SPEED OF REACTION

BASIC CONCEPTS:

- **The Amount of reactant used or the amount of product obtained per unit time is called speed of reaction.**

- **The minimum amount of energy that the reacting particles must possess for a reaction to occur is called Activation energy.**

- **A Collision that is successful in producing a chemical reaction is called Effective Collision.**

  - **A substance that increases the speed of a chemical reaction without involving itself is called a Catalyst.**

- **A Substance that catalyses biochemical reactions (Chemical reactions in plants and animals) is called enzyme.**

TEST YOURS SELF:

- **Study methods for investing the speed of reaction.**

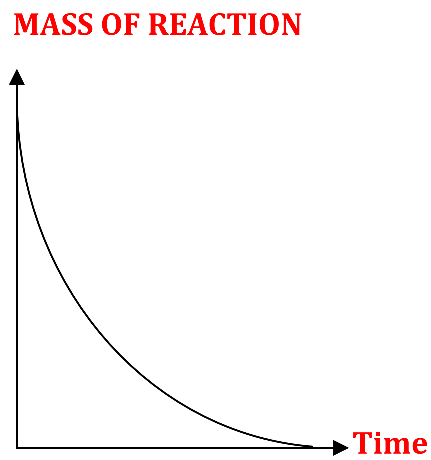
- **Interpret data obtained from experiments on speed of reaction.**

1.1 SPEED OF REACTION:

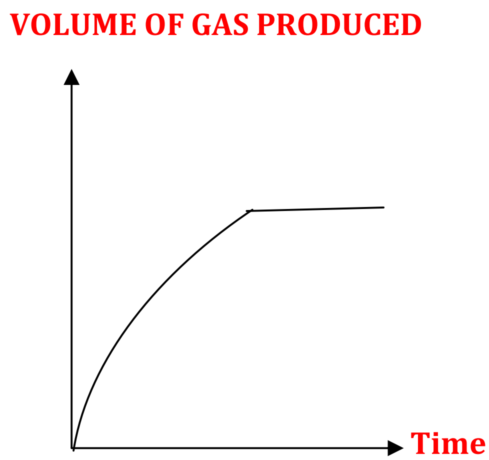
1. During a chemical reaction,

a) The amount of reactant decreases with time, and

b) The amount of product increases with time.



a) Graph of amount of reactant against time



b) Graph of amount of product against time

2. The amount of reactant or product can be expressed in

a) Mass of solid (in g),

b) Number of moles,

c) Volume of gas produced (cm^3),

d) Concentration of solution.

3. The speed of reactions inversely proportional to the time taken for the reaction to Complete.

$$\text{Speed of reaction} = \frac{1}{\textit{time taken}}$$

The reaction is slow, if it takes a long time for the reaction to complete.

The reaction is fast, if takes a short time for the reaction to complete.

4. Measuring the speed of reaction by volume of gas produced

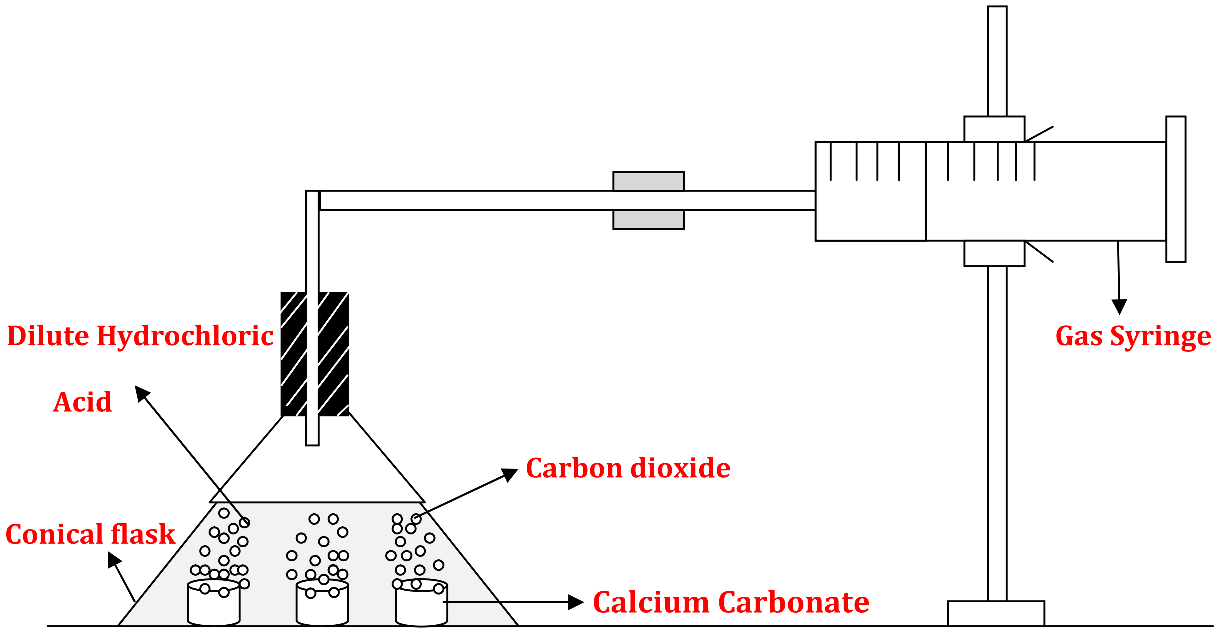
a) For the reaction between calcium carbonate and hydrochloric acid, the speed of reaction can be determined by measuring the volume of carbon dioxide produced at regular intervals .

