Edexcel GCSE Chemistry

Your notes

Rates of Reaction

Contents

Core Practical: Investigating Rate of Reaction

Your notes

Determining the Rate of a Reaction

- To measure the **rate of a reaction**, we need to be able to measure either 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 some property that changes during the course of the reaction
- That property is taken to be **proportional** to the concentration of the reactant or product, e.g., colour, mass, volume
- Some reaction rates can be measured as the reaction proceeds (this generates more data);
  - faster reactions can be easier to measure when the reaction is over, by averaging a collected measurement over the course of the reaction
- 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**

Changes in Mass

- When a gas is produced in a reaction it usually escapes from the reaction vessel, so the mass decreases
  - This can be used to measure the rate of reaction
  - For example, the reaction of calcium carbonate with hydrochloric acid produces CO_2
  - The mass is measured every few seconds and change in mass over time is plotted as the CO_2 escapes

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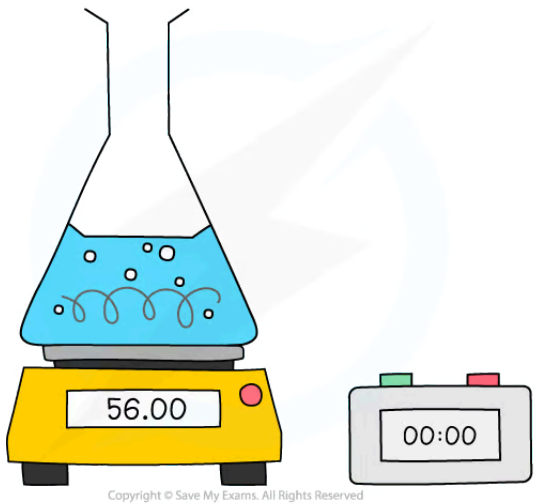
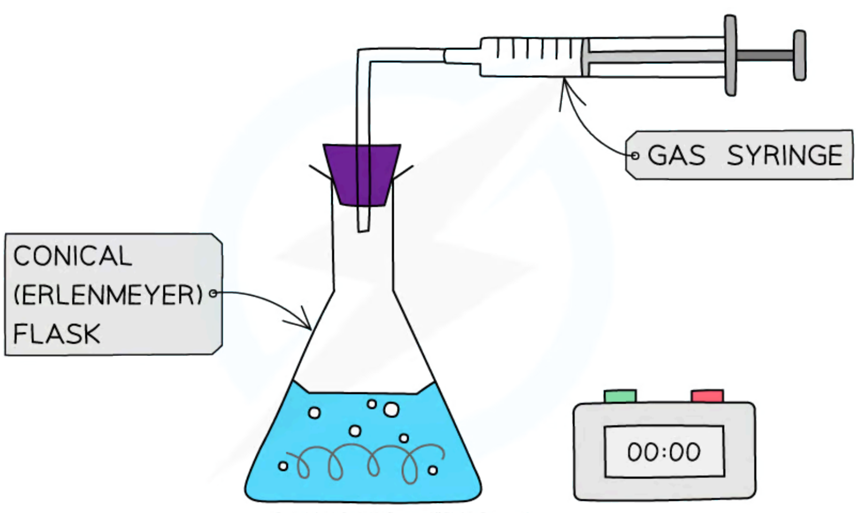


Measuring mass changes on a balance

Volumes of Gases

- When a gas is produced in a reaction, it can be trapped and its volume measured over time
  - This can be used to measure the rate of reaction.
  - For example, the reaction of magnesium with hydrochloric acid produces hydrogen

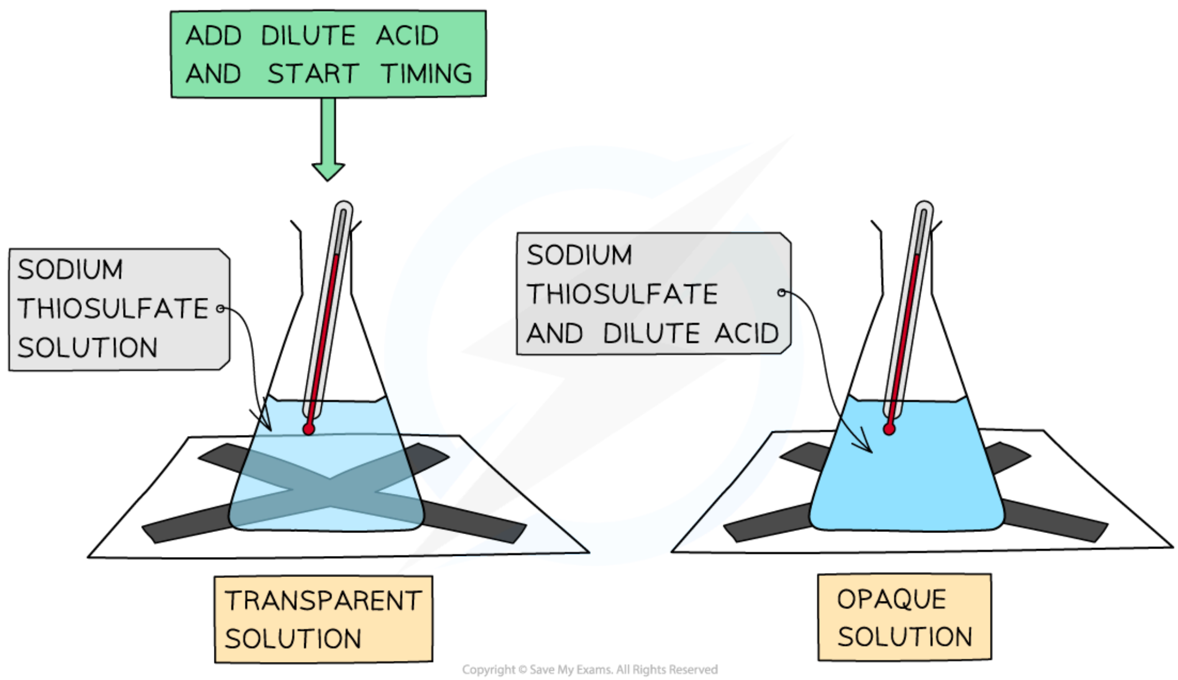


Measuring changes in gas volume

Measuring concentration changes

- Measuring concentration changes during a reaction is not easy; the act of taking a sample and analysing it by **titration** can affect the rate of reaction (unless the reaction is deliberately stopped- this is called **quenching**).
- Often it is more convenient to 'stop the clock' when a specific (visible) point in the reaction is reached
  - For example when a piece of magnesium dissolves completely in hydrochloric acid
  - Another common rate experiment is the reaction between sodium thiosulfate and hydrochloric acid which slowly produces a yellow precipitate of sulfur that obscures a cross when viewed through the solution:

$$Na_2S_2O_3\,(aq) + 2HCl\,(aq) \rightarrow 2NaCl\,(aq) + SO_2\,(g) + H_2O\,(l) + S\,(s)$$



The disappearing cross experiment

Calculating rates of reaction

- Reactions take place at different rates depending on the identities and conditions
- Some are extremely slow e.g. rusting and others are extremely fast e.g. explosives
- Rates of reaction can be measured either by how fast a **reactant** is used up or by how fast the **product** is made

