CHEMICAL REACTION RATES

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LEARNING OUTCOMES

The learner should be able to:

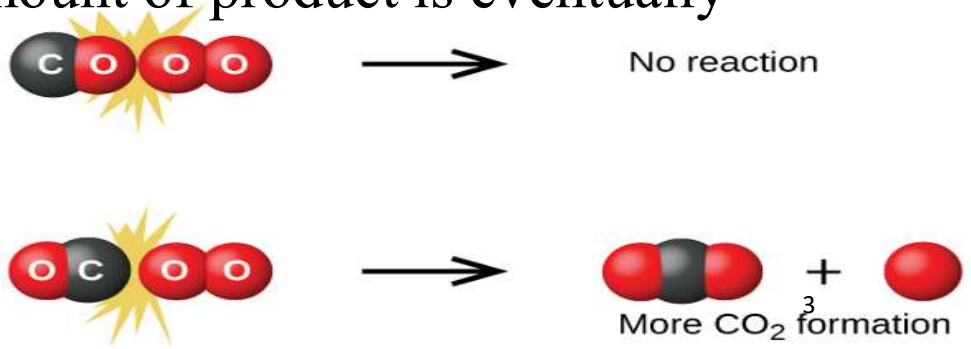
- a. understand and appreciate that chemical reactions take place at different rates (u)
- b. understand the effect of various factors on the rate of chemical reactions and recognize that many reactions are reversible (u, s)
- c. Understand the importance of reversible reactions in industrial processes (u)

INTRODUCTION

When chemicals come into contact with one another, a chemical reaction may or may not take place. During the reaction, substances that take part in the reaction are **reactants** as the substances formed are called **products**.

During a chemical reaction, there are **three** main events that usually occur.

- The reactants (substances at the start)get used up and new substances (products) form in their place.
- Heat energy is either evolved (exothermic reaction) or taken in(endothermic reaction).
- For a fixed amount of reactant, a fixed amount of product is eventually formed



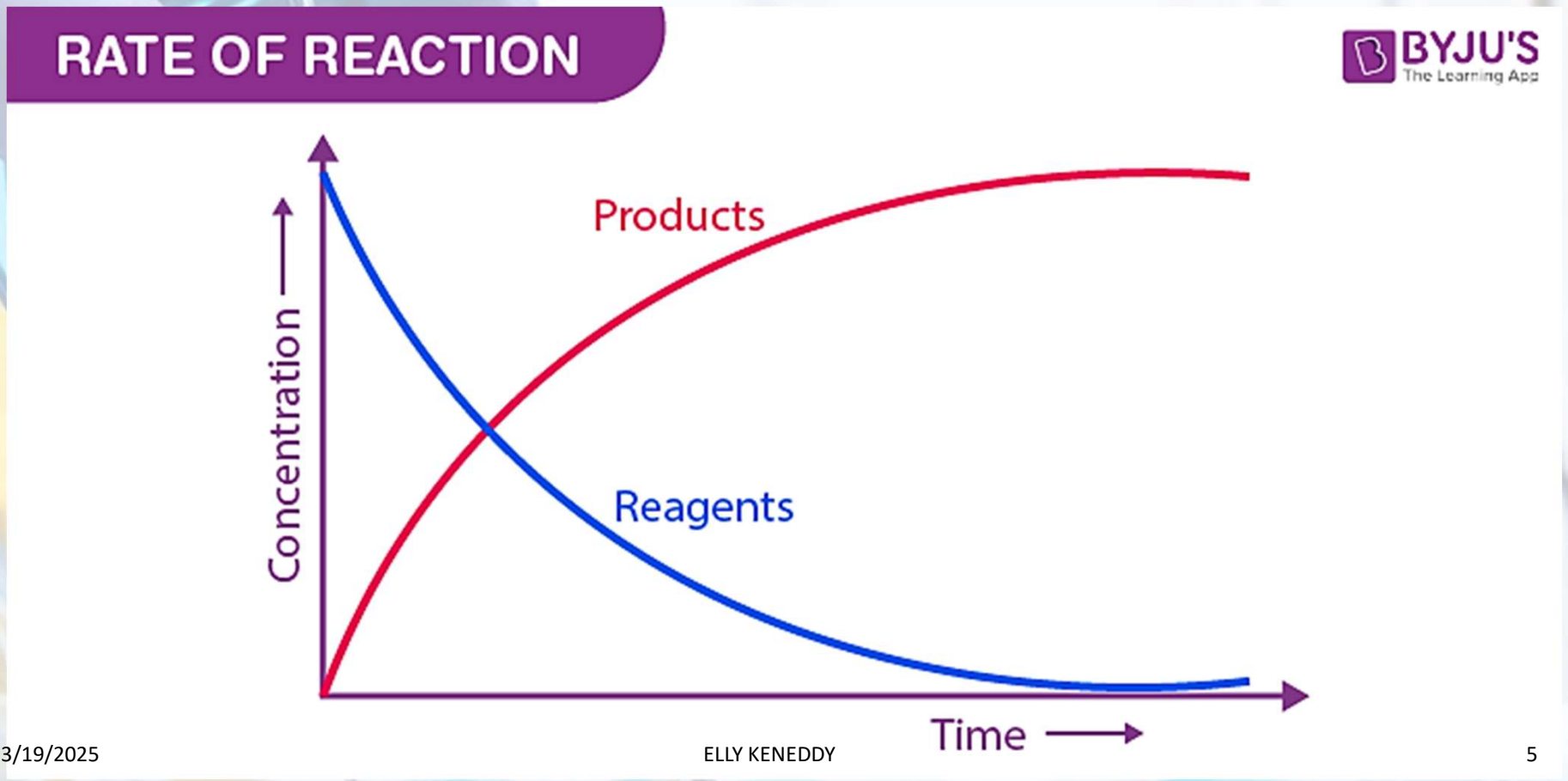
CONT……

- During a chemical reaction, **substances that take in the reaction reduce** and with time, they **get used up**. The amount of **products formed increase with time.**
- A reaction rate is the ***measure of how much of reactants are consumed*** or **how much products are formed per unit time** .
- It is the measure of how fast the reaction takes place

$$\text{Rate of reaction} = \frac{\textit{change in amount of reactant to product}}{\textit{change in time}}$$

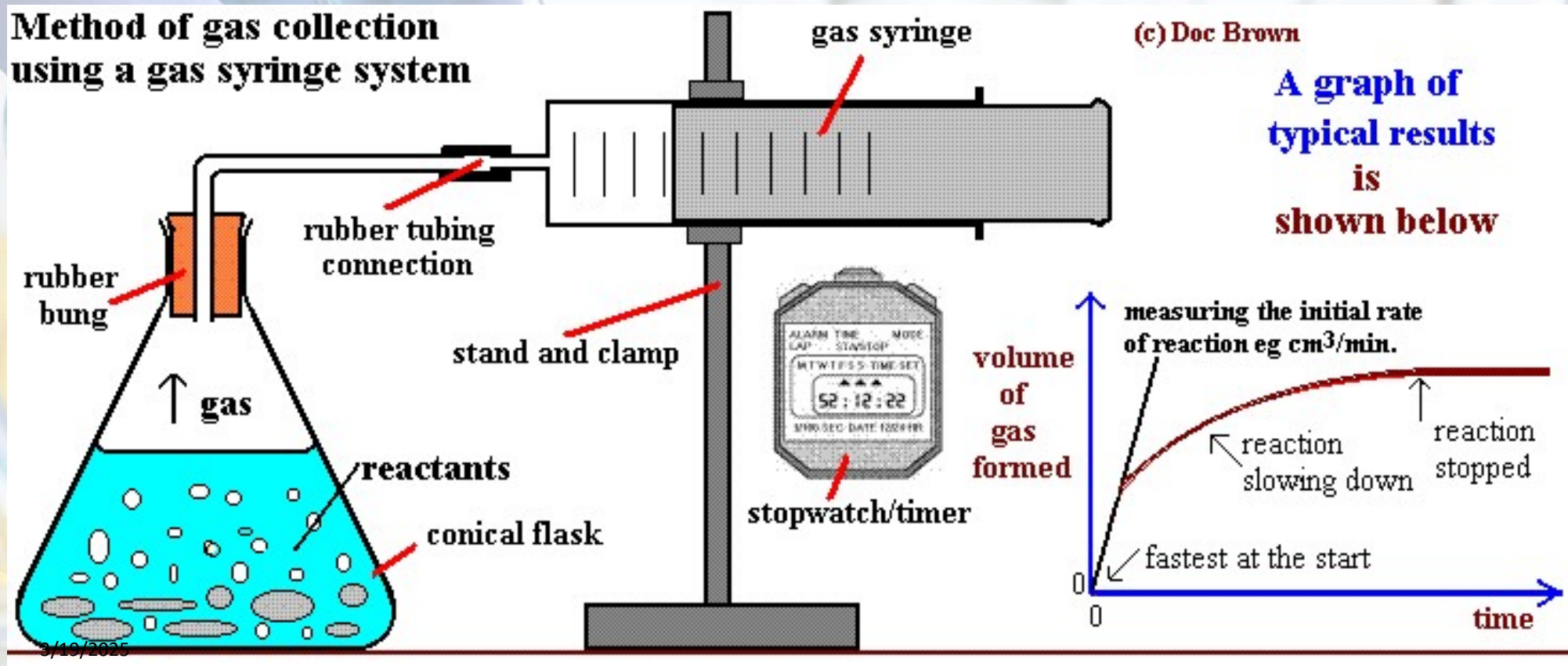
- Unit = **Moles per litre / s**

GRAPH SHOWING CHANGE IN THE AMOUNT OF PRODUCTS AND REACTION



DETERMINATION OF RATE OF REACTION BETWEEN MAGNESIUM RIBBON AND DILUTE HYDROCHLORIC ACID.

