

# CHEMISTRY

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# States of Matter and Phase Changes

## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Explain changes of state and internal energy with change in temperature (melting, boiling, freezing, condensation, sublimation and deposition) in terms of kinetic particle theory.
- Distinguish between evaporation and boiling.
- Interpret heating and cooling curves in terms of kinetic theory
- Interpret in terms of kinetic particle theory the effects of changing pressure, temperature and volume of a gas on the other two with regards to Boyle's law, Charles' Law, and Avogadro's Law.
- Explain qualitatively the effect of external pressure on rate of boiling and evaporation
- Explain diffusion of gases in terms of kinetic particle theory.
- Examine qualitatively the effect of molecular mass and temperature on the rate of diffusion
- Discuss applications of sublimation around us.
- {Examples may include: solid air fresheners and 3D printing}
- Explain, with the help of kinetic particle theory, the importance of rates of diffusion of medicines in the body





Matter in this world exists in four physical states namely gas, liquid, solid and plasma. Out of these four states the properties of gases were studied first. It was suggested that physical properties of gases such as their ability to compress or expand, or diffuse could be understood by assuming that these gases consist of particles which are continuously moving randomly. This idea then led to formulation of kinetic particle theory for gases.

Kinetic particle theory not only explains all the laws which govern the behaviour of gases, it also explains the composition of liquid and solid states of matter and the interconversion of all the three states. This is natural because all the three physical states are distinct in their physical properties only while their chemical nature remains the same. For example, water in all its three physical states remains chemically the same compound.

According to kinetic particle theory gases are composed of particles which are in a continuous state of random motion in all the possible directions. The pressure exerted by a gas is due to the collisions of its particles with the walls of the container. Since the pressure of a gas in a container does not change with time at constant temperature, it is assumed that the collisions between its particles do not involve any loss or gain of energy due to friction. The attractive forces between the particles of a gas are assumed as negligible since the particles are widely apart at low pressure. The average kinetic energy of the particles is directly proportional to the temperature measured on kelvin scale. The average kinetic energy is the same for all gases at the same temperature.

According to kinetic theory, the particles in a liquid are quite close to one another. They are also moving in all possible directions. As a result the particles of a liquid do not have any fixed position and shape. Owing to the presence of inter-particle forces, however, a liquid has a fixed volume and it keeps its level as well. In a liquid, the particles show all the three types of movements.

Solid substances may consist of ions, atoms and molecules. According to kinetic particle theory the inter-particle forces in the solid substances are so strong that they keep their particles arranged in a fixed position.



Molecules present in a gas and a liquid show all the three types of movements simultaneously namely, translational, rotational and vibrational.





These particles possess vibrational motion only. These restricted movements force solid substances to have a fixed shape and a fixed volume.

## 14.1 Internal Energy

The internal energy of a substance is the total energy it contains. It includes the kinetic energy of its particles and the potential energy due to bonding between them. Heat increases the internal energy of a system.



### 14.1 Quick Check!

1. What is translational motion?
2. Is the average kinetic energy possessed by the particles of a gas and a liquid, same at the same temperature?

## 14.2 Interconversion of Physical States

### Conversion of a Solid into a Liquid (Melting)

The physical state of a solid substance can be changed by simple heating. Heat increases the kinetic energy of the particles and they start vibrating at a higher frequency. At a particular temperature their vibrational motion becomes so fast that it overcomes the cohesive forces. As a result the solid starts melting and this temperature is called the **melting point** of the solid. At the melting point, the particles of a solid not only lose their mean positions but the arrangement as well. The solid collapses and turns to a liquid (Figure 14.1).

Heating a solid below its melting point increases its kinetic energy and temperature that weakens the force of attraction between its particles. Further heating the solid after it has started melting does not increase its temperature. Instead, all the heat energy provided at this moment is utilized to convert the solid into its liquid.



Figure 14.1: Melting of ice

### Conversion of a Liquid into a Gas (Boiling)

The molecules of a liquid keep on coming out from the surface of a liquid at all temperatures and such an escape of molecules from surface is called **Evaporation**. Heating a liquid increases the kinetic energy of its molecules and so does the process of evaporation. Heating the liquid further, increases the





kinetic energy so much that the inter-particle forces are weakened to a large extent. At this point the bubbles start coming out of the liquid at a rapid pace. At this stage if the vapour pressure of the liquid becomes equal to the external pressure, the liquid starts boiling. The temperature of a liquid at which its vapour pressure becomes equal to the atmospheric or external pressure is called its **boiling point**.

At the boiling point, the heat provided to the liquid is used to convert it into gaseous form and during this its temperature remains constant. In other words, the heat provided is used only to break the forces of attraction between its particles.

### Conversion of a Gas into its Liquid (Condensation)

When a gas is cooled, the kinetic energy of its molecules decreases, as a result the molecules come closer with a significant force of attraction between them. At a suitable lower temperature the increased attractions bring the molecules so close that they are changed into a liquid form. This is called **condensation**. During this transition the temperature of the gas remains constant until all the gas is changed into its liquid.

## 14.3 Heating and Cooling Curves

Interconversion of physical states can also be understood with the help of a graph drawn between the internal energy and the temperature of a system. Such a graph is also called a heating or cooling curve. Figure 14.2 shows such a curve when a substance is heated or cooled.

When a solid substance at a point A is heated, its temperature increases. On attaining a specific temperature, it melts as shown by the point B in the Figure 14.2. This point represents the melting point of the given solid. Further heating does not increase the temperature because the heat provided here is being utilized to melt all the solid substance as represented by the line B to C. When all the solid converts into the liquid the temperature starts rising again as shown in the graph for the points

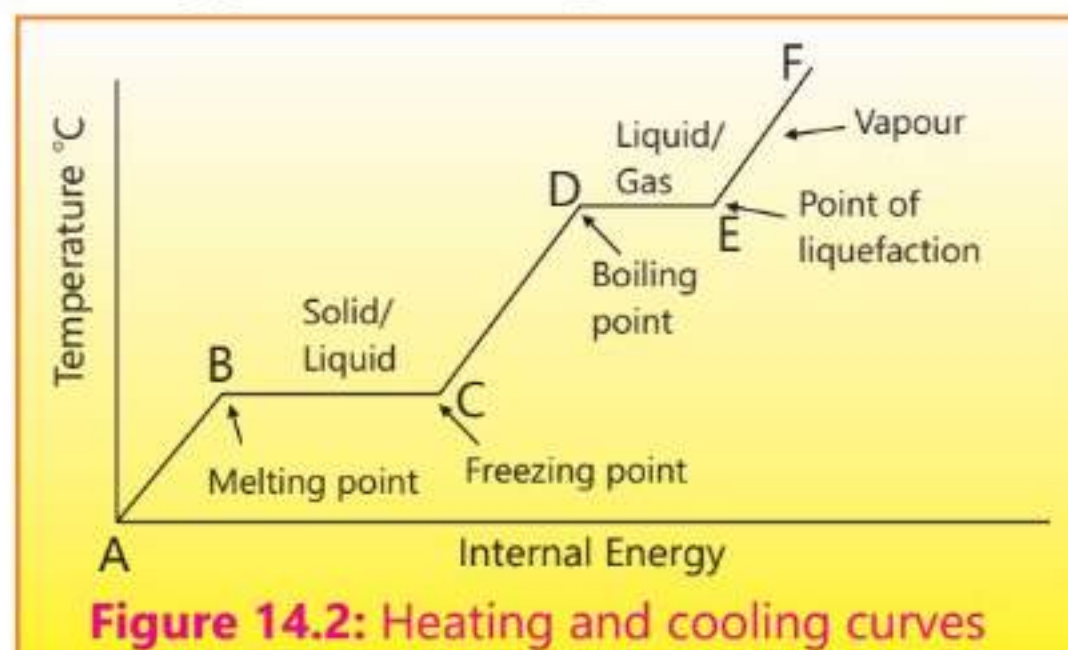


Figure 14.2: Heating and cooling curves





C to D. At the temperature corresponding to point D the liquid starts boiling. This represents the boiling point of the liquid. Again, further heating does not increase the temperature till the whole liquid is converted into gas. A line D to E in the figure shows no further rise in the temperature. The temperature again starts rising after the point E. This curve represented by the steps from A to F is called a heating curve.

#### Interesting Information

Phase change materials are used in thermal regulation, such as in clothing or building insulation, to store and release thermal energy.

The same graph in the Figure 14.2 can be studied in the reverse direction from the point F to A. It is called a cooling curve. When the gas present at the point F is cooled its temperature starts decreasing. At the point E it starts converting into a liquid. This is called the condensation point or liquefaction point and it represents the same temperature as the boiling point. The temperature will however remain constant during this process of condensation or liquefaction. Further cooling will convert the liquid into solid at the point C which is called the freezing point and it represents the same temperature as the melting point. The line C to B shows that the process of cooling is converting all the liquid into solid state at constant temperature.

For water, a heating curve will show the rise of temperature of ice until it reaches  $0^{\circ}\text{C}$  (melting point), then it remains constant while the ice melts into liquid water. Further heating will increase the temperature again until it reaches  $100^{\circ}\text{C}$  (boiling point). At this point it remains constant while the liquid water is converted into steam. A cooling



#### 14.2 Quick Check!

1. Why do water vapour at  $100^{\circ}\text{C}$  cause more severe burns as compared to liquid water at the same temperature?
2. Why do we feel comfortable wearing cotton clothes in summer?

#### Did you know?

Interconversion of physical states of matter may not be brought about by changing the temperature only. Sometimes their interconversion may be affected more conveniently by changing both the temperature and pressure at the same time or by varying the pressure only at constant temperature. For example, ice melts from pressure in the hands of a snowball maker. Ammonia gas can be liquefied at atmospheric pressure and at a temperature of  $-34^{\circ}\text{C}$ . Alternatively, it can also be liquified by exerting a pressure 1MPa and at room temperature ( $25^{\circ}\text{C}$ ).





curve for water will show the temperature of the steam decreasing until it reaches  $100^{\circ}\text{C}$ , it then remains constant while the steam condenses into liquid water. The temperature decreases again until it reaches  $0^{\circ}\text{C}$ . Finally it remains constant while the liquid water changes to ice. Lines B to C and D to E show that here the given energy is being utilized to change the phase from solid to liquid and from liquid to gas respectively.

## 14.4 Evaporation and Boiling

When water is taken in an open container at normal external pressure, vapours start coming out of its surface silently and steadily. It is shown by the decrease in the level of water surface in the open container. It is called evaporation and it is known to occur at all temperatures.

Increasing the temperature of water increases the rate of evaporation because the number of water molecules escaping the surface also increases. The temperature will keep on increasing until a stage will come at which the water molecules acquire the maximum value of kinetic energy while in a liquid state. The heat which is provided at this stage will be utilized to change the liquid water into gaseous water while keeping the temperature of water constant. This stage is called boiling. The whole process is being carried out at constant atmospheric pressure.

### Difference between Evaporation and Boiling

Evaporation	Boiling
1. It is a surface phenomenon. It occurs slowly and only at the surface of the liquid.	1. A phase change when a liquid turns into a gas throughout the entire liquid forming bubbles, at a definite external atmospheric pressure.
2. It occurs at all temperatures but below the boiling point. It increases with increase in temperature and vice versa.	2. It occurs at a specific temperature at normal pressure and called the boiling point.
3. It produces cooling.	3. It does not result in cooling.
4. It requires a smaller amount of energy which is provided from inside the liquid.	4. It requires an external energy source.

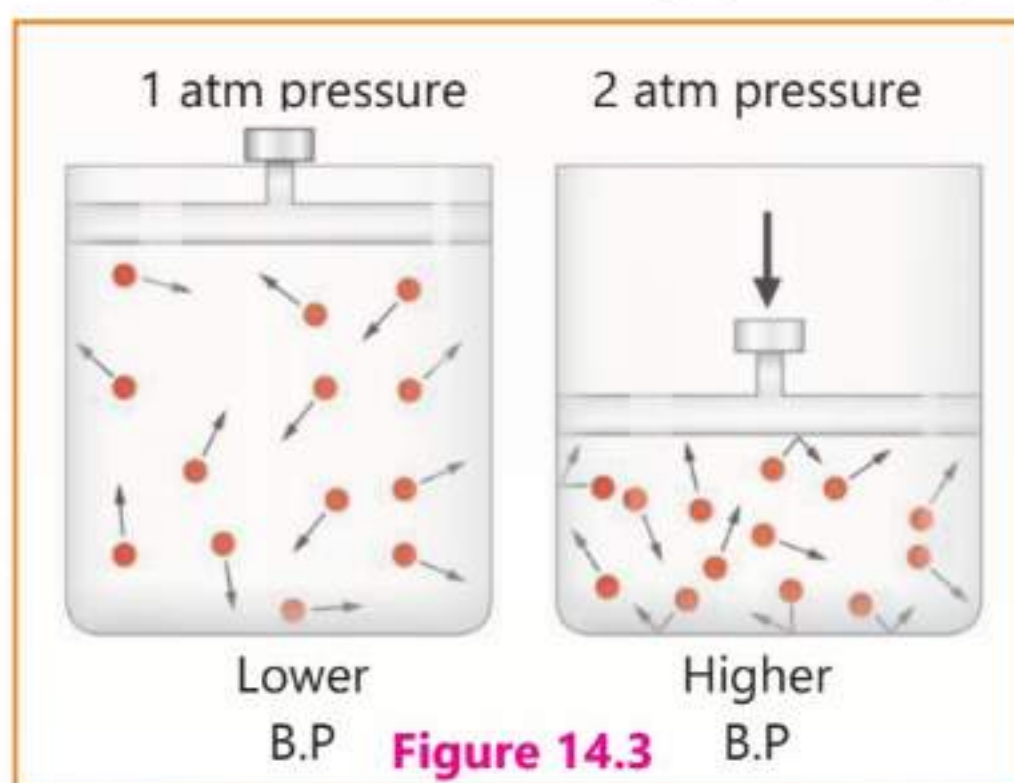


## Effect of External Pressure on the Rates of Evaporation and Boiling

Rates of both evaporation and boiling are affected by the variation in the external pressure to which the liquid is subjected.

Rate of evaporation tends to increase by the decrease in external pressure and vice versa. If a liquid is in an open container, most of the molecules that escape into the vapour phase will not return to the liquid phase. Instead, they will diffuse through the atmosphere away from the container. Increasing the external pressure will force these molecules to return back to the liquid surface making evaporation difficult.

When a liquid boils, bubbles are formed inside the container, which then rise to the surface. At this stage, the temperature of the liquid remains constant till all the liquid boils over. This temperature is called the boiling point. If you measure the boiling point of water at Karachi it will be  $100^{\circ}\text{C}$ . However, if you will measure this boiling point at Murree it will be  $98^{\circ}\text{C}$ . The atmospheric pressure at Murree is lower than that in Karachi, so we find that the boiling point has decreased at lower atmospheric pressure.



### 14.5 Sublimation

The direct conversion of a solid to vapours without melting is called sublimation. For example, solid carbon dioxide which is also called dry ice, changes directly to gaseous carbon dioxide at room temperature without first melting to liquid state. Another common example of sublimation is the disappearance of naphthalene balls which are used to keep the insects away from the woolen clothes. Just like evaporation, the energy needed for sublimation also comes from within the substance which then absorbs energy from the surrounding. This energy is sufficient to overcome the attractive forces of the neighbouring molecules which then escape into the vapour phase.