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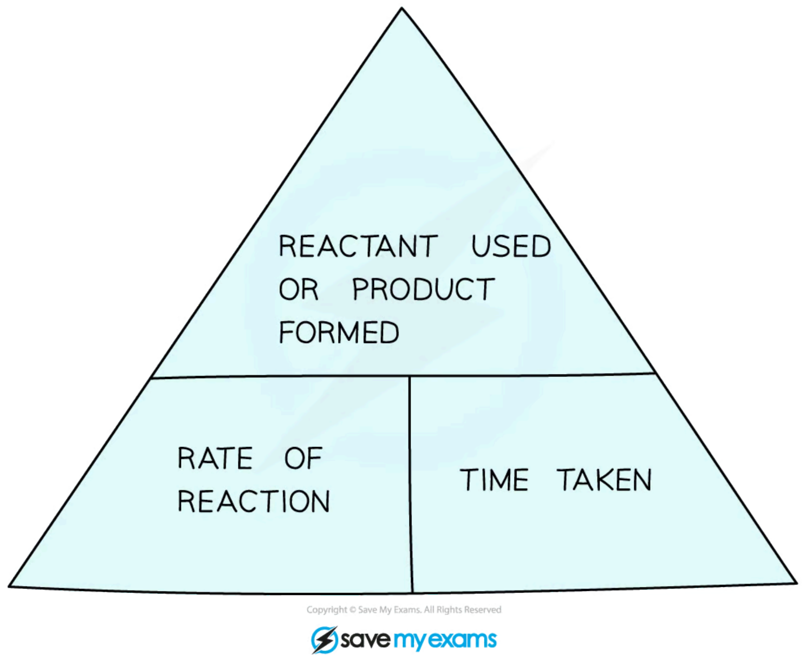
- Rate is concerned with amounts of substances and time and can be calculated using the formula:



A formula triangle for calculating the rate of reaction

- In order to provide sufficient data to establish a conclusion several measurements need to be made during the reaction
- The product is usually the one that is measured as it is usually easier to measure a product forming than it is a reactant disappearing
- The quantity to be measured depends on the reaction and may be in grams for mass or cm^3 or dm^3 for volume if the product is a gas
- The units of the rate of reaction would therefore be g/s or cm^3/s or dm^3/s
- Time is usually in **seconds** as many reactions studied in the lab are quite quick
- If one of the products is a gas which is given off, then 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)

Calculating Gradients

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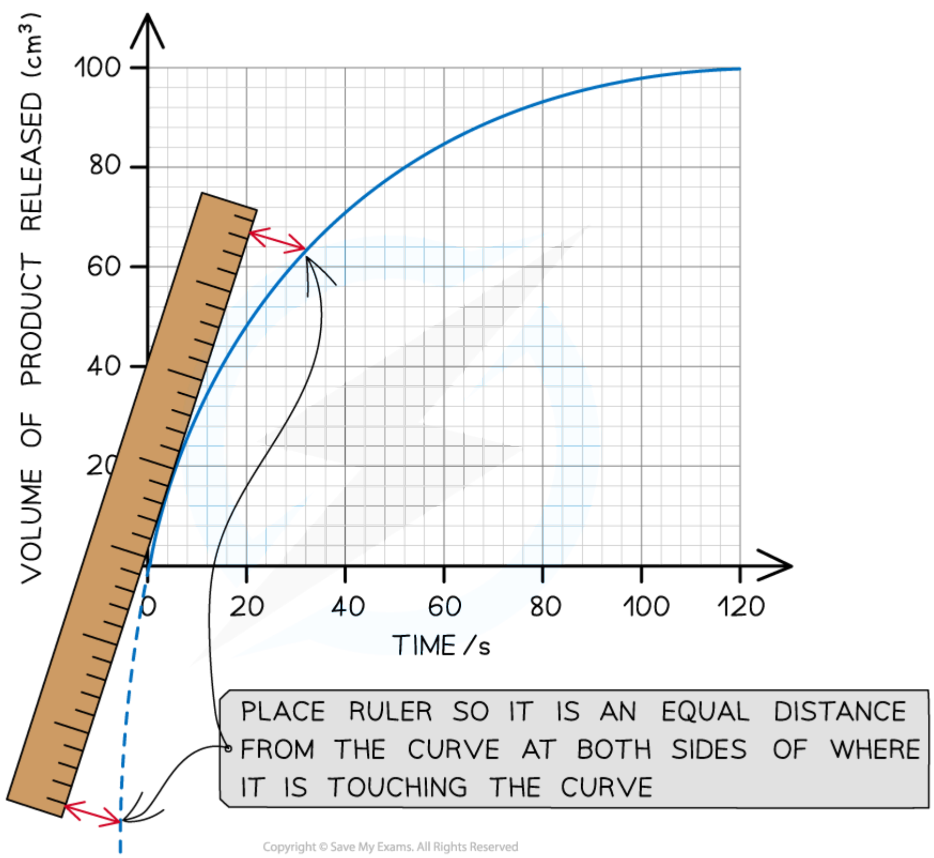
- Often a curved graph is obtained or a graph which starts out as a straight line but then curves to form a horizontal line as the reaction peters out, usually due to one of the reactants running out
- The curved section signifies that the relationship between rate and the factor being measured is not **directly proportional**, so the rate of reaction is **different** along each point of the curve
- For a curve graph a **tangent** must be drawn to calculate the change in x and y so the rate of reaction at a **particular point** during the reaction can be calculated
- Place a ruler on the point being studied and adjust its position so the space on either side of the point between the ruler and curve are equal:



Drawing a tangent to a curve using a ruler

- Use the tangent to calculate the rate of reaction as shown below:

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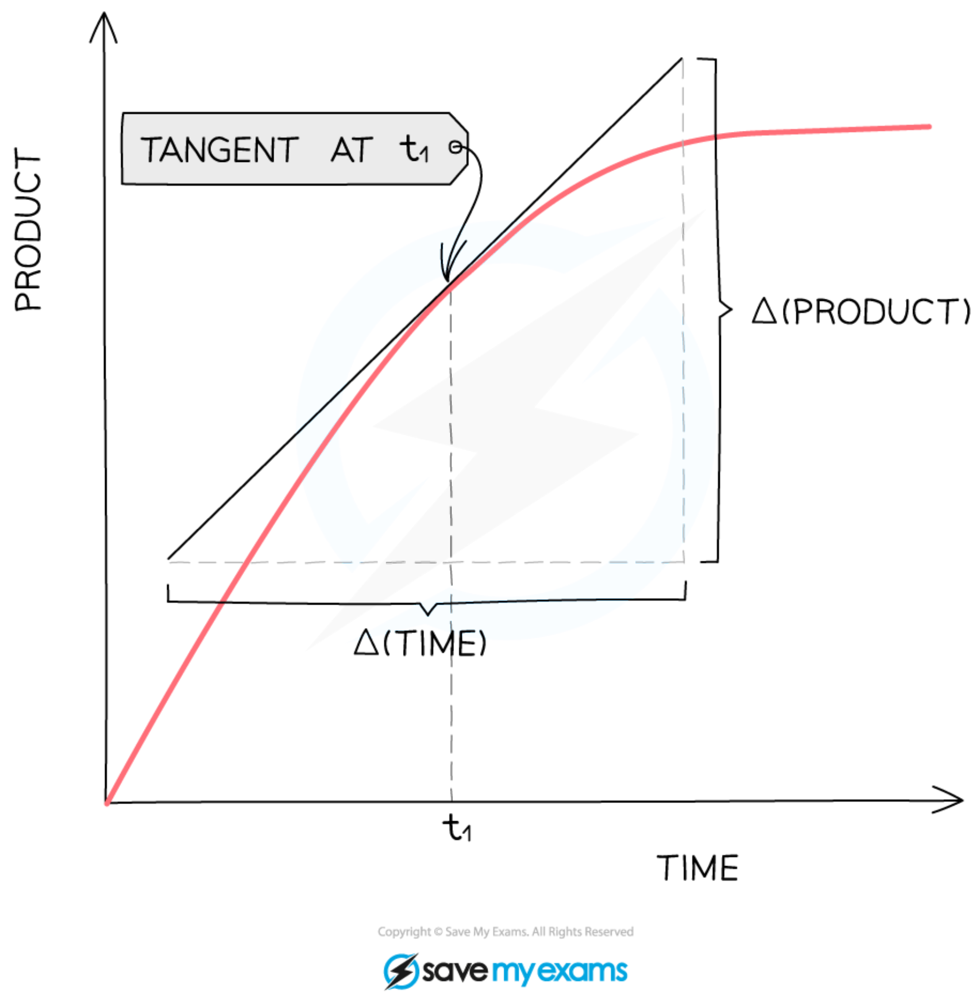


Obtaining a tangent on a curve

- The gradient at that point is

GRADIENT = Δ (PRODUCT) ÷ Δ (TIME)

- You can use this formula to calculate the gradient at any particular point in the curve

Examiner Tips and Tricks

Your notes

> When drawing tangents, the line should be extended as far as is convenient for you to perform the calculations. Extending the tangent in this way decreases the amount of uncertainty.