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2$$

Calcium Carbonate	Hydrochloride Acid	Calcium Chloride	Water	Carbon Dioxide

Speed of reaction is the volume of carbon dioxide produced per unit time.

The speed of reaction is also called the **rate of reaction**.



Experiment to study the speed of reaction by measuring volume of gas evolved.

The apparatus can be used to measure the speed of reaction for the following reactions:

- **Reaction of carbonates with acids, e.g.**

  $MgCO_3\ (s) + 2HCl\ (aq) \longrightarrow MgCl_2\ (aq) + H_2O\ (l) + CO_2\ (g)$

- **Reaction of metals with acids, e.g.**

  $Zn\ (s) + H_2SO_4\ (aq) \longrightarrow ZnSO_4\ (aq) + H_2\ (g)$

- **Decomposition of hydrogen peroxide in the presence of a catalyst.**

  $2H_2O_2\ (aq) \longrightarrow 2H_2O\ (l) + O_2\ (g)$

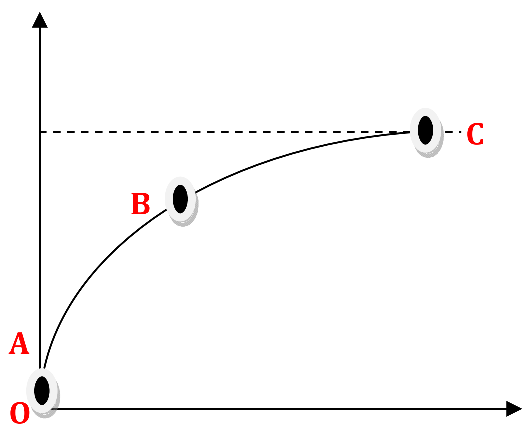
b) Analysing speed of reaction curve

- **The graph of carbon dioxide produced against time for the reaction between calcium**

  Carbonate and hydrochloric acid is shown below.

- **The steeper the gradient of the curve, the higher the speed of reaction.**

VOLUME OF CARBON DIOXIDE (cm³)



GRAPH OF CARBON DIOXIDE PRODUCED AGAINST TIME

- ✓ **At A (the start of reaction), the gradient is the steepest because the speed of reaction is the highest.**
- ✓ **At B the gradient decreases because the speed of reaction is decreasing has stopped.**
- ✓ **At C (end of reaction), the gradient is zero because the reaction has stopped.**

EXAMPLE1.1:

Excess zinc metal is added to cm^3 of dilute hydrochloric acid to react with zinc metal .

VOLUME OF HYDROGEN (cm3)

GRAPH DIAGRAM

a) What is the time taken for the reaction to complete?

b) Estimate the time required for 50 cm^3 of dilute hydrochloric acid to react with zinc metal.

TIPS FOR STUDENTS :

The term 'estimate' implies an approximate calculation based on the information given (in this case, based on the graph given) .

c) Calculate the speed of reaction in cm^3/min. or cm^3/s.

SOLUTION:

a) 9 minutes

b) Time = 2.4 minutes

EXPLANATION

The limiting reactant is hydrochloric acid.

When 100 cm^3 of dilute hydrochloric acid reacts with excess zinc,

The total volume of hydrogen released = 40 cm^3.