## Deposition

The process reverse to sublimation is called deposition where a gas changes directly to a solid without going into the liquid state. Formation of frost in winter season is an example of deposition.



### 14.3 Quick Check!

1. Does the change in temperature occur during the process of evaporation?
2. Does ice sublime?
3. Give one example each for sublimation and deposition other than mentioned in the text.

## 14.6 Applications of Sublimation

### (a) Solid air fresheners

The process of sublimation is used in the working of air fresheners. Solid air fresheners contain a scented substance which may evaporate with or without heating. The scented substance undergoes sublimation and disperse scented vapours throughout the room and mask unpleasant odours.

When a solid air freshener is exposed to the atmosphere or heated in the air, its solid particles gain enough energy to overcome the attractive forces holding them together in the solid state. These particles then spread in the nearby atmosphere in the form of sweet smelling vapours.

### (b) Sublimation Printing

When the process of sublimation is used to print a design into a material or fabric, it is called sublimation printing. Essentially the process involves printing that transfers a design into a fabric using ink and heat.

In sublimation printing the first step is to print a design onto a special paper using sublimation inks. The printed paper is then placed onto a fabric and heat and pressure are applied. The inks used are converted into vapour. The printing is permanent which does not fade away with time because the ink is embedded in the fabric rather than simple attaching with the top of the fabric in a normal printing. The heat supplied during the process opens up the pores present in the fabric, the ink enters into these pores under applied pressure, cools down and returns to a solid form. The method is popular for print on demand t-shirts and it is also available on ceramic, wood and metal that have a special coating on to receive the inks which are sublimed.



## 14.7 Kinetic Theory and The Gas Laws

### Pressure –Volume Relationship (Boyle's Law)

According to Kinetic Theory, the pressure exerted by the gas in a container is caused by the collisions of its molecules with the walls of the container. The pressure changes directly with the number of molecules colliding with the wall per unit of time. When the pressure on the given mass of a gas is increased at constant temperature it will decrease the distance between its molecules and the volume of gas will also decrease. If the volume of the gas will be reduced to one half of its original volume, it will double the number of molecules per unit of volume. Hence the number of collisions per unit of time on the same area of the surface will also be doubled. As a consequence of these collisions, the pressure of the gas will also be doubled. These observations form the basis of pressure-volume relationship first observed by an Irish chemist, Robert Boyle, and is called Boyle's law. The law states that the volume of a given mass of a gas is inversely proportional to its pressure at constant temperature.

Mathematically Boyle's law is written as:

$$V \propto \frac{1}{P} \quad (\text{V is the volume of given mass of gas and P is its absolute pressure})$$

#### Activity 14.1

#### Experimental verification of Boyle's law

Robert Boyle proved this pressure-volume relationship by performing a simple experiment. He used a simple J shaped tube and sealed its shorter limb as shown in the Figure 14.4. He then poured a small amount of mercury through its open end until it just trapped the air in the sealed end. Since he used a small amount of mercury it did not squeeze the air inside the limb and it was now at atmospheric pressure (760 mm Hg). Boyle then added

more mercury until the difference in the height of the two columns of mercury was close to 760mm. This mercury exerted the extra pressure on the entrapped

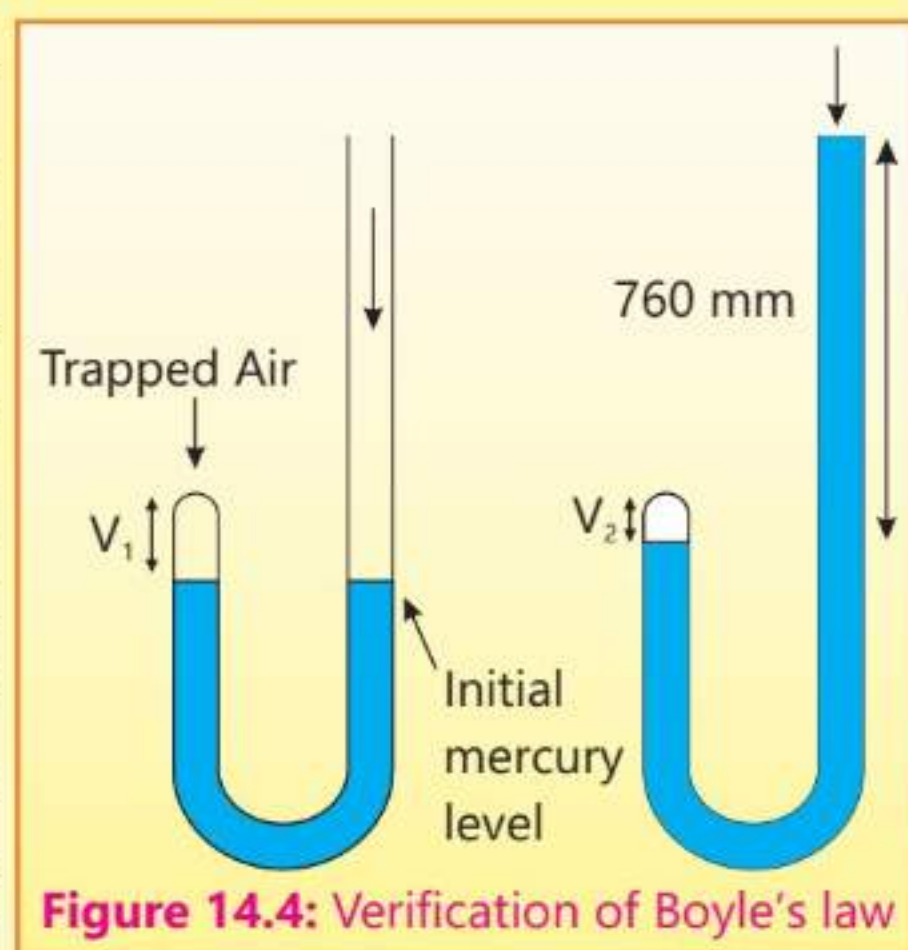


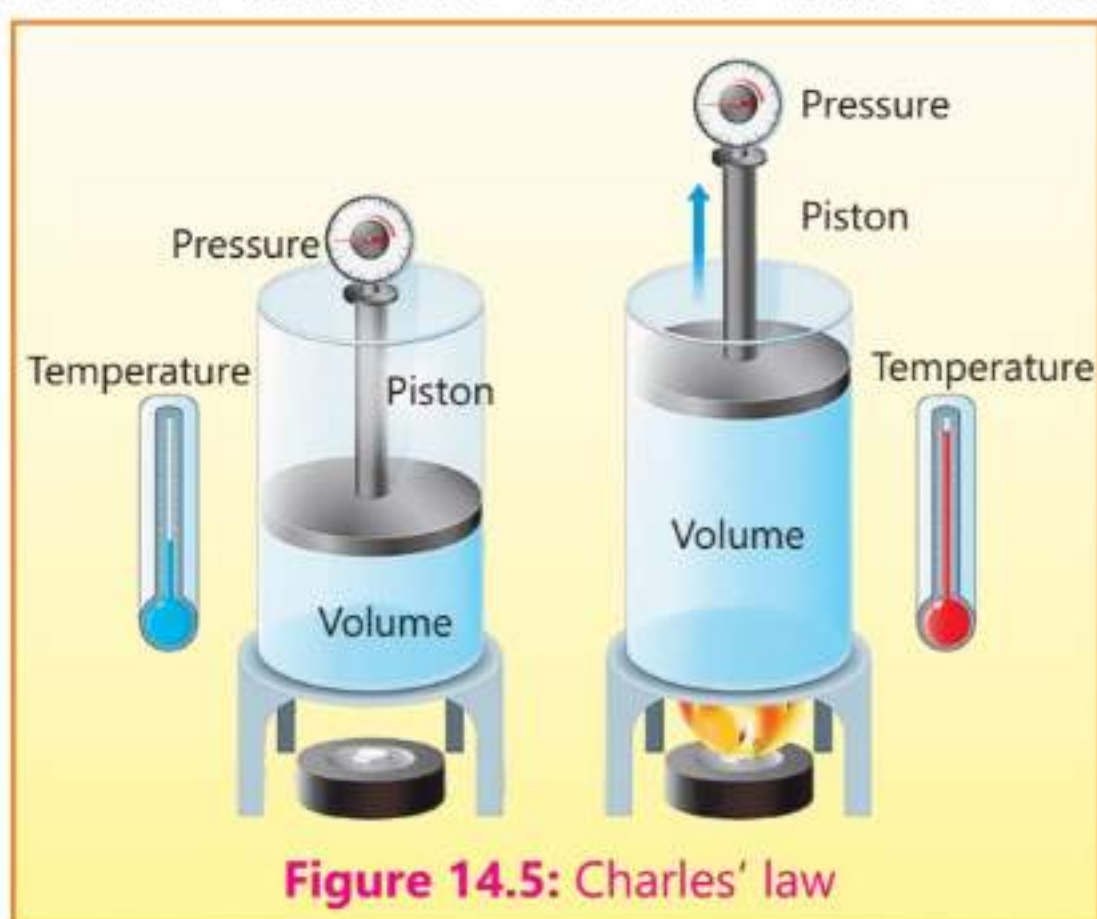
Figure 14.4: Verification of Boyle's law



air which was now about 2 atmosphere ( 2 x 760 mm). When he read the new volume of the entrapped air it was one half of the initial volume. During the experiment the mass of the gas remained fixed and the temperature also did not change. By doubling the pressure, Boyle had reduced the volume by one half.

## Temperature – Volume Relationship – Charles' law

According to kinetic theory, if temperature of a gas increases, it increases the average speed and kinetic energy of its molecules. An increase in average speed results in more frequent and harder collisions with the walls of the container and hence its pressure increases. If the pressure of the gas is kept constant, the increase in the temperature must increase the volume of the gas. This may be visualized easily if a gas is taken in a cylinder to which a piston is attached. When the gas is heated the piston must move up to increase the volume if the pressure is to remain constant Figure 14.5.



French scientist Jacques Alexander Charles summed up these observations in the form of a law which is called Charles' law. The law states that the volume of a given mass of a gas varies directly with temperature when pressure is kept constant. The temperature must, however, be measured on absolute or kelvin scale.

Mathematically,  $V \propto T$  (P and mass of gas are kept constant)

## Avogadro's Law

According to kinetic theory, the pressure exerted by a gas is due to the number of collisions of its particles per unit area. This, in turn, depends upon the number of particles and their speed.

If you have two containers containing the same amount of a gas at the same temperature and pressure, and you increase the amount of gas in one container. Naturally the pressure of the gas in this container will increase. To keep





the pressure constant the volume of the gas must increase. This larger volume compensates for the increased number of particles, ensuring the pressure remains the same. Therefore, at constant temperature and pressure, a greater number of molecules simply requires a larger volume to maintain the same pressure.

These observations led Avogadro to formulate a law which states that equal volumes of different gases must contain an equal number of molecules if the temperature and pressure are kept constant.

Mathematically Avogadro's law is written as:

$$V \propto n \text{ (at constant temperature and pressure)}$$

#### 14.4 Quick Check!

With the help of kinetic particle theory explain:

- (i) How does a gas exert pressure?
- (ii) How does the volume of a gas change when its temperature is decreased? (Pressure and mass constant)

## 14.7 Diffusion

Molecules present in gases are in a constant state of random motion. Due to this molecular motion the gas particles spread out and intermix from an area of high concentration to an area of low concentration. This property of gases is called diffusion. When a bottle of body perfume is opened in one corner of a room its sweet smell slowly spreads throughout the room after sometime due to the process of diffusion. Figure 14.6 shows the diffusion of hydrogen gas from one container to another one. Diffusion is a spontaneous process during which gas particles spread out.



The difference in the rates of diffusion of gases can be explained with the help of kinetic particle theory of gases. According to the kinetic theory, molecules of all the gases possess same average kinetic energy at constant temperature. Since hydrogen is lighter than oxygen its molecules will move faster than oxygen at a given temperature. The rate at which hydrogen gas will diffuse is thus much faster than that of oxygen.





Rate of diffusion increases with the increase in temperature as the particles have more kinetic energy and hence they move faster. This eventually leads to rapid mixing and spreading.

### Activity 14.2

#### Different gases diffuse at different rates

Two cotton plugs soaked in hydrogen chloride gas and ammonia solutions are introduced in the open ends of a 100 cm long glass tube simultaneously as shown in Figure 14.7. The two gases produce white dense fumes of ammonium chloride at the point at which they meet in the tube. HCl molecules travel a distance of 40.5 cm while ammonia molecules cover 59.5 cm in the same duration.

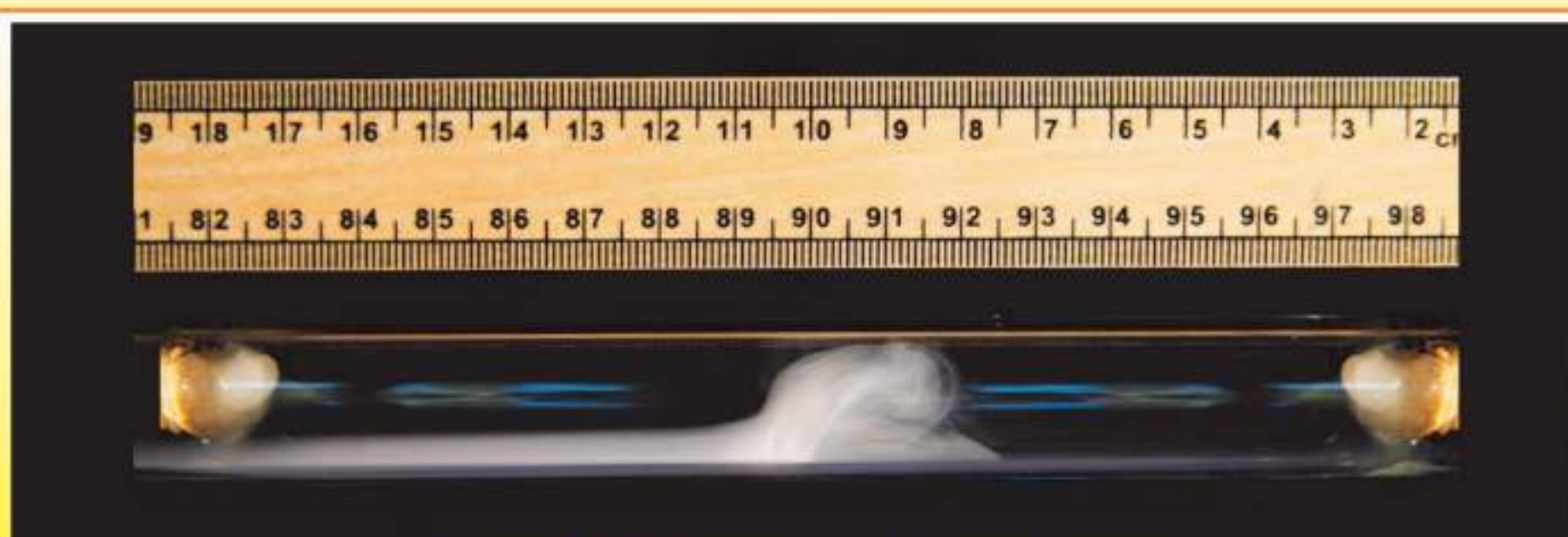


Figure 14.7: Rates of diffusion of gases

Thus ammonia diffuses faster than hydrogen chloride gas because it is lighter than hydrogen chloride gas.



