Rate of Reactions

Chemistry 17

The cause of most changes around us is chemical reactions. Given below are some of those changes.

- Rusting of iron
- Ripening of fruits
- Digestion of food
- Manufacturing yoghurt from milk
- Burning firewood
- Reaction of zinc with a dilute acid
- Reaction of sodium metal with water
- Ignition of petrol
- Blast of a cracker

Assignment - 17.1

- Prepare a list of chemical changes including the above changes.
- Considering rates of chemical reactions that take place in those changes, tabulate them as given below.

Fast reactions	Slow reactions
i.	.....
ii.	.....
iii.	.....

The speeds of various chemical reactions vary. Reactions like ripening of fruits, digestion of food and rusting of iron are slow. But combustion of petrol, reacting zinc with dilute acid and blasting of a cracker are comparatively fast.

Accordingly, some reactions are instantaneous or rapid, while some others are very slow. There are reactions that take place in a second, in a minute, in an hour, during several days, during several months or even during several years.

When a chemical reaction occurs, reactants are used up and new products are formed. This can be easily understood by considering the following reaction.

$$\underbrace{CaCO_3(s) + 2HCl(aq)}_{\text{Reactants}} \longrightarrow \underbrace{CaCl_2(aq) + H_2O(l) + CO_2(g)}_{\text{Products}}$$

The rate of this reaction can be determined by the speed of loss of reactants or by the speed of formation of products. What is observable easily in this reaction is the rate of disappearance of calcium carbonate or the rate of evolution of carbon dioxide.

Rate of reaction is the amount of change occurred in unit time.

That is ;

$$\textbf{Rate of reaction} = \frac{\textbf{Amount of reactants used up}}{\textbf{Time taken}} \quad \text{or} \quad \frac{\textbf{Amount of products formed}}{\textbf{Time taken}}$$

How is the rate of a reaction determined ? There are two principal ways for this.

i. Measuring the amount of reactants used up or the amount of products formed during a given period of time
ii. Measuring the time taken for loss of a given amount of reactants or formation of a given amount of products

17.1 Factors Affecting the Rate of Reactions

When a chemical reaction occurs, the chemical bonds between the particles of reactants (atoms or molecules) are broken. Different products are formed as a result of building of new bonds.

Particles of the reactants should collide with one another for this breaking and building of bonds.

Factors that affect the rate of reactions are given below.

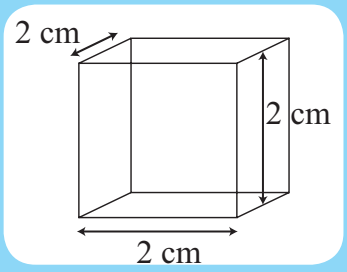
- Surface area of reactants
- Temperature at which the reaction occurs
- Concenration of reactants (Pressure for gaseous reactants)
- Presence of catalysts

• Surface area of reactants

A large log of wood can easily be burnt when it is split into small splints. Physicians advise to chew food well for easy digestion. What is the reason for all this ?

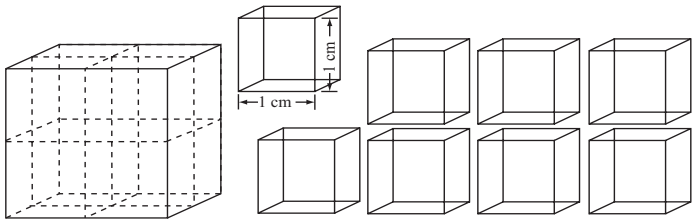
When a solid reacts with a liquid or a gas, the reaction occurs only on the surface of the solid. The reason for this is that the particles of reactants collide only on the surface of the solid. Let us carry out assignment 17.2, for futher clarification.

Assignment - 17.2



- Conside a cube of marble ($CaCO_3$), of a side 2 cm, put into dilute hydrochloric acid solution.Calculate the surface area of marble that comes into contact with the acid.

- Suppose that marble cube is cut into 8 small cubes, a side of each is 1cm in length.



- Calculate the total surface area of the marble cubes touching the acid, if those 8 small cubes are put into the acid solution.