When 50 cm^3 dilute hydrochloric acid reacts with excess zinc,

Total volume of hydrogen released = $\frac{1}{2}$ X 40 = 20 cm^3.

From the graph, the time taken to produce 20 cm^3 of hydrogen = 2.4 minutes

c)

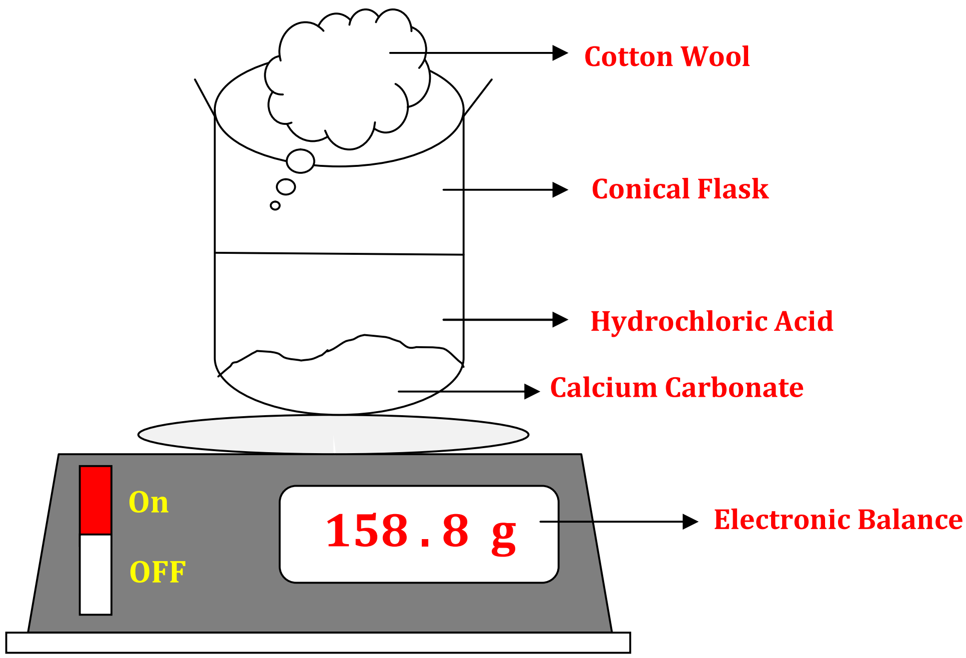
- Total volume of hydrogen liberated = 40 cm^3.

  Speed of Reaction = $\frac{Volume\ of\ gas\ produced}{Time\ taken} = \frac{40}{9}$ = 4.44 cm^3/min.

- Speed of reaction = $\frac{40}{9\ X\ 60}$ = 0.074 cm^3/s.

5. Measuring the speed of reaction by change in mass of reaction

a) The speed of reaction between calcium carbonate and dilute hydrochloric acid can be studied using the apparatus as shown in the diagram below .



EXPERIMENT TO STUDY THE SPEED OF REACTION BY MEASURING MASS

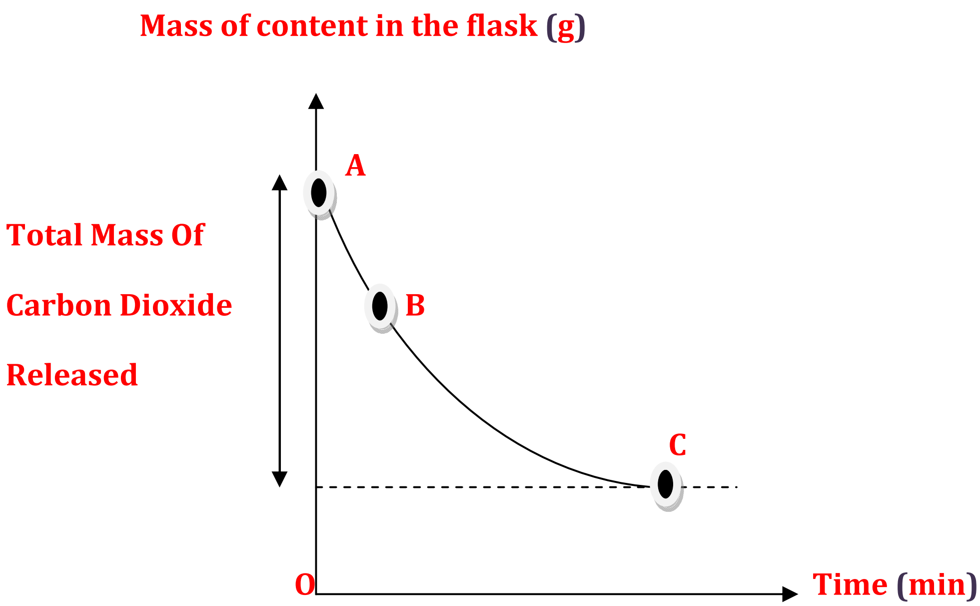
The cotton wool is used to prevent spills from the reaction mixture so that the decrease in mass is only due to the loss of carbon dioxide.