### 14.5 Quick Check!

1. Which gas among the following will diffuse at the fastest speed and which will diffuse at the slowest speed under similar conditions of temperature and pressure?  
 $\text{NO}_2$ ,  $\text{SO}_2$ ,  $\text{H}_2\text{S}$
2. Explain with the help of kinetic particle theory why does ammonia gas diffuse faster than hydrogen chloride gas?

## 14.8 Importance of Rates of diffusion of Medicines in Human Body

The tendency of the molecules contained in a medicine to move from a region of higher concentration to one of lower concentration is called diffusion.





The diffusion rates of medicines control how rapidly and effectively they can be absorbed, distributed and eliminated from the body.

When the medicines are taken orally, the rates of their diffusion between the stomach and intestine control how quickly they are absorbed in the blood. A faster diffusion rate means early absorption and hence a faster onset of action.

Once the drug molecules are absorbed by the blood, they start diffusing into various tissues and organs. The rate of diffusion here determines how quickly the drug becomes effective. For example, lipid-soluble drugs diffuse more easily through cell membranes, making them more effective in shorter time. Generally, a faster rate of diffusion leads to higher drug concentration at its target organ which means a more effective response.

In short, rates of diffusion play a crucial role in the delivery and movement of drugs throughout the body. This process of diffusion ensures that essential substances reach their target locations quickly which eventually helps in the treatment of diseases.

## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

- According to kinetic theory, the basic difference between solid, liquid and gas is due to:
  - the difference in the movements of the particles.
  - the chemical properties of the particles.
  - the size of the particles.
  - the shape of the particles.
- Upon heating the rate of evaporation:
  - decreases
  - increases
  - remains the same
  - initially decreases and then increases upon further heating
- The inter-particle attractions are the strongest in:

(a) Solids	(b) Liquids
(c) Plasma	(d) Gas





4. Cooling the vapours of some gases change them directly into solid state. This phenomenon is called:
- (a) evaporation (b) condensation  
(c) sublimation (d) deposition
5. Physical state in which the particles possess the maximum energy:
- (a) Solid (b) Liquid  
(c) Gaseous (d) Vapour
6. How does the process of evaporation depend on the force of attraction present among the molecules of a liquid?
- (a) It decreases with the increasing strength of attraction.  
(b) It increases with the increasing strength of attraction.  
(c) It is independent of the strength of the force of attraction.  
(d) It first increases and then decreases with the increasing strength of the force of attraction.
7. Which gas will diffuse at the fastest rate?
- (a) HCl (b) SO<sub>2</sub>  
(c) H<sub>2</sub>S (d) CO<sub>2</sub>
8. The phase changes A and B in gas  $\xrightarrow{A}$  liquid  $\xrightarrow{B}$  solid are:
- (a) Melting, evaporating (b) Condensation, melting  
(c) Condensation, freezing (d) Boiling, freezing
9. A student noticed frost falling on the ground at 6.30 am and disappearing by 8.30 am. Which phase change was responsible for changing the frost into water vapours?
- (a) Melting (b) Evaporation  
(c) Sublimation (d) Deposition

## B Short Answer Questions

- 14.1 From where does the energy come when a liquid evaporates?
- 14.2 Is condensation an endothermic process?
- 14.3 Why naphthalene balls (used to repel insects) disappear after sometime?
- 14.4 Why does the temperature remain constant during a phase change?
- 14.5 Is it possible to compress a liquid like a gas?
- 14.6 Can you change the temperature at which water boils in an experiment in your lab?





- 14.7 In which season the wet clothes get dry after a relatively longer time?
- 14.8 When a solid is heated, what happens to its particles which are vibrating?
- 14.9 Do solids and liquids also diffuse just like gases?
- 14.10 Why dew is formed in the early hours of the morning?

### **C** Constructed Response Questions

- 14.1 Differentiate between evaporation and boiling.
- 14.2 Describe how boiling is related to the external pressure?
- 14.3 Why the process of evaporation does not need the input of energy?
- 14.4 Why the heating and cooling curves for the phase changes adopt the same path?
- 14.5 Why ice melts when the pressure is exerted on it?
- 14.6 Why do phase changes occur?

### **D** Descriptive Questions

- 14.1 Explain the difference in the rates of diffusion of two gases based on kinetic theory.
- 14.2 How does the process of sublimation helpful in printing and in the usage of air freshner?
- 14.3 Draw heating curve for the physical changes water undergoes with change in temperature.



# Stoichiometry

## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Use the molar gas volume,  $24 \text{ dm}^3$  at room temperature and pressure, in calculations involving gases
- Define concentration, use both  $\text{g/dm}^3$  and  $\text{mol/dm}^3$ , and convert between them
- Calculate stoichiometric relationships between substances relationships (specifically:
  - reacting masses, limiting reactants,
  - volume of gasses at r.t.p.,
  - volumes of solution and concentrations of solutions in  $\text{g/dm}^3$  or  $\text{mol/dm}^3$ , including conversion between  $\text{cm}^3$  and  $\text{dm}^3$ )
- Calculate concentration of a solution in a titration using empirical data
- Calculate empirical formula and molecular formula from appropriate data
- Calculate percentage yield, percentage composition by mass and percentage purity from appropriate data.



## 15.1 Molar Volume

The volume of a gas varies with changes in pressure and temperature. In order to compare the volumes occupied by different gases, we must adopt a set of standard conditions of temperature and pressure called room temperature and pressure (RTP). Accordingly, 25 °C (298.15K) and one atmosphere (760 torr) are used as standard conditions of temperature and pressure for measurement of volumes of gases at room temperature.

It has been found that one mole of all gases occupies a volume of 24 dm<sup>3</sup> at RTP. This is called molar volume. It is worth noting that one mole of each gas contains the same number of molecules, occupies the same volume and at the same time has different mass. In other words the masses and the sizes of the molecules of gases do not change the volume occupied by them. The concept of molar volume is useful because it enables us to calculate the number of moles or masses of the gases if we know their volumes.

### 15.1 Example

Calculate the number of moles of nitrogen gas present when it occupies a volume of 2.5 dm<sup>3</sup> at RTP.

#### Solution:

$$\begin{aligned}
 24 \text{ dm}^3 \text{ is occupied by how many moles of nitrogen} &= 1 \text{ mole} \\
 1 \text{ dm}^3 \text{ will be occupied by how many moles of nitrogen} &= \frac{1}{24} \text{ mole} \\
 2.5 \text{ dm}^3 \text{ will be occupied by how many moles of nitrogen} &= \frac{1}{24} \times 2.5 \\
 &= 0.10 \text{ mole}
 \end{aligned}$$

You can use the following equation as well to solve this problem.

$$\text{No. of moles of a gas} = \frac{\text{Volume of the gas at RTP}}{\text{Molar volume of the gas}} \dots\dots\dots 1$$

### 15.2 Example

Calculate the volume of 0.5 mol of hydrogen at RTP.



### Solution:

Apply the equation (1)  $0.5 = \frac{\text{Volume of hydrogen}}{24}$

$$\text{Volume of hydrogen} = 0.5 \times 24 = 12 \text{ dm}^3$$

### 15.3 Example

Calculate the volume occupied by 200 g carbon dioxide at RTP.

### Solution:

$$\text{No. of moles} = \frac{\text{Volume}}{\text{Molar Volume}}$$

$$\text{Volume} = \text{No. of moles} \times \text{Molar volume}$$

$$\text{Since no. of moles} = \frac{\text{Mass}}{\text{Molar Mass}}$$

$$\text{So, Volume} = \frac{\text{Mass}}{\text{Molar Mass}} \times \text{Molar volume}$$

$$\text{Volume} = \frac{200 \text{ g}}{44 \text{ g}} \times 24 \text{ dm}^3 = 109 \text{ dm}^3$$



### 15.1 Quick Check!

Calculate the amount of  $\text{CO}_2$  in  $100 \text{ dm}^3$  at RTP?

## 15.2 Concentration of a solution

Concentration of a solution is a measure of the amount of solute that has been dissolved in a given amount of solution or solvent. The amount of solute dissolved is expressed either in grams or in moles whereas the quantity of solution is expressed in terms of its volume,  $\text{dm}^3$  or  $\text{cm}^3$ .

The unit used for the mass/volume concentration is then  $\text{g/dm}^3$  while for the molar concentration it is  $\text{mol/dm}^3$ .

### 15.4 Example

Calculate concentration of a solution in  $\text{g/dm}^3$  which contains 20 g of sodium chloride dissolved in  $0.2 \text{ dm}^3$  of water.

### Solution:

$$\text{Concentration} = \frac{\text{Mass of solute in gram}}{\text{Volume of solution in dm}^3}$$

$$= \frac{20}{0.2} = 100 \text{ g/dm}^3$$



### 15.5 Example

500 cm<sup>3</sup> of hydrochloric acid contains 1.8 g of dissolved hydrogen chloride. Calculate the concentration of the acid in g/dm<sup>3</sup>.

#### Solution:

$$\text{Volume of hydrochloric acid in dm}^3 = \frac{500 \text{ cm}^3}{1000} = 0.5 \text{ dm}^3$$

$$\text{Concentration of hydrochloric acid} = \frac{1.8}{0.5} = 3.6 \text{ g/dm}^3$$

### 15.6 Example

Calculate the mass of copper sulphate in grams dissolved in 2 dm<sup>3</sup> of the solution to get a solution with a concentration 15 g/dm<sup>3</sup>.

#### Solution:

$$\begin{aligned} \text{Mass of solute in gram} &= \text{Concentration in g/dm}^3 \times \text{volume in dm}^3 \\ &= 15 \times 2 = 30 \text{ g} \end{aligned}$$

### 15.7 Example

A solution is prepared by dissolving 10 g of NaOH in 1.2 dm<sup>3</sup> of water. Calculate the concentration of the solution in mol/dm<sup>3</sup>.

#### Solution:

$$\begin{aligned} \text{Amount of NaOH} &= 10 \text{ g} \\ \text{No. of moles of NaOH} &= \frac{10}{40} = 0.25 \text{ mol} \\ \text{Concentration of the solution} &= \frac{0.25}{1.2} \\ &= 0.21 \text{ mol/dm}^3 \end{aligned}$$

#### Point to note

Molar concentration and molarity both refer to the concentration of a solute in a solution.

#### 15.2 Quick Check!

What mass of CuSO<sub>4</sub> is present in 50 cm<sup>3</sup> of a 5 × 10<sup>-2</sup> mol/dm<sup>3</sup> aqueous solution?

## 15.3 Calculate the Concentration of a Solution in Titration using Empirical Data

The concentration of a solution can be determined by titrating it with a solution of known concentration till the end point is reached. For this purpose, you need to know the balanced chemical equation for the reaction between the two solutions, the volumes of the two solutions used during the titration and the concentration of the other solution.

### 15.8 Example

A titration is performed between NaOH and HCl till the end point is reached.  $15\text{cm}^3$  of solution of sodium hydroxide having a molar concentration  $0.5\text{ mol/dm}^3$  is used to neutralize  $23\text{ cm}^3$  of HCl. Find out the concentration of HCl in  $\text{mol/dm}^3$ .

#### Solution:

1. Balanced chemical equation for this reaction



2. Convert the volume of NaOH used to  $\text{dm}^3$

$$\text{Volume of the solution} = \frac{15}{1000} = 0.015\text{ dm}^3$$

3. Convert the volume of HCl required to neutralize NaOH solution in  $\text{dm}^3$

$$\text{Volume of HCl required} = \frac{23}{1000} = 0.023\text{ dm}^3$$

4. No. of moles of NaOH

$$\begin{aligned} &= \text{molar concentration} \times \text{Volume} \\ &= 0.5\text{ mol/dm}^3 \times 0.015\text{ dm}^3 \\ &= 0.0075 \end{aligned}$$

5. According to the balanced chemical equation 1 mol of NaOH has reacted with 1 mol of HCl.

6. No. of moles of HCl

$$= 0.0075$$

7. Concentration of HCl solution

$$\begin{aligned} &= \frac{\text{No. of moles}}{\text{Volume in dm}^3} = \frac{0.0075}{0.023} \\ &= 0.326\text{ mol /dm}^3 \end{aligned}$$

Therefore, the molar concentration of the HCl solution is  $0.326\text{ mol /dm}^3$ .

#### 15.3 Quick Check!

Calculate the volume of  $0.1\text{ mol/dm}^3$  oxalic acid ( $\text{C}_2\text{O}_4\text{H}_2$ ) solution to exactly neutralize  $25\text{ cm}^3$  of  $0.1\text{ mol/dm}^3$  KOH solution.

#### Interesting Information

Stoichiometry is essential for optimizing chemical reactions in many industries.

## 15.4 Percentage Composition by Mass, Empirical

### Formula and Molecular Formula

#### Percentage Composition by Mass

Percentage composition of a compound refers to the percentage mass of each element present in the compound. The percentage of an element in a compound is the number of grams of that element present in 100 grams of the compound. The percentage of an element can be determined by applying the following formula.



$$\text{Percentage of an element} = \frac{\text{Mass of the element in the compound}}{\text{Formula mass of the compound}} \times 100 \dots\dots\dots 2$$

Percentage composition is a useful concept to determine the purity of a compound and its empirical and molecular formulae. Percentage composition of a compound can be determined both theoretically as well as by performing quantitative analysis. The following examples will illustrate both these methods.

### 15.9 Example

Find out the percentage composition of  $\text{Ca(OH)}_2$

#### Solution:

$$\text{Formula mass of Ca(OH)}_2 = 40 + 32 + 2 = 74$$

Applying the formula given in equation (2)

$$\text{Percentage of an element} = \frac{\text{Mass of the element in the compound}}{\text{Formula mass of the compound}} \times 100$$

$$\text{Percentage of Ca} = \frac{40}{74} \times 100 = 54.05 \%$$

$$\text{Percentage of Oxygen} = \frac{32}{74} \times 100 = 43.24 \%$$

$$\text{Percentage of Hydrogen} = \frac{2}{74} \times 100 = 2.70 \%$$

#### Interesting Information

The composition of all the chemical products which are in our daily use, such as shampoos, cleaners, soaps, perfumes and fertilizers are formed using stoichiometric calculations.

### 15.10 Example

8.657 g of a compound were decomposed into its elements. It gave 5.217 g of carbon, 0.962 g of hydrogen and 2.478 g of oxygen. Find out the percentage composition of the compound.

#### Solution:

Applying the following formula

$$\text{Percentage of element} = \frac{\text{Mass of element}}{\text{Mass of compound}} \times 100$$

$$\text{Percentage of carbon} = \frac{5.217 \text{ g}}{8.657 \text{ g}} \times 100 = 60.26\%$$





$$\text{Percentage of hydrogen} = \frac{0.962 \text{ g}}{8.657 \text{ g}} \times 100 = 11.11\%$$

$$\text{Percentage of oxygen} = \frac{2.478 \text{ g}}{8.657 \text{ g}} \times 100 = 28.62\%$$

So, 100 g of the compound under study contains 60.26 g of carbon, 11.11 g of hydrogen and 28.62 g of oxygen.



#### 15.4 Quick Check!

Calculate the percentage of sulphate ions ( $\text{SO}_4^{2-}$ ) in  $\text{Al}_2(\text{SO}_4)_3$ .