- **Materials** :

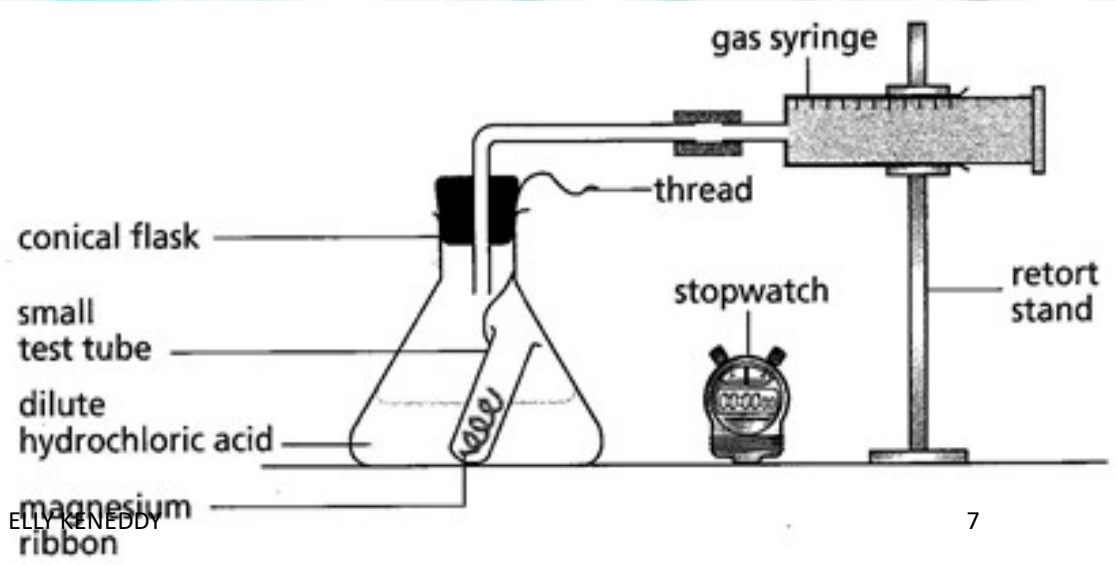


PROCEDURE

- Clean a piece of magnesium ribbon using sand paper.
- Measure a known volume of hydrochloric acid into a conical flask. Remove the rubber bung for a moment and drop in the clean magnesium ribbon.
- Immediately start the stop clock and rapidly replace the rubber bung.
- The volume of hydrogen in the syringe is recorded at regular time intervals until the reaction is complete

Equation

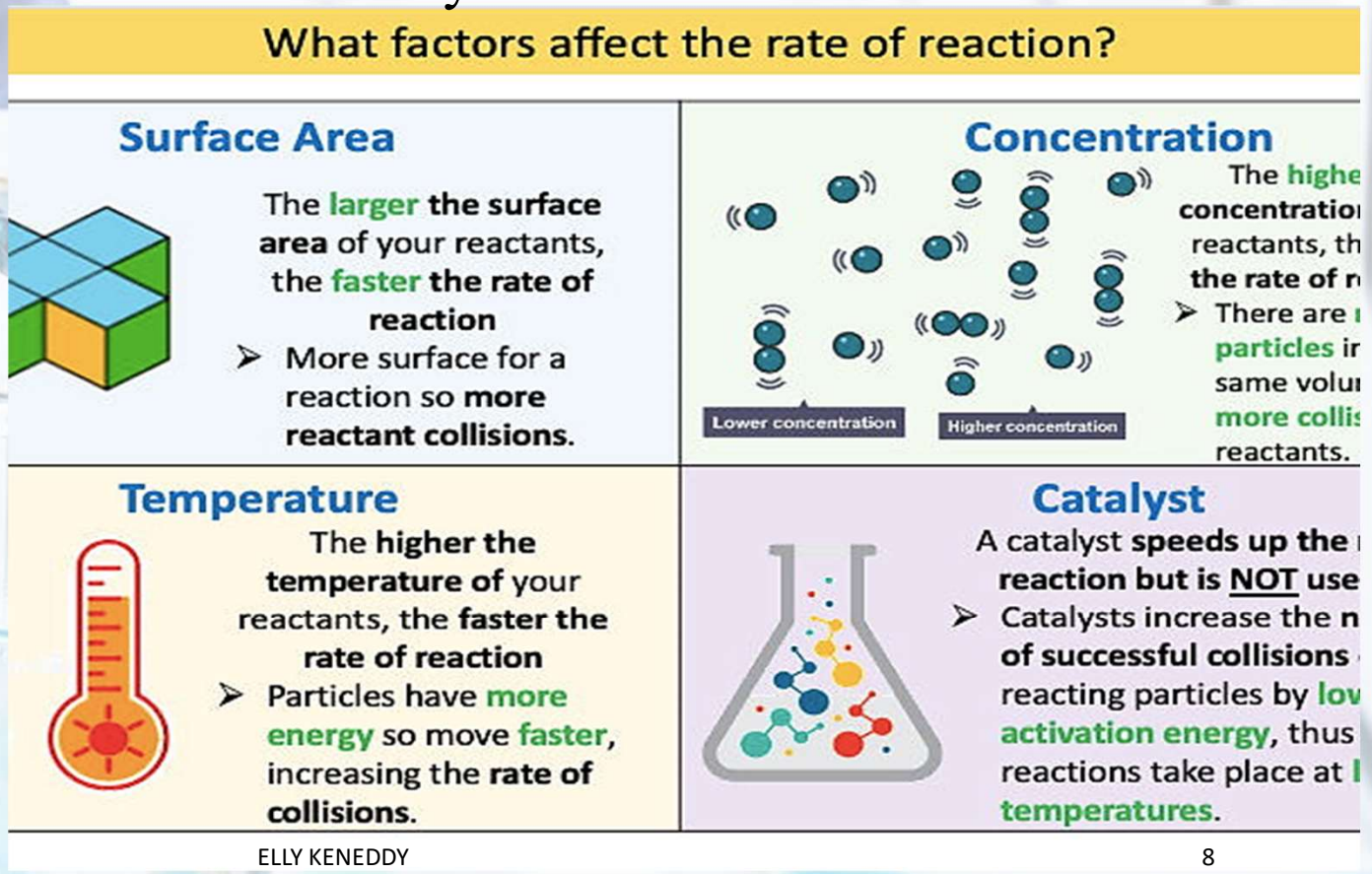
$Mg_{(g)} + 2HCl_{(aq)} \; MgCl_{2(aq)} + H_{2(g)}$



FACTORS THAT AFFECT THE RATE OF REACTION.

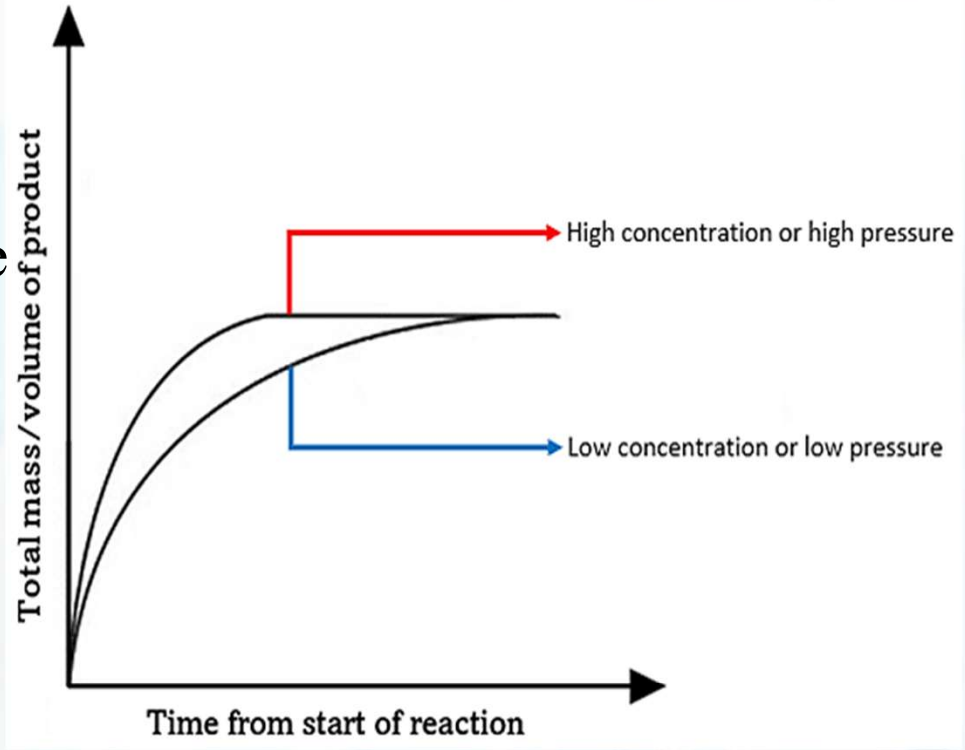
The rate of a chemical reaction is affected by **6** factors.

