Cambridge (CIE) IGCSE Chemistry

Your notes

Chemical Change & Rate of Reaction

Contents

Physical & chemical changes

Physical changes

- Physical changes do not produce any new chemical substances
- These changes are often:
  - **Easy to reverse**
  - Relatively **easy to separate**
- Examples of physical changes include:
  - Changing state, e.g. melting / solid → liquid
  - Making a mixture from 2 or more substances
  - Dissolving a solute in a solvent

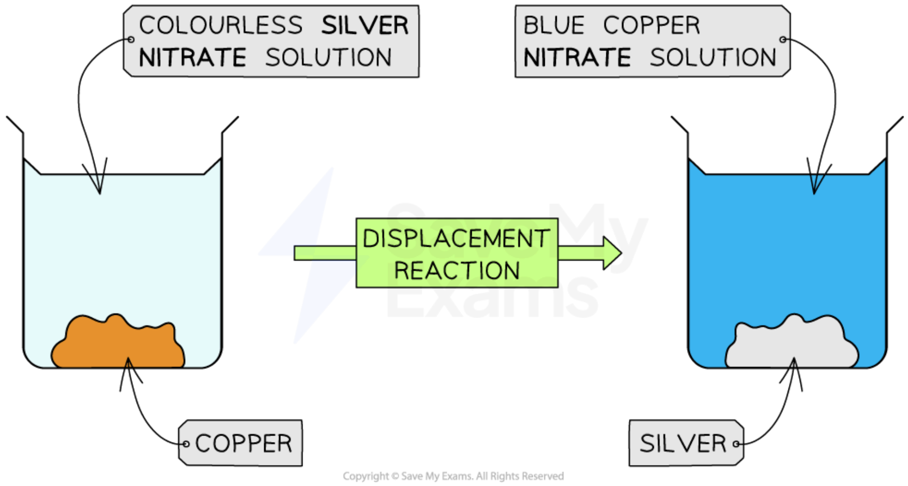
Chemical changes

- During chemical changes / reactions, **new chemical** substances are formed that have very different **properties** to the reactants
- Most chemical changes are **difficult to reverse**
- There may be signs that a new substance has formed, such as:
  - Colour changes
  - Temperature changes
  - Effervescence (fizzing)

Colour change

- One example of a reaction that shows a colour change is the metal displacement reaction of silver and copper
  - Orange-brown copper metal is added to a colourless solution of silver nitrate
  - As the reaction proceeds the copper displaces the silver from the solution
  - This causes two colour changes:
    1. The solid inside the beaker changes from orange-brown to silver
    2. The solution changes from colourless to blue

The metal displacement reaction of silver and copper



The reaction shows two colour changes; one in the colour of the solution and one in the colour of the solid

- Another reaction, from the syllabus, that shows a clear colour change is the halide ion test
  - From colourless to cream / white / yellow depending on the halide ion
  - This also includes a change of state as a solid / precipitate is formed

Temperature change

- Chemical reactions that give a **temperature change** can be grouped into two categories:
  - Those that give out heat / thermal energy - **exothermic**
  - Those that take in heat / thermal energy - **endothermic**

Exothermic reactions

- Some examples of reactions that cause an **increase in temperature** are:
  - The reaction of calcium oxide with water to form calcium hydroxide is highly exothermic
  - The reaction of sodium with water is exothermic and effervesces

Endothermic reactions

- Reactions that cause a **decrease in temperature** are less commonly talked about than exothermic reactions
- Examples include:
  - Photosynthesis
    - Light energy is absorbed during the process of converting carbon dioxide and water into glucose and oxygen

- When solid ammonium chloride is dissolved in water
  - Heat / thermal energy is absorbed from the surroundings, causing the temperature to decrease
  - This reaction is commonly used in cold packs

Effervescence

- Effervescence, or fizzing, is another sign of a chemical reaction
- Chemical reactions that cause effervescence often involve acids:
  - The reaction of alkali metals with water
    - The reaction of the alkali metals, such as sodium, with water releases hydrogen gas
    - Metal + water → metal hydroxide + hydrogen
- There are other signs of a chemical reaction including:
  - Light being produced
  - A smell being produced
  - A change in pH

Your notes

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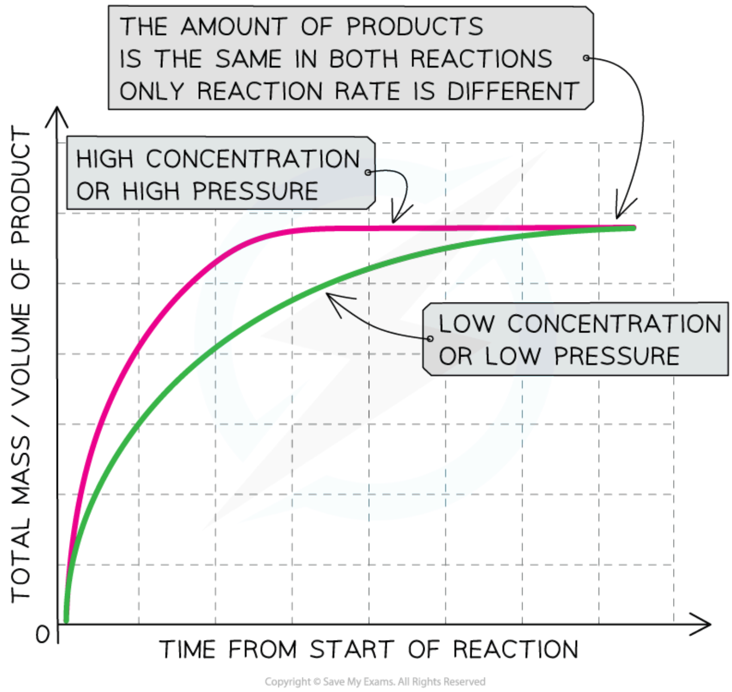
Rates of reaction factors

- Factors that can affect the rate of a reaction are:
  - The **concentration** of the reactants in solution or the **pressure** of reacting gases
  - **Surface area** of solid reactants
  - The **temperature** of the reaction
  - The presence of a **catalyst**
- Changes in these factors directly influence the rate of a reaction
- It is of **economic interest** to have a higher rate of reaction as this implies a higher rate of production and hence a more efficient and sustainable process

The effect of increased concentration or pressure

Graph showing the effect of concentration on rate of reaction



Increasing the concentration of a solution or gas pressure increases the rate of reaction

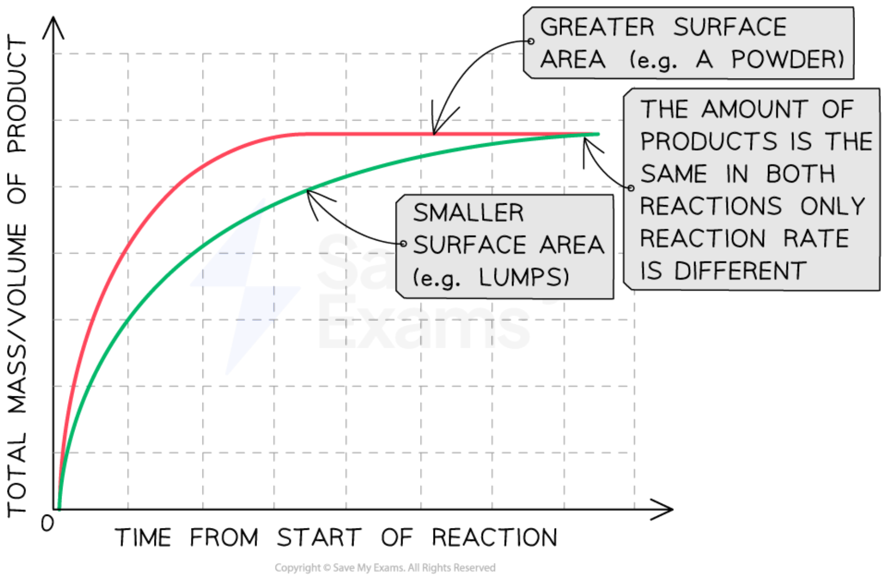
Explanation:

- Compared to a reaction with a reactant at a low concentration (or pressure), the line graph for the same reaction at a higher concentration (or pressure):

- Has a steeper gradient at the start
- Becomes horizontal sooner
- Forms the same amount of product
- This shows that **increasing the concentration (or pressure) increases the rate of reaction**

The effect of increasing surface area

Graph showing the effect of surface area on rate of reaction



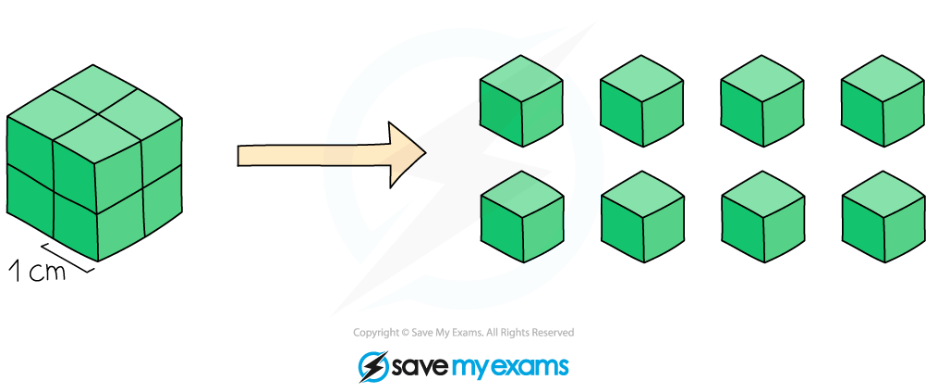
Increasing the surface area increases the rate of reaction

Explanation:

- Compared to a reaction with lumps of reactant, the line graph for the same reaction with powdered reactant:
  - Has a steeper gradient at the start
  - Becomes horizontal sooner
  - Forms the same amount of product
- This shows that **increasing the surface area increases the rate of reaction**
  - Increasing surface area can sometimes be described as decreasing solid particle size

Surface area and particle size

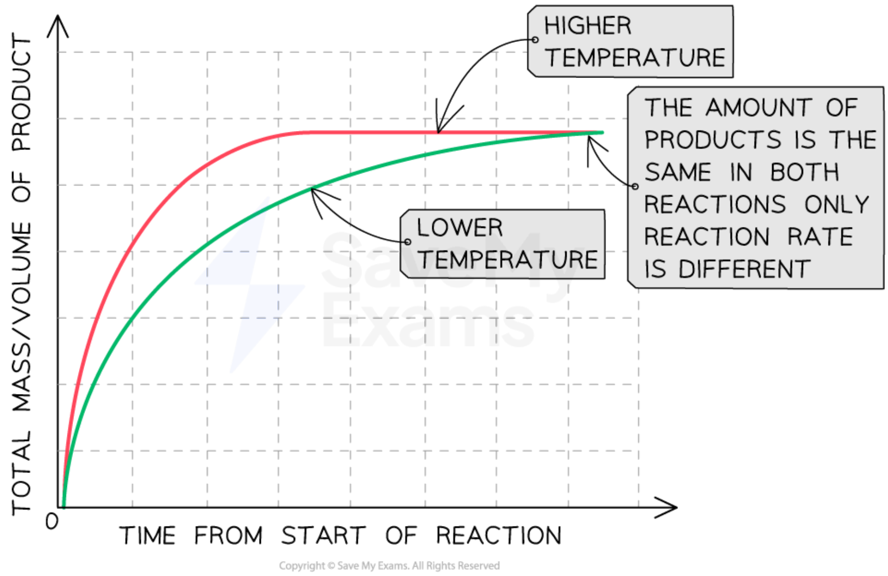
Your notes



Surface area increases as particle size decreases. A 2 cm^3 cube has a surface area of 24 cm^2 and the same cube cut up into 8 cubes has a surface area of 48 cm^2

The effect of increasing temperature

Graph showing the effect of temperature on rate of reaction



Increasing the temperature increases the rate of reaction

Explanation:

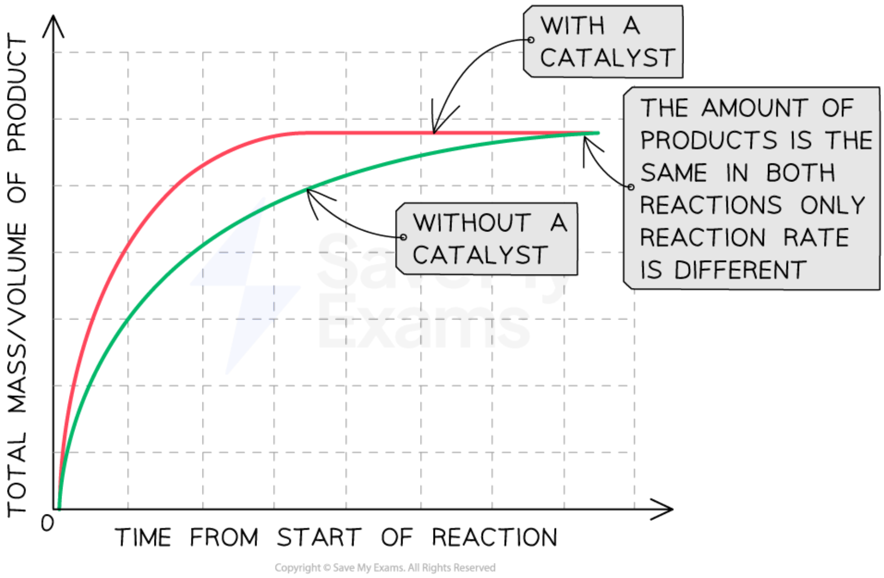
- Compared to a reaction at a low temperature, the line graph for the same reaction at a higher temperature:
  - Has a steeper gradient at the start
  - Becomes horizontal sooner
  - Forms the same amount of product

- This shows that **increasing the temperature increases the rate of reaction**

The effect of using a catalyst

- Catalysts are substances which **speed up** the **rate** of a reaction without themselves being **altered** or **consumed** in the reaction
- The mass of a catalyst at the beginning and end of a reaction is the **same** and they do not form part of the equation

Graph showing the effect of using a catalyst on rate of reaction



Graph showing the effect of using a catalyst on the rate of reaction

Explanation:

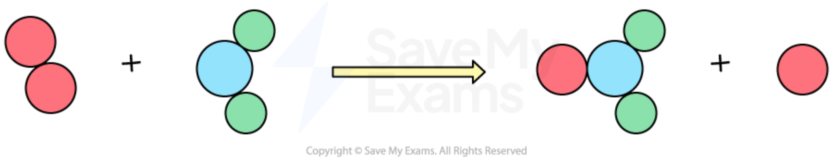
- Compared to a reaction without a catalyst, the graph line for the same reaction but with a catalyst has a steeper gradient at the start and becomes horizontal sooner
- **This shows that with a catalyst, the rate of reaction will increase**

Collision theory

Extended tier only

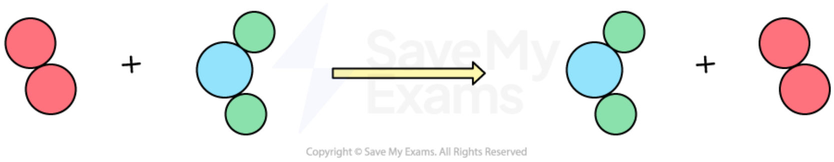
What is collision theory?