### 15.5 Empirical Formula

The formula which shows the simplest whole number ratio of atoms present in a compound is called empirical formula. For example, empirical formula of hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) is HO, that of water ( $\text{H}_2\text{O}$ ) is  $\text{H}_2\text{O}$  and for benzene ( $\text{C}_6\text{H}_6$ ) is CH.


All the ionic compounds are represented by their empirical formulae. These formulae show the simplest ratio present between their ions. The formula of sodium chloride ( $\text{NaCl}$ ) represents the simplest ratio between sodium and chloride ions present in it. Similarly the formula of calcium chloride ( $\text{CaCl}_2$ ) shows the ratio present between calcium and chloride ions.

Since an empirical formula does not tell us about the actual number of atoms present in that compound rather it represents the simplest ratio of minimum ratio between atoms, it is possible that some compounds may have same empirical formula. For example, both acetylene ( $\text{C}_2\text{H}_2$ ) and benzene ( $\text{C}_6\text{H}_6$ ) have same empirical formula CH. In the same way acetic acid ( $\text{CH}_3\text{COOH}$ ) and glucose ( $\text{C}_6\text{H}_{12}\text{O}_6$ ) also have the same empirical formula  $\text{CH}_2\text{O}$ .

Empirical formula of a compound can be calculated following the steps shown below.

- i. Determine the percentage composition of the compound.
- ii. Find out the number of moles of each element. This is done by dividing the mass of each element (percentage of element) by its atomic mass.
- iii. Determine the atomic ratio of each element in the compound. This ratio can be found by dividing the number of moles of each element by the smallest number of moles.



- 
- iv. If the atomic ratio obtained is simple whole number, it gives the empirical formula, otherwise multiply this ratio with suitable digit to get the whole number ratio.
- v. Use this whole number ratio as a subscript for the elements to get the empirical formula.

### 15.11 Example

The percentage composition of a compound shows it to contain 25.26% Mg and 74.74% Chlorine. Find out its empirical formula.

#### Solution:

1. Change the percentage of elements to grams

$$\text{Mg} = 25.26 \% = 25.26 \text{ g} \quad \text{Cl} = 74.74 \% = 74.74 \text{ g}$$

2. No. of moles of each element

$$\text{Mg} = \frac{25.26}{24} = 1.05 \quad \text{Cl} = \frac{74.74}{35.5} = 2.10$$

3. Atomic ratio of each element

$$\text{Mg} = \frac{1.05}{1.05} = 1 \quad \text{Cl} = \frac{2.10}{1.05} = 2$$

#### 15.5 Quick Check!

A 0.5 g sample of compound contains 0.418 g of antimony (Sb) and 0.082 g of oxygen. What is the empirical formula of the compound?

The empirical formula of magnesium chloride is  $\text{MgCl}_2$ .

### 15.12 Example

The percentage composition of an organic compound by mass is 64.8% carbon, 15.62% hydrogen and 21.58% oxygen. Find out its empirical formula.

#### Solution:

1. Change the percentages into grams

$$\begin{array}{lll} \text{C} = 64.8 \% & \text{H} = 15.62 \% & \text{O} = 21.58 \% \\ = 64.8 \text{ g} & = 15.62 \text{ g} & = 21.58 \text{ g} \end{array}$$

2. No. of moles of each element

$$\text{C} = \frac{64.8}{12} = 5.4 \quad \text{H} = \frac{15.62}{1} = 15.62 \quad \text{O} = \frac{21.58}{16} = 1.35$$

3. Atomic ratio of each element

$$\text{C} = \frac{5.4}{1.35} = 4 \quad \text{H} = \frac{15.62}{1.35} = 10 \quad \text{O} = \frac{1.35}{1.35} = 1$$

The empirical formula of the compound is  $\text{C}_4\text{H}_{10}\text{O}$ .



## Molecular Formula

Molecular formula of an element or a compound represents the actual number of atoms present in the molecule of these substances. Water, hydrogen peroxide, ethylene and sulphur have molecular formulae  $\text{H}_2\text{O}$ ,  $\text{H}_2\text{O}_2$ ,  $\text{C}_2\text{H}_4$  and  $\text{S}_8$  respectively. Molecular formula of a compound can be calculated by multiplying a whole number with the empirical formula of that compound as shown in the following equation.

$$\text{Molecular Formula} = n (\text{Empirical Formula})$$

$$\text{Where } n = \frac{\text{Molecular Mass}}{\text{Empirical Formula Mass}}$$

### 15.13 Example

Benzene is represented by its empirical formula  $\text{CH}$  while its molecular mass is 78. Find out its molecular formula.

#### Solution:

$$\begin{aligned} \text{Empirical formula of benzene} &= \text{CH} \\ \text{Empirical formula mass of benzene} &= 12+1=13 \\ \text{Molecular mass of benzene} &= 78 \\ n &= \frac{78}{13} \\ \text{Therefore the molecular formula of benzene} &= 6 (\text{Empirical formula}) \\ &= 6 \times \text{CH} = \text{C}_6\text{H}_6 \end{aligned}$$

#### Interesting Information

Stoichiometry is used to determine the optimal dosages of medications for patients based on their weight, age and other factors.

So molecular formula of benzene comes out to be  $\text{C}_6\text{H}_6$ .

### 15.14 Example

Glucose has an empirical formula  $\text{CH}_2\text{O}$  and its molecular mass is  $180 \text{ g mol}^{-1}$ . What will be its molecular formula?

#### Solution:

$$\begin{aligned} \text{Empirical formula of glucose} &= \text{CH}_2\text{O} \\ \text{Empirical formula mass of glucose} &= 12 + 2 + 16 = 30 \\ \text{Molecular mass of glucose} &= 180 \\ n &= \frac{180}{30} = 6 \end{aligned}$$

#### 15.6 Quick Check!

An unknown hydrocarbon contains 85.71% carbon. Its molar mass is  $84 \text{ g/mol}$ . What is its molecular formula?



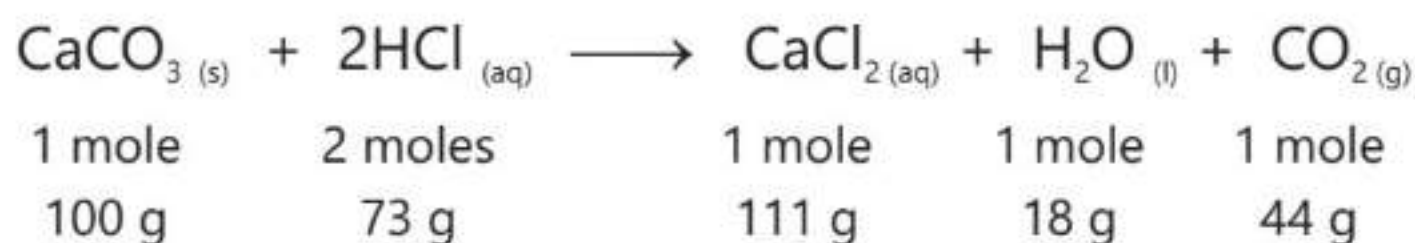
Molecular formula of glucose =  $6(\text{CH}_2\text{O}) = \text{C}_6\text{H}_{12}\text{O}_6$

So, molecular formula of glucose will be  $\text{C}_6\text{H}_{12}\text{O}_6$ .

## Calculations Based on Chemical Equation

A complete and balanced chemical equation tells us the mole ratio or mass ratio between the reactants and the products. With the help of this ratio we can find out the masses of the products from the given masses of the reactants or the masses of the reactants from the given masses of the products.

For example, the following equation tells us that one mole (100 g) calcium carbonate reacts with two moles (73 g) of hydrochloric acid to produce one mole (111 g) of  $\text{CaCl}_2$ , one mole (18 g) of water and one mole (44 g) of carbon dioxide.



### 15.7 Quick Check!

Why it is necessary for a chemical equation to be balanced before it can be used in calculation?

### 15.15 Example

25 g of lime stone ( $\text{CaCO}_3$ ) react with an excess of hydrochloric acid according to the above equation. How much calcium chloride ( $\text{CaCl}_2$ ) will be produced?

### Solution:

According to the equation

100 g of lime stone react to produce calcium chloride = 111 g

1 g of lime stone will react to produce calcium chloride =  $\frac{111}{100}$  g

25 g of lime stone will react to produce calcium chloride =  $\frac{111}{100} \times 25$   
= 27.75 g

## 15.6 Limiting Reactant

In a chemical reaction, reactants are not always mixed according to stoichiometric ratio shown in the balanced chemical equation. Most often in experimental works, one or more reactants is /are used in large excess. This is done deliberately to ensure that the other expensive reactant is used completely.





In this way the reactant which is used in excess is left behind at the end of the reaction and the other reactant is consumed completely.

This reactant which is consumed earlier is called the limiting reactant. In fact, it is the limiting reactant which controls the amount of the product formed in a chemical reaction.

### How to Identify a Limiting reactant

A limiting reactant present in a chemical reaction can be identified by carrying out the following steps.

1. Calculate the number of moles of the reactants from the amounts provided.
2. Calculate the number of moles of the product which will form with the given moles of reactants.
3. Identify the reactant which gives the least amount of the product. This reactant will be the limiting reactant.

### 15.16 Example

Calculate the amount of carbon dioxide in grams produced when 25 g of glucose reacts with 40 g of oxygen in the following photosynthesis reaction.



### Solution:

In order to find out the amount of  $\text{CO}_2$  in this reaction, we will have to identify which of the reactants is a limiting reactant

1. No. of moles of the reactants

$$\text{No. of moles of glucose} = \frac{25}{180} = 0.148 \text{ mol}$$

$$\text{No. of moles of oxygen} = \frac{40}{32} = 1.25 \text{ mol}$$

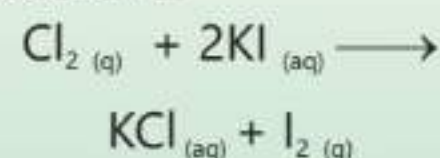
2. Calculate the no. of moles of  $\text{CO}_2$ , which will be given by each of the reactants as shown in the equation:

$$1 \text{ mole of glucose gives} = 6 \text{ moles of } \text{CO}_2$$

$$\begin{aligned} 0.138 \text{ mol of glucose will give} &= \frac{6}{1} \times 0.148 \\ &= 0.848 \text{ mol} \end{aligned}$$

### 15.8 Quick Check!

If you react 100 g of chlorine gas with 500 g of KI, which reactant will be the limiting reactant?





6 moles of oxygen gives = 6 moles of  $\text{CO}_2$

1.25 mol of oxygen will give =  $\frac{6}{6} \times 1.25$   
= 1.25 mol

Since  $\text{CO}_2$  obtained from glucose is less than that of oxygen, so glucose is the limiting reactant.

Amount of  $\text{CO}_2$  produced =  $0.878 \times 44 = 36.96 \text{ g}$

## 15.7 Yield

The quantity of the product obtained when chemical reaction is performed is called the actual yield. This yield is always less than the theoretical yield. The theoretical yield is the amount of product which we calculate assuming that all the reactants react according to the balanced chemical equation.

A chemist is usually interested in the efficiency of the reaction which is commonly expressed by comparing the actual yield with the theoretical yield in the form of percentage yield. Percentage yield is calculated by applying the following formula.

$$\text{Percentage Yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

### 15.17 Example

A chemist reacts 50 g of Zn with excess of nitric acid to get 80.2 g  $\text{Zn}(\text{NO}_3)_2$ . Calculate the theoretical yield and the percentage yield of this reaction.

### Solution:

1. Balanced chemical equation for the reaction



2. No. of moles of Zn =  $\frac{50}{65.37} = 0.76 \text{ mol}$

Amount of  $\text{Zn}(\text{NO}_3)_2 = 80.2 \text{ g}$

### Theoretical yield

According to the balanced chemical equation

1 mol of Zinc gives = 1 mol of  $\text{Zn}(\text{NO}_3)_2$

0.76 mol of Zinc gives = 0.76 mol of  $\text{Zn}(\text{NO}_3)_2$

Amount of  $\text{Zn}(\text{NO}_3)_2$  in grams =  $0.76 \times 189.38 = 143.92 \text{ g}$

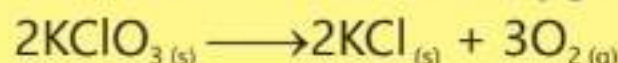


## Percentage yield

$$\begin{aligned}\text{Percentage Yield} &= \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100 \\ &= \frac{80.2}{143.92} \times 100 = 55.7 \%\end{aligned}$$

### 15.9 Quick Check!

Find out the theoretical yield and percent yield of oxygen generated by heating 40 g of  $\text{KClO}_3$  ( $M = 122.5$ ). The mass of oxygen gas produced is 14.9g



## Percentage Purity

In chemistry, purity refers to the degree to which a substance is free from impurities. Percentage purity of compound indicates the amount of pure compound present in an impure sample. Percentage purity of a sample is calculated by the following formula.

$$\text{Percentage purity} = \frac{\text{Mass of the pure sample}}{\text{Total mass of the impure sample}} \times 100$$

### 15.18 Example

12.0 g sample of a pharmaceutical product was found to contain 11.57 g of the active drug. Find out the percentage purity of the sample.

#### Solution:


$$\begin{aligned}\text{Percentage purity} &= \frac{\text{Mass of the pure drug}}{\text{Total mass of sample}} \times 100 \\ &= \frac{11.57}{12.0} = 96.4 \%\end{aligned}$$

## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

- Volume occupied by 15 moles of ammonia gas at RTP:  
(a)  $224 \text{ dm}^3$  (b)  $160 \text{ dm}^3$   
(c)  $360 \text{ dm}^3$  (d)  $265 \text{ dm}^3$

- 
2. How many moles of natural gas  $\text{CH}_4$  will be present in a cylinder if its volume is  $18 \text{ dm}^3$  at RTP?
- (a) 0.75 mol (b) 0.67 mol  
(c) 0.85 mol (d) 0.56 mol
3. What will the molar concentration of potassium hydroxide solution if 2.0 g of it are dissolved in  $100 \text{ cm}^3$  of solution?
- (a)  $0.36 \text{ mol/dm}^3$  (b)  $0.53 \text{ mol/dm}^3$   
(c)  $0.70 \text{ mol/dm}^3$  (d)  $0.45 \text{ mol/dm}^3$
4. What will be the mass of NaCl needed to make up  $15 \text{ dm}^3$  of its solution with a concentration of  $0.7 \text{ g/dm}^3$ ?
- (a) 21 g (b) 10.5 g  
(c) 31.5 g (d) 5.4 g
5. Find out the concentration of  $\text{H}_2\text{SO}_4$  in  $\text{mol/dm}^3$  if its  $10 \text{ cm}^3$  react with  $20 \text{ cm}^3$  of NaOH solution having concentration  $0.1 \text{ mol/dm}^3$ .
- (a)  $0.01 \text{ mol/dm}^3$  (b)  $0.001 \text{ mol/dm}^3$   
(c)  $0.1 \text{ mol/dm}^3$  (d)  $0.15 \text{ mol/dm}^3$
6. If the molar mass of a compound is  $178 \text{ g/mol}$  and its empirical formula is  $\text{C}_3\text{H}_5\text{O}_3$ . What is its molecular formula?
- (a)  $\text{C}_3\text{H}_5\text{O}_3$  (b)  $\text{C}_6\text{H}_{10}\text{O}_6$   
(c)  $\text{C}_9\text{H}_{15}\text{O}_9$  (d)  $\text{C}_8\text{H}_{10}\text{O}_8$
7. When natural gas burns in air, which component is the limiting reactant?
- (a) Both components  
(b) Neither component is a limiting reactant  
(c) Air  
(d) Natural gas
8. If the actual yield of a compound is  $0.198 \text{ g}$  while the theoretical yield is  $0.217 \text{ g}$ . What will be the percentage yield?
- (a) 50% (b) 91.2%  
(c) 80% (d) 90%

## **B** Short Answer Questions

- 15.1. What is the molar volume of a gas at RTP?
- 15.2. How does the concept of molar volume useful for us?
- 15.3. How does the molar volume relate to the Avogadro's law?
- 15.4. Why two different compounds may show the same empirical formula?