Core Practical: Investigating Rate of Reaction

Part A– Measuring the Production of a Gas

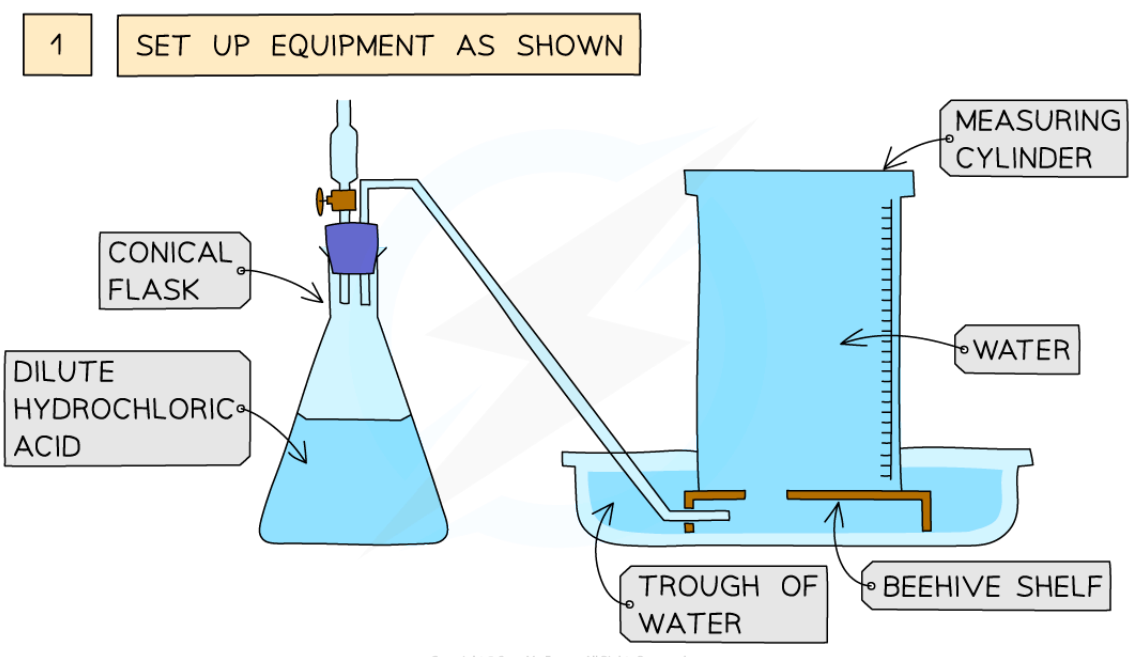
Aim:

To investigate the effect of changing surface area of marble chips in the reaction between marble chips and hydrochloric acid

Materials:

- Marble chips, small and large
- Hydrochloric acid 1 mol dm^{-3}
- Conical flask (100 cm^3)
- Safety goggles
- Gas syringe
- Stop clock

Diagram:



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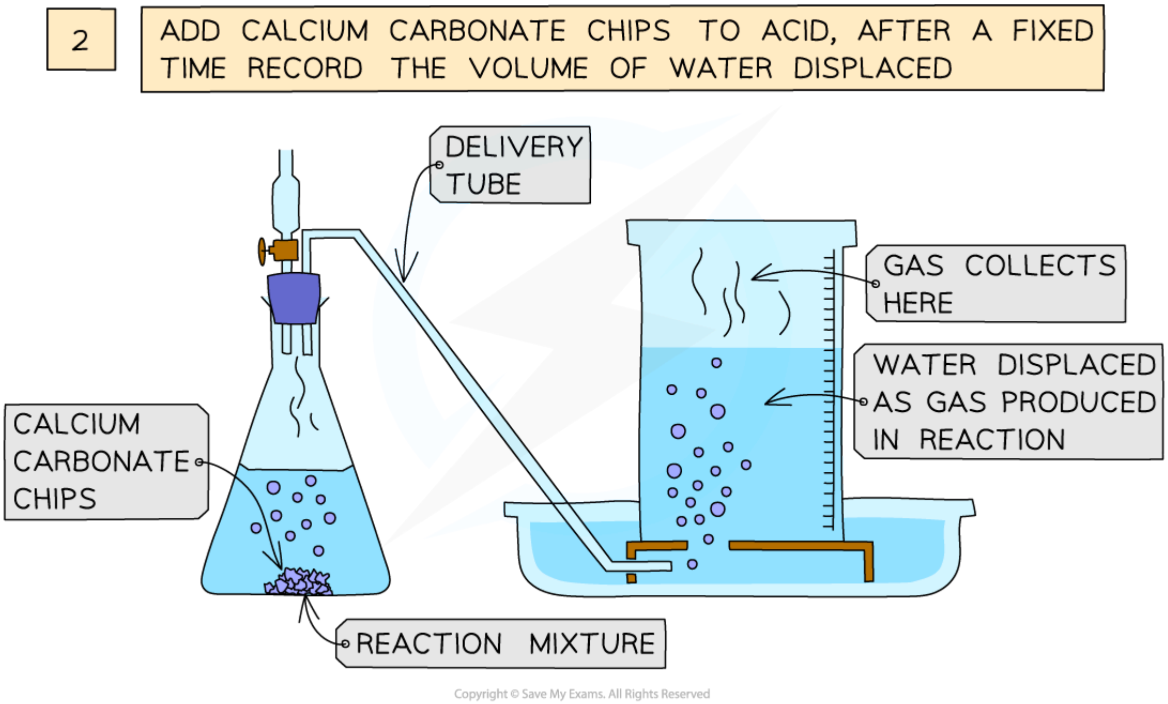
2
ADD CALCIUM CARBONATE CHIPS TO ACID, AFTER A FIXED TIME RECORD THE VOLUME OF WATER DISPLACED
DELIVERY TUBE
GAS COLLECTS HERE
WATER DISPLACED AS GAS PRODUCED IN REACTION
CALCIUM CARBONATE CHIPS
REACTION MIXTURE
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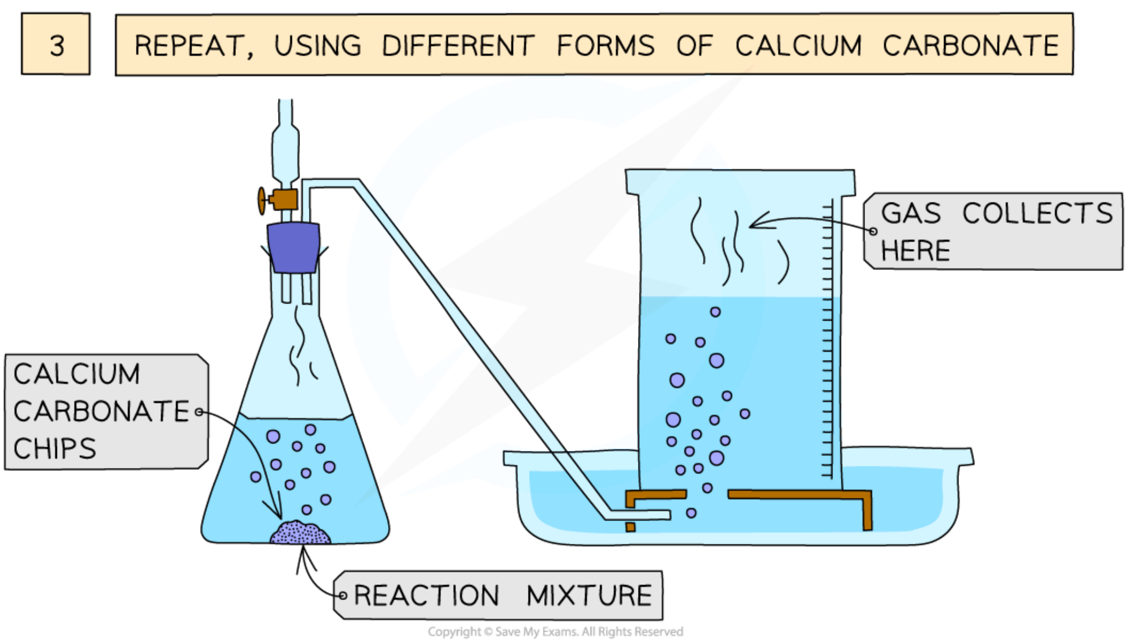
3
REPEAT, USING DIFFERENT FORMS OF CALCIUM CARBONATE
GAS COLLECTS HERE
CALCIUM CARBONATE CHIPS
REACTION MIXTURE
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Investigating the effect of different size marble chips on the rate of reaction between calcium carbonate and hydrochloric acid