- Collision theory states that in order for a reaction to occur:
    - The particles must **collide** with each other
    - The collision must have **sufficient energy** to cause a reaction i.e. enough energy to break bonds
    - The minimum energy that colliding particles must have to react is known as the **activation energy**
- Collisions can be described as **successful** or **unsuccessful**
    - A **successful collision** means that the reactant particles collide and rearrange to form the products
        - This happens when the particles have sufficient energy (i.e. energy greater than the activation energy) to react



The collision is successful resulting in a rearrangement of atoms to form the products

- An **unsuccessful collision** means that the reactant particles just bounce off each other and remain unchanged
    - This happens when the particles do not have sufficient energy to break the necessary bonds or do not collide in the correct orientation



The collision is unsuccessful resulting in no rearrangement of atoms

How to increase the number of successful collisions

- Increasing the number of successful collisions means that a greater proportion of reactant particles collide to form product molecules
- The number of successful collisions depends on:
  - The **number of particles per unit volume** - more particles in a given volume will produce more frequent successful collisions
  - The **frequency of collisions** - a greater number of collisions per second will give a greater number of successful collisions per second
  - The **kinetic energy of the particles** - greater kinetic energy means a greater proportion of collisions will have an energy that exceeds the activation energy and the more frequent the collisions will be as the particles are moving quicker, therefore, more collisions will be successful
  - The **activation energy** - fewer collisions will have an energy that exceeds higher activation energy and fewer collisions will be successful
- These all have an impact on the rate of reaction which is dependent on the number of successful collisions per unit of time

Explaining rates using collision theory

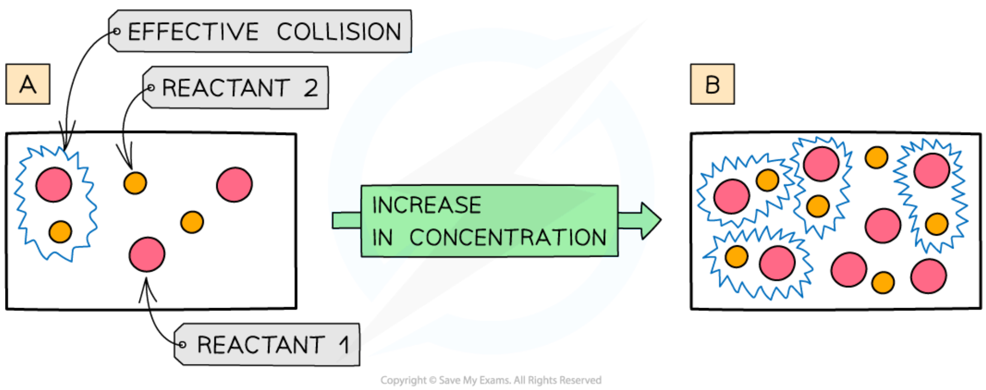
Extended tier only

- Collision theory can explain why concentration, pressure, surface area, temperature and catalysts affect the rate of a chemical reaction

How increasing concentration affects rate

- Increasing the concentration of a solution increases the rate of reaction
- Increasing the concentration means that there are more reactant particles in a given volume
  - This causes more collisions per second
  - Leading to more frequent and successful collisions per second
  - Therefore, the rate of reaction increases
- If you double the number of particles, you will double the number of collisions per second
  - The number of collisions is **proportional** to the number of particles present

Diagram showing the effect of increasing concentration



A higher concentration of particles in (b) means that there are more particles present in the same volume than (a) so the number of collisions and successful collisions between particles increases causing an increased rate of reaction

Examiner Tips and Tricks

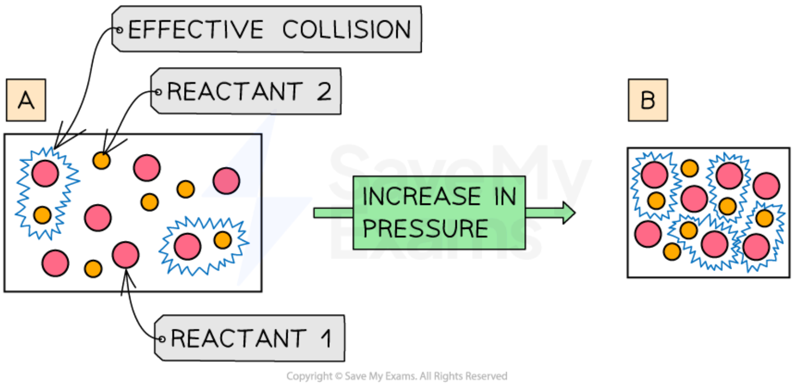
Your notes

When answering questions on the effect of concentration on the rate of reaction, you should mention that there are more particles **per unit volume** (usually cm^3) and this causes an increase in the rate of collisions.

How increasing pressure affects rate

- Increasing the pressure of a gas increases the rate of reaction
- Increasing the pressure means that there are the same number of reactant particles in a smaller volume
  - This causes more collisions per second
  - Leading to more frequent and successful collisions per second
  - Therefore, the rate of reaction increases

Diagram showing the effect of increasing pressure

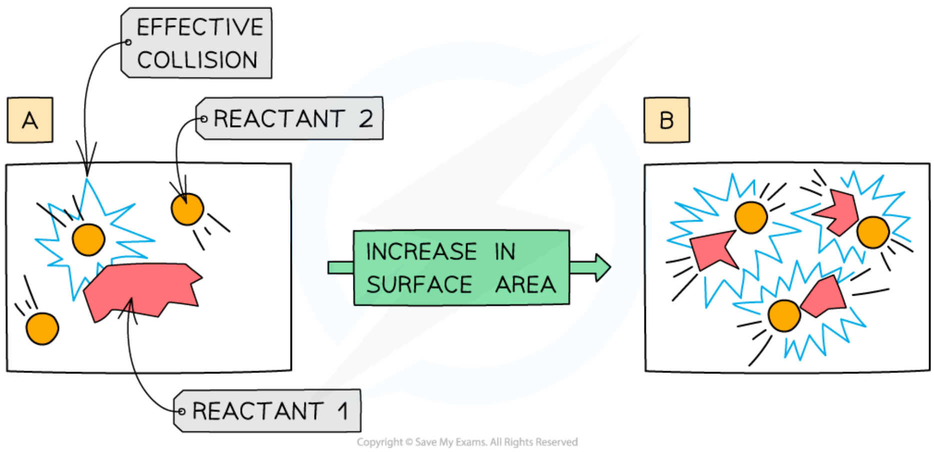


The higher pressure (b) means that there are the same number of particles present in a smaller volume than (a) so the number of collisions and successful collisions between particles increases causing an increased rate of reaction

How increasing the surface area affects rate

- Increasing the surface area increases the rate of reaction
- Increasing the surface area means that a greater **surface area** of **particles** will be exposed to the other reactant
  - This causes more collisions per second
  - Leading to more frequent and successful collisions per second
  - Therefore, the rate of reaction increases
- If you double the surface area, you will double the number of collisions per second