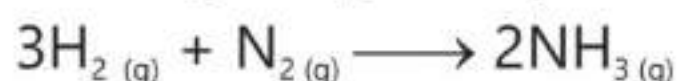
- 15.5. Why is percentage yield important?
- 15.6. What is the concentration of a solution in  $\text{mol/dm}^3$  if it contains 49 g of  $\text{H}_2\text{SO}_4$  in one  $\text{dm}^3$  of solution?

### C Constructed Response Questions

- 15.1. How would you identify the limiting reactant in a chemical reaction?
- 15.2. Why is it important to find the purity of a compound which is used as a medicine?
- 15.3. Will there be a limiting reactant in a reversible reaction?
- 15.4. How do you know if a formula is empirical or not?
- 15.5. Write down one method to find out the molecular mass of a compound without knowing its molecular formula.

### D Numerical Problems

- 15.1. Calculate the number of moles, volume and number of molecules in 4.0 g of  $\text{CH}_4$  at RTP.
- 15.2. What mass of  $\text{NaCl}$  need to be dissolved in  $150 \text{ cm}^3$  of a solution if the concentration of the solution is  $0.4 \text{ mol/dm}^3$ ?
- 15.3. Find out the percentage of sodium in  $\text{NaHCO}_3$ .
- 15.4. A sulphide of iron contains 1.926 g of sulphur and 2.333 g of iron. Find out the empirical formula of this compound.
- 15.5. A compound contains by mass, 40.0% C, 6.71 % H and 53.3 % oxygen. A 0.320 mole of this compound weighs 28.8 g. What is the molecular formula of this compound?
- 15.6. The formation of ammonia gas is given by the following equation:



If you start reacting 12 g of  $\text{H}_2$  with 64 g of  $\text{N}_2$ , which will be the limiting reactant?

- 15.7. When 305 g of  $\text{AgNO}_3$  is reacted with excess of  $\text{MgCl}_2$  it produces 23.7 g of  $\text{Mg}(\text{NO}_3)_2$ . What is the percentage yield of the reaction?



- 15.8. A sample of metal has a total mass of 3.66 kg and contains 2.45 kg of gold. What is the percentage purity of gold in this sample?



## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Define redox reactions as simultaneous oxidation and reduction in terms of oxygen, hydrogen, electrons and changes in oxidation state
- Use roman numerals to indicate oxidation number of an element in a compound
- Identify oxidizing and reducing agents in a redox reaction
- Recognize that the oxidation number of elements in their free state is zero
- Derive the formula of ionic compounds from ionic charges and oxidation numbers
- Identify that the oxidation number of a monatomic ion is the same as the charge on the ion
- Explain that the sum of the oxidation numbers in a neutral compound is zero
- Explain that the sum of the oxidation numbers in an ion is equal to the charge on the ion
- Identify redox reactions by the colour changes involved when using acidified aqueous potassium manganate (VII) to (II) or aqueous potassium iodide
- Define electrolysis as decomposition of ionic compound, in molten or aqueous solution, by passage of electric current
- Identify and label in simple electrolytic cells, the anode (+), cathode (-), electrolyte and direction of flow of electrons in external circuit,
- Describe the transfer of charge in external circuit, movement of ions in the electrolyte and transfer of electrons at electrodes
- Identify the products formed at electrodes and describe the observations made during the electrolysis of molten lead (II) chloride, concentrated dilute sulfuric acid using inert electrodes (platinum or carbon/graphite)
- State that hydrogen- oxygen fuel cell uses hydrogen and oxygen to produce electricity with water as the only chemical product
- Describe the advantages and disadvantages of using hydrogen-oxygen fuel cells in comparison with gasoline /petrol engines in vehicles.
- Define corrosion and discuss methods to prevent it. (some examples may include barrier method such as using paint, galvanizing, electroplating; sacrificial protection such as using magnesium blocks in ships)
- Identify the products formed at electrodes and describe the observations made during the electrolysis of dilute copper (II) sulphate using inert electrode or copper electrode
- Predict the identity of products of electrolysis of a halide compound in dilute or concentrated solution
- Construct ionic half- equations for reaction at either electrode.
- Describe electroplating and its applications.
- Sketch a schematic diagram for a voltaic cell e.g., Daniel cell
- Use the voltage data given for voltaic cells to determine order of reactivity of any two metals

## 16.1 Oxidation Number of Atoms in compounds and Ions

The assignment of oxidation number to atoms in compounds and ions helps us to identify whether the reaction involves oxidation and reduction or not. It also helps to identify oxidizing and reducing agents in a given oxidation-reduction reaction. Oxidation numbers are also used to write chemical formulas and names of the chemical compounds. This concept also helps to keep track of the new distribution of electrons during an oxidation-reduction reaction.

The oxidation number is an apparent charge on an atom in a compound or an ion. It may have a positive or a negative sign.

The oxidation number of atoms can be found out by applying the following rules.

1. Atom present in a free element has an oxidation number zero.

**Example:** The oxidation number of sodium in sodium metal is zero. Similarly, oxidation number of oxygen in ozone ( $O_3$ ) is also zero.

2. For monoatomic ions, the oxidation number is equal to the charge present on the ion.

**Example:** The oxidation number of  $Ca^{2+}$  is +2 while that of  $Al^{3+}$  is +3.

3. The elements present in group 1 (except hydrogen) in the periodic table are assigned oxidation number +1, those of group 2, +2 and those of group 3, +3.

4. In binary compounds the more electronegative atom is always assigned a negative oxidation number. For example, fluorine, being the most electronegative atom, will always be given -1 oxidation number. Similarly, in  $NH_3$  and  $H_2S$ , nitrogen and sulphur are assigned the oxidation number of -3 and -2 respectively.

5. The elements of group 17 are normally given oxidation number -1 when they are combined with less electronegative element.

**Example:** Chlorine in all such compounds as  $HCl$ ,  $PCl_3$ ,  $CHCl_3$  has been assigned an oxidation number -1.

6. Hydrogen is assigned an oxidation number +1 when it is in combination with more

### Point to note

Oxidation numbers do not represent the real electrical charges present on atoms except in simple ions. However, the oxidation numbers are useful for keeping track of the redox reactions.



electronegative atoms while it is given oxidation number -1 when it is combined with less electronegative atoms.

**Example:** In HCl, the oxidation number of hydrogen is +1, while in sodium hydride (NaH) it bears an oxidation number -1.

### Point to note

The term oxidation state is also used interchangeably of oxidation number. In water, hydrogen has an oxidation number of +1 and it is said to be in the +1 oxidation state.

- The element oxygen is assigned an oxidation number -2 in most of its compounds.
- The sum of oxidation numbers of all the atoms present in a neutral compound is always zero. In a polyatomic ion the sum of oxidation numbers is equal to the charge present on that ion.

### 16.1 Example

Assign oxidation number to sulphur in  $\text{SO}_4^{2-}$

#### Solution:

$$\begin{aligned} \text{S} + 4\text{O} &= -2 \\ \text{S} + 4(-2) &= -2 \\ \text{S} - 8 &= -2 \\ \text{S} &= 8 - 2 \\ \text{S} &= +6 \end{aligned}$$

The oxidation number of S in  $\text{SO}_4^{2-}$  is +6.

### 16.2 Example

Find out the oxidation number of manganese in  $\text{KMnO}_4$ .

#### Solution:

$$\begin{aligned} \text{K} + \text{Mn} + 4\text{O} &= 0 \\ (+1) + \text{Mn} + 4(-2) &= 0 \\ \text{Mn} - 7 &= 0 \\ \text{Mn} &= +7 \end{aligned}$$

The oxidation number of Mn in  $\text{KMnO}_4$  is +7.

### 16.3 Example

Find out the oxidation number of Fe in  $\text{Fe}_2\text{O}_3$ .

#### Solution:

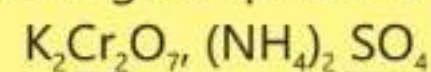
$$\begin{aligned} 2\text{Fe} + 3\text{O} &= 0 \\ 2\text{Fe} + 3(-2) &= 0 \\ 2\text{Fe} - 6 &= 0 \\ 2\text{Fe} &= +6 \\ \text{Fe} &= +3 \end{aligned}$$

Oxidation number of one atom of Fe is +3



### 16.1 Quick Check!

Assign oxidation number to the marked atom of the following compounds:



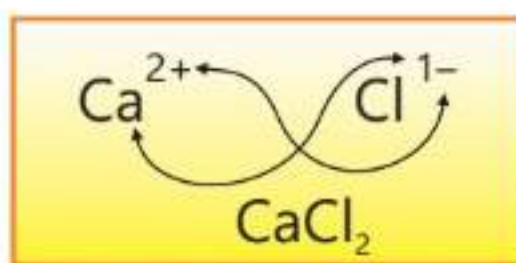


## 16.2 Writing Chemical Formulas of Ionic Compounds by applying Oxidation Numbers

We can write the chemical formula of a compound if we know the oxidation numbers of its constituent elements. The periodic table and the electronic structure of the atoms can help us in predicting the principal oxidation number of the element. The formula of the compound may then be written using the oxidation number of the atoms present in that compound. For example, we shall write the formula of calcium chloride in the following way.

The element calcium is present in group II of the periodic table and its principal oxidation number is +2.

Chlorine is present in Group 17 and we know that when it is attached with less electronegative element in binary compounds its oxidation number is -1. The formula for calcium chloride will, therefore, be  $\text{CaCl}_2$  because only with this formula the sum of the oxidation numbers of both the elements will add up to zero.

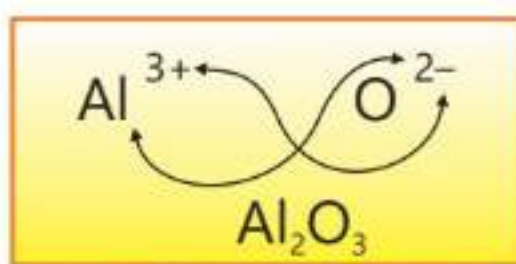


### 16.4 Example

Write the chemical formula of aluminum oxide with the help of oxidation numbers of the elements involved.

#### Solution:

Aluminum is present in Group 13 so its principal oxidation number shall be +3. Oxygen being more electronegative atom normally shows -2 oxidation state in normal oxides. The formula of aluminum oxide will then be  $\text{Al}_2\text{O}_3$  because the sum of oxidation numbers of both elements will be equal to zero with this formula.

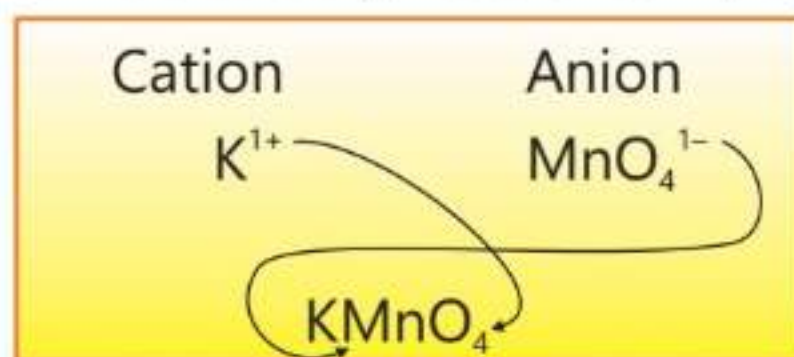


## 16.3 Writing Chemical Formulas of Ionic Compounds using Ionic Charges

In order to write the formula of potassium permanganate, write first the

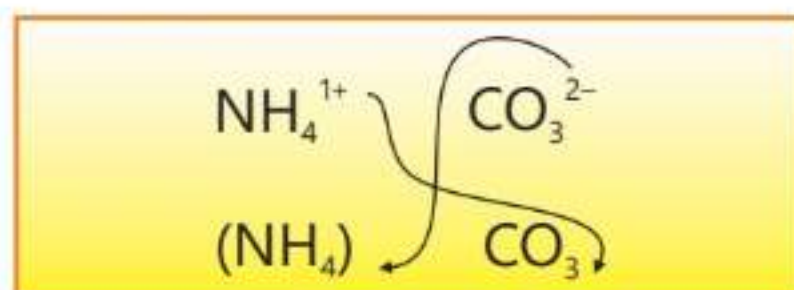


formulae of permanganate ion,  $\text{MnO}_4^{1-}$  and potassium ion  $\text{K}^{1+}$ . Then combine the two ions together to form an electrically neutral compound.



The formula for potassium permanganate will, therefore, be  $\text{KMnO}_4$ .

When writing the formulae of ionic compounds containing more than one polyatomic ions, we take the formula of the ion in brackets and indicate the number of such ions with a subscript. The formula for ammonium carbonate will be written as follows.

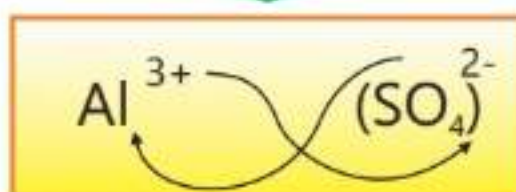


The formula for ammonium carbonate will, therefore, be  $(\text{NH}_4)_2\text{CO}_3$ .

### 16.5 Example

Write down the formula for aluminum sulphate.

**Solution:**



The formula for aluminum sulphate is  $\text{Al}_2(\text{SO}_4)_3$ .

Examples of several polyatomic ions are given in Table 16.1

**Table 16.1 – Common Polyatomic ions**

$\text{CH}_3\text{COO}^-$	acetate	$\text{Cr}_2\text{O}_7^{2-}$	dichromate	$\text{NO}_2^{1-}$	nitrite
$\text{NH}_4^{1+}$	ammonium	$\text{HCO}_3^{1-}$	bicarbonate	$\text{C}_2\text{O}_4^{2-}$	oxalate
$\text{CO}_3^{2-}$	carbonate	$\text{HSO}_4^{1-}$	bisulfate	$\text{ClO}_4^{1-}$	perchlorate
$\text{ClO}_3^{1-}$	chlorate	$\text{HSO}_3^{1-}$	bisulfite	$\text{MnO}_4^{1-}$	permanganate
$\text{ClO}_2^{1-}$	chlorite	$\text{OH}^{1-}$	hydroxide	$\text{PO}_4^{3-}$	phosphate
$\text{CrO}_4^{2-}$	chromate	$\text{ClO}^{1-}$	hypochlorite	$\text{SO}_4^{2-}$	sulfate
$\text{CN}^{1-}$	cyanide	$\text{NO}_3^{1-}$	nitrate	$\text{SO}_3^{2-}$	sulfite



### 16.2 Quick Check!

1. Write the formulae of the following ionic compounds with the help of oxidation numbers of their constituent atoms.

Aluminum nitride, Sodium sulfite and Sodium hydrogen carbonate.

