text{change in the amount of reactants or products } (\text{mol dm}^{-3})}{\text{time } (\text{s})}$

Worked Example

Calculating the rate of reaction

Calculate the rate of reaction when 0.0440 g of ethyl ethanoate, $CH_3COOC_2H_5$, is formed in 1.0 minute from 400 cm^3 of a reaction mixture

Answer

- **Step 1:** Calculate the amount of ethyl ethanoate formed in mol:
  - Moles = $\frac{\text{mass } (\text{g})}{\text{molar mass } (\text{g mol}^{-1})}$
  - Moles = $\frac{0.0440 \text{ g}}{88.0 \text{ g mol}^{-1}}$
  - Moles = 0.0005 mol
- **Step 2:** Calculate the volume of the reaction mixture in dm^3:
  - **400 cm^3 = 0.400 dm^3**
- **Step 3:** Calculate the concentration change of product formed:
  - Concentration = $\frac{\text{amount } (\text{mol})}{\text{volume } (\text{dm}^3)}$
  - Concentration = $\frac{0.0005 \text{ mol}}{0.400 \text{ dm}^3}$
  - Concentration = 0.00125 mol dm^{-3}
- **Step 4:** Calculate the time in seconds:
  - **1.0 min = 60.0 s**
- **Step 5:** Use the equation to calculate the rate:
  - **Rate of reaction =** $\frac{\text{change in the amount of reactants or products } (\text{mol dm}^{-3})}{\text{time } (\text{s})}$

- Rate of reaction = $\frac{0.00125 \text{ mol dm}^{-3}}{60 \text{ s}}$
- Rate of reaction = 2.08×10^{-5} mol dm^{-3} s^{-1}

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Collision theory

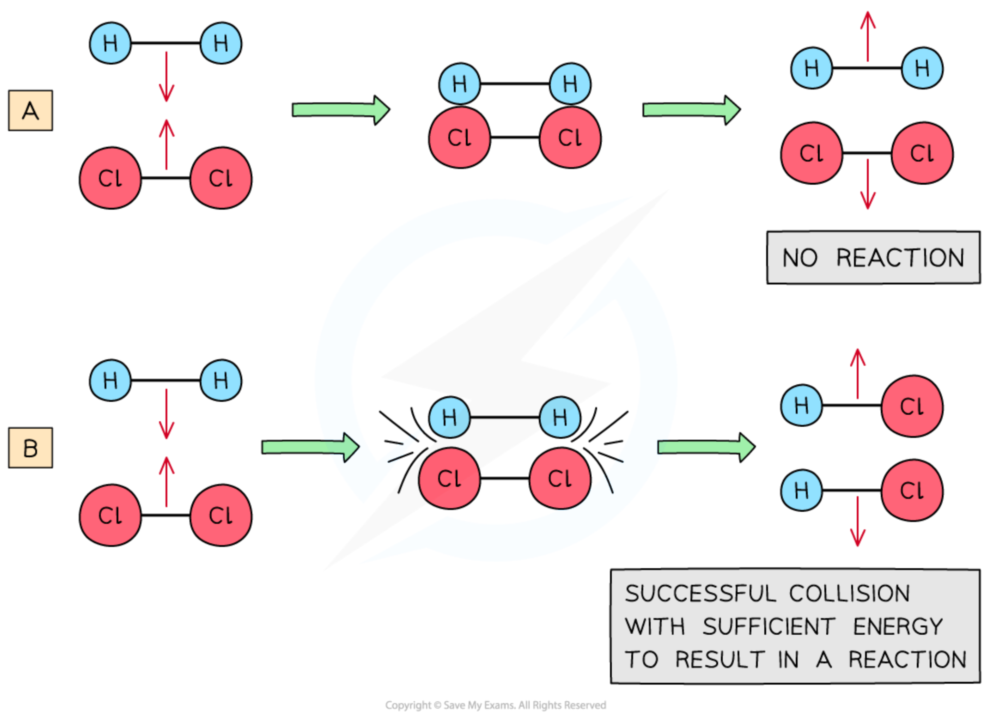
- The **collision theory** states that for a chemical reaction to take place, the particles need to **collide** with each other in the correct **orientation** and with enough **energy**
- The minimum energy that colliding particles must have for a collision to be **successful** and a reaction to take place is called the **activation energy** (***E*$_a$**)

Collision theory table

	Effective collision	Ineffective collision
Orientation	Correct	Incorrect
Energy	Sufficient energy (E_a)	Not enough energy
Chemical reaction	Yes	No