Diagram showing the effect of increasing surface area

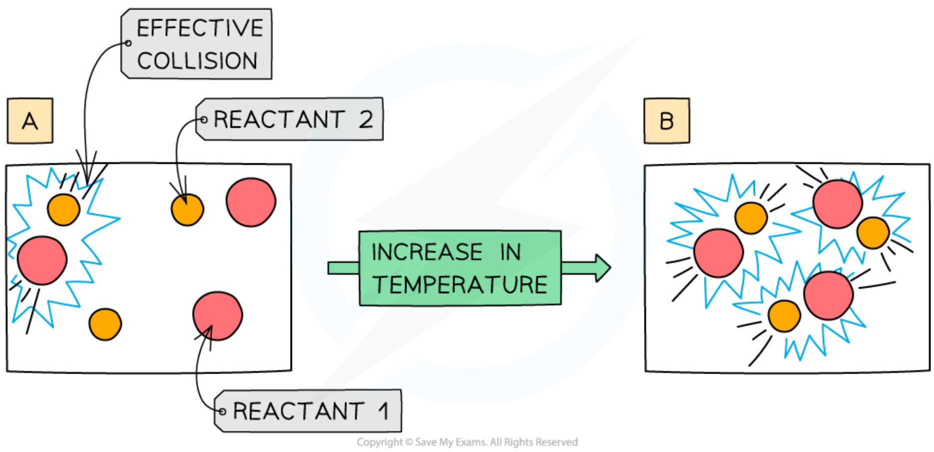


An increase in surface area means more collisions per second

How increasing temperature affects rate

- Increasing the temperature increases the rate of reaction
- Increasing the temperature means that the particles have more kinetic energy
  - This causes more collisions per second
  - Leading to more frequent and successful collisions per second
  - Therefore, the rate of reaction increases
- The effect of temperature on collisions is not so straightforward as concentration or surface area; a small increase in temperature causes a large increase in rate
- For aqueous and gaseous systems, a rough rule of thumb is that for every 10 °C increase in temperature, the rate of reaction approximately doubles

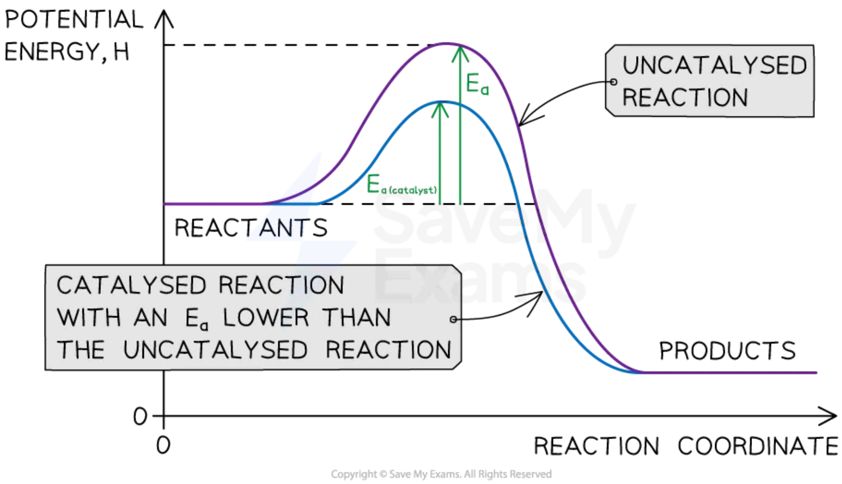
Diagram showing the effect of increasing temperature



An increase in temperature causes an increase in the kinetic energy of the particles. The number of successful collisions increases

How a catalyst affects rate

- Catalysts are substances which **speed up** the **rate** of a reaction without themselves being **altered** or **consumed** in the reaction
- Different processes require different types of catalysts but they all work on the same principle
- A catalyst provides a **different reaction pathway** that has a **lower activation energy**
  - This means a higher proportion of the reactant particles have energy greater than the activation energy and will result in more successful collisions per second



A catalyst lowers the activation energy of a reaction by providing an alternative reaction pathway

- An important industrial example is iron, which is used to catalyse the Haber Process for the production of ammonia
  - Iron **beads** are used to increase the **surface area** available for catalysis
- Enzymes are **biological** catalysts, they work best at specific temperature and pH ranges
- Normally only **small amounts** of catalysts are needed to have an effect on a reaction

Examiner Tips and Tricks

- Temperature is the only factor that **directly** affects the energy of collisions because the increased thermal energy is converted to increased kinetic energy in the particles
  - Concentration, pressure and surface area only affect the number of collisions
- Temperature affects reaction rate by increasing the number of collisions and increasing the energy of the collisions

- Of these two, the increase in energy is the more important one.

Your notes

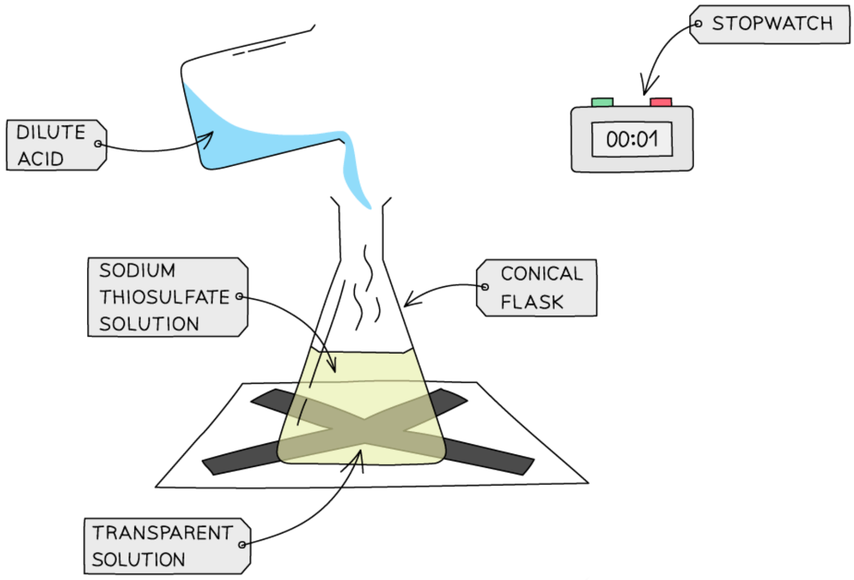
Investigating the rate of a reaction

- To measure the **rate of a reaction**, we need to be able to measure:
  - How quickly the reactants are used up
    OR
    How quickly the products are formed
- The method used for measuring depends on the substances involved
- There are a number of ways to measure a reaction rate in the lab
  - They all depend on a property changing during the course of the reaction
  - Properties that change during the course of a reaction include:
    - Colour
    - Mass
    - Volume
- The changing property is taken to be **proportional** to the concentration of the reactant or product
- Faster reactions can be easier to measure when the reaction is over
  - This can be done by averaging a collected measurement over the course of the reaction
- Some reaction rates can be measured as the reaction proceeds (this generates more data)
- Three commonly used techniques are:
  - **measuring mass loss on a balance**
  - **measuring the volume of a gas produced**
  - **measuring a reaction where there is a colour change at the end of the reaction**

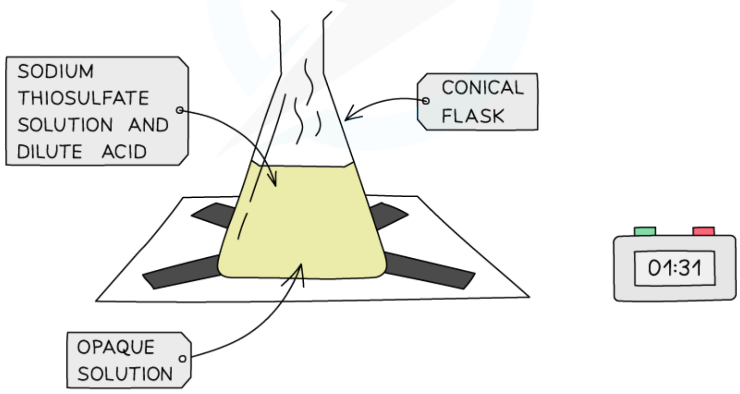
Investigating the effect of concentration of a solution on the rate of reaction