- ❑Concentration
- ❑Temperature
- ❑Surface area
- ❑Catalyst
- ❑Pressure
- ❑Light.



EFFECT OF CONCENTRATION ON THE RATE OF REACTION.

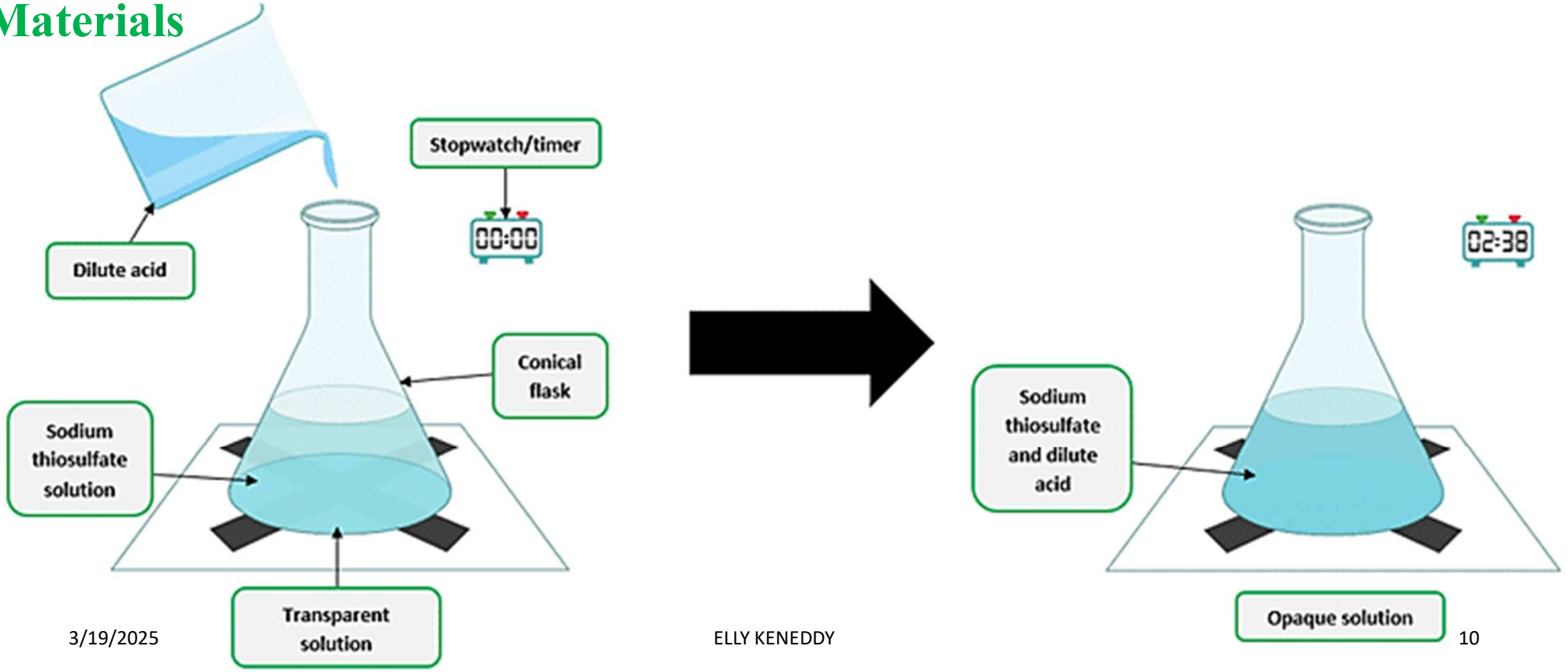
- Increase in concentration of one or more of the reactants increase the rate of the reaction.
- Increase in concentration leads to increase in number of reacting particles which in turn leads to increase in the number collisions per unit time.
- The reaction proceeds faster and takes a shorter time to reach completion.



AN EXPERIMENT TO DETERMINE THE EFFECT OF CONCENTRATION ON THE RATE OF REACTION.

Hypothesis : increase in concentration increases the rate of reaction.

Materials



PROCEDURE

- Make a mark with blue or black ink on a piece of paper.
- Place 50 cc of 0.05 M sodium thiosulphate solution into a beaker.
- Add 10 cc of 1 M hydrochloric acid to the sodium thiosulphate and at the same time start the stop clock.
- Gently shake the mixture to mix the solution well and place the beaker on the paper over the mark.
- Watch the mark through the solution from above the beaker.
- Stop the clock when the mark just disappears.
- Vary the concentration of the thiosulphate solution by taking 40, 30, 20 and 10 cc each time by adding distilled water to make 50cc.
- Tabulate your results including 1/time.

- Plot graph of volume of sodium thiosulphate solution against 1/time (time-1) and against time.
- The rate of reaction is proportional to the reciprocal of time (time-1). Your graphs should appear as shown in figure 11.4a and 11.4b.

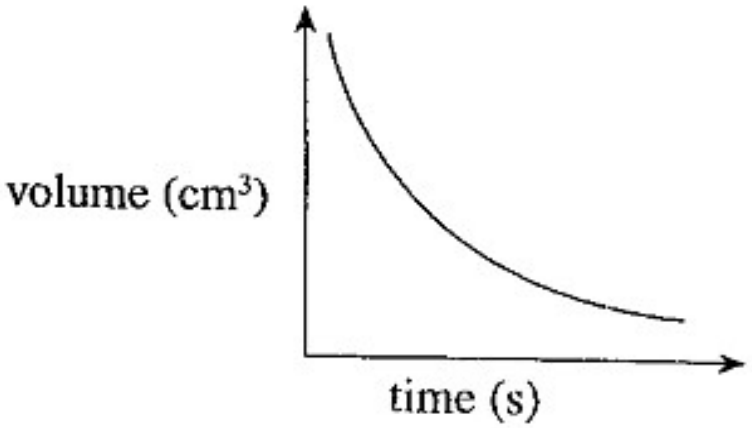


Fig 11.4a Graph of volume of sodium thiosulphate against time

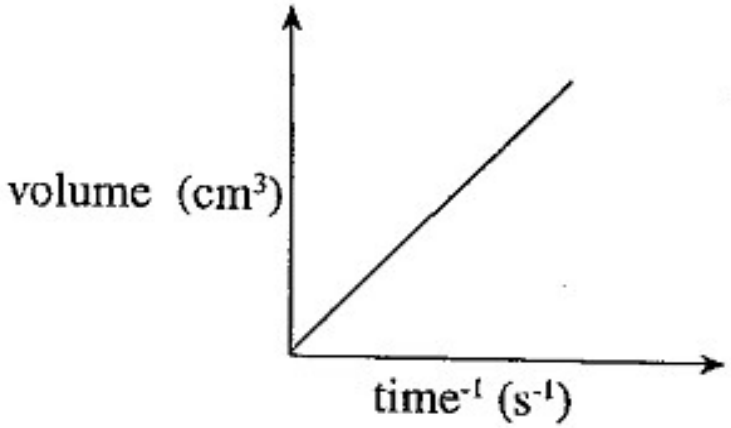


Fig 11.4b Graph of volume of sodium thiosulphate agaist time $^{-1}$

- The mark disappears because the reaction between hydrochloric acid and sodium thiosulphate forms a precipitate of Sulphur which renders the mixture opaque.

$$NaS_2O_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + S_{(s)} + H_2O_{(l)} + SO_{2(g)}$$

- Figure 11.4a shows that ***the higher the volume of the sodium thiosulphate***, ***the less the time taken to form a precipitate.***
- Figure 11.4b shows that the **rate of the reaction increases** with **increase in volume of sodium thiosulphate solution.**