- An **ineffective collision** is when particles collide in the wrong orientation or when they don't have enough energy and **bounce off** each other without causing a chemical reaction

Effective and ineffective collisions



(A) shows an ineffective collision due to the particles not having enough energy whereas (B) shows an effective collision where the particles have the correct orientation and enough energy for a chemical reaction to take place

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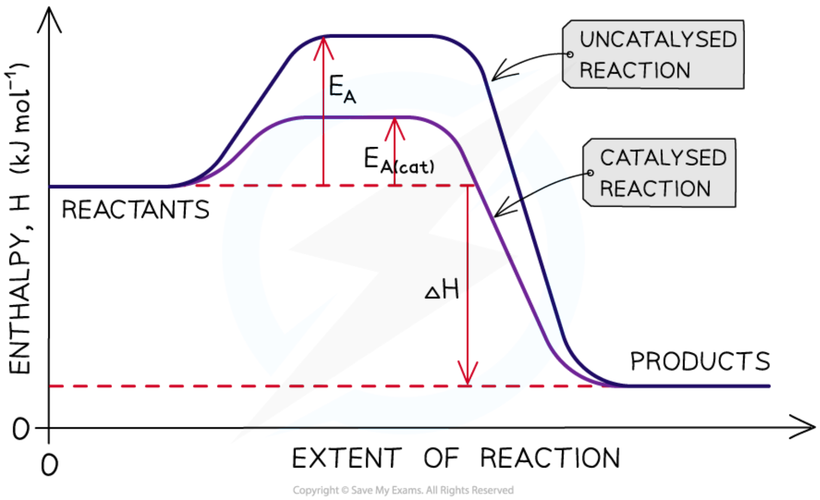
Increase in reaction rate

- The **collision frequency** is the number of collisions per unit time
- When there are more collisions per unit time, the number of particles with energy greater than the E_a increases
- This causes an **increase** in the **rate of reaction**
- A **catalyst** is a substance that **increases** the **rate of reaction** without taking part in the chemical reaction by providing the particles with an alternative mechanism with a lower activation energy

How catalysts affect reaction pathways

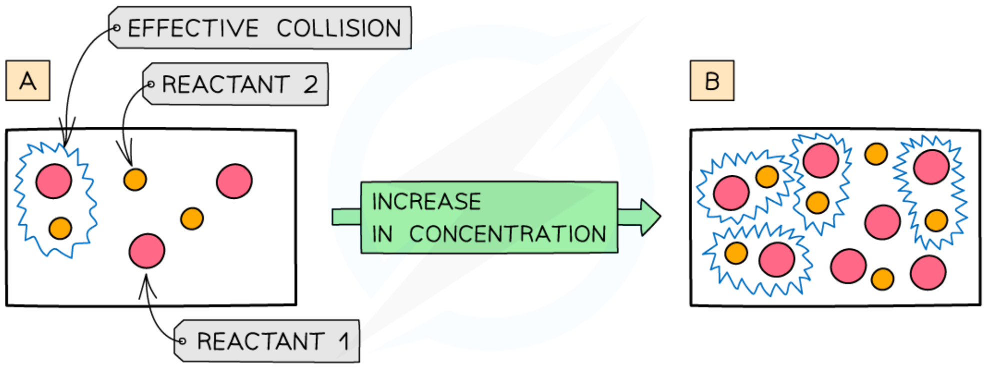


A catalyst increases the rate of a reaction by providing an alternative pathway which has a lower activation energy

Concentration

- The more **concentrated** a solution is, the **greater** the number of **particles** in a given volume of solvent
- An increase in **concentration** causes an increased **collision frequency** and therefore an increased **rate of reaction**

How increasing concentration affects collisions

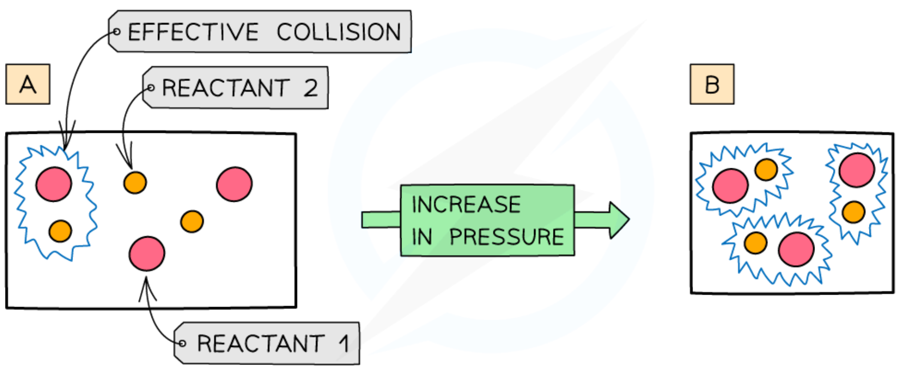


The higher concentration of particles in (B) means that there are more particles present in the same volume than (A) so the chance and frequency of collisions between reacting particles increase causing an increased rate of reaction