Your notes

1 ADD ACID TO SODIUM THIOSULFATE SOLUTION, START TIMER.



2 STOP TIMER WHEN 'X' IS NO LONGER VISIBLE. RECORD TIME.



3 REPEAT STEPS 1–2 WITH DIFFERENT CONCENTRATIONS OF SODIUM THIOSULFATE (MADE BY MIXING DIFFERENT VOLUMES OF WATER AND SODIUM THIOSULFATE)

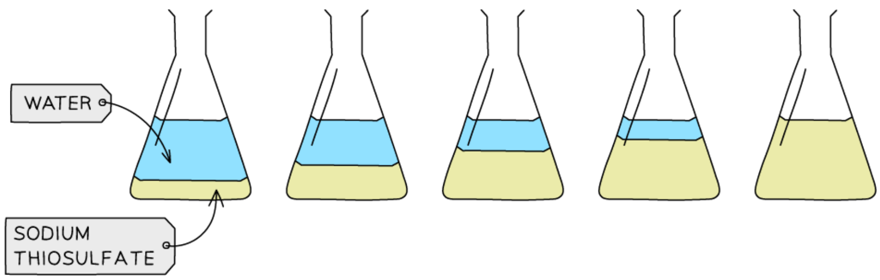


Diagram showing the apparatus needed to investigate the effect of concentration on the rate of reaction

Method:

- Measure 50 cm^3 of sodium thiosulfate solution into a flask
- Measure 5 cm^3 of dilute hydrochloric acid into a measuring cylinder
- Draw a cross on a piece of paper and put it underneath the flask
- Add the acid into the flask and immediately start the stopwatch
- Look down at the cross from above and stop the stopwatch when the cross can no longer be seen
- Repeat using different concentrations of sodium thiosulfate solution (mix different volumes of sodium thiosulfate solution with water to dilute it)

Result:

- With an increase in the concentration of a solution, the rate of reaction will increase
- This is because there will be more reactant particles in a given volume, allowing more frequent and successful collisions, increasing the rate of reaction

Investigating the effect of surface area on the rate of reaction

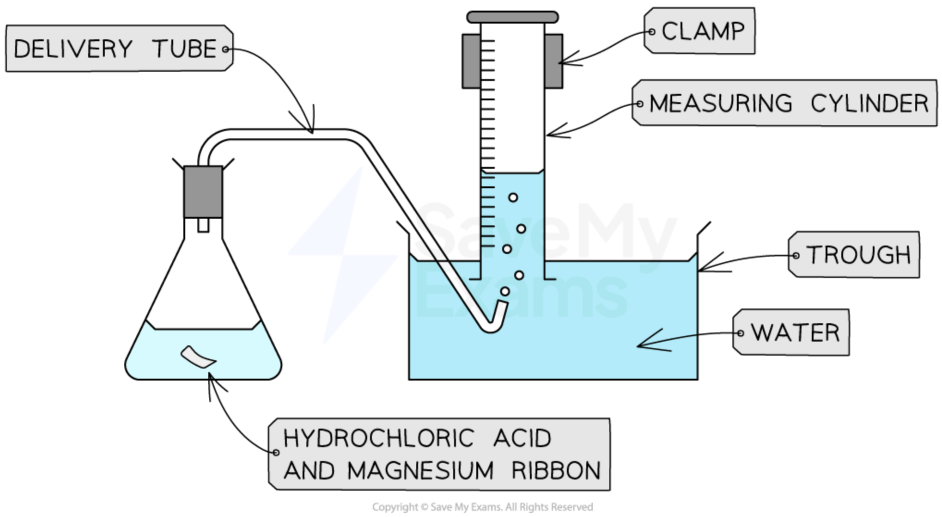


Diagram showing the process of downwards displacement to investigate the effect of the surface area of a solid on the rate of reaction

Method:

- Add dilute hydrochloric acid into a conical flask

- Use a delivery tube to connect this flask to a measuring cylinder upside down in a bucket of water (downwards displacement)
- Add magnesium ribbon to the conical flask and quickly put the bung back into the flask
- Measure the volume of gas produced in a fixed time using the measuring cylinder
- Repeat with different size pieces of magnesium ribbon
  - The same total mass of magnesium must be used

Result:

- Smaller pieces of magnesium ribbon cause an increase in the surface area of the solid, so the rate of reaction will increase
- This is because more surface area of the particles will be exposed to the other reactant so there will be more frequent and successful collisions, increasing the rate of reaction

Investigating the effect of temperature on the rate of reaction

Your notes

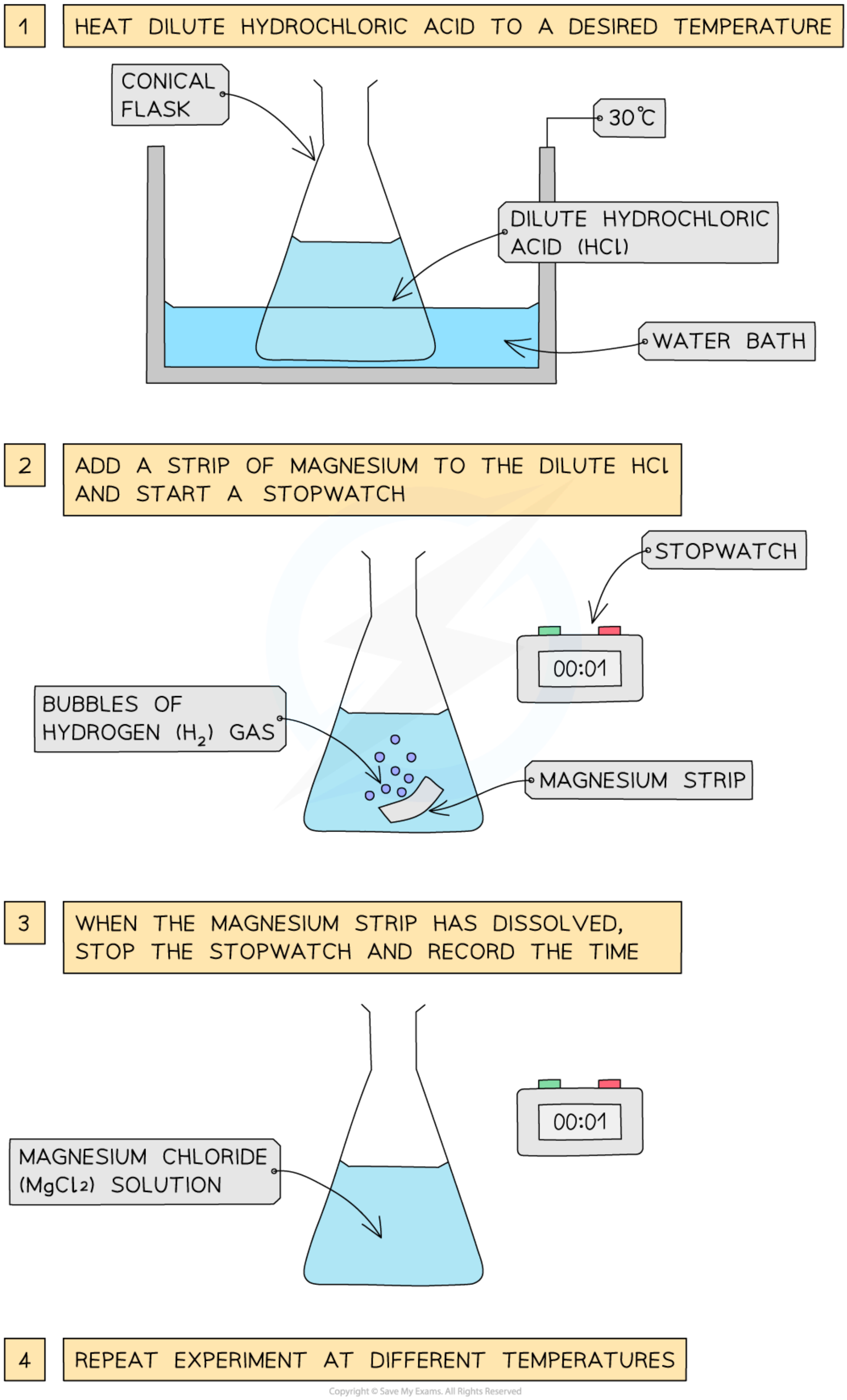


Diagram showing the apparatus needed to investigate the effect of temperature on the rate of reaction