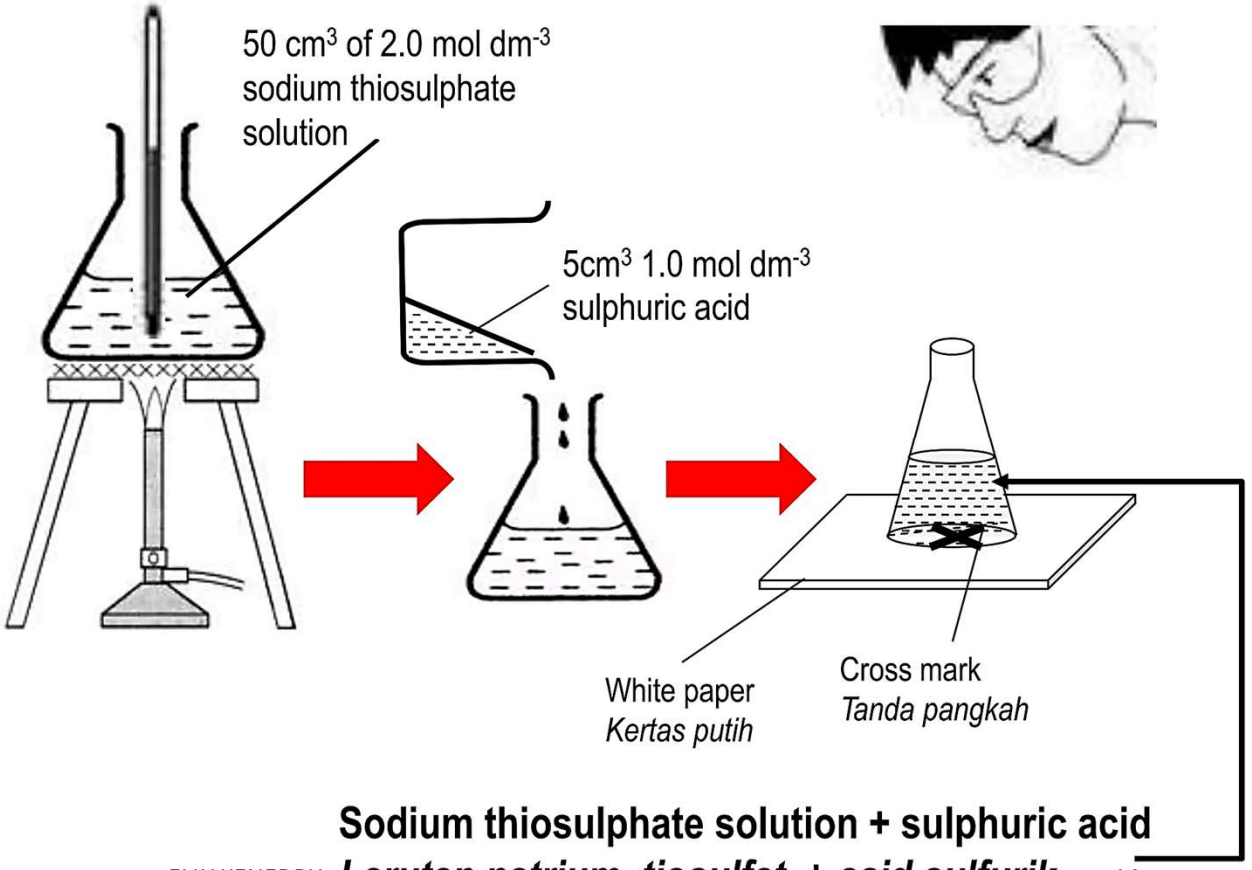
Explanation

- The rate of the reaction ***depends on the frequency with which reacting particles collide***, which frequency **depends on the concentration of the reactants.** The **higher the concentration**, the **higher the frequency of collision** and therefore the **higher the rate of the chemical reaction**.

INVESTIGATION OF THE EFFECT OF TEMPERATURE ON THE RATE OF REACTION

Materials

- Sodium thiosulphate
- Conical flask
- Blue or black mark
- White sheet of paper
- Measuring cylinder
- Heat source
- Thermometer
- Beaker



PROCEDURE.

- Measure 50cc of sodium thiosulphate made by dissolving 20g of thiosulphate in 500cc in a beaker and note its temperature.
- Place the beaker on a piece of paper marked with a cross.
- Add 10cc of hydrochloric acid(2M) to the thiosulphate solution and swirl the mixture. At the same time start the stop clock.
- Look through the mixture and note the time it takes for the cross to disappear.
- Repeat the experiment with sodium sulphate solution heated to different temperatures e.g. , 30C ,40C, 50c and 50C.
- Each case note the time for the cross to disappear
- Tabulate your results including 1/time. Plot graphs of temperature against 1/time.

- Figure 11.5a shows that the higher the temperature the less the time taken to form a precipitate.
- Figure 11.5b shows that the rate of the reaction increases with increase in temperature.

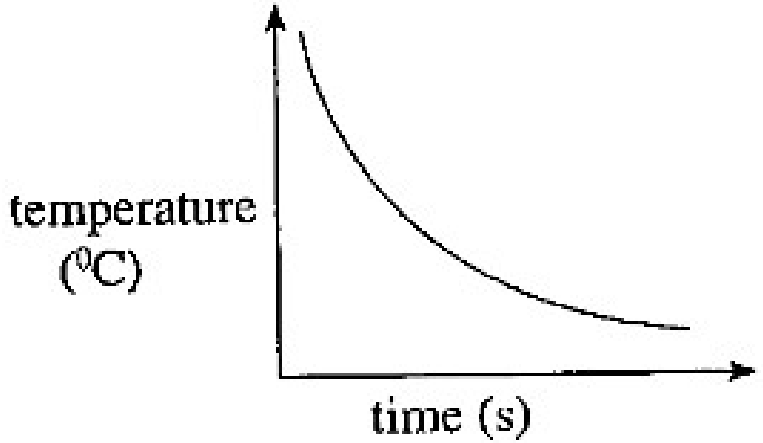


Fig 11.5a
Graph of temperature against time

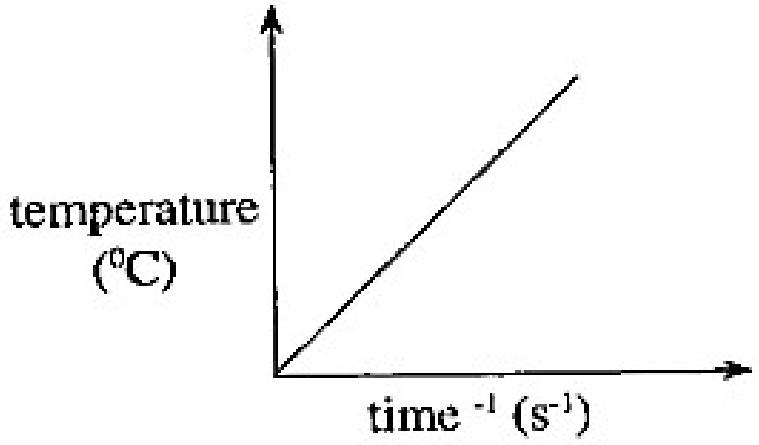
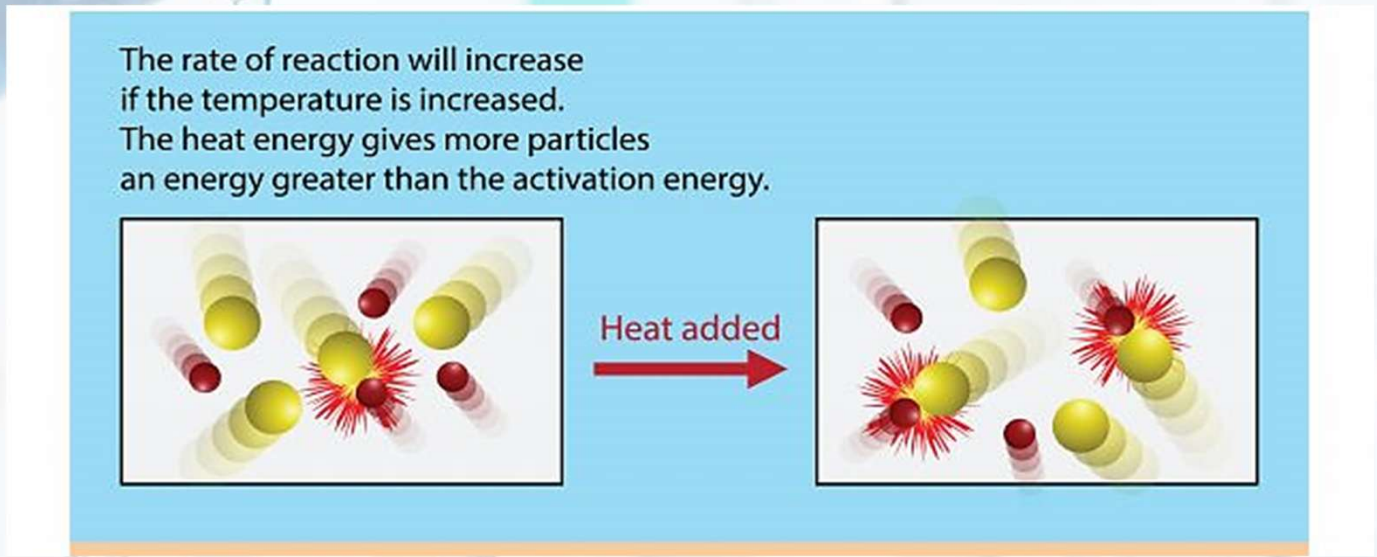


Fig 11.5b
Graph of temperature against time -1

EXPLANATION.

- When the **temperature is increased**, the **reacting particles gain more kinetic energy** and move at a greater speed.
- The **frequency at which the reacting particles collide increases** and thus, the **rate of the reaction increases**.
- Therefore, the higher the temperature, the higher the rate of reaction.