b) When calcium carbonate reacts with dilute hydrochloric acid, carbon dioxide is released from the reaction mixture. As a result, the mass of the contents in the flask decreases.

Ca CO_3(s)	+	**2HC*l* (aq)**	⟶	**CaCl_2(aq)**	+	**H_2O (*l*)**	+	**CO_2**
Calcium Carbonate		**hydrochloride acid**		**calcium chloride**		**water**		**carbon dioxide**

c) The mass of the conical flask and its contents is measured at regular time intervals.

Mass of contents in the flask = balance reading -0 mass of conical flask



Graph showing the mass of the system at different time intervals

Total mass of Carbon dioxide released = Mass of contents in the flask at A = Mass of contents in the flask at C

- The gradient of the graph decreases from A to C because the reaction slows down as it proceeds.
- Excess calcium carbonate is used in this experiment.

  The reaction stops at C when all the hydrochloric acid is used up.

COMMON ERROR	ACTUAL FACT
✗ The speed of reaction increases with time because the amount of products increases .	✓ The speed of reaction decreases with time because the amount of reactants decreases .

LEARNING OUTCOMES

- ✓ Describe the factors that affect the speed of reactions and explain in terms of collision between reacting particles .
- ✓ Describe catalysts and study the effect of catalysts (including enzymes) on the speed of reactions
- ✓ Relate pathways with lower activation energies to the increases in speed of reactions

1.2 FACTORS AFFECTING THE SPEED OF REACTION

1. For a reaction to occur between two reactant particles,

a) The particles must collide, and

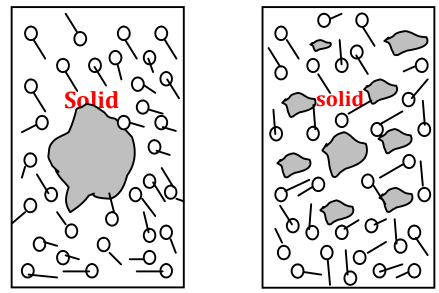
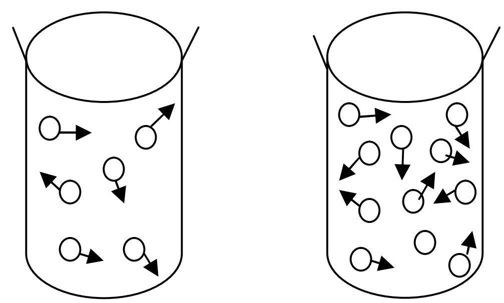
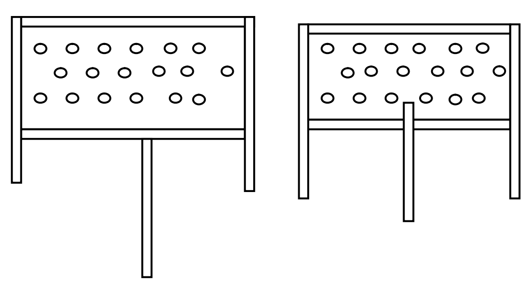
b) They must collide with a minimum energy called the activation energy .