Method:

- Dilute hydrochloric acid is heated to a set temperature using a water bath
- Add the dilute hydrochloric acid into a conical flask
- Add a strip of magnesium and start the stopwatch
- Stop the time when the magnesium fully reacts and disappears
- Repeat at different temperatures and compare results

Result:

- With an increase in the temperature, the rate of reaction will increase
- This is because the particles will have more kinetic energy than the required activation energy, therefore more frequent and successful collisions will occur, increasing the rate of reaction

Investigating the effect of a catalyst on the rate of reaction

Your notes

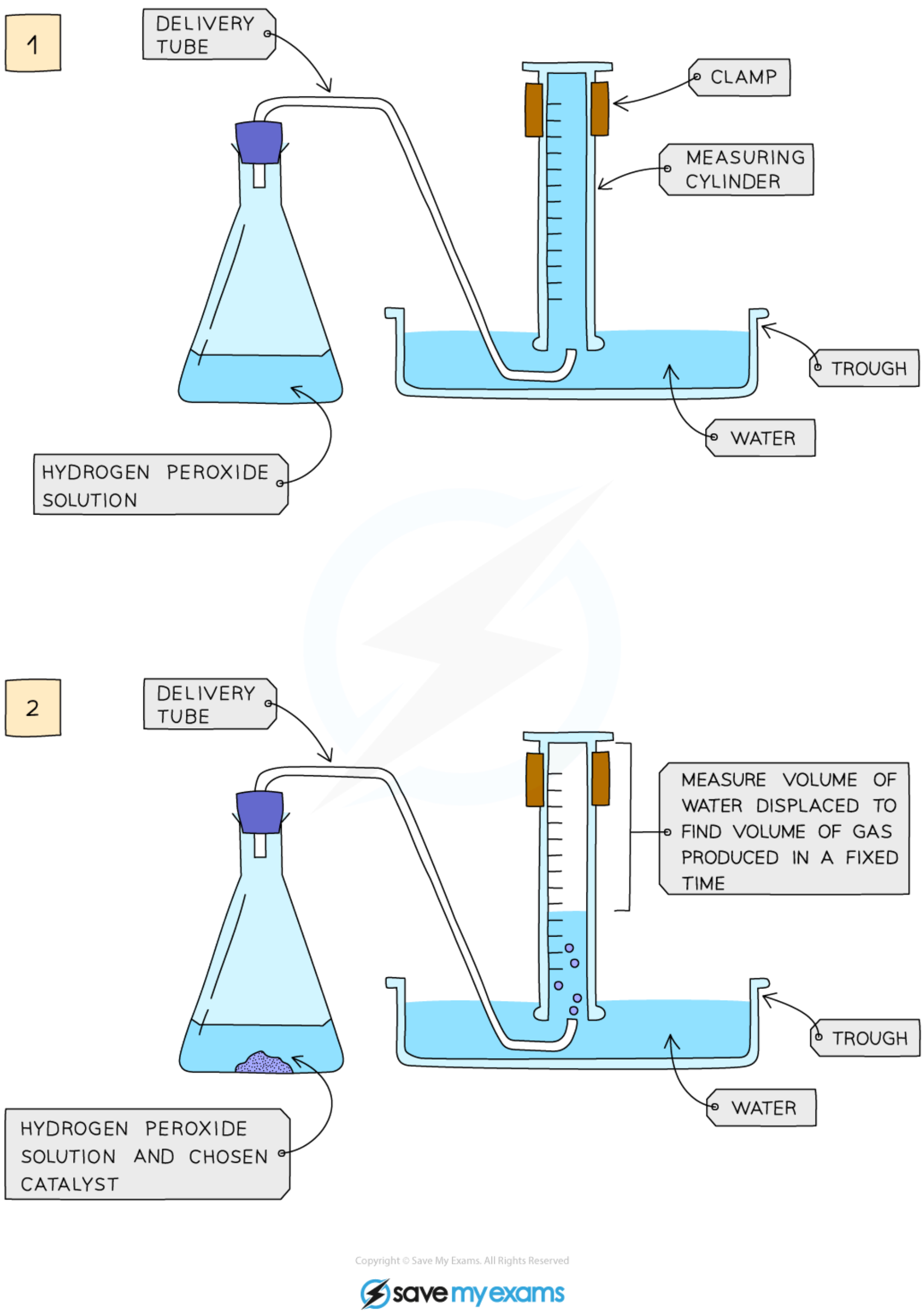


Diagram showing the apparatus needed to investigate the effect of a catalyst on the rate of reaction

Method:

- Add hydrogen peroxide into a conical flask
- Use a delivery tube to connect this flask to a measuring cylinder upside down in a tub of water (downwards displacement)

- Add the catalyst manganese(IV) oxide into the conical flask and quickly place the bung into the flask
- Measure the volume of gas produced in a fixed time using the measuring cylinder
- Repeat experiment without the catalyst of manganese(IV) oxide and compare results

Result:

- Using a catalyst will increase the rate of reaction
- The catalyst will provide an alternative pathway requiring lower activation energy so more colliding particles will have the necessary activation energy to react
- This will allow more frequent and successful collisions, increasing the rate of reaction

Monitoring changes in mass

- Many reactions involve the production of a gas which will be released during the reaction
- The gas can be collected and the volume of gas monitored as per some methods above
- Alternatively, the reaction can be performed in an **open flask** on a balance to measure the loss in mass of reactant
- Cotton wool is usually placed in the mouth of the flask which allows gas out but prevents any materials from being ejected from the flask (if the reaction is vigorous)

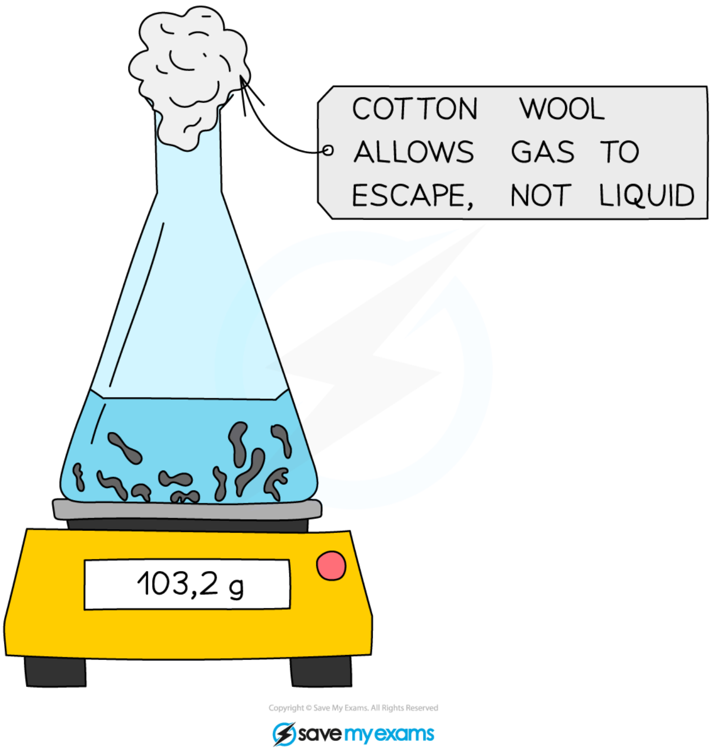


Diagram showing the set-up for measuring the rate of reaction by loss in mass

- This method is not suitable for hydrogen and other gases with a small relative formula mass, M_r as the loss in mass may be too small to measure

Your notes

Examiner Tips and Tricks

There are many different methods of investigating the rate of reaction.