Method:

- Add hydrochloric acid into a conical flask
- Use a delivery tube to connect this flask to an inverted measuring cylinder
- Add marble chips into the conical flask and close the bung
- Measure the volume of gas produced in a fixed time using the measuring cylinder
- Repeat with different sizes of marble chips

Result:

- Increase in the surface area of the marble chip, the rate of reaction will increase
- This is because more surface area particles of the marble chips will be exposed to the dilute hydrochloric acid so there will be more frequent and successful collisions, increasing the rate of reaction

Part B– Observing a Colour Change

Aim:

To investigate the effect of changing concentration in the reaction between sodium thiosulfate and hydrochloric acid

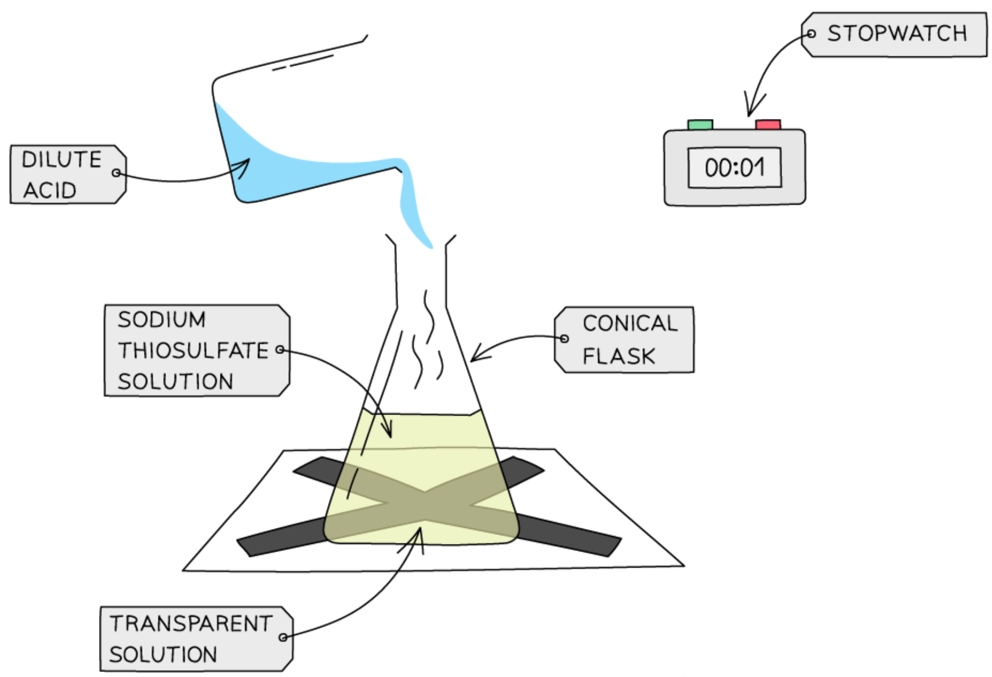
Materials:

- 40 g dm^{-3} sodium thiosulfate solution
- 1.0 mol dm^{-3} dilute hydrochloric acid
- Conical flask (100 cm^3)
- Black cross on paper
- White paper or white tile
- Stopwatch or timer

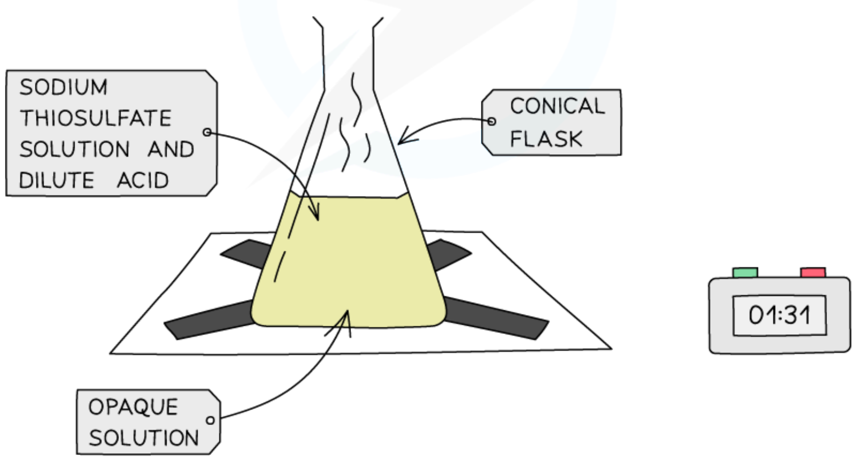
Diagram:

Your notes

1 ADD ACID TO SODIUM THIOSULFATE SOLUTION, START TIMER.



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



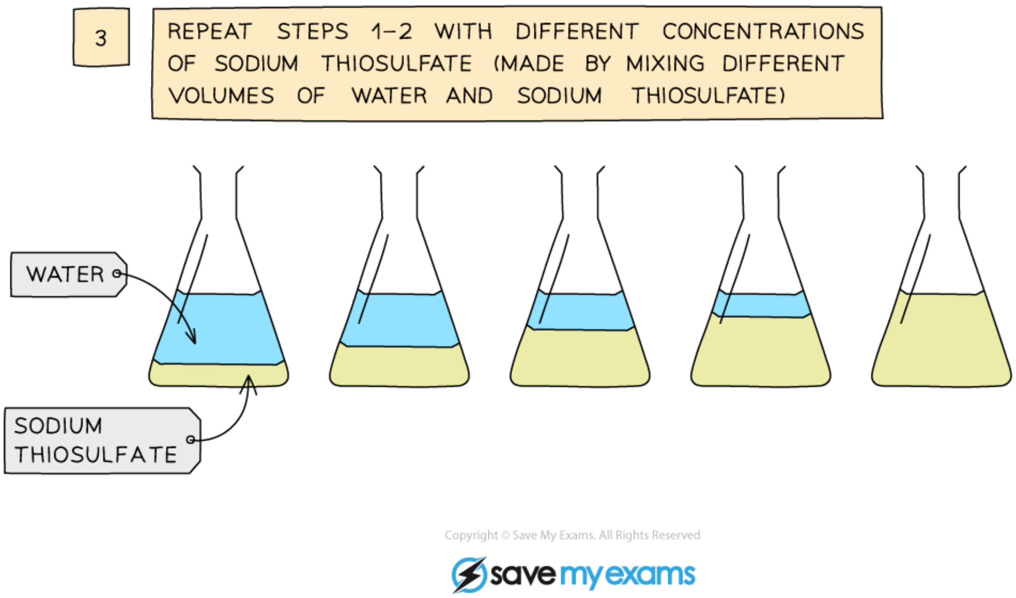


Diagram showing the apparatus needed to investigate the effect of concentration on the rate of reaction