Pressure

- An increase in pressure in reactions that involve gases has the same effect as an increased concentration of solutions
- When the **pressure** is increased, the molecules have less space in which they can move
- This means that the number of **effective collisions** increases due to an increased **collision frequency**
- An increase in pressure therefore increases the **rate of reaction**

How increasing pressure affects collisions



The higher pressure in (B) means that the same number of particles occupy a smaller volume, resulting in an increased collision frequency and therefore increased rate of reaction

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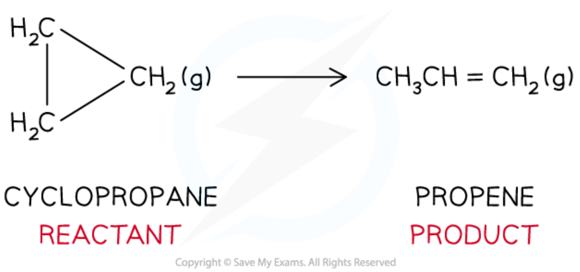
Rate of Reaction Experimental Calculations

- During a reaction, the **reactants** are used up and changed into the **products**
- This means that as the reaction proceeds, the concentration of reactants **decreases** and the concentration of products **increases**
- Therefore, the **rate of the reaction** is not the same throughout the reaction but **changes**
- The rate of reaction during the reaction can be calculated from a **concentration-time graph.**
- The **isomerisation of cyclopropane** to propene will be taken as an example:

Isomerisation of cyclopropane



The reactant cyclopropane isomerises to form propene

- The concentrations of reactant (cyclopropane) and product (propene) over time can be experimentally obtained

Concentrations of cyclopropane & propene results table

Time (min)	[cyclopropane] (mol dm^{-3})	[propene] (mol dm^{-3})
0	1.50	0.00
5	1.23	0.27
10	1.00	0.50
15	0.82	0.68
20	0.67	0.83

25	0.55	0.95
30	0.45	1.05
35	0.37	1.13
40	0.33	1.17

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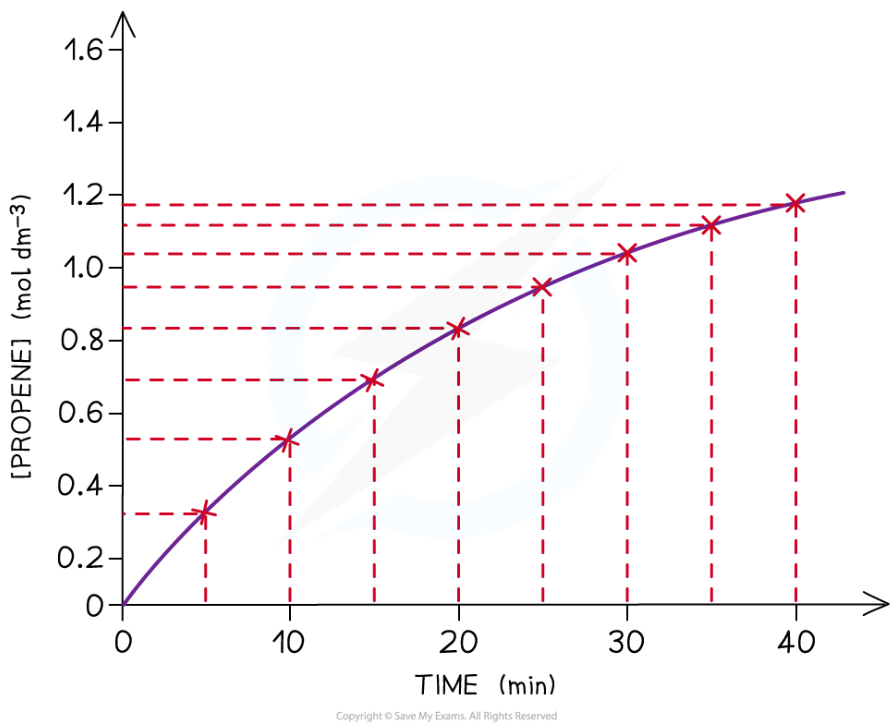
- When taking the measurements, the **temperature** should be kept the same at all times as a **change** in temperature will change the **rate of reaction**
- A **concentration-time graph** for the **concentration of propene as well as cyclopropane** can be obtained from the above results
  - As an example, the concentration-time graph for propene is shown below:

Concentration-time graph for propene



The graph shows that the concentration of propene increases with time

Calculating the rate at the start of a reaction

- At the start of the reaction, the concentration-time curve looks almost linear
- The rate at this point can therefore be found by treating the curve as a linear line and by using:

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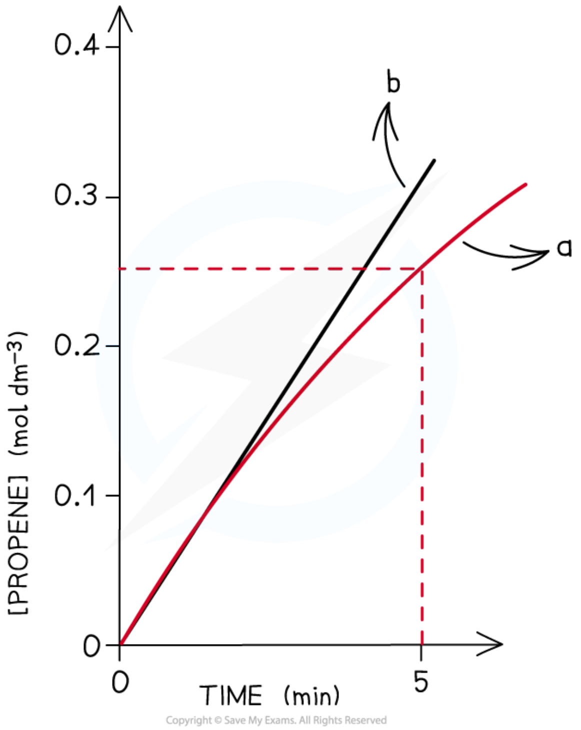
Rate of reaction = $\frac{\text{change in the amount of reactants or products (mol dm}^{-3})}{\text{time (s)}}$

- Using the graph, the average rate of the reaction over the first 5 minutes for propene is:

Applying tangents to curves



Line (a) shows the average rate over the first five minutes whereas line (b) shows the actual initial rate found by drawing a tangent at the start of the curve. The calculated rates are very similar for both methods.

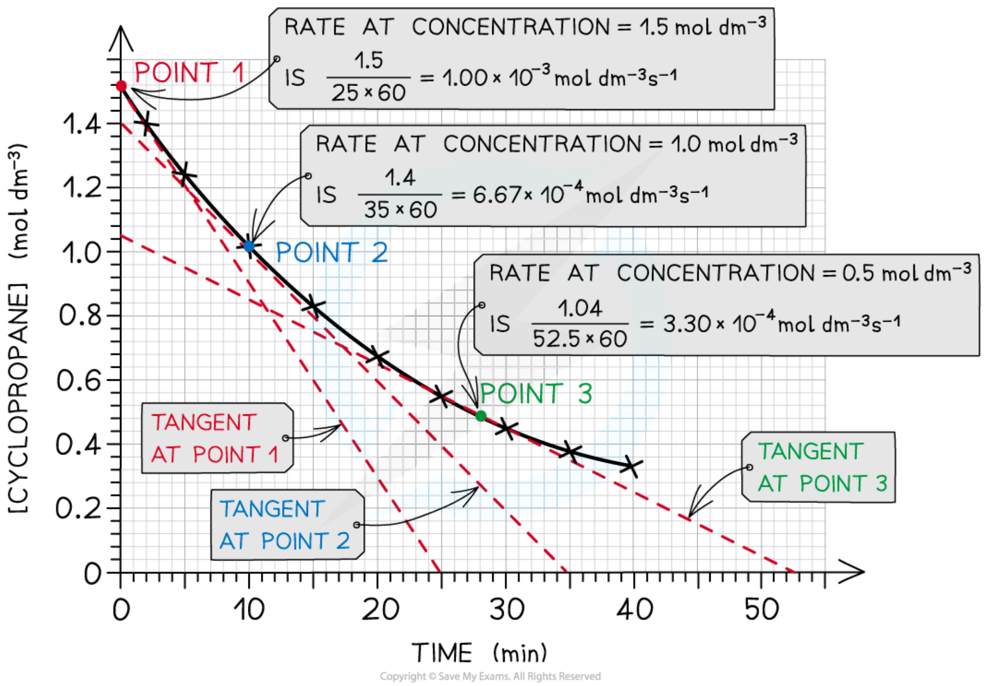
- Rate of reaction = $\frac{\text{change in the amount of reactants or products (mol dm}^{-3})}{\text{time (s)}}$
  - Rate of reaction = $\frac{0.27}{300}$
  - Rate of reaction = 0.0009 mol dm^{-3} s^{-1}