EFFECT OF A CATALYST ON THE RATE OF REACTION

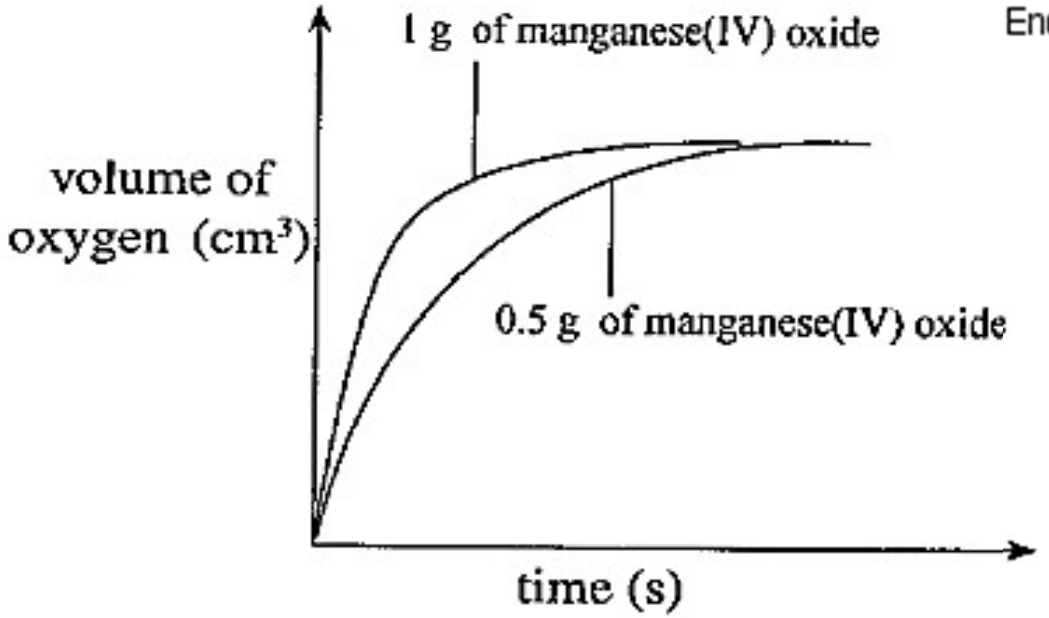
- A catalyst is a ***substance which alters the rate of chemical reactions without undergoing any overall chemical change itself***.
- Most catalysts speed up the rate of reaction. The greater the amount of the catalyst but within the limits, the higher the rate of reaction.
- Powdered catalysts offer a larger surface area over which the reaction takes place and therefore are more effective than one in lump form.
- Catalysts remain unchanged chemically after a reaction has taken place.
- A catalyst which slows down a reaction is called a negative catalyst.

CHARACTERISTICS OF A CATALYST

- A catalyst is unchanged chemically at the end of the reaction.
- A small amount of catalyst is able to bring about significant change in a chemical reaction.
- A catalyst does not affect the position of chemical equilibrium of reversible reactions.
- A catalyst does not initiate a reaction, it only accelerates a reaction that is already taking place.
- A catalyst is specific to a particular chemical reaction.

PROCEDURE.

- Place 100 cm3of 0.1 M hydrogen peroxide in a conical flask. Add 0.5 g of manganese(IV) oxide to the hydrogen peroxide in conical flask.
- Then set up the experiment as shown in figure above.
- record the volume of oxygen in the syringe at regular intervals until the reaction is complete.
- Repeat the experiment using 1 g of manganese(IV) oxide.
- When the graphs of volume of oxygen against time are plotted using the same axes, they appear as shown in figure 11.6.



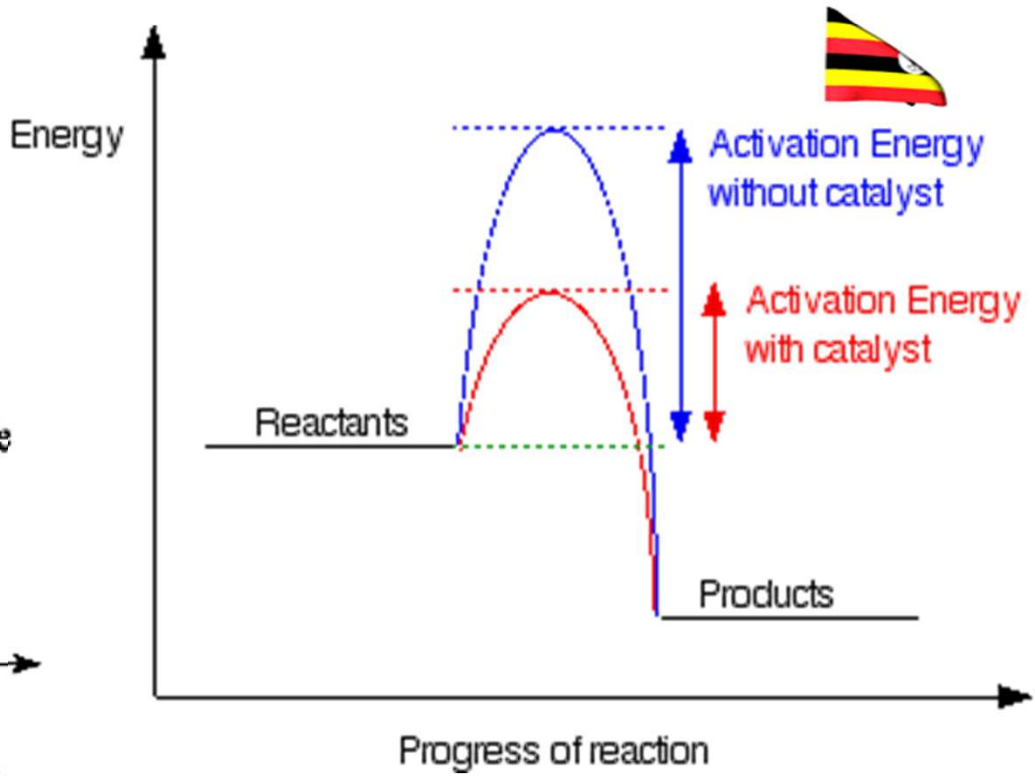


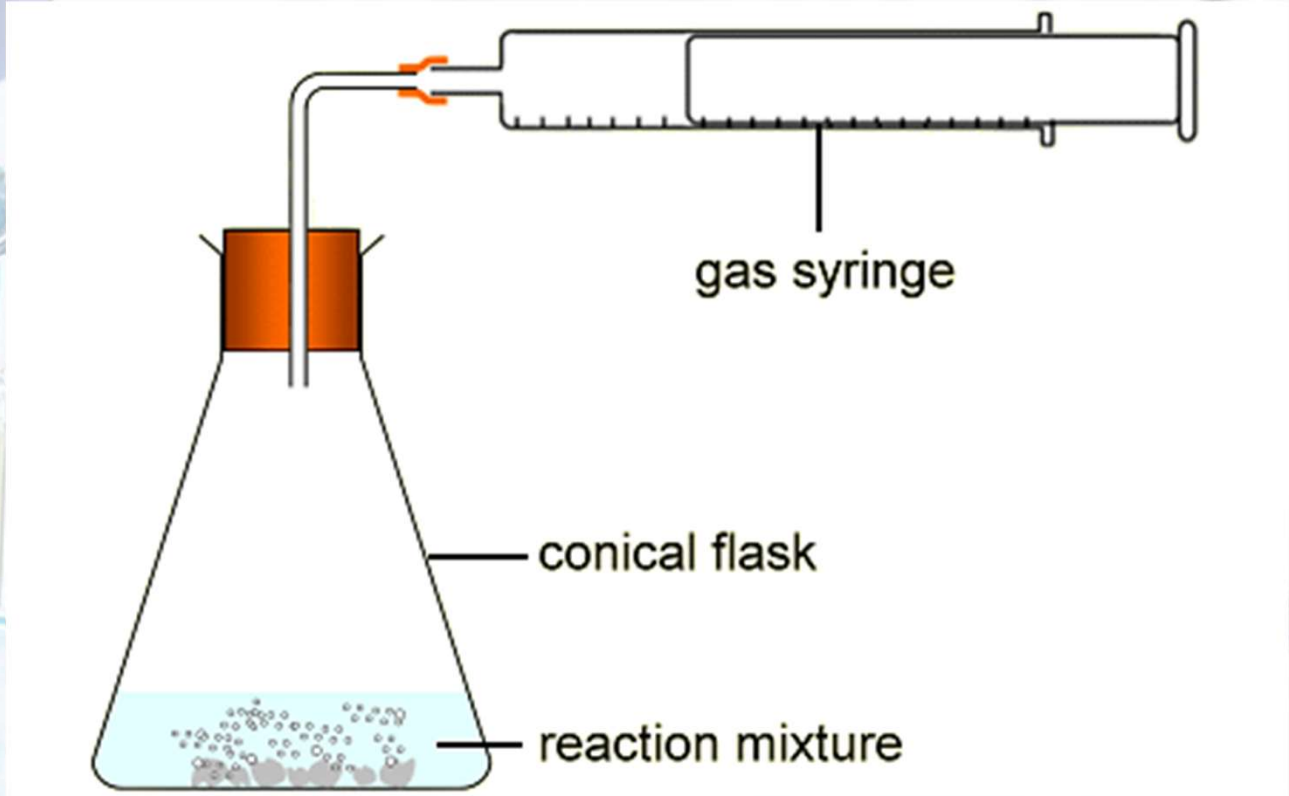
Fig 11.6 Graphs of volume of oxygen against time

NB. The rate of reaction increases when the catalyst is used. A **catalyst lowers activation energy so that more molecules can react.**

EFFECT OF SURFACE AREA ON THE RATE OF REACTION

Materials

- Retort stand
- Dilute HCL
- Conical flask
- Calcium carbonate
- Delivery tubes
- syringe
- Stop watch



PROCEDURE

- Pour 20 cm3of 1 M hydrochloric acid in a test-tube.
- To the conical flask add 10 g of calcium carbonate lumps and then set up the experiment as shown in figure above.
- Record the volume of carbon dioxide in the syringe at regular intervals until the reaction is complete.
- Repeat the experiment using the same mass of powdered calcium carbonate.
- Plot a graph of volume of carbon dioxide produced against time
- When the graphs of volume of carbon dioxide against time for both powdered calcium carbonate and calcium carbonate lumps, are plotted using the same axes.
- They appear as shown in figure 11.7.