Another method of gas collection you may see uses a gas syringe.

Extended tier students may be required to devise and evaluate methods of investigating rates of reaction.

Evaluating investigations of rates of reactions

Extended tier only

- When investigating rates of reaction, there are a number of different methods that can be used to carry out the same investigation
- Evaluating what is the best method to use is part of good experimental planning and design
- This means appreciating some of the advantages and disadvantages of the methods available

Advantages and disadvantages of methods of investigating rates of reaction

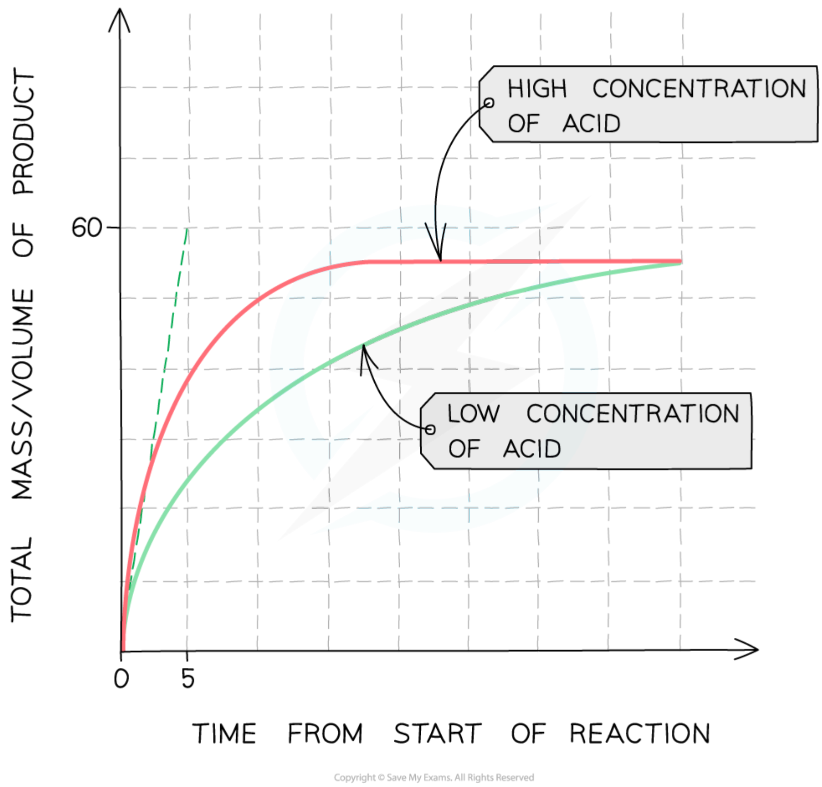
Experiment	Advantage	Disadvantage
Formation of a solid / precipitate (Disappearing cross experiment)	Simple experiment with no specialist equipment	Difficult to determine when the cross is obscured as people will determine the cross to have disappeared at different levels of cloudiness Easy to contaminate equipment
Gas collection using a gas syringe	Works for all reactions that produce a gas All the gas collected is from the reaction Easy to set up	Gas syringes are fragile and expensive Gas syringes can stick They can collect limited volumes Gas can be lost before the bung is securely connected to the reaction flask, especially in fast reactions

Gas collection using an inverted measuring cylinder	Works for all reactions that produce a gas Uses common lab equipment	The delivery tube can pop out of the measuring cylinder It can be difficult to read the scale as it is upside down and may be obscured by bubbles Gas is lost while the bung is connected to the reaction flask
Measuring mass lost on a balance	Easy to set up Uses common lab equipment	Not suitable for gases with low molecular mass

Your notes

Interpreting data

- Data recorded in rate studies is used to **plot graphs** to calculate the rate of a reaction
- Plotting a graph until the completion of the reaction shows how the rate of reaction changes with time
- The rate of reaction is always quickest at the start of the chemical reaction
  - This is when there are the most reactants available to collide and form products
  - On a graph, the line at the start of the reaction has the steepest gradient
- As the reaction progresses, the rate of reaction decreases
  - This is because the concentration of reactants decreases as they are being used up
  - On a graph, the line becomes less steep
- The reaction eventually stops
  - This is because at least one of the reactants has been used up
  - The rate of reaction is now zero
  - On a graph, this is when the line becomes horizontal
- The amount of product formed in a reaction is determined by the limiting reactant:
  - If the amount of limiting reactant increases, the amount of product formed increases
  - If the amount of the reactant in excess increases, the amount of product remains the same
- You can plot more than one run of a variable on the same graph making it easier to see how the variable influences the rate
  - For example, plotting the effect of concentration on a reaction between the acid and marble chips

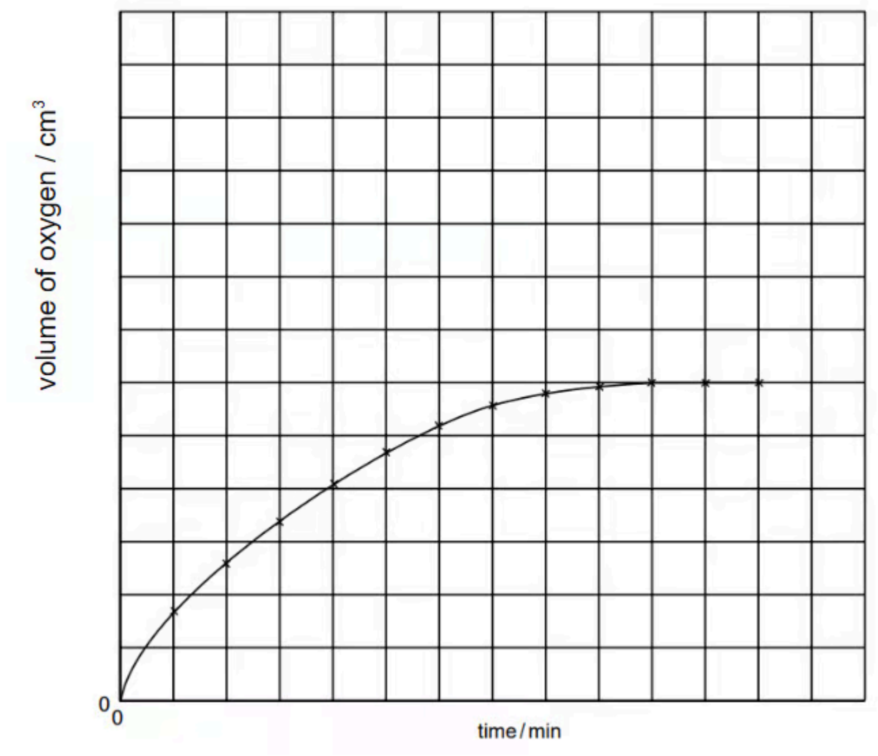


- Drawing a **tangent** to the slope allows you to show the gradient at any point on the curve
    - A steeper slope means a quicker reaction and a higher rate of reaction
- The volume of a gaseous product would increase to a maximum over time
    - So, the line levels out indicating the reaction is over
    - Since the volume and mass would be proportional, this could also be a graph of the mass of product versus time

Worked Example

0.2 g of manganese(IV) oxide was added to 25 cm^3 of 0.1 mol / dm^3 hydrogen peroxide solution. The volume of oxygen produced every minute was recorded and the results are shown on the graph.