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

Hazards, risks and precautions

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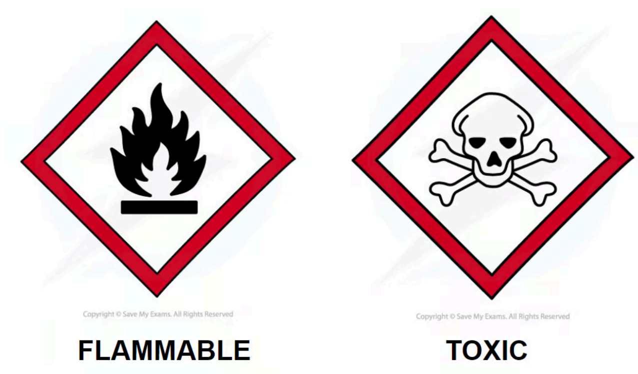


Hazard symbols to show substances that are flammable and toxic

- Magnesium is a flammable metal
- Dilute hydrochloric acid is not classified as hazardous at the concentrations typically used in this practical, however it may still cause harm to the eyes or the skin
- The reaction between sodium thiosulfate and hydrochloric acid produces sulfur dioxide which is toxic if inhaled
- Magnesium should be kept away from naked flames, e.g. a Bunsen burner
- For dilute hydrochloric acid, avoid contact with the skin and use safety goggles
- Take care not to inhale sulfur dioxide gas; asthmatics need to be especially careful and a fume cupboard can be used to avoid exposure

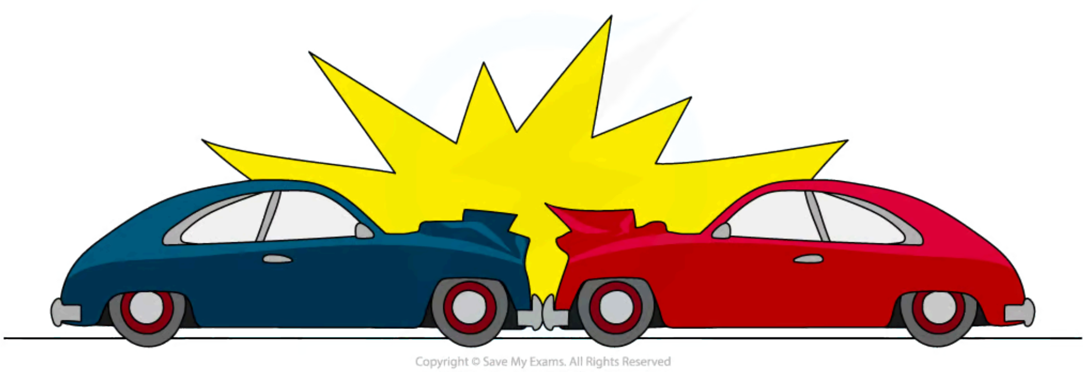
Collision Theory

Your notes

Collision Theory

Collision Theory

- When reactants come together the kinetic energy they possess means their particles will collide and some of these collisions will result in chemical bonds being broken and some new bonds being formed
- Increasing the number of successful collisions means that a greater proportion of reactant particles collide to form product molecules
- We can use collision theory to explain why these factors influence the reaction rate
- Not all collisions result in a chemical reaction
  - Most collisions just result in the colliding particles bouncing off each other
  - Collisions which do not result in a reaction are known as **unsuccessful collisions**
- **Unsuccessful collisions** happen when the colliding species do not have enough energy to break the necessary bonds
- If they do not have sufficient energy, the collision will not result in a chemical reaction
- If they have sufficient energy, they will react, and the collision will be successful



Collision theory helps to explain the energy process when particles react in chemical changes

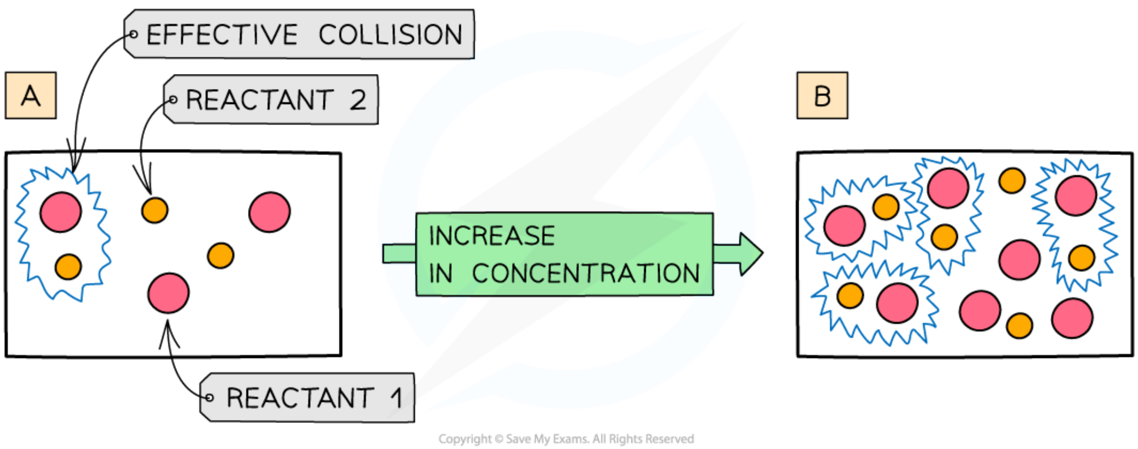
Explaining Rates

- There are several factors that can affect the rate of a reaction. These are:

Your notes

  - **Concentration** of the reactants in solution
  - **Temperature** at which the reaction is carried out
  - **Surface** area of solid reactants
- Changes in these factors directly influence the rate of a reaction

Concentration of a Solution

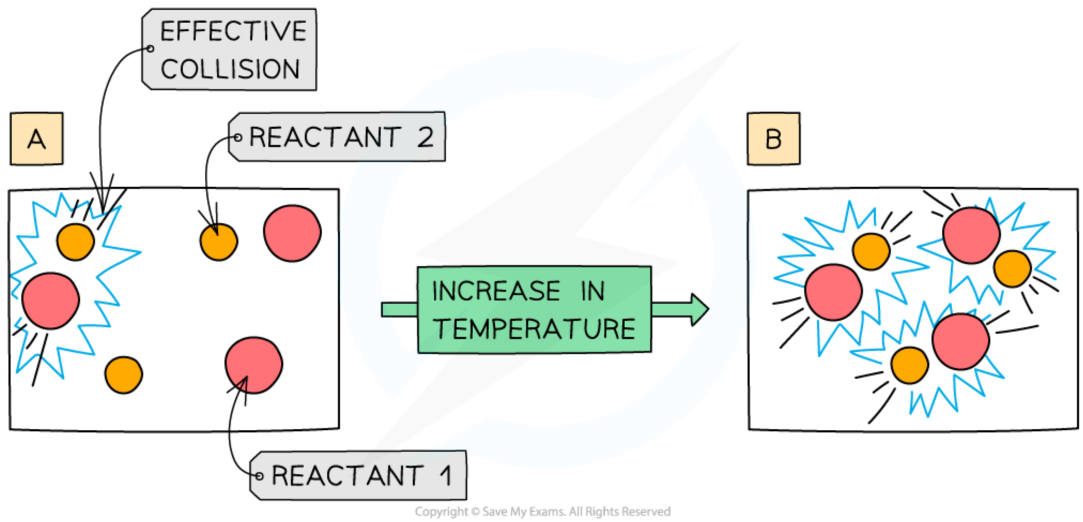


The diagram shows a higher concentration of particles in (b) which means that there are more particles present in the same volume than (a) so the number of collisions between reacting particles is increased causing an increased rate of reaction

Explanation:

- **Increasing the concentration of a solution will increase the rate of reaction**
- This is because there will be more reactant particles in a given volume, allowing more frequent and successful collisions per second
- 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