Note

- Solid react much more rapidly when powdered than when in large lumps.

Explanation

- This is because reactions with solids take place at the surface.
- Powdered solids present a large surface area over which the reaction occurs than solids in lump form.

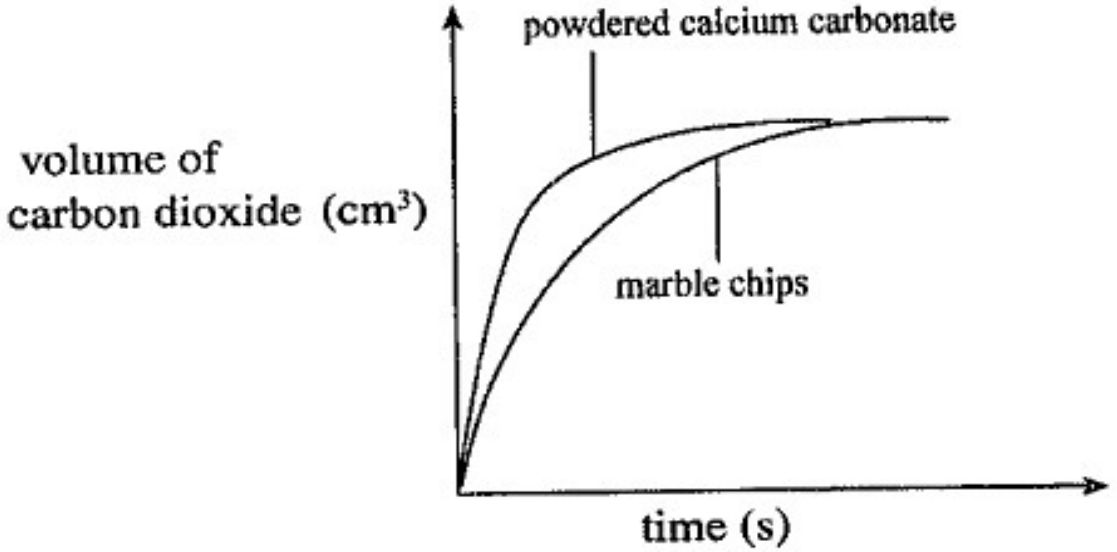
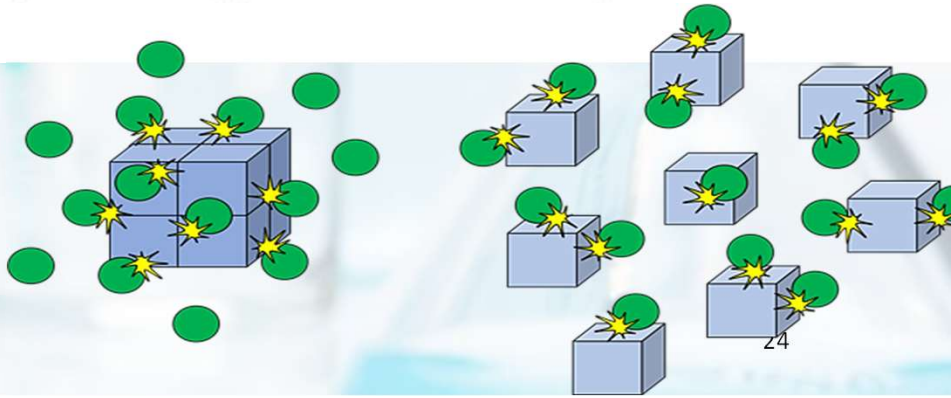


Fig 11.7 Graphs of volume of carbon dioxide against time



OTHER FACTORS.

Pressure

- Pressure affect reactions which occur in gas phase only. High pressure brings gas molecules

closer so they collide more frequently leading to increase in the rate of the reaction.

- **Light**
- Some reactions are speeded p considerably when exposed to bright sun light.The molecules absorb energy in form of light rather than heat, such reaction are called photochemical reactions.

Processes which are affected by light include;

- **Photosynthesis**, in which plants are unable to manufacture starch when placed in the dark.
- **Decomposition of silver bromide** into silver and bromine, a basis of photography.
- Photographic film consists of tiny silver bromide crystals. When light falls on the film, it causes the decomposition of the bromide and the extent of decomposition depends upon the brightness of the light.

REVERSIBLE REACTIONS

- This is a reaction which occurs in both forward and backward directions at the same time.

Examples

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

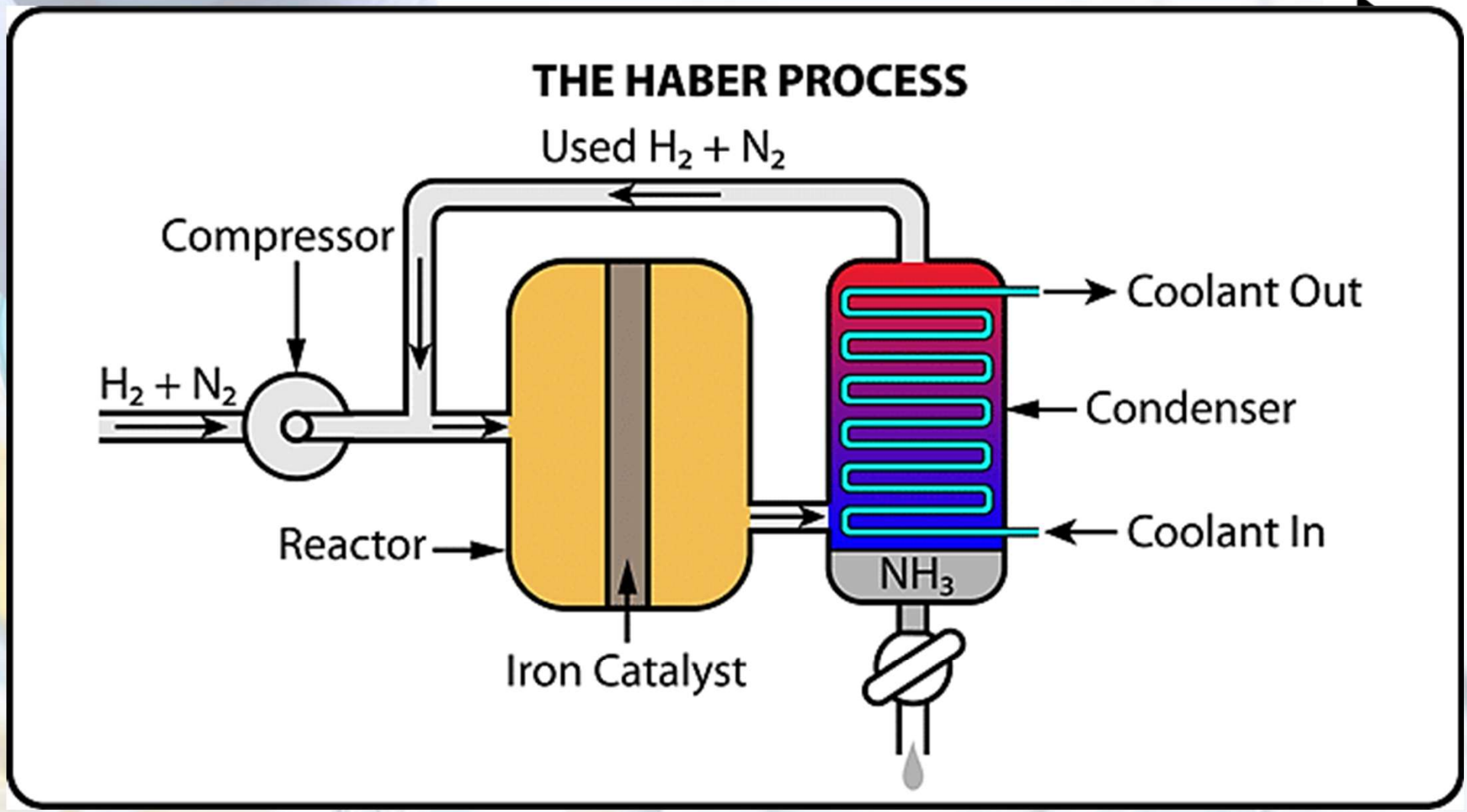
$$N_2(g) + H_2(g) \rightleftharpoons 2NH3(g)$$

$$3Fe(s) + 4H_2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g)$$

INDUSTRIAL PREPARATION OF AMMONIA (HABER PROCESS)

- Dry nitrogen and hydrogen in the ratio of **one** to **three** respectively, are passed over a catalyst of iron with some traces of aluminium oxide present.
- The **reaction occurs at the surface of the catalyst;** therefore, **the catalyst should be finely divided to increase the surface area over** which the reaction occurs.
- Aluminium oxide improves the performance of the catalyst by making it more porous thus providing a higher surface area for the reaction.
- The **temperature is between 450C – 500C**. The **gases are under a pressure of 250 atmospheres to 500 atmospheres**. Ammonia is produced.