2. Not all collision between reactant particles produced a chemical reaction is called the effective collision .

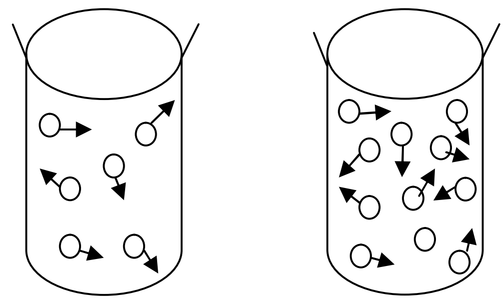
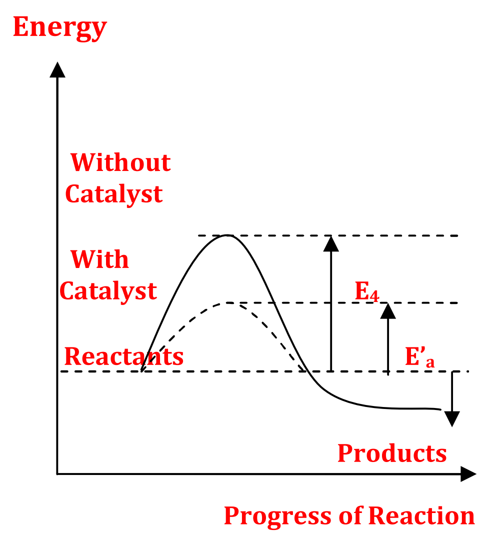
3. Any factor that increases the rate of effective collision between reacting particles will also increase the speed of reaction.

Increase in frequency of collisions → Increase in frequency of effective collisions → Increase in speed of reaction

4. The Factors that affect the speed of a reaction are described in the table below:

FACTOR	**EXPLANATION**	**DIAGRAM**
Size of solid reactant	***The smaller the particle size .*** ✓ **The larger is the total surface area exposed to collisions,** ✓ **The higher is the frequency of effective collisions,** ✓ ***The greater is the speed of reaction***	**Diagram**  **Big Piece** **Small Pieces**
Concentration of reactant in solution	***The higher the concentration of the reactant,*** ✓ **The greater is the number of particles per unit volume,** ✓ **The higher is the frequency of effective collisions,** ✓ ***The greater is the speed of reaction .***	 **Low Concentration** **High Concentration**
Pressure of gaseous reactants	***The higher the pressure of gaseous reactants,*** ✓ **The smaller is the volume,** ✓ **The greater is the number of particles per unit volume,** ✓ ***The greater is the speed of reaction.***	**Gaseous Molecule** **Gaseous Molecule**  **Low Pressure** **High Pressure**

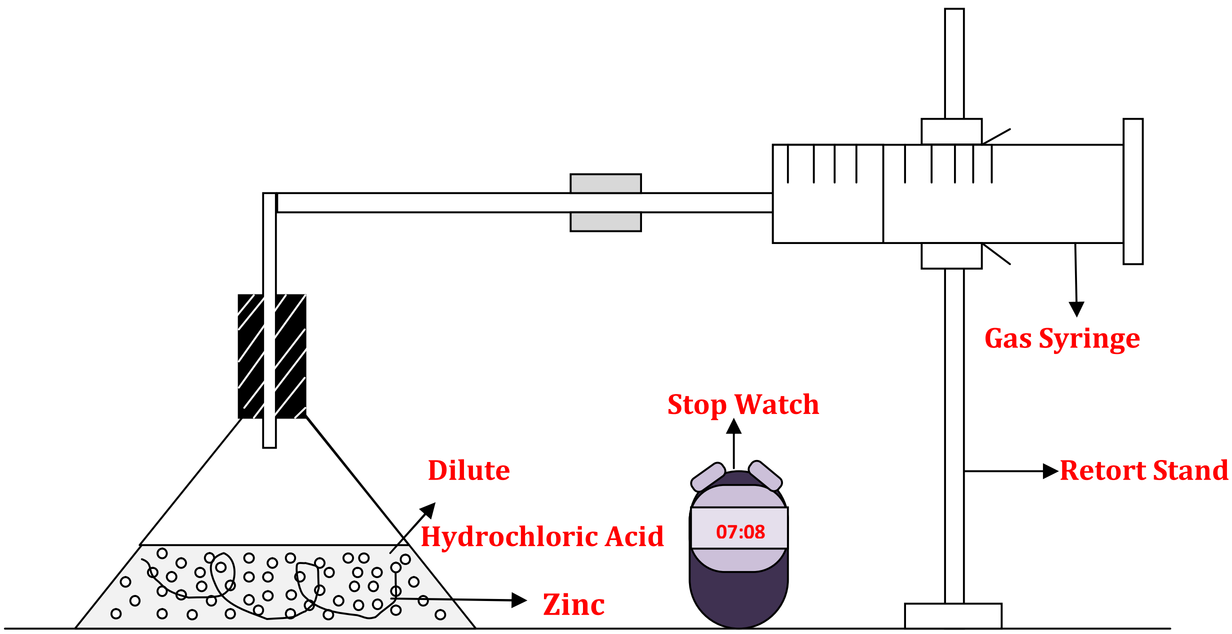
	Pressure has no effect on reaction that do not involves gases.	