Temperature



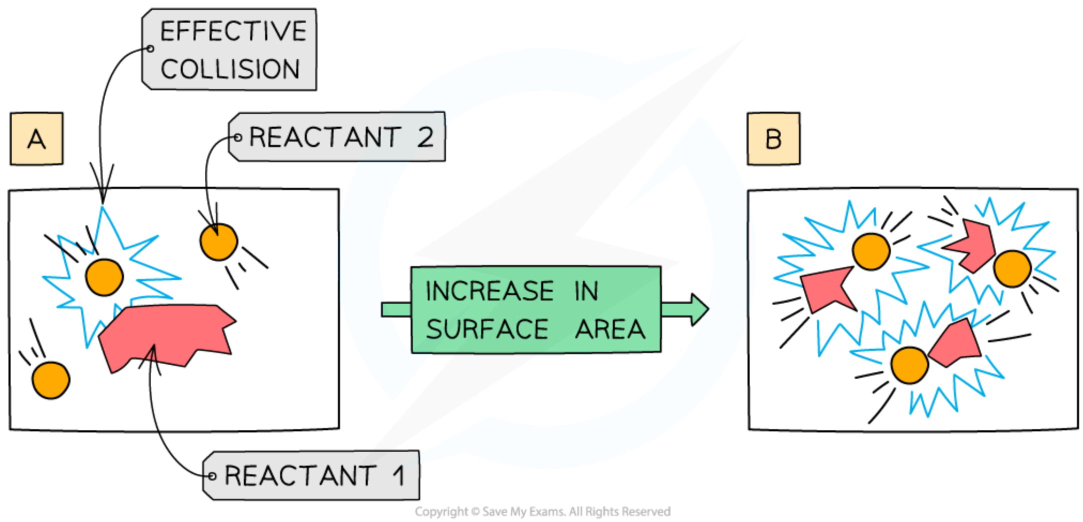
An increase in temperature causes an increase in the kinetic energy of the particles. The number of successful collisions increases

Explanation:

- **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 there will be more frequent and successful collisions per second, increasing the rate of reaction
- The effect of temperature on collisions is not so straight forward 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 degree (Kelvin) increase in temperature the rate of reaction approximately doubles

Surface area of a solid

Your notes



An increase in surface area means more collisions per second

Explanation:

- With an increase in the surface area of a **solid reactant**, the rate of reaction will **increase**
- This is because more **surface area** of the **particles** will be exposed to the other reactant, producing a higher number of collisions per second
- If you double the surface area you will double the number of collisions per second

Surface Area and Particle Size

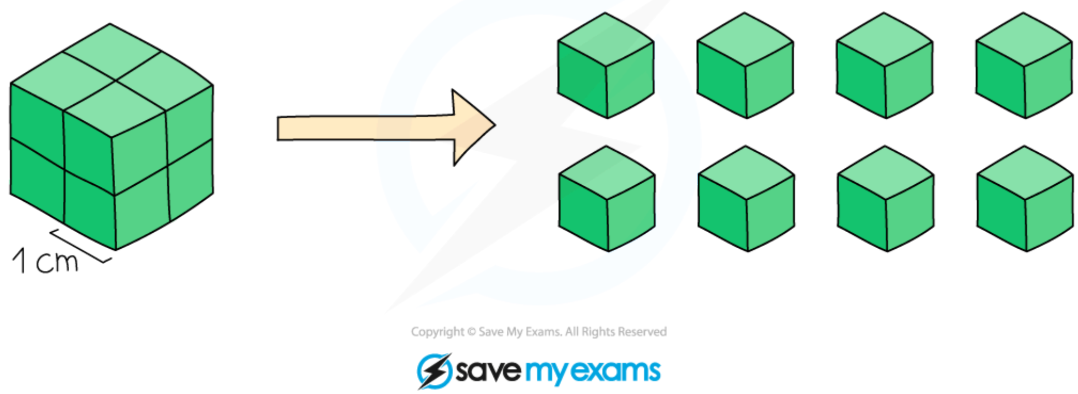


Diagram showing that surface area increase as particle size decreases. A 2 cm^3 cube has a surface area of 24 cm^2 and the same cube cut up into 8 cubes has a surface area of 48 cm^2

Your notes

Examiner Tips and Tricks

You should be able to recall how changing the concentration, pressure, temperature and surface area affect the rate of reactions

Your notes

Rate Graphs

Rate Graphs

- Data recorded in rate studies is used to **plot graphs** to calculate the rate of a reaction
- Time is normally plotted on the **x-axis** with the **concentration** of the reactant or product on the **y-axis**
- A number of measurements should be taken to provide a complete set of data
- If the relationship between the factor being measured and the amount produced is **directly proportional** (i.e. if the concentration of a reactant doubles the rate also doubles) then the resulting graph will be a **straight line graph** going through the origin
- The **gradient** of the line is equal to the **initial rate** of **reaction** and the **steeper** the gradient of the line then the **faster** the rate of reaction

Initial Rate Graphs

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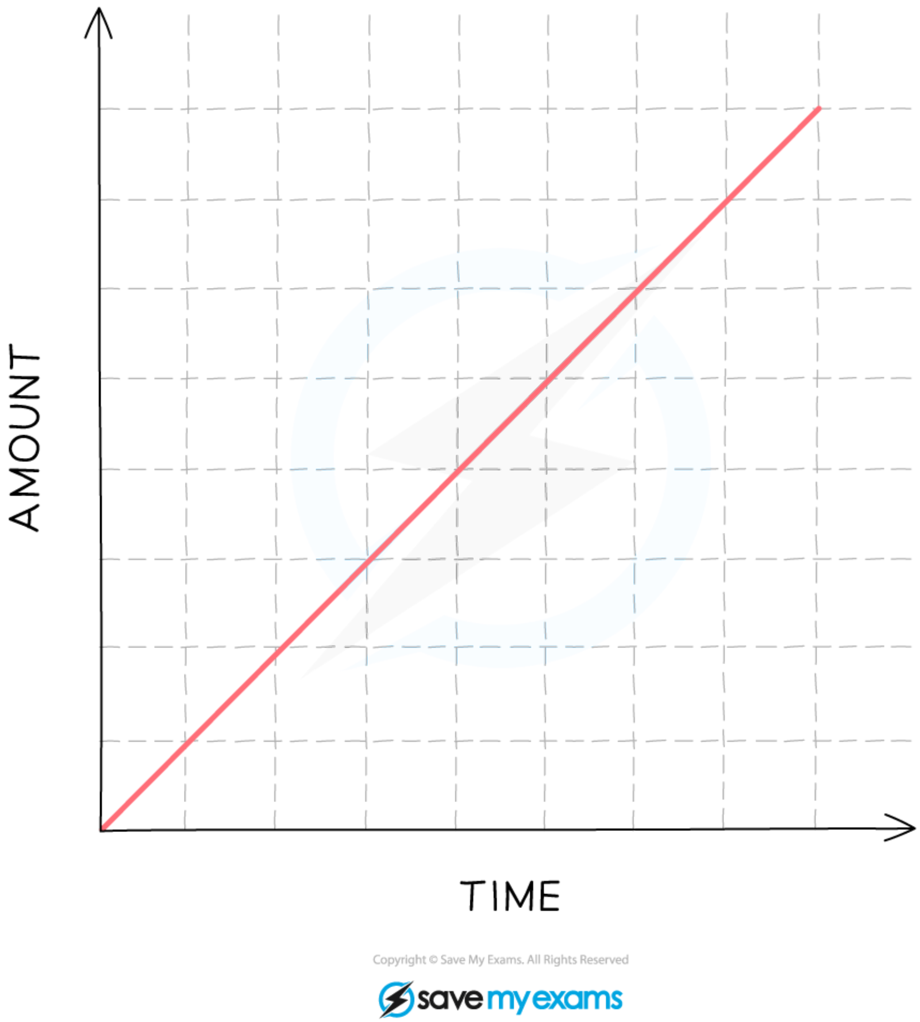
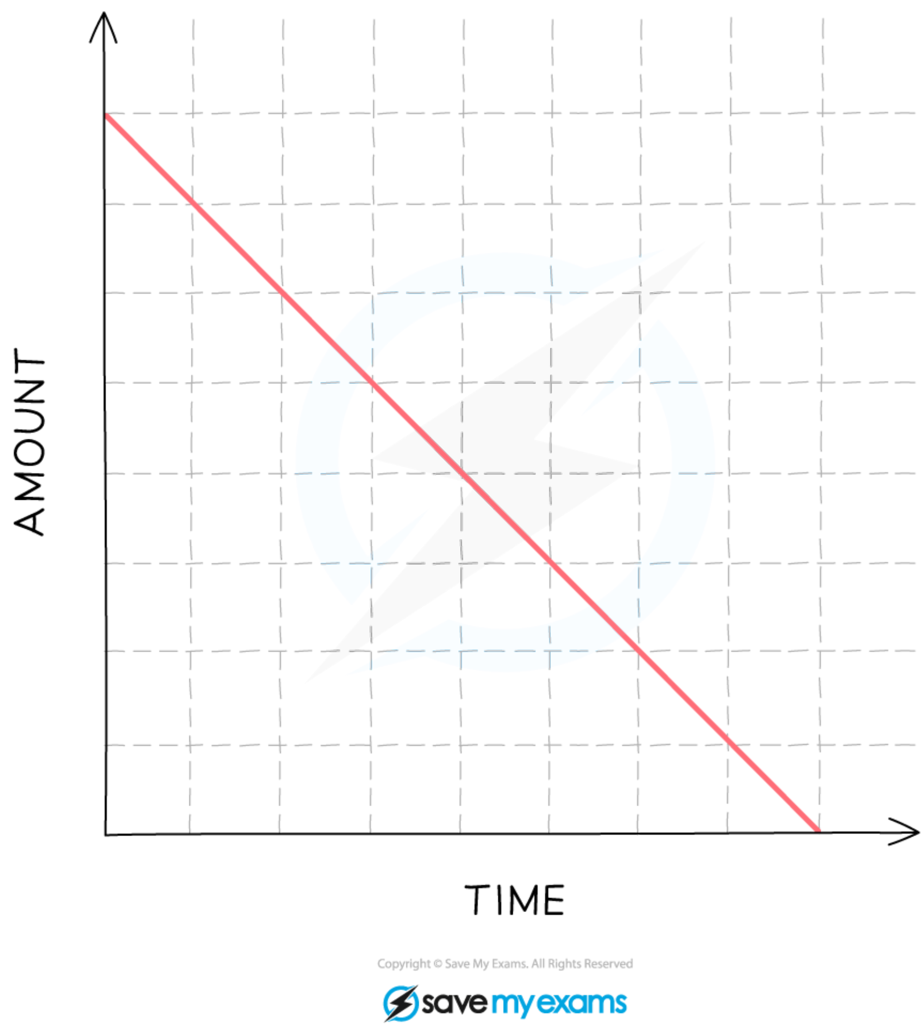