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$$


THE HABER PROCESS
Used $H_2 + N_2$
Compressor
$H_2 + N_2$
Reactor
Iron Catalyst
NH_3
Coolant Out
Condenser
Coolant In

CONT……

- Ammonia is removed from the mixture of gases by cooling the mixture with a freezing mixture.
- It is only ammonia that liquefies and can be removed from the mixture.
- The unreacted nitrogen and hydrogen are recycled

Note

- Nitrogen used in this process is obtained by **fractional distillation** of liquid air and hydrogen is obtained from natural gas or electrolysis of brine.

USES OF AMMONIA.

- pH Adjustment: Helps control acidity in industrial wastewater.
- Used as a building block for producing certain drugs, such as sulfa drugs
- Ammonia solutions are used for cleaning glass, surfaces, and removing stains.
- **Fertilizer**: Ammonia is a key ingredient in fertilizers like ammonium nitrate, urea, and ammonium sulfate, essential for plant growth.
- **Manufacturing Chemicals**: Used to produce nitric acid, hydrogen cyanide, and various amines.
- **Plastics and Textiles**: Used in the production of synthetic fibers like nylon and rayon.
- Explosives: Acts as a precursor for ammonium nitrate, used in explosives.

INDUSTRIAL MANUFACTURE OF SULPHURIC ACID BY THE CONTACT PROCESS

The **raw materials** are sulphur, oxygen and water.

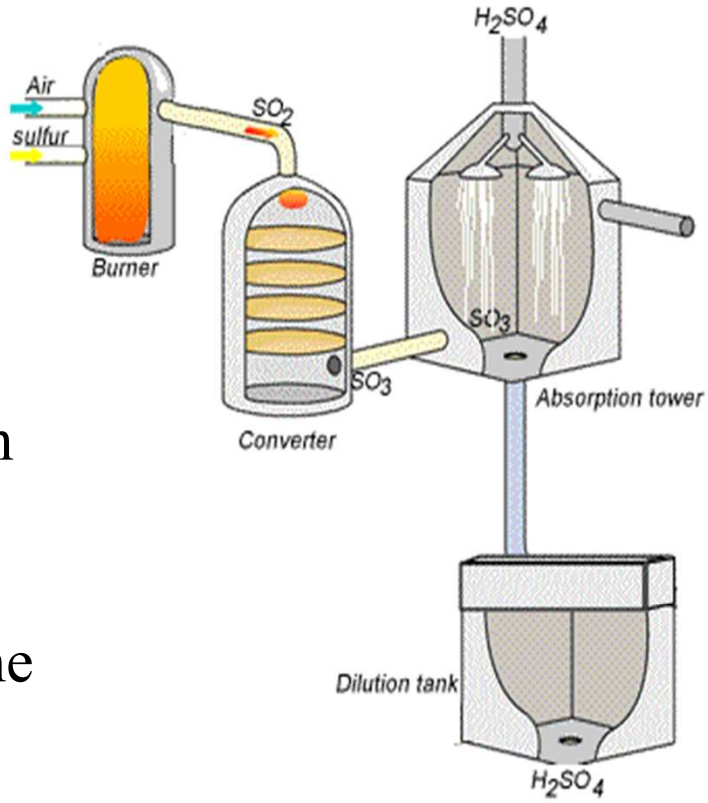
The reaction vessel is a

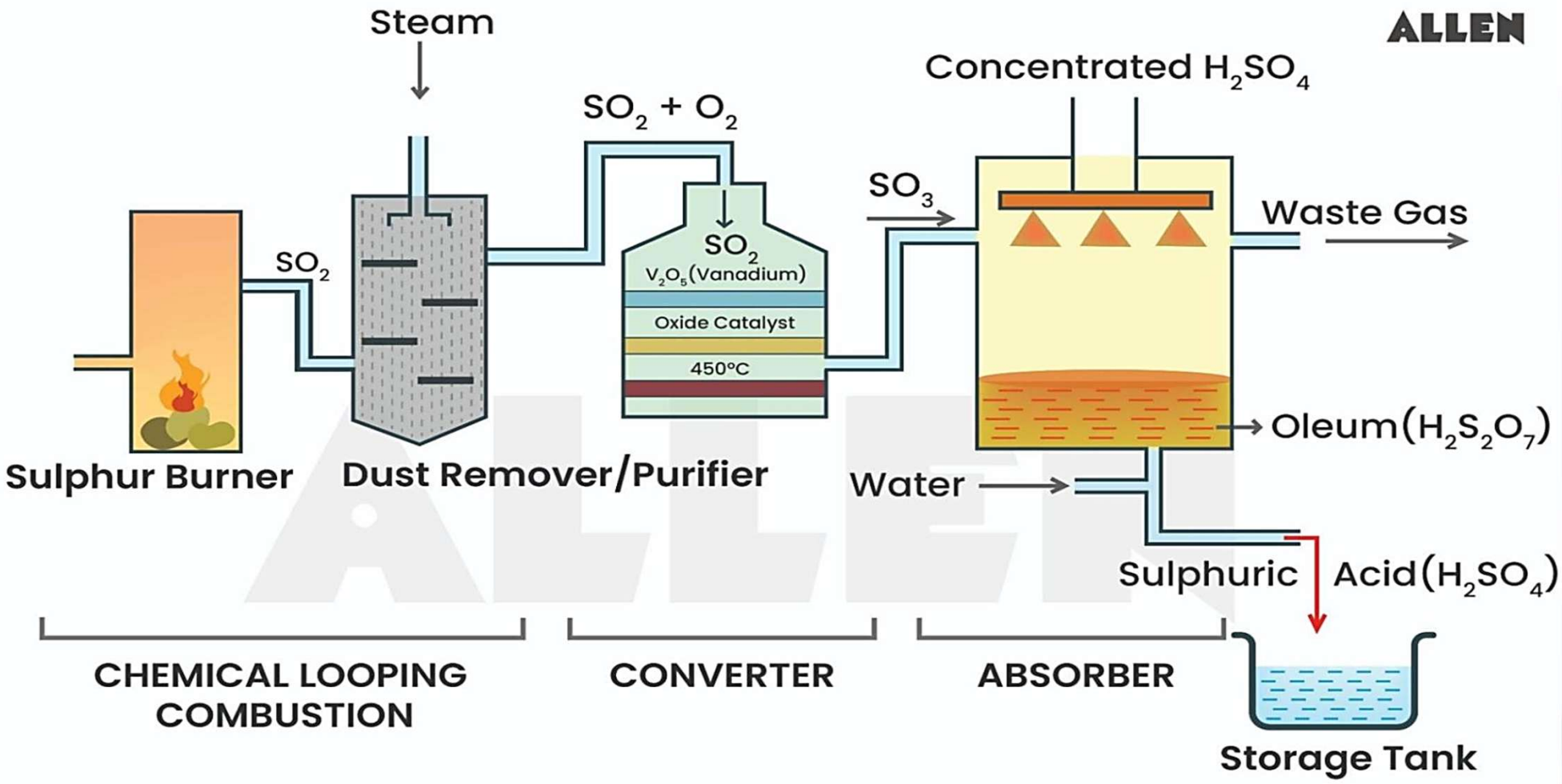
Stage 1: preparation of sulphur dioxide

- Sulphur is burnt in air to produce sulphur dioxide

$$S_{(s)} + O_{2\ (g)} \rightarrow SO_{2\ (g)}$$

- Sulphur dioxide may contain some impurities such as arsenic compounds which may '**poison the catalyst**', that is, make the catalyst ineffective.
- Therefore, sulphur dioxide is cleaned to remove the impurities then is dried.





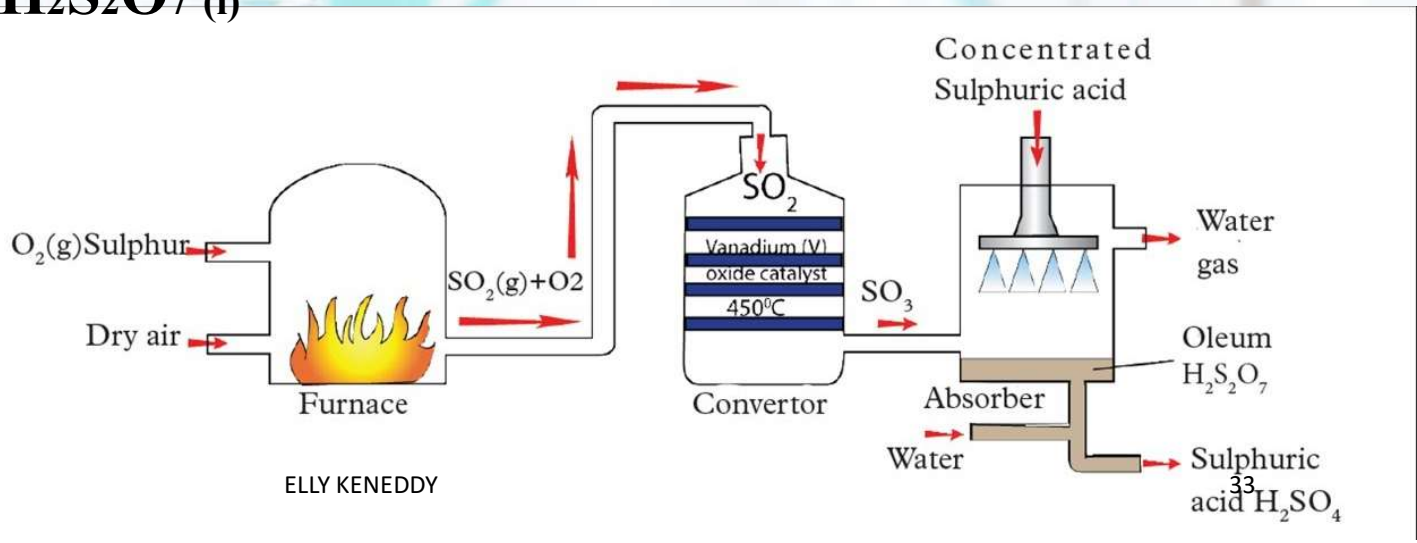
Manufacture of H_2SO_4 By Contact Process

- **Stage II**: Conversion of sulphur dioxide to sulphur trioxide
- Then sulphur dioxide is mixed with air and passed along heated pipes containing pellets of vanadium pentoxide (V_2O_5) (catalyst) at a temperature of 450 – 500 C under a pressure of 200 atmospheres. Sulphur trioxide is formed.

$$2SO_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2\,SO_{3\,(g)}$$

- Sulphur trioxide formed is dissolved in concentrated sulphuric acid to produce a fuming liquid called oleum.