FACTOR	EXPLANATION	DIAGRAM
Temperature	*At a higher temperature,* ✓ The reactant particles absorb energy and move faster, ✓ More reactant particles have the minimum activation energy to react, ✓ The number of effective collisions increases, ✓ ***The greater is the speed of reaction*.**	**Diagram**  **Low temperature** **High Temperature**
Presence of a catalyst or enzyme	✓ A catalyst provides an ***alternative route*** that requires a **lower activation energy**. ✓ More reactant particles can overcome the lower **activation energy**. ✓ This increases the frequency of effective collision s and hence ***the speed of reaction increases*.**	 E_4 = Activation energy of uncatalysed reaction E'_a = Activation energy of catalysed reaction ΔH = Heat of reaction (**Exothermic**)

EXAMPLE:

In an experiment, Zinc is reacted with dilute hydrochloric acid.

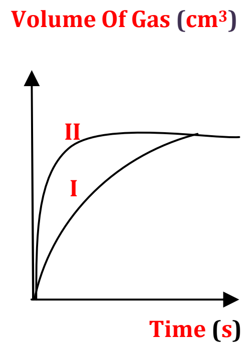
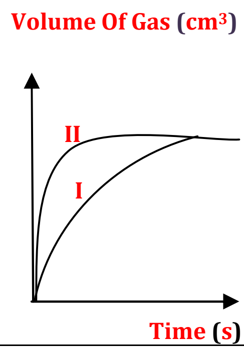
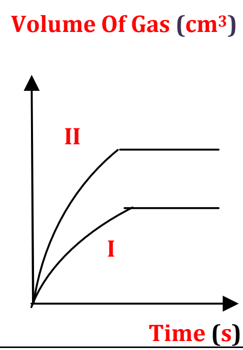
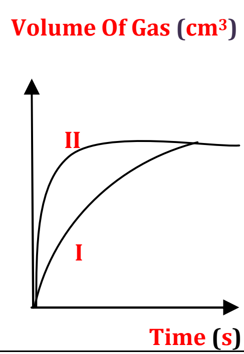
$$Zn\,(s) + 2HCl\,(aq) \longrightarrow ZnCl_2\,(aq) + H_2\,(g)$$



EXPERIMENT TO STUDY THE EFFECTS OF THE DIFFERENT VARIABLES ON THE SPEED OF REACTION

The experiment is repeated to show the effects of surface area, temperature, concentration and catalyst on the speed of the reaction.

In comparing the speed of two reactions, only one factor is varied, and the other factors are kept constant.

SET	CONDITION THAT IS VARIED	CONDITION THAT ARE FIXED	SHAPE OF GRAPH	OBSERVATION
a)	**Size of zinc particles** **Experiment I :** **Granulated zinc** **Experiment II :** **Powdered zinc**	✓ Mass of zinc ✓ Volume of dilute Hydrochloric acid ✓ Concentration of dilute hydrochloric acid ✓ Temperature ✓ No catalyst		✓ Graph II has a steeper gradient. ✓ Reaction II is a faster reaction. ✓ The smaller the particle size, the faster the reaction.
b)	**Temperature** **Of aqueous** **Hydrochloric acid** **Experiment I:** **$HCl(aq)$ at 25^0C** **Experiment II :** **$HCl(aq)$ at 35^0C**	✓ Mass of zinc powder ✓ Volume of dilute Hydrochloric acid ✓ Concentration of dilute hydrochloric acid ✓ No catalyst		✓ Graph II has a steeper gradient. ✓ Reaction II is a faster reaction. ✓ The higher the temperature, the faster the reaction
c)	**Concentration** **Of dilute hydrochloric acid** **Experiment I:** **1 mol/dm^3 HCl** **Experiment II:** **2 mol/dm^3 HCl**	✓ Mass of zinc powder (excess) ✓ Volume of dilute hydrochloric acid ✓ Temperature ✓ No catalyst		✓ Graph II has a steeper gradient. ✓ Reaction II is a faster reaction. ✓ The higher the concentration, the faster the reaction
d)	**Presence** **Catalyst, aqueous** **Copper (II) sulfate** **Experiment I:** Without catalyst **Experiment II:** With catalyst	✓ Mass of zinc powder ✓ Volume of dilute Hydrochloric acid ✓ Concentration of dilute hydrochloric acid ✓ Temperature		✓ Graph II has a steeper gradient. ✓ Reaction II is a faster reaction. In the presence of a catalyst, the reaction is faster.