An initial rate graph for the formation of a product shows a straight line with a positive correlation starting from the origin

- A reaction rate graph based on measurements of a reactant being used up will have a negative correlation



An initial rate graph for a reactant shows a straight line with a negative correlation starting from the y-axis

Rate Graphs Until Completion

- Plotting a graph until the completion of the reaction shows how the rate changes with time
- The concentration of a reactant or product may be plotted against time and will produce one of the following curves:

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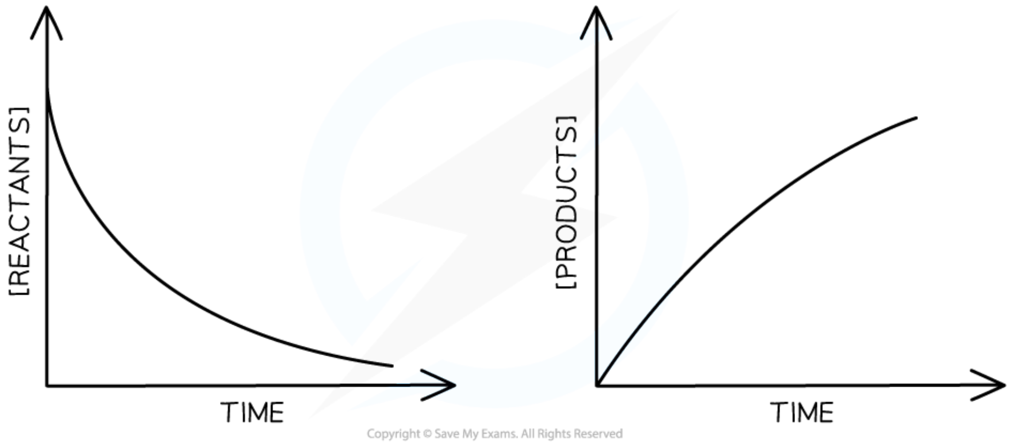

The concentration of a reactant or product against time

- Over time the rate of reaction slows as the reactants are being used up so the line becomes less steep and eventually becomes **horizontal**, indicating the reaction has finished
- Often it is more practical to measure a property like mass of volume against time
- 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 acid and marble chips:

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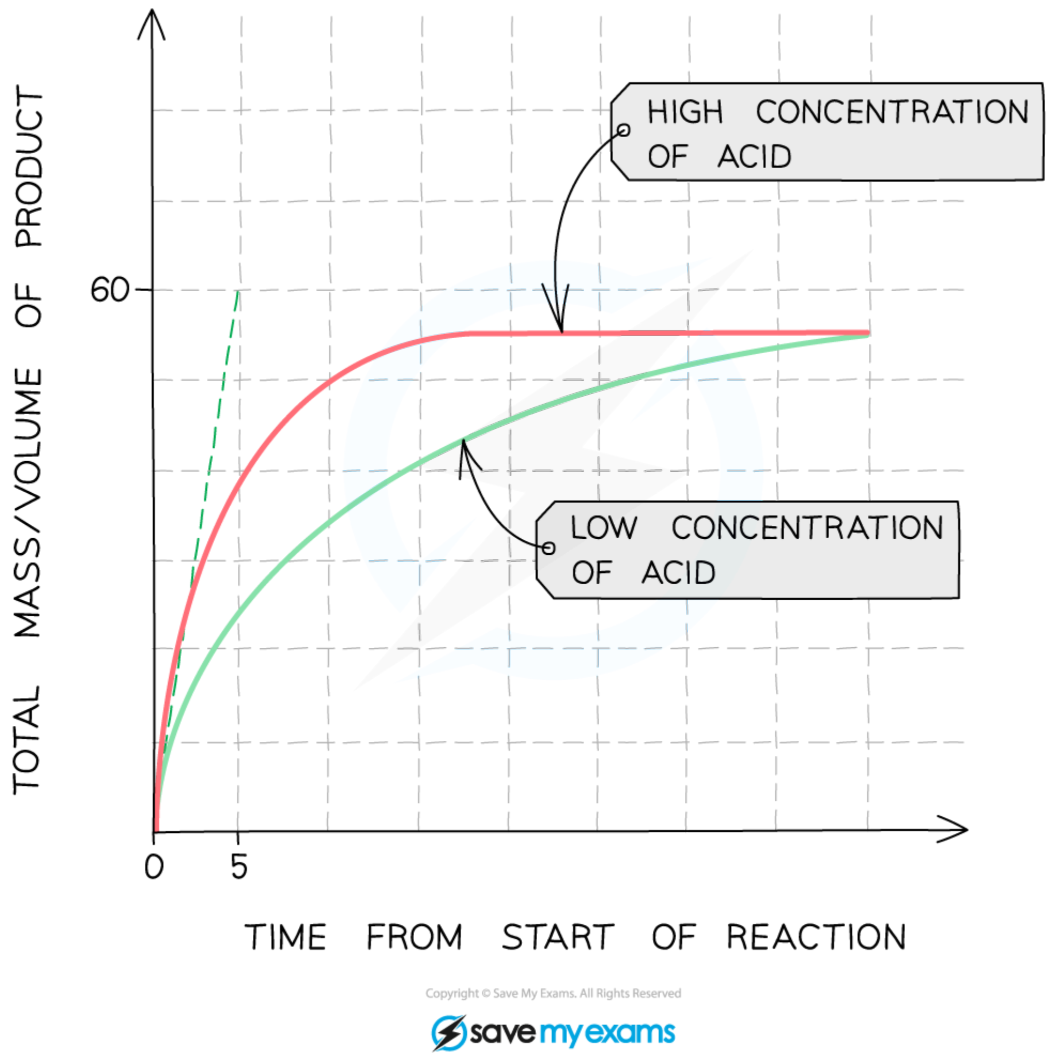


This graph shows how the mass/volume of a product changes over time for a high concentration and a low concentration

- Drawing a **tangent** to the slope allows you to show the gradient at any point on the curve
- 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 mass of product versus time

Examiner Tips and Tricks

Make sure you can interpret reaction graphs and use them to describe how a reaction proceeds as questions do come up on this topic.