2. Write the formulae of following ionic compounds with the help of charges present on their ions.

Ammonium acetate, Calcium phosphate and Potassium chromate.

## 16.4 Oxidation and Reduction

Oxidation and reduction are simultaneous but opposite processes. They always occur together. Oxidation and reduction changes are described in three principal ways.

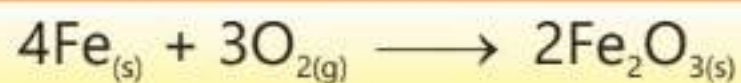
### (A) Oxidation

1. Oxidation is defined as a process in which oxygen is either added or hydrogen is removed.

For example;

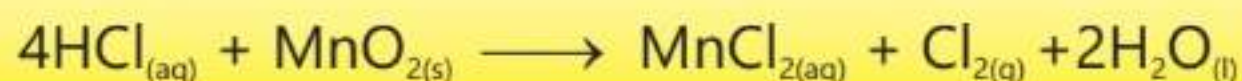
(i) Oxygen combines with other elements in the formation of their oxides. Elements in these processes are said to be oxidized and oxygen is reduced.

Rusting of iron or burning of magnesium in air are oxidation processes.



In the above reactions Fe and Mg are being oxidized while oxygen is being reduced. Oxygen is an oxidising agent while iron and magnesium are reducing agents.

(ii) Hydrogen is removed from a compound by oxygen in the following examples; hydrogen is removed from  $\text{CH}_4$  and  $\text{HCl}$  by oxygen or a compound containing oxygen.

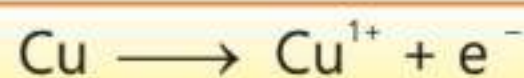


$\text{CH}_4$  and  $\text{HCl}$  in these reactions are being oxidized while  $\text{O}_2$  and  $\text{MnO}_2$  are being reduced.  $\text{CH}_4$  and  $\text{HCl}$  are called reducing agents while  $\text{O}_2$  and  $\text{MnO}_2$  are called oxidising agents.





2. Oxidation is a process in which electron or electrons are lost. For example; Copper may lose one or two electrons to give  $\text{Cu}^{1+}$  or  $\text{Cu}^{2+}$  ions respectively. In both these processes, we say, copper is being oxidised. Hence, copper is called an reducing agent.



3. Oxidation is process in which oxidation number or oxidation state of an element increases.

In the above two processes, the oxidation number of copper has increased from zero to +1 [Cu (I)] and +2 [Cu (II)] respectively.

## (B) Reduction

1. Reduction is defined as either addition of hydrogen or removal of oxygen. For example,  
(i) hydrogen is added in chlorine to give hydrogen chloride gas.



- (ii) In the following reaction, hydrogen is heated with metal oxide when oxygen comes out of the compound and combines with hydrogen to give a molecule of water.



In the above examples,  $\text{Cl}_2$  and  $\text{CuO}$  are being reduced and hydrogen (in both cases) is being oxidized.  $\text{Cl}_2$  and  $\text{CuO}$  are called oxidizing agents while hydrogen in both the reactions will be reducing agent.

2. Reduction is a process in which electron or electrons are gained. For example,



In both the above examples, ions of iron and manganese are being reduced. Hence, they are called oxidising agents.

3. Reduction is a process in which oxidation number of an element decreases. In the above examples oxidation number of iron is reduced





from +3 [Fe(III)] to +2[Fe(II)] while oxidation number of manganese is reduced from +7[Mn(VII)] to +2 [Mn(II)].

## 16.5 Oxidation-Reduction Reactions

A chemical reaction which involves simultaneous oxidation and reduction is called an oxidation-reduction or redox reaction. The reaction may involve the complete transference of electron or electrons to form ionic bonds or a partial transfer or shift of electron or electrons to form covalent bonds.

Potassium permanganate acts as a very powerful oxidising agent in acidic medium. It oxidizes oxalic acid into carbon dioxide. During the reaction the dark purple solution of potassium permanganate changes to colourless as shown in Figure 16.1. In the presence of dilute sulphuric acid the reaction proceeds as follows.

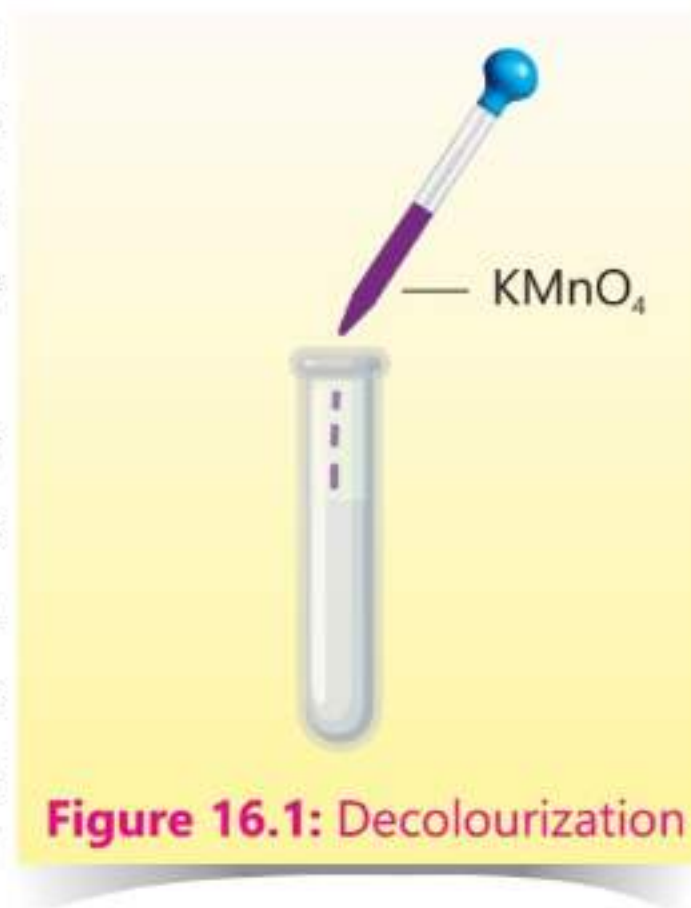
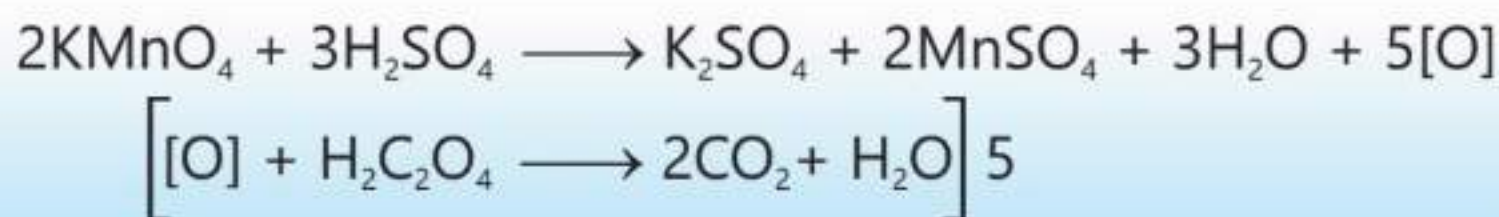
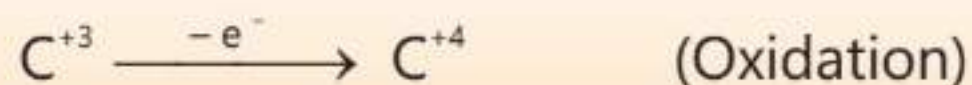
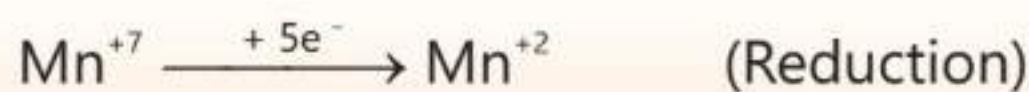


Figure 16.1: Decolourization



Let us assign oxidation number to each element in these compounds to find out the oxidising and reducing agents.



Oxidation number of manganese has decreased from +7 to +2 and that of carbon has increased from +3 to +4.

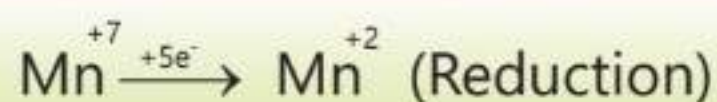
So, each manganese atom accepts five electrons to get reduced and each carbon atom loses one electron to get oxidized.  $\text{KMnO}_4$  is therefore an oxidizing





agent while oxalic acid in this reaction acts as a reducing agent.

Aqueous potassium iodide is also oxidized to iodine in acidified potassium permanganate. The formation of iodine in this reaction results in a colour change, typically from colourless to yellow-brown.

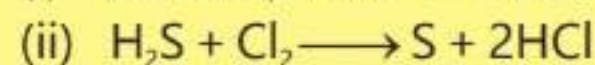
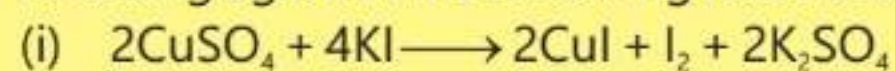


In this reaction, the permanganate ion ( $\text{MnO}_4^{4-}$ ) is reduced to manganese (II) ion ( $\text{Mn}^{2+}$ ) and the iodide ion ( $\text{I}^{-1}$ ) is

oxidized to iodine ( $\text{I}_2$ ). Potassium permanganate, therefore, acts as an oxidizing agent while potassium iodide acts as a reducing agents.

### 16.3 Quick Check!

Identify the oxidising agent and the reducing agent in the following reactions.



## 16.6 Electrolysis

When electricity is passed through fused ionic compounds or their aqueous solutions, they are decomposed into their constituents. Such compounds are called Electrolytes and the process is called Electrolysis. During electrolysis, a non-spontaneous chemical reaction takes place with the help of electrical energy.

The process of electrolysis can be carried out in an electrolytic bath called an electrolytic cell with the help of two electrodes through which electric current enters and leaves the cell, These electrodes may be made of graphite or any other metal.

**Anode:** It is a positive electrode through which electrons enter the external circuit.

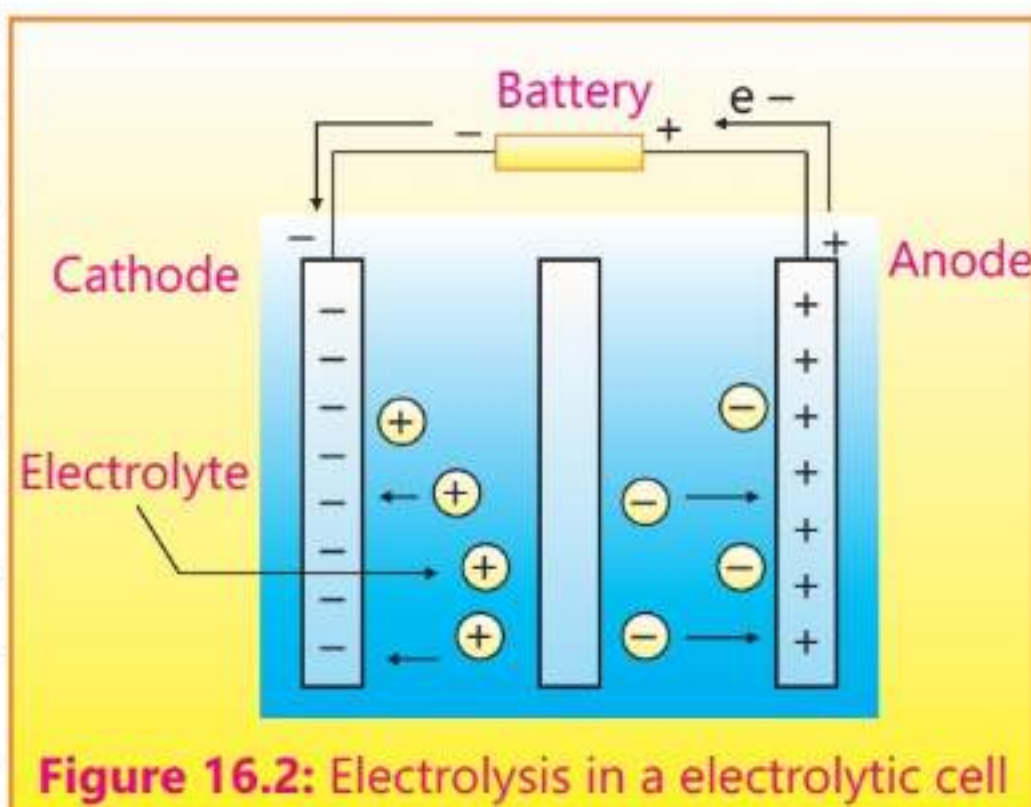
**Cathode:** It is a negative electrode through which electrons leave the external circuit.

Electrolyte present in the cell is in the form of freely moving ions. During electrolysis, the electrolyte is decomposed into its components by applying an external voltage. Thus external voltage source (battery) forces the non-spontaneous reaction to occur by pumping electrons towards one of the electrodes, thereby, giving it a negative charge. The positive ions of






the electrolyte are attracted towards the negative electrode and get reduced by accepting electrons from it, making it the cathode. The battery simultaneously withdraws electrons from the other electrode, giving it a positive charge. The negative ions of the electrolyte are attracted towards this and get oxidized by losing their electrons, making it the anode. Electrons flow in the external circuit while ions move towards their respective electrodes inside the cell. If the oxidation and reduction at the electrodes cease, the flow of electricity in the external circuit also stops.



**Figure 16.2:** Electrolysis in an electrolytic cell

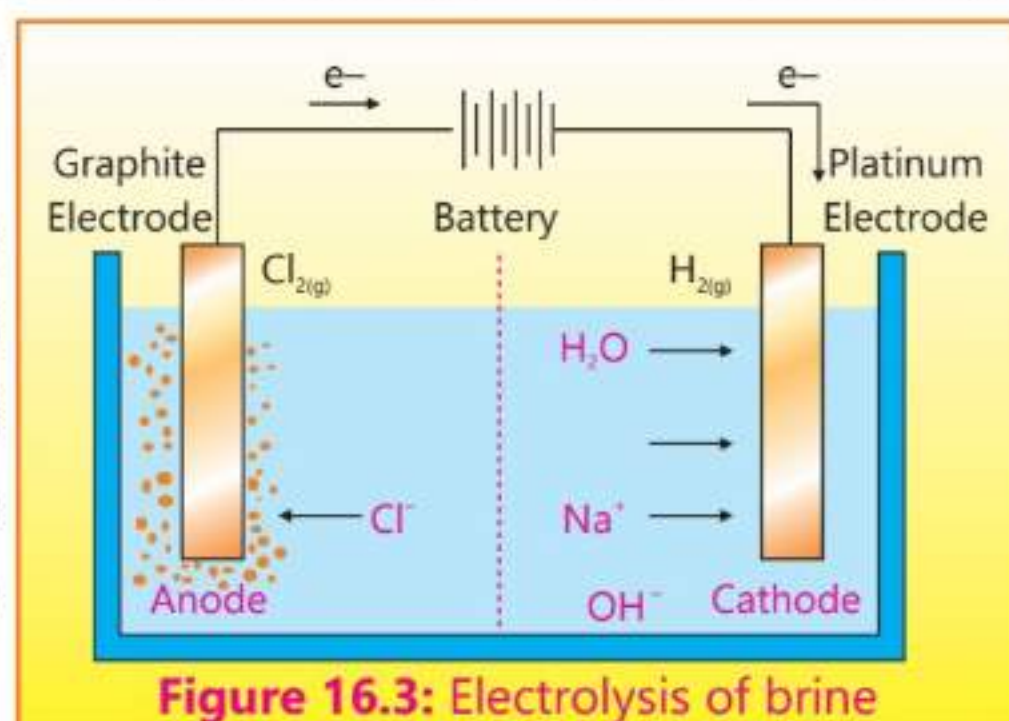
	Battery	Electrolytic Cell	Electrode	Function	Charge
 <b>THINGS TO KNOW</b>			Anode	Oxidation	Negative
			Cathode	Reduction	Positive
			Anode	Oxidation	Positive
			Cathode	Reduction	Negative

The terms anode and cathode always refer to the electrodes at which oxidation and reduction occur respectively. However, the charges carried by electrodes in a battery and electrolytic cell are different.