In study the shape of a graph, you need to note

- The gradient to the graph, which shows the speed of reaction,
- The height of the graph, which shows the amount of product formed.

a) For the experiments in sets (a), (b), (c) and (d), the graphs for experiments I and II are the same. This means that the same volume of hydrogen is produced because the same amount of the reactants (Zinc and Hydrochloric Acid)are used.

b) Experiments I and II in set (d) also show that a catalyst increase the speed of reaction but has no effect on the yield of the product .

c) For experiments I and II in set (c), the height of graph II is twice the height of graph I . This means that the volume of hydrogen produced in experiment II is twice of that produced in experiment I, because the amount (in mol) of hydrochloric acid used in experiment II is twice of that in experiment I .

TIPS FOR STUDENTS:

- You are often asked to sketch the graph of volume against time or the graph of mass against time.

The term ‘ sketch ’ implies that the graph need not be accurately drawn on a graph paper .

- However, the graph must display some important characteristics. For Example, the shape of the curve must be accurate and it should be clear whether the curve passes through the origin

5. Characteristics of catalysts remains chemically unchanged at the end of a Reaction.

a) A catalyst remains chemically unchanged at the end of a reaction.

This means

- The quantity,
- The chemical and physical properties, and
- The chemical composition of the catalyst remain unchanged after the reaction

b) Only a small amount of catalyst is needed to increase the speed of reaction .

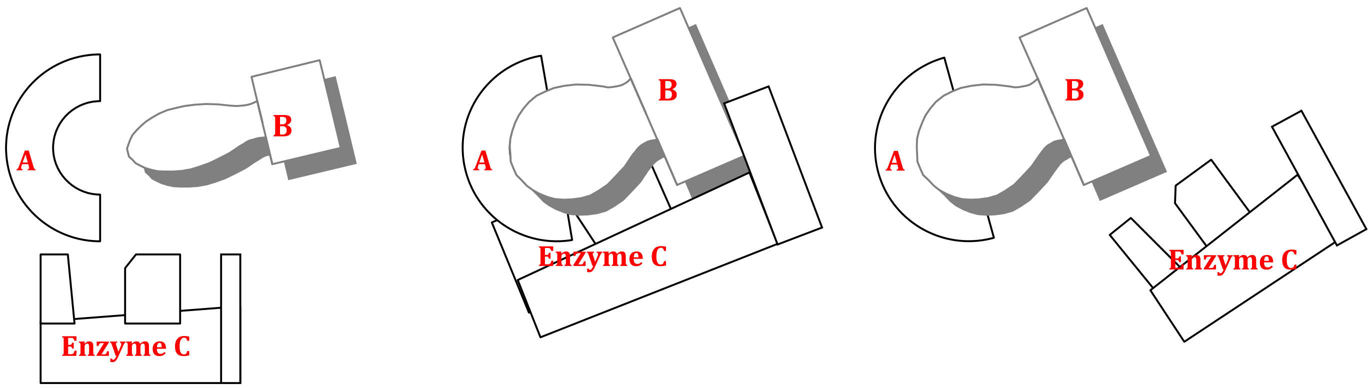
c) Most catalysts catalyses the reaction but not other reactions .

For example, iron catalyses one particular reaction between nitrogen and hydrogen to form ammonia but not the decomposition of hydrogen peroxide .

d) Most catalysts are transition metals or compounds of transition metals. Some common catalysts are shown in the table below .

REACTION	CATALYSTS
Decomposition of hydrogen peroxide $2H_2O_2(aq) \longrightarrow 2H_2O\ (l) + O_2\ (g)$ Hydrogen peroxide → water + oxygen	Manganese (IV) oxide, MnO_2
Haber process to manufacture ammonia $N_2\ (g) + 3H_2(g) \longrightarrow 2NH_3(g)$ Nitrogen + hydrogen → ammonia	Finely divided iron, Fe
Contact process to produce sulfur trioxide for the manufacture of sulfuric acid $2SO_2(g) + O_2(g) \longrightarrow 2SO_2\ (g)$ Sulfur dioxide + oxygen → sulfur trioxide	Vanadium (V) oxide, V_2O_5
Conversion of harmful pollutants to harmless gases in catalytic converters $2NO_2(g) + 2CO(g) \longrightarrow N2(g) + 2CO_2\ (g)$ nitric oxide + carbon monoxide → nitrogen + carbon dioxide	Platinum , Pt or rhodium , Rh

6. An enzyme is a biological catalyst. Enzymes are protein molecules that controls many of the chemical reactions that occur in living cells .