Your notes

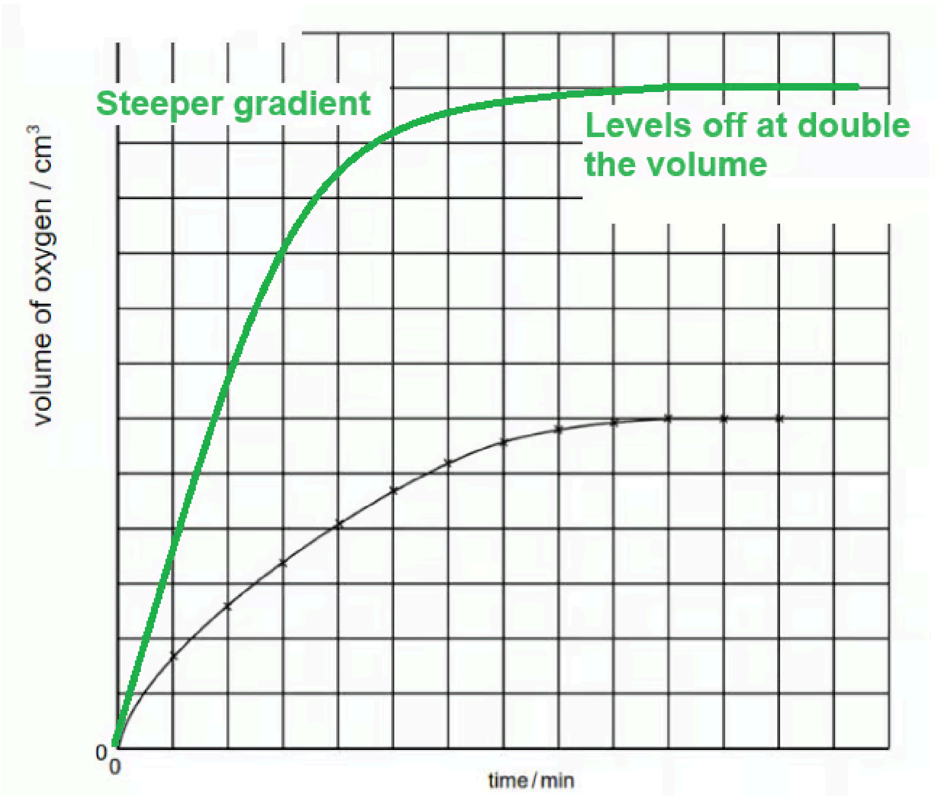


The experiment was repeated using the same mass of manganese(IV) oxide and at the same temperature but using 25 cm^3 of 0.2 mol / dm^3 of hydrogen peroxide solution.

Sketch the curve for the results of this experiment on the same grid.

Answer:

1. Deduce how the initial gradient will be different from the original graph
   - The hydrogen peroxide solution is twice as concentrated
   - So, the rate of reaction will be greater and the initial **gradient will be steeper**
2. Deduce how much product will be formed compared to the original experiment
   - The amount of hydrogen peroxide determines the amount of oxygen produced
   - In the 2nd experiment, there are twice as many hydrogen peroxide molecules in the same volume
   - So, this will produce **double** the amount of oxygen **in the same time**
3. Sketch the graph



Your notes

Calculating the rate of reaction at a particular point

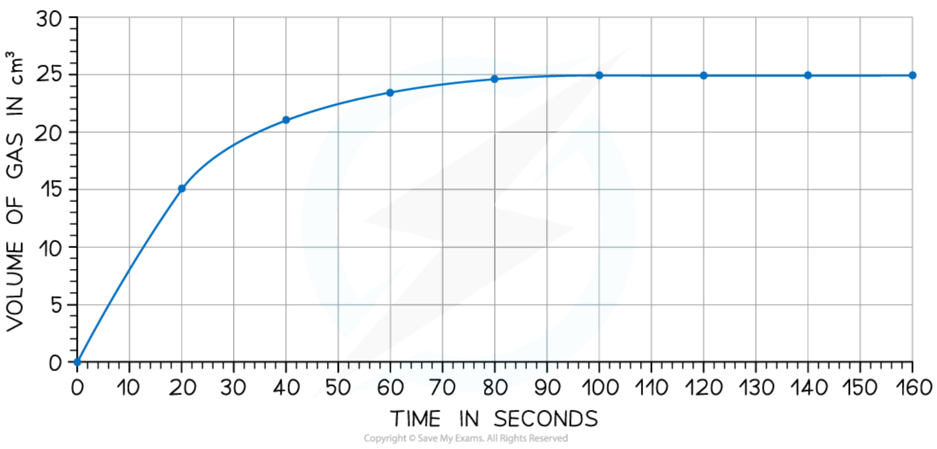
- To calculate the rate of reaction at any given time / point in a chemical reaction, you need to find the **gradient of the curve** at that time / point
- To do this:
  - Draw a **tangent to the curve**
  - Calculate the change in the y-axis
  - Calculate the change in the x-axis
  - Calculate the gradient of the tangent using:
    - Rate of reaction (or gradient) = $\frac{\text{change in y}}{\text{change in x}}$

Worked Example

Iodine and methanoic acid react in aqueous solution.

$$I_2\,(aq) + HCOOH\,(aq) \rightarrow 2I^-\,(aq) + 2H^+\,(aq) + CO_2\,(g)$$

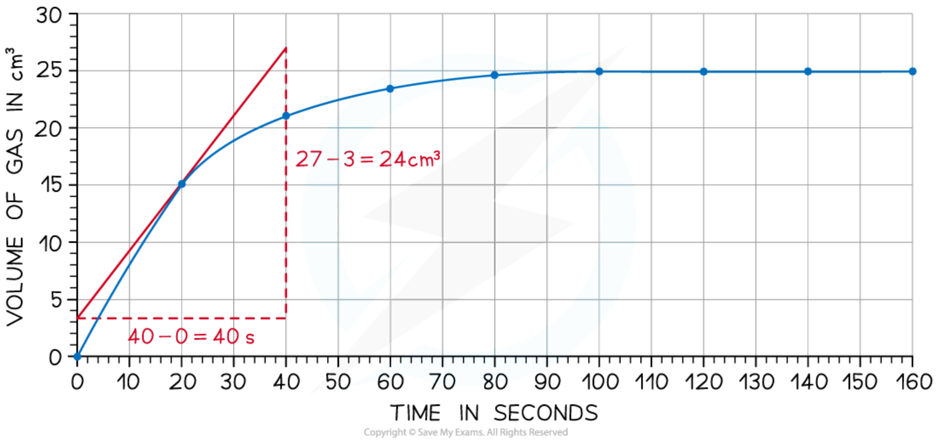
The rate of reaction can be found by measuring the volume of carbon dioxide produced per unit time and plotting a graph as shown:



Calculate the rate of reaction at 20 seconds.

Answer:

- Draw a tangent to the curve at 20 seconds:



- Complete the triangle and read off the values of x and y
- Determine the rate of reaction / gradient of the line:
  - Rate of reaction (or gradient) = $\frac{\text{change in y}}{\text{change in x}}$
  - Rate of reaction (or gradient) = $\frac{24}{40}$ = 0.60 cm^3 / s

Your notes

Examiner Tips and Tricks

If the amount of reactant used up is being monitored, then the graph will **fall** with the steepest gradient at the start, becoming less steep until it levels off to a horizontal line.