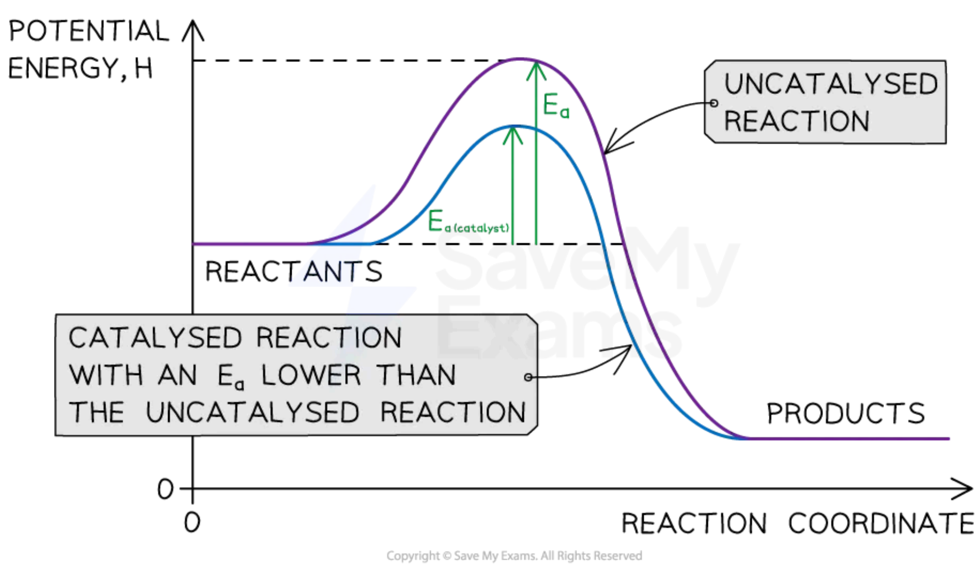
Your notes

Catalysts

Your notes

Catalysts

- 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
- Normally only **small amounts** of catalysts are needed to have an effect on a reaction
- Different processes require different types of catalysts but they all work on the same principle of providing an **alternate route** for the reaction to occur
- They do this by lowering the activation energy required, hence providing a reaction pathway requiring less energy
- Catalysis is a very important branch of chemistry in commercial terms as catalysts increase the rate of reaction (hence the production rate) and they reduce energy costs



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

Examiner Tips and Tricks

Although catalysts are not part of the overall reaction, you may see them written over the arrow in reaction equations in the same way you can add reaction conditions above or below the arrow.

Your notes

Enzymes

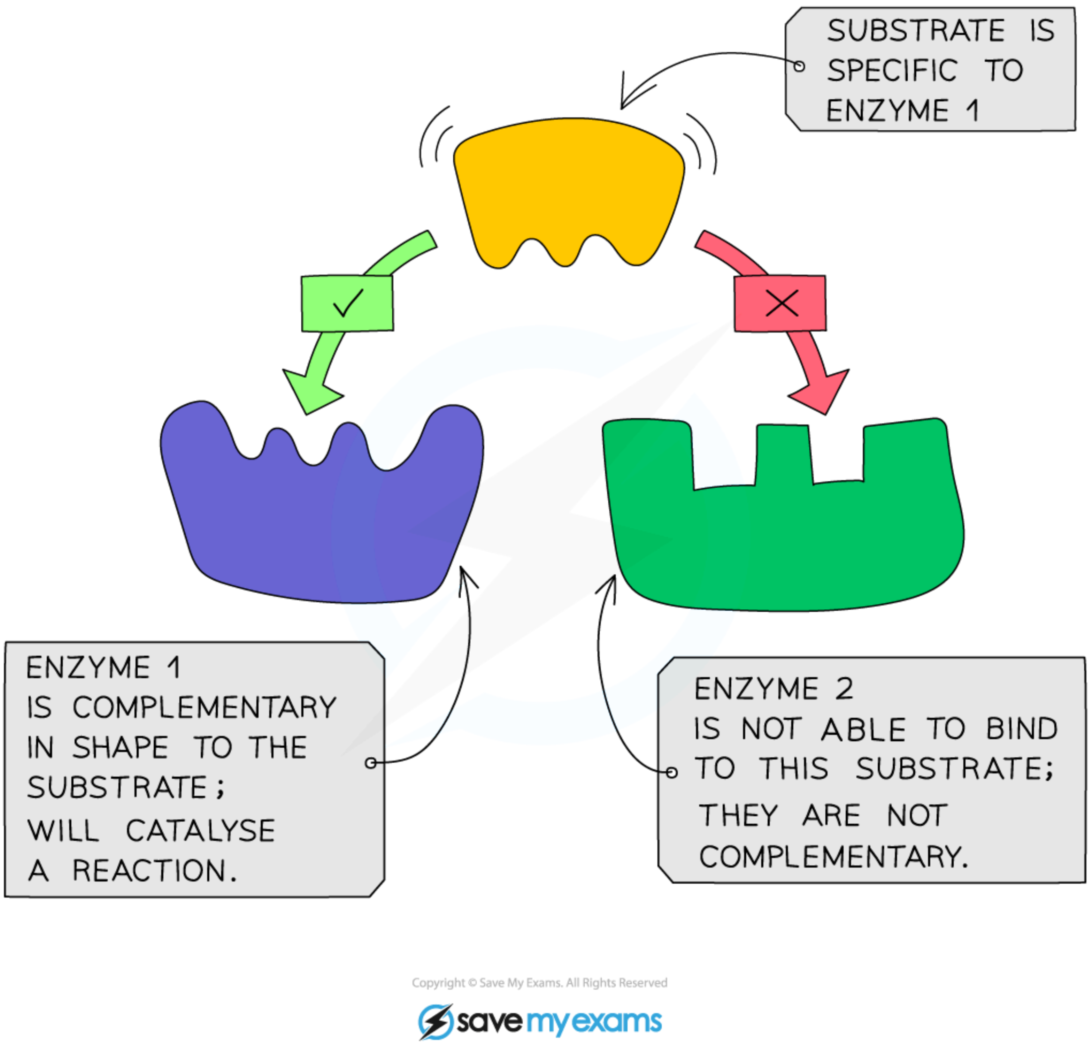
Your notes

Enzymes

- Enzymes are nature's catalysts
- They are biological substances that catalyse reactions in **living cells**
- Enzymes are **biological catalysts** made from **protein**
- Enzymes **speed up chemical reactions** in cells, allowing reactions to occur at much faster speeds than they would without enzymes at relatively low temperatures (such as human body temperature)
- Important reactions that are biologically catalysed include **respiration**, **photosynthesis** and **protein synthesis**
- The production of **alcohol** by the **fermentation** of sugars occurs in the presence of a biological catalyst, **yeast enzymes**:

$$C_6H_{12}O_6 + \text{enzymes} \rightarrow 2CO_2 + 2C_2H_5OH$$

- This reaction is very important to the production of alcoholic drinks such as beer and wine
- Not only do enzymes work at low temperatures, but they are very selective and will only work on very specific molecules when presented with a mixture of reactants



Enzymes are very selective which means they will work only on molecules which have exactly the right shape to fit into the active site of the enzyme