Surface area of one side of the large cube	= 2 cm X 2 cm	= 4 cm^2
Total area of 6 sides	= 4 cm^2 X 6	= 24 cm^2
Surface area of one side of a small cube	= 1 cm X 1 cm	= 1 cm^2
Total area of 6 sides of one small cube	= 1 cm^2 X 6	= 6 cm^2
The total surface area of 8 small cubes	= 6 cm^2 X 8	= 48 cm^2

Accordingly it is clear that the surface area increases, when a large cube is divided into small cubes.

Let us carry out the activity 17.1 to find out, how surface area of reactants affects the rate of a reaction.

Activity - 17.1

Requirement : Calcium carbonate chips and powder of equal mass, dilute hydrochloric acid, two beakers, a stop watch

- Add equal volumes of acid into two beakers.
- Add calcium carbonate chips into one beaker with hydrochloric acid and using the stop watch measure the time taken by the chips to disappear. Repeat the same procedure using calcium carbonate powder.

Gas bubbles evolve faster in the beaker with calcium carbonate powder. It is observable that calcium carbonate powder disappears faster than the chips. That is, the reaction occurs in a shorter period of time.

Accordingly the rate of reactions in those two instances can be ascertained, comparing the time taken for equal amounts of reactants to be used up.

$$\text{Rate of reaction} = \frac{\text{Amount of the reactants used up}}{\text{Time taken}}$$

Above activity confirms that the rate of a reaction increases when calcium carbonate powder is used. Therefore it can be concluded that the rate of reactions increases when the surface area of the reactants is increased. The cause for this is that, the number of collisions between the particles of reactants increases when their surface area is increased.

Assignment - 17.3

- Surface area of reactants is increased to increase the rate of reactions in day - to- day life.
- Prepare a list of such instances.

• Temperature of the reaction

Food spoils because of biochemical reactions. Refrigerators or deep freezers are used to keep food unspoilt for a long time. This implies that the rates of biochemical reactions are reduced at low temperatures.

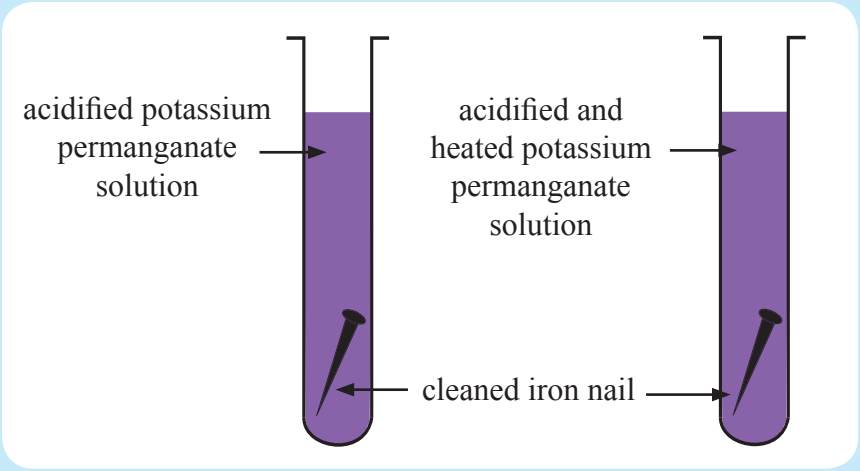
It is experienced that sugar dissolves more readily in hot water than in cold water.

Let us engage in activity 17.2 to find out how temperature affects the rate of reactions.

Activity - 17.2

Requirement : Two iron nails, water, dilute potassium permanganate solution dilute sulphuric acid, a stop watch, two test tubes, a burner.

- Prepare a very dilute potassium permanganate solution.
- Add equal volumes of dilute potassium permanganate solution into the two test tubes. Acidify them with equal volumes of sulphuric acid. Heat one test tube to a fairly higher temperature.
- Add equal number of cleaned iron nails equal in size, into the two test tubes.
- Using the stop watch, measure the time to disappear the colour in each.



In the above activity, it is observed that the time taken to decolourise potassium permanganate solution at higher temperature is less. Therefore it can be concluded that the rate of reactions increases with the increase in temperature. At a higher temperature, the kinetic energy of the reacting particles is greater. This increases the number of collisions per unit time among them thus increasing the rate of the reaction.