Calculating the rate as the reaction proceeds

- The curve becomes shallower with time which means that the rate decreases with time
- The rate of reaction can be calculated by taking short time intervals
  - For example, the rate of reaction from 15 to 20 mins
  - During this time, the concentration of propene increases from 0.68 to 0.83 mol dm^{-3}:

- Rate of reaction = $\frac{\text{change in the amount of reactants or products (mol dm}^{-3})}{\text{time (s)}}$
    - Rate of reaction = $\frac{(0.83)-(0.68)}{(1200)-(900)}$
    - Rate of reaction = $\frac{0.14}{300}$
    - Rate of reaction = 0.0005 mol dm^{-3} s^{-1}
- The smaller the time intervals, the more accurate the reaction rate value is
- Even more accurate is to find the rate of reaction at **different concentrations** of reactant or product at **particular time points**
- This can be done by drawing **tangents** at several points on the graph
    - As an example, the rates of reaction at different concentrations of cyclopropane are calculated by drawing the appropriate tangents:

Calculating rate as a reaction progresses



The rate of reaction at 3 different concentrations of cyclopropane is calculated by drawing tangents at those points in the graph

Rate-concentration graph

- The calculated rates can then be summarised in a table to show how the rate of reaction changes with changing concentration of the reactants or products

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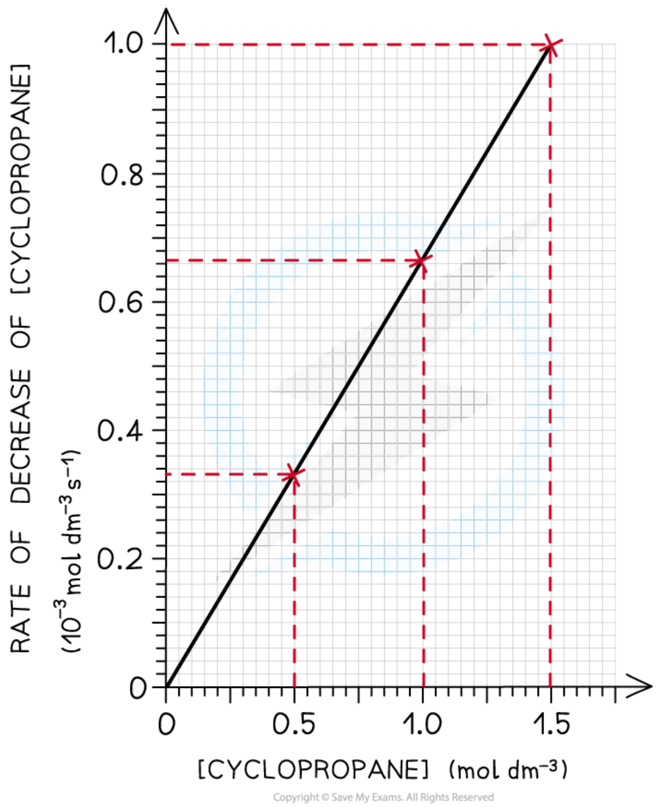
Change in rate with decreasing concentration of cyclopropane table

[cyclopropane] (mol dm^{-3})	Rate (10^{-3} mol dm^{-3} s^{-1})
0.5	0.33
1.0	0.67
1.5	1.0

- This data can then be used to plot a rate-concentration graph
- The graph shows that the rate is directly proportional to the concentration of cyclopropane
  - If you double the concentration of cyclopropane the rate of reaction will double too

Rate-concentration graph



The graph shows a directly proportional correlation between the concentration of cyclopropane and the rate of reaction

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Examiner Tips and Tricks

To calculate the rate of reaction you can either use the increase in concentration of products (like in the example above) or the decrease in concentration of reactants.

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