## 16.7 Electrolysis of a Concentrated Aqueous Solution of Sodium Chloride (Brine) using inert electrodes (Graphite /Pt)

The electrolysis of a concentrated solution of sodium chloride, also called brine, produces hydrogen gas at the cathode, chlorine gas at the anode, and sodium hydroxide solution as a by-product.

The electrolytic cell used in this electrolysis is shown in Figure 16.3. The cathode used in this cell is made of platinum while the anode must be made of graphite to avoid the reaction with chlorine gas.



**Figure 16.3:** Electrolysis of brine





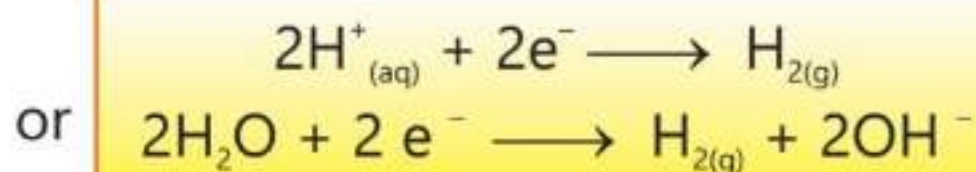
The following ions are present in the solution

$\text{Na}^+_{(\text{aq})}$ ,  $\text{Cl}^-_{(\text{aq})}$  from sodium chloride

$\text{H}^+_{(\text{aq})}$ ,  $\text{OH}^-_{(\text{aq})}$  from water

$\text{Na}^+$  and  $\text{H}_2\text{O}$ , both migrate towards the cathode. Since water molecules and hydrogen ions have a greater tendency to get reduced as compared to sodium ions ( $\text{Na}^+$ ), so they pick up electrons from the cathode to form hydrogen gas.

### At the Cathode



The ionic equilibrium of water is, thus, disturbed due to the discharge of  $\text{H}^+$  and more water molecules are ionized to restore it.

### Did You Know?

Spontaneous reactions occur naturally without any energy input, while non-spontaneous reactions require a continuous input of energy.

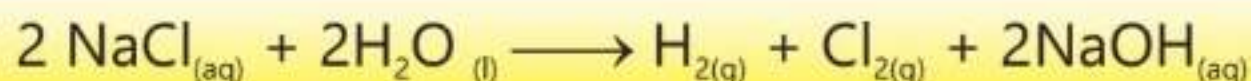
The solution around the cathode becomes alkaline due to the formation of hydroxide ions ( $\text{OH}^-$ ).

### At the Anode



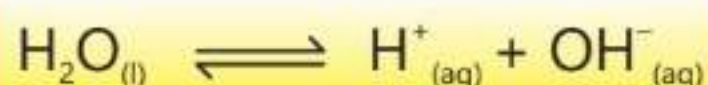
The solution gradually gets alkaline due to the presence of  $\text{OH}^-$ . The volumes of hydrogen and chlorine gases obtained are equal.

The overall equation for this electrolysis is:



## 16.8 Electrolysis of Dilute and Concentrated Aqueous solutions of Metal Halides

When the aqueous solutions of metal halides are subjected to electrolysis, the situation becomes more complicated due to the presence of water. Water is a very weak electrolyte and upon ionization it gives very small amount of hydrogen and hydroxide ions.



This will mean that the electrolyte will consist of more than one type of ions which will approach both cathode and anode. Hence there can be a choice over which ions will get discharged.





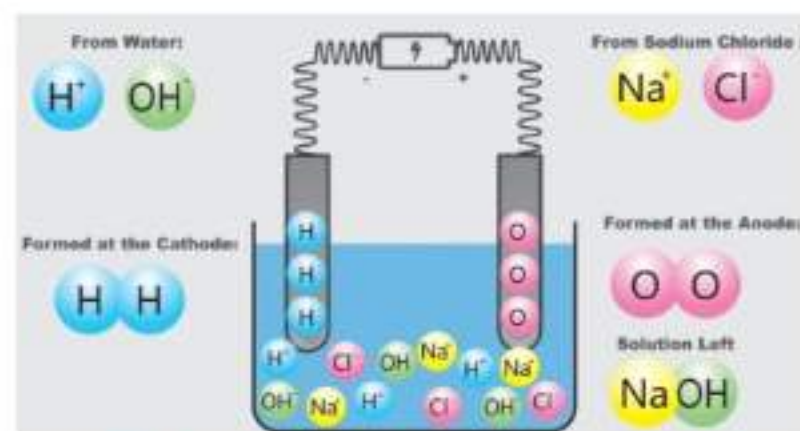
For example, if an aqueous solution of sodium chloride is electrolyzed, both sodium and hydrogen cations are attracted towards the cathode and both chlorides and hydroxide ions are attracted towards the anode. Which of these ions will preferentially be discharged depends upon the tendency of the elements to lose or gain electrons. The elements present at the top of electrochemical series shown in Table (16.2) possess more tendency to lose electrons as compared to the elements present at the bottom.

If a metal is below hydrogen in the electrochemical series, then the metal ion is discharged. Metals like this include copper and silver. If dilute copper chloride is electrolyzed, copper metal is obtained at the cathode.

If a metal is placed higher in the electrochemical series then hydrogen ion is discharged. Metals like this include lithium, sodium and magnesium. If dilute solution of sodium chloride is electrolyzed, hydrogen gas is obtained at the cathode.

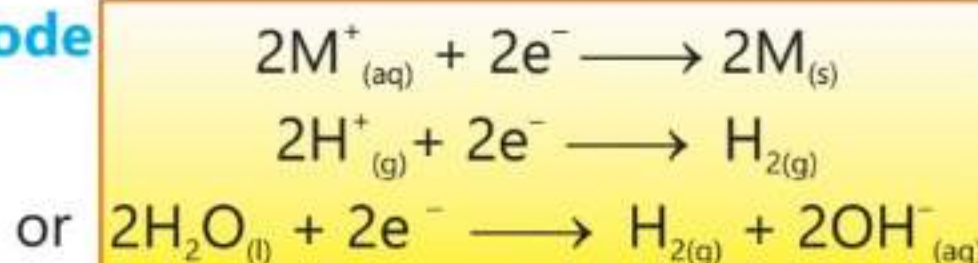
Metals like lead and nickel present a more complicated picture. If aqueous solutions of halides of these metals are electrolyzed, then the products obtained at the cathode depends on the concentrations of the halide solutions. If the solution is concentrated then metal is deposited at the cathode. If the solution is very dilute, hydrogen is evolved. At in-between concentrations both metal and hydrogen are obtained.

At anode, the electrolysis of dilute solutions of halides will deposit oxygen because hydroxide ions are preferentially discharged due to their higher concentrations.

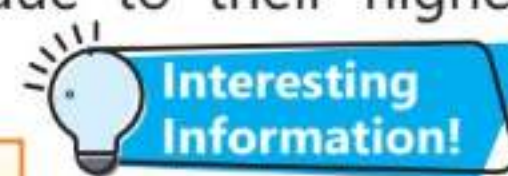
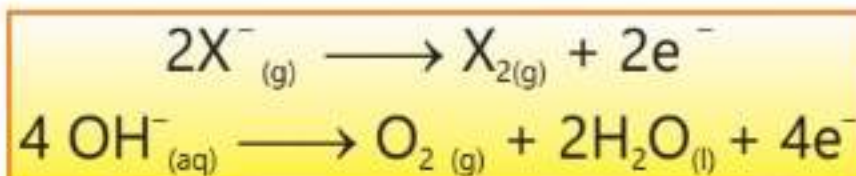


**Figure 16.4:** Electrolysis of dilute solutions of halides

### Reaction at the Cathode



### Reaction at the Anode



### Interesting Information!

Electrolysis played a crucial role in the discovery and industrial production of elements like fluorine and aluminum.



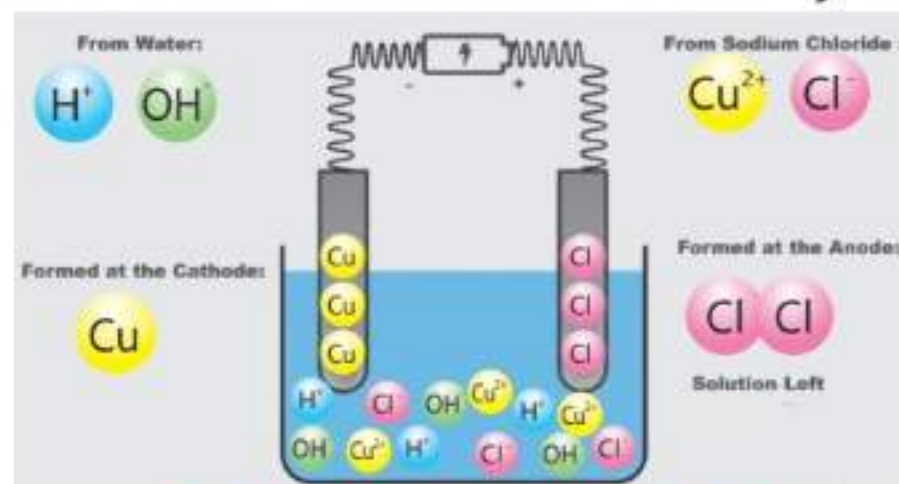


**Table 16.2 – Electrochemical Series**

Stronger reducing agent ↑	Electrode	Half Reaction	Standard Potential (V)	↓ Weaker oxidizing agent
	Lithium	$\text{Li}^+ (\text{aq}) + \text{e}^- \rightleftharpoons \text{Li} (\text{s})$	-3.04	
	Potassium	$\text{K}^+ (\text{aq}) + \text{e}^- \rightleftharpoons \text{K} (\text{s})$	-2.93	
	Calcium	$\text{Ca}^{2+} (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ca} (\text{s})$	-2.86	
	Sodium	$\text{Na}^+ (\text{aq}) + \text{e}^- \rightleftharpoons \text{Na} (\text{s})$	-2.71	
	Magnesium	$\text{Mg}^{2+} (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mg} (\text{s})$	-2.37	
	Aluminum	$\text{Al}^{3+} (\text{aq}) + 3\text{e}^- \rightleftharpoons \text{Al} (\text{s})$	-1.66	
	Water	$2\text{H}_2\text{O} (\text{l}) + 2\text{e}^- \rightleftharpoons \text{H}_2 (\text{g}) + 2\text{OH}^- (\text{aq})$	-0.82	
	Zinc	$\text{Zn}^{2+} (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn} (\text{s})$	-0.76	
	Iron (II)	$\text{Fe}^{2+} (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe} (\text{s})$	-0.44	
	Cadmium	$\text{Cd}^{2+} (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cd} (\text{s})$	-0.40	
	Nickel	$\text{Ni}^{2+} (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ni} (\text{s})$	-0.25	
	Lead	$\text{Pb}^{2+} (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb} (\text{s})$	-0.12	
	Hydrogen	$2\text{H}^+ (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2 (\text{g})$	0	
	Sulfur	$\text{S} (\text{aq}) + 2\text{H}^+ (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{S} (\text{aq})$	0.14	
	Tin	$\text{Sn}^{4+} (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+} (\text{aq})$	0.15	
	Copper	$\text{Cu}^{2+} (\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu} (\text{s})$	0.34	
	Iodine	$\text{I}_2 (\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{I}^- (\text{aq})$	0.53	
	Iron (III)	$\text{Fe}^{3+} (\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+} (\text{aq})$	0.77	
	Silver	$\text{Ag}^+ (\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag} (\text{s})$	0.79	
	Bromine	$\text{Br}_2 (\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^- (\text{aq})$	1.06	
	Chlorine	$\text{Cl}_2 (\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^- (\text{aq})$	1.35	
	Gold	$\text{Au}^+ (\text{aq}) + \text{e}^- \rightleftharpoons \text{Au} (\text{s})$	1.69	
	Hydrogen peroxide	$\text{H}_2\text{O}_2 (\text{aq}) + 2\text{H}^+ (\text{aq}) + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O} (\text{l})$	1.77	
	Fluorine	$\text{F}_2 (\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{F}^- (\text{aq})$	2.87	↓ Stronger oxidizing agent

## 16.9 Electrolysis of Concentrated Aqueous Solutions of Metal Halides

If the concentrated aqueous solutions of metal halides are electrolyzed the hydrogen ions are discharged at the cathode if the metal is present higher than hydrogen in electrochemical series. For example, electrolysis of concentrated aqueous solution of sodium chloride will produce hydrogen gas at the cathode. However, for less reactive metals like



**Figure 16.5:** Electrolysis of concentrated solution of copper chloride

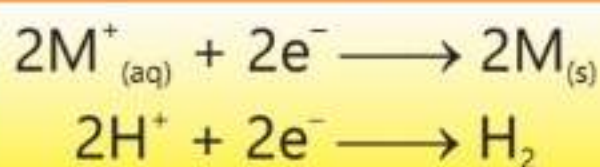




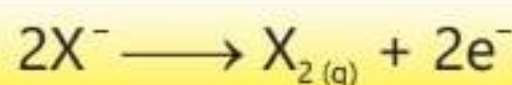
copper and silver the metal ions are discharged at the cathode.

At the anode, the halide ions are preferentially discharged due to their higher concentration.

### Reaction at the Cathode



### Reaction at the Anode

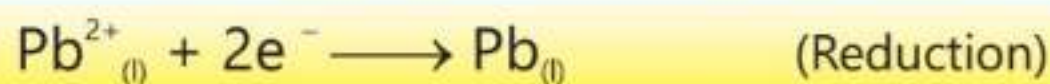


## 16.10 Electrolysis of Molten Lead (II) Chloride

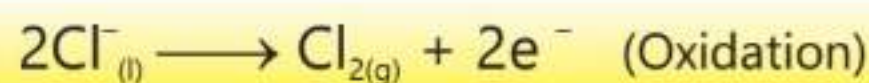
Lead (II) chloride is solid at room temperature. To make it an electrolyte it must be heated upto 501 °C to get molten lead chloride. Heat will render ions free to move and conduct electricity. The molten lead is then taken in a heated crucible where its temperature is maintained above 500 °C.

Two inert electrodes (graphite or platinum) are then immersed in it. Upon electrolysis the lead (II) ions will move towards the cathode where they are discharged forming lead in the liquid state. The chloride ions migrate towards the anode where they lose electrons to give chlorine gas. The electrolysis must be carried out at the temperature above the melting point of lead chloride.