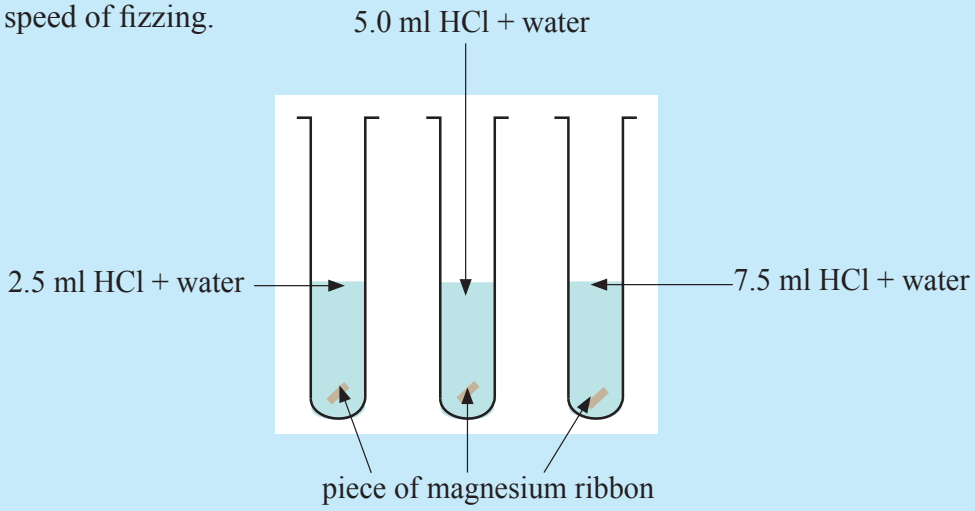
• Concentration of reactants

Let us carry out the activity 17.3 below, to find out how concentration of reactants affects the rate of reactions.

Activity - 17.3

Requirement **:** Three pieces of cleaned magnesium ribbon of equal surface area, three test tubes, dilute hydrochloric acid, water

- Take three test tubes and add 15 ml of water to each tube. Mark water level of each tube with a rubber band and empty the water. Add 2.5 ml, 5.0 ml, and 7.5 ml of dilute hydrochloric acid to the three test tubes, and fill water to the rubber band mark of each tube.
- Introduce to each test tube a piece of magnesium ribbon and observe the speed of fizzing.

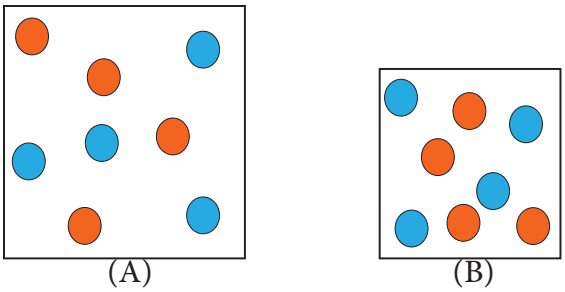


It is observed that the speed of evolution of gas bubbles is higher when the concentration of hydrochloric acid is high. So, it is clear that the rate of reaction increases with the increase in concentration of hydrochloric acid.

When the concentration of reactants is increased, the number of particles of reactants in a unit volume increases. Therefore the number of collisions of reactants per unit time increases. This is why the rate of a reaction increases, when the concentration of reactants is increased.

• Pressure of gaseous reactants

When gaseous reactants are involved, the rate of reaction can be increased by inereasing the pressure. Consider the instances A and B illustrated in Fig.17.1.



High pressure condition Low pressure condition

Fig. 17.1

Masses of reactants in the case of A and B are the same. But the pressure of the reactants in B is higher than that of A, as the volume of B is reduced. Then the rate of reaction in B is higher than that of A, because the number of collisions of reactants per unit time is higher in B.

• Catalysts

Catalysts are the substances that increase the rate of a reaction, without being chemically consumed during the reaction. Given below is an activity to find out the effect of a catalyst on the rate of a chemical reaction.

Activity - 17.4

Requirement **:** Two test tubes, a solution of fresh hydrogen peroxide, 0.2 g of manganese dioxide

- Add equal volumes of fresh hydrogen peroxide solutions into the two test tubes.
- Tip accurately weighed 0.2 g of manganese dioxide into one of the test tubes.
- Observe the speed of evolution of gas bubbles from the above test tubes.
  $2H_2O_2(aq) \longrightarrow 2H_2O\ (l) + O_2(g)$
- When the reaction is over, filter the solution with manganese dioxide, dry the residue and weigh it.

The speed of evolution of gas bubbles is higher in the test tube with manganese dioxide. Manganese dioxide has increased the rate of this reaction. Since the mass of manganege dioxide remains the same, it has not been consumed during the reaction. That is, manganese dioxide has acted as a catalyst for this reaction.