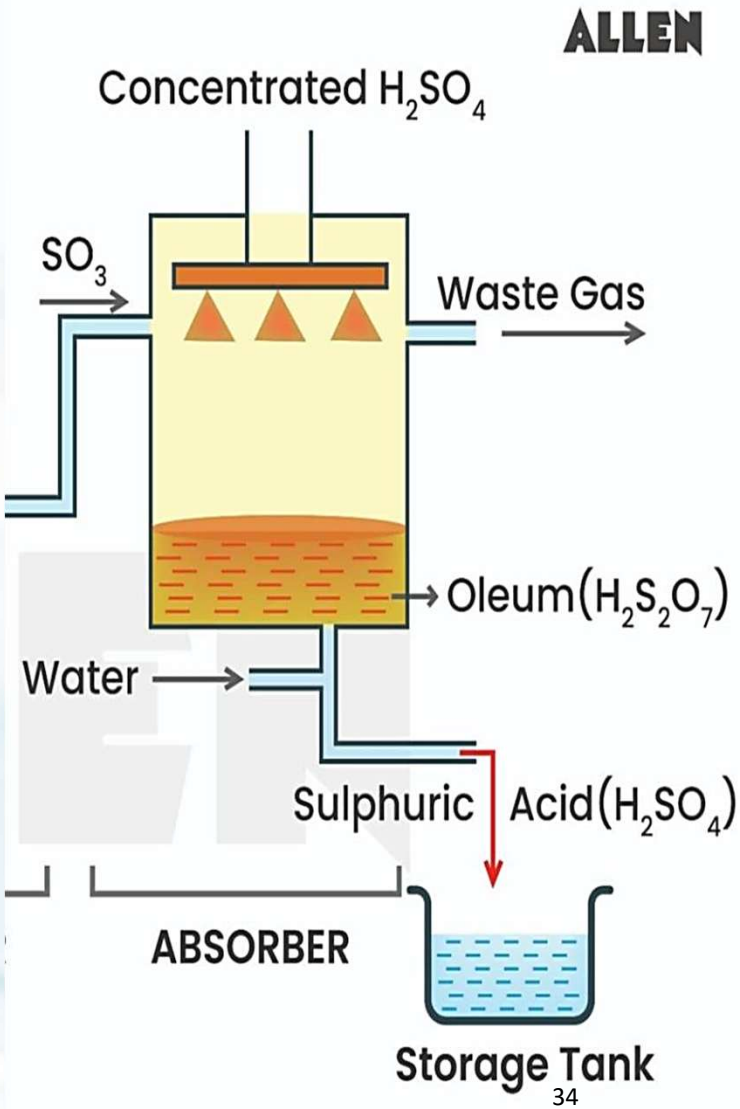
$$SO_{3\,(g)} + H_2SO_{4\,(l)} \rightarrow H_2S_2O_{7\,(l)}$$



- **Stage III**: Conversion of sulphur trioxide to acid
- The oleum is **diluted with a known amount of water to give concentrated sulphuric acid**.

$$H_2S_2O_7\ (l) + H_2O\ (l) \rightarrow H_2SO_4\ (l)$$

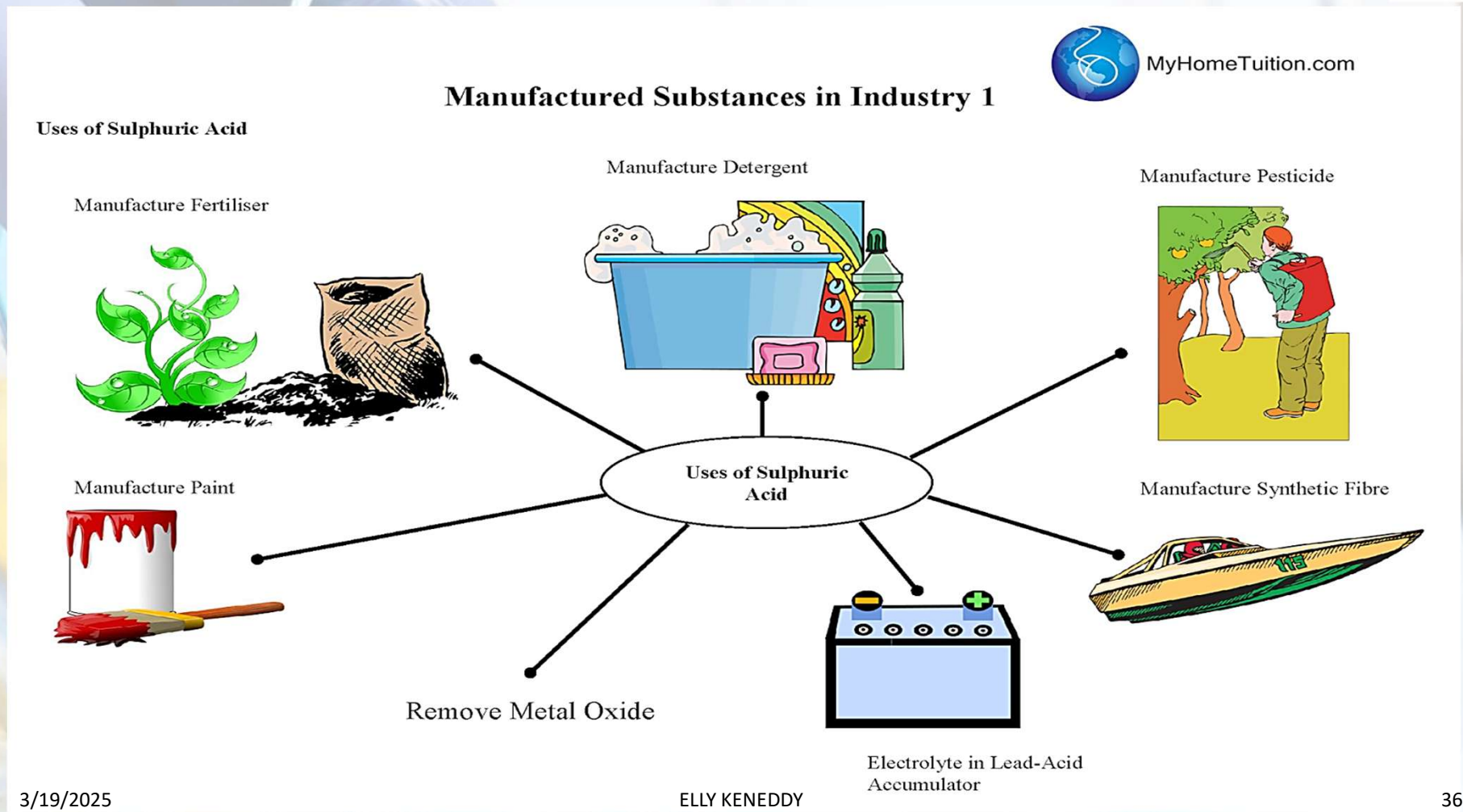
- **Note**: Sulphur trioxide is not dissolved in water directly because the **reaction is too exothermic**.
- The **heat produced from the reaction vapourises the acid forming only tiny droplets** of the acid **leading to a spray of sulphuric acid which would affect the workers** in the factory.



PROPERTIES OF SULPHURIC ACID

- It is a colourless and ordourless oily liquid
- Has a high affinity for water (hygroscopic) and that is why it is used as a drying agent
- It has a density of 1.86g/cc and boils at 338C
- It does not show any acidic properties unless water is present.

USES OF SULPHURIC ACID



USES OF SULPHURIC ACID

- It is used in the manufacture of detergents
- It is used in car batteries and accumulators as an electrolyte
- It is used in manufacture of fertilizers such as ammonium sulphate

$$NH_{3(g)} + H_2SO_{4\ (aq)} \rightarrow (NH_4)_2SO_{4\ (s)}$$

- Used in extraction of metals and also cleaning them prior to plating
- Used in manufacture of paints, dyes and explosives

ALWAYS AIM FOR EXCELLENCE

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