Enzyme C

Reactant A + Reactant B ⟶ Product AB

7. Uses of Enzymes:

a) Enzymes in yeast convert sugars into alcohol and carbon dioxide .

b) Enzymes in washing powders break down protein stains such as blood and tomato sauce .

EXAMPLE : 1.2

Magnesium reacts with hydrochloric acid to form magnesium chloride and hydrogen gas.

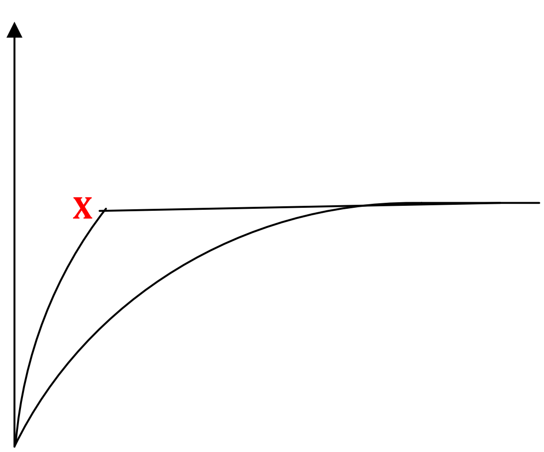
$$Mg\,(s) + 2HCl\,(aq) \longrightarrow MgCl_2(aq) + H_2\,(g)$$

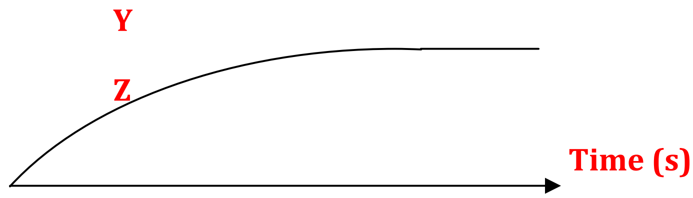
Two Experiments were performed to study speed of reaction between magnesium and hydrochloric acid. In both experiments,

- **Hydrochloric acid is in excess,**
- **The volume of hydrochloric acid is kept constant,**
- **The mass of magnesium is kept constant.**

	VOLUME OF HYDROCHLORIC ACID(cm^3)	CONCENTRATION OF HYDROCHLORIC ACID(mol/dm^3)
EXPERIMENT I	50	1.0
EXPERIMENT II	50	0.5

VOLUME OF HYDROGEN (cm^3)





a) **Which of the curves X, Y and Z in the graph above shown the results of experiments I and II?**

b) **Explain your answer in (a)**

SOLUTION:

a) Curve X shows the results off experiment I, while curve Y shows the results of experiment II.

b) ***Height of the curves***

Hydrochloric acid is in excess and magnesium is the limiting reactant . Since the same mass of magnesium is used for both experiments, the volume of hydrogen released should be the same in both experiments . This means that curve Z does not represent the results for experiment I or II .

Gradient of the curves

EXPERIMENT I is a faster reaction because the hydrochloric acid used has a higher concentration . The curve for a faster reaction has a steeper slope . Thus, curve X represents the faster reaction in experiment I and curve Y represents the slower reaction in experiment II .

8. Examples of controlling the speed of reaction in daily life:

a) By breaking the charcoal into smaller pieces and fanning the charcoal to supply more oxygen when grilling, the charcoal will burn faster to give out more heat.

b) Coal dust or flour dust floating in the air is highly combustible and has caused explosions in coal mines or flour mills.

c) Food can be kept longer by storing them in refrigerators. At low temperatures, the decay and decomposition of food is slowed down .

d) Water and oil in the pressure cooker boils at higher temperatures than their normal boiling points. With increased temperature, food cooks faster.

COMMON ERROR	ACTUAL FACT
✗ A catalyst increases the speed of reaction because it increases the speed of reactant particles.	✓ A catalyst has no effect on the speed of reactant particles. It increases the speed of reaction by lowering the activation energy.
✗ A catalyst remains chemically unchanged at the end of the reaction because catalyst does not take part in the reaction.	✓ A catalyst does take part in a chemical reaction. It combines with the reactions to form an unstable intermediate species (Alternative route) This species then decomposes to produce the catalyst and the

	products. ✓