In addition to the substances that speed up reactions, there are substances that reduce the rate of reactions. These are known as inhibitors.

e.g. A few drops of sulphuric acid can be used to reduce the rate of dissociation of hydrogen peroxide.

Small amount of a catalyst is sufficient for a large amount of reactants. Catalysts are specific for each reaction. The catalyst is not chemically changed during a reaction though its physical nature may change. Catalysts are widely used in various industries and in industrial processes. Some facts on this are given in Table 17.1.

Table - 17.1

Chemical industry	Catalyst used
Haber process of manufacturing ammonia	Porous iron
Contact method of manufacturing sulphuric acid	Vanadium pentoxide
Manufacturing nitric acid by oxidizing ammonia	Platinum
Manufacturing margarine by hydrogenation of unsaturated fats	Nickel

For extra knowledge

- Enzymes necessary for biochemical reactions in organisms like respiration, digestion, photosynthesis and protein synthesis are also biological catalysts. Some synthetic biological catalysts are used as detergents.

Knowledge of the factors affecting rate of chemical reactions can be effectively used in day - to - day life as well as in various chemical industries.

For extra knowledge

Calalytic converters

In modern motor vehicles, there is a part fitted to the exhaust system called catalytic converter. Its function is the conversion of pollutant gases like carbon monoxide and nitric oxide into non - pollutant gases. Catalysts in these converters increase the rate of following reactions.

$2CO(g) + O_2(g) \longrightarrow 2CO_2(g)$

$2NO(g) + 2CO(g) \longrightarrow N_2(g) + 2CO_2(g)$

Assignment - 17.4

Study the catalysts used in various chemical industries and chemical processes as well as the biological catalysts or enzymes involved in biochemical reactions. Prepare a booklet using the information collected. Libraries as well as printed and electronic media can be used for this purpose.

Summary

- Various chemical reaction occur at various speeds.
- Rate of a reaction is the amount of change taking place in unit time.
- Factors affecting the rate of reactions are;
  - » surface area of reactants (physical nature);
  - » temperature at which the reaction occurs;
  - » concentration of reactants (pressure for gaseous reactants); and catalysts.
- Knowledge of rate of reactions is widely applied in chemical industries and chemical processes.
- Knowledge of rate of reactions is important for day - to - day activities also.

Exercises

1. What do you mean by the rate of a chemical reaction ?
2. One factor that affects the rate of reactions is the presence of catalysts. State three other factors that affect the rate of reactions.
3. Briefly explain, how each factor you stated above, changes the rate of a reaction.
4. What is a catalyst ?
5. Equal masses of calcium cabonate chips and powder are separately reacted with equal volumes of dilute hydrochloric acid. Time taken and mass of calcium carbonate used up are given in the table below.

Time /min		1	2	3	4	5	6	7	8	9	10	11	12
Mass of $CaCO_3$ used up/g	Chips	2.1	2.9	3.5	3.9	4.2	4.4	4.5	4.6	4.7	4.8	4.8	4.8
	Powder	3.1	4.0	4.4	4.6	4.7	4.8	4.8	4.8	4.8	4.8	4.8	4.8

I. Draw the graphs for both instances above, on the same grid.

II. In which instance, is the rate of reaction higher?

III. Explain the reasons for the difference of rates of reaction in these two instances.

Technical Terms				
Reaction	-	ප්‍රතික්‍රියාව	-	தாக்கம்
Rate of reaction	-	ප්‍රතික්‍රියා ශීඝ්‍රතාව	-	தாக்கவீதம்
Chemical changes	-	රසායනික විපර්යාස	-	இரசாயன மாற்றம்
Surface area	-	පෘෂ්ඨ වර්ගඵලය	-	ஊக்கி
Reactant	-	ප්‍රතික්‍රියක	-	தாக்க மேற்பரப்பு
Catalysts	-	උත්ප්‍රේරක	-	தாக்கிகள்
Produts	-	ඵල	-	விளை
Concentration	-	සාන්ද්‍රණය	-	செறிவு
Inhibitors	-	නිශේධක / මන්ධක	-	நிரோதியுள்
Precipitate	-	අවක්ෂේපය	-	வீழ்படிவு
Residue	-	අවශේෂය	-	மீதி