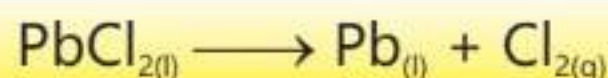
### Reaction at the Cathode



### Reaction at the Anode



### Overall Reaction



## 16.11 Electrolysis of Dilute solution of Sulphuric Acid using inert electrodes (Carbon or Pt)

Electrolysis of dilute aqueous solution of sulphuric acid produces hydrogen and oxygen gases. In other words this electrolysis involves the decomposition of water. Inert electrodes like platinum or graphite are used for this electrolysis because they did not react with the electrolyte.

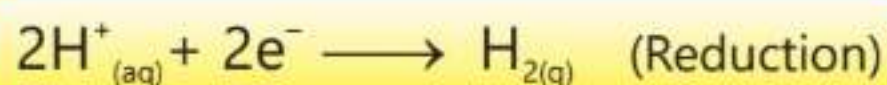
In an aqueous solution of dilute sulphuric acid  $H^+$  and  $SO_4^{2-}$  are given by sulphuric acid while the ionization of water forms  $H^+$  and  $OH^-$ .

At the cathode, hydrogen ions gain electrons to give hydrogen gas. At the anode both  $SO_4^{2-}$  and  $OH^-$  are attracted but  $OH^-$  lose electrons to give oxygen

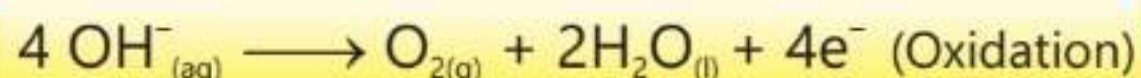


gas. Sulphate ions are not discharged at the anode because they are difficult to be oxidized compared to hydroxide ions. As the electrolysis moves ahead, the concentration of sulphuric acid increases because the water present is being decomposed.

#### Reaction at the Cathode



#### Reaction at the Anode



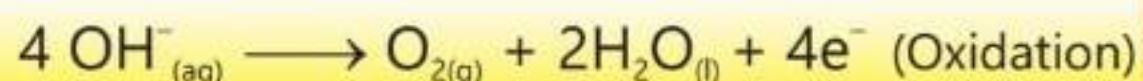
## 16.12 Electrolysis of Dilute Aqueous solution of Copper Sulphate using Inert electrodes or Copper electrodes

The electrolysis of aqueous solution of copper(II) sulphate with inert electrodes result in the decomposition of water and the copper(II) sulphate. Copper metal is deposited at the cathode (inert) and oxygen gas is produced at the anode (inert).

#### Reaction at the Cathode



#### Reaction at the Anode



#### 16.4 Quick Check!

Why carbon electrodes are used in the electrolysis of concentrated solution of NaCl?

Since the concentration of copper ions decreases slowly so the blue colour of the solution fades away with the passage of time.

If copper electrodes are used instead of inert electrodes, the copper metal atoms from the copper anode start going into the solution in the form of copper ions and the electrode mass starts decreasing.

#### Reaction at the Cathode



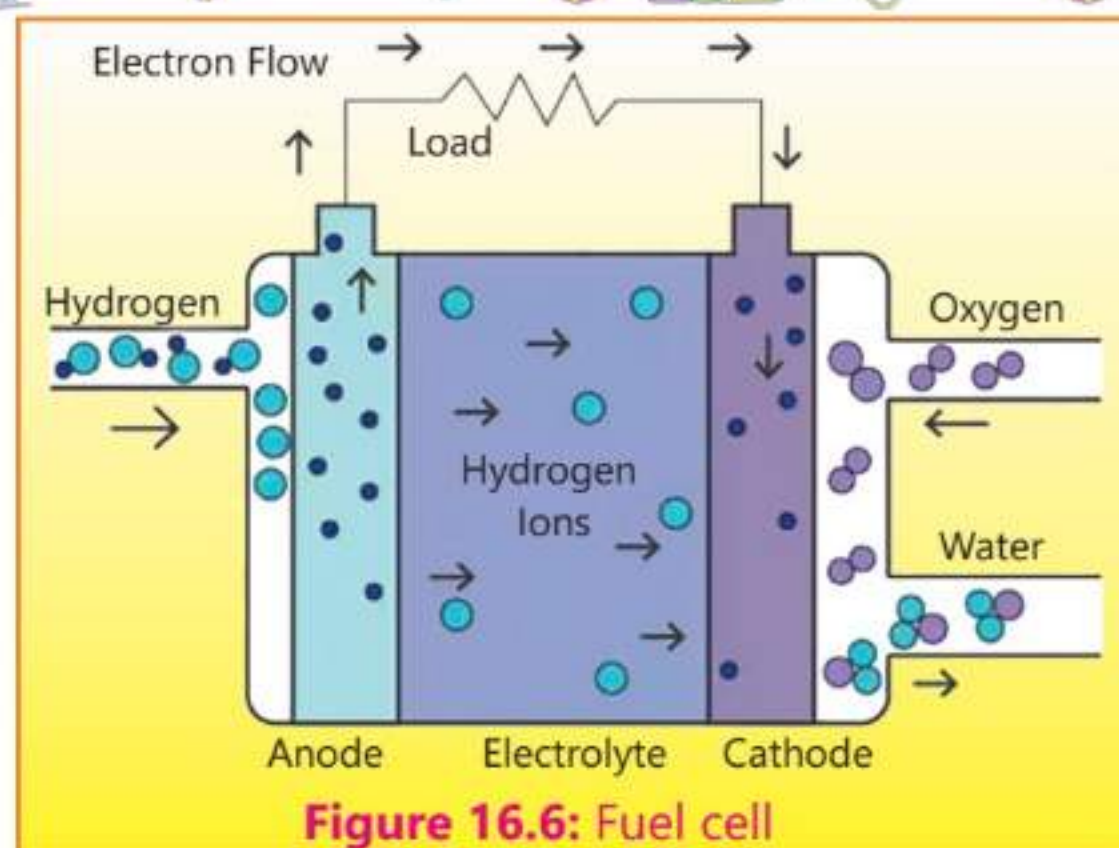
#### Reaction at the Anode



## 16.13 Fuel cells

Fuel cells provide a method in which chemical energy is converted to electrical energy. These cells use gaseous fuels like hydrogen and oxygen to produce electricity. A fuel cell is composed of two hollow tubes which act as

electrodes. They are made of porous compressed carbon saturated with platinum which acts as a catalyst. The electrolyte used in this cell is aqueous potassium hydroxide. At the anode, hydrogen is oxidized to water and at the cathode oxygen is reduced to hydroxide ions.

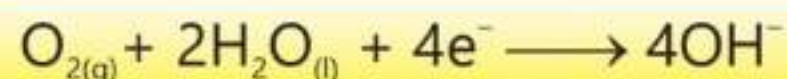


**Figure 16.6: Fuel cell**

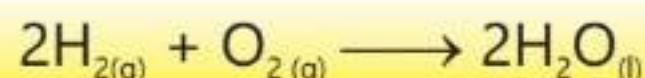
### At Anode



### At Cathode



### Overall Reaction



The fuel cell produces electricity and water continuously provided the reactants are continuously supplied. They are very efficient because they convert 75% of the bond energy of fuels to electricity.

## Advantages

1. The hydrogen-oxygen fuel cells have a clear advantage over the traditional fossil fuels, petrol and diesel, used to drive the vehicles. They produce zero emission of carbon dioxide because water is the only product. Fossil fuels, on the other hand, produce carbon dioxide, nitrogen oxides and sulphur oxides which are very harmful to the environment.
2. Fuel cells can convert a large proportion of chemical energy present in fuels into electrical energy as compared to the energy conversion of the fossil fuels. In other words, they are more efficient.
3. Fuel cells produce less noise pollution.
4. Hydrogen used in fuel cells can be obtained from renewable sources like solar or wind power. This fact renders fuel cells more sustainable.

## Disadvantages

1. Fuel cells at present, are very expensive because the production of hydrogen by electrolysis of water incurs high cost.
2. Hydrogen being highly inflammable requires very special storage and transportation facilities which further increases the cost of fuel cells.
3. Fuel cells and electric motors are less durable than petrol and diesel engines so they are not so long lasting.

### 16.5 Quick Check!

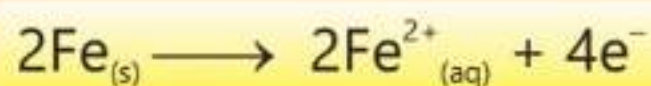
Which other electrolyte can be used in hydrogen-oxygen fuel cell?

## 16.14 Corrosion

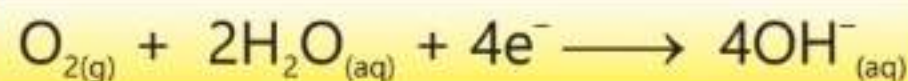
Corrosion is a natural process due to which a metal suffers gradual decay when it interacts chemically with its environment. During this interaction the surface of metal is coated with compounds such as oxides, sulphides and carbonates.

A common example is rusting of iron, where iron reacts with oxygen and water present in the atmosphere to form hydrated iron (III) oxide. Once iron begins to rust, the process will continue as rust is porous and allows both air and moisture to come into contact with fresh metal underneath. Hence, all the metal will corrode given enough time.

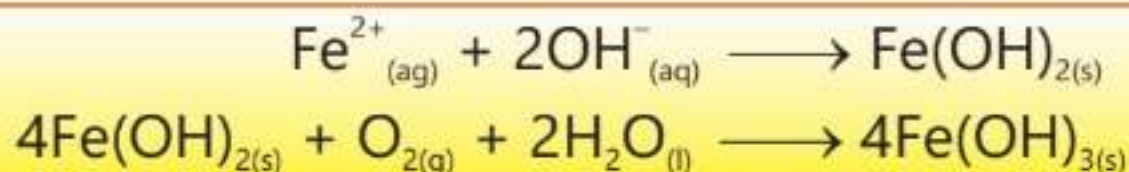
The process of corrosion of iron appears to require two important chemicals, oxygen and water, which are involved in the following electrochemical reactions. Iron loses electrons to form Fe (II) ions.



Oxygen gains these electrons in the presence of water to form hydroxide ions.



$\text{Fe}^{2+}$  then react with more oxygen and water to form iron (III) hydroxide which is rust.





## Prevention of Corrosion

### Coating of the metal surface

Corrosion can be avoided by coating the metal surface with some barriers that prevent the contact of metal surface with the atmosphere. For this purpose, the metal surfaces are protected by either greasing with oil or painting. Other methods of protection are galvanizing, electroplating and sacrificial protection.

### Galvanization

Galvanization is a common method to protect iron or steel from rusting. It involves the dipping of an iron sheet in a bath of molten zinc. A layer of zinc metal gets deposited on the iron sheet and prevents rusting. Tin cans are actually steel cans which have been coated with a thin layer of tin.

### Sacrificial Protection

In sacrificial protection a more reactive metal like zinc or magnesium is used which will corrode in place of the less reactive metal like iron. Magnesium is often employed to protect steel in buried fuel tanks and pipe lines and ship hulls submerged in sea water.

The difference in the activity of the two metals (Mg and Fe) causes a current to flow between them, producing corrosion on the more active metal protecting the less active metal iron.



### 16.6 Quick Check!

1. What conditions are required for rusting of iron.
2. If a sample of iron and a sample of zinc come into contact, which will corrode? Explain your answer.

## 16.15 Electroplating

It is a process in which a metal is deposited on another metal electrolytically.

There are three main objectives of electroplating.

### 1. Decoration

To deposit the noble metals like gold and silver on the inexpensive metals to enhance their beauty.

### 2. Protection

To protect the metals from rusting as well as from the reaction of organic acids.



### 3. Repair

To weld the broken parts of the machinery by electrodeposition of metals. Generally copper, silver, chromium, nickel and gold are electroplated.

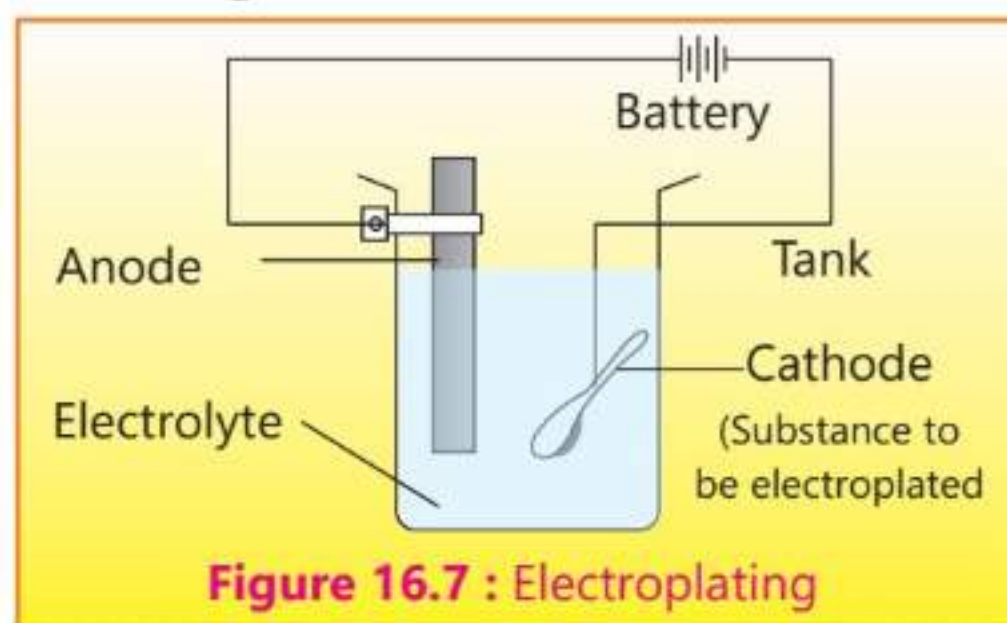
#### Procedure of Electroplating

The article to be electroplated is first cleaned with sand and then washed with caustic soda solution and finally with plenty of water. This article is then, made a cathode, while the metal to be deposited is made anode. The electrolyte is a salt of the metal being deposited and the electroplating is carried out in a tank made of cement, glass or wood. It is called an electrolytic tank.

This process of electroplating is shown in Figure 16.7.

The electrolyte chosen should have the following properties:

1. very soluble in water
2. good conductor
3. not easily oxidized or reduced or hydrolyzed
4. inexpensive



Electrodes are dipped in the electrolytic tank containing the electrolyte and electric current is passed. A thin layer of the noble metal is deposited on the article to be electroplated. The following conditions should be fulfilled to get good deposits.

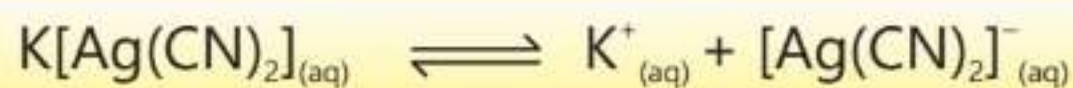
- i. High current density
- ii. Low temperature
- iii. Higher concentration of the metal in its electrolyte



A group of chemically unreactive and valuable metals are called noble metals. They include gold, silver and platinum.

#### Silver Plating

The procedure for silver plating is the same as described in the previous topic except that the electrolyte used is the solution of potassium argento cyanide,  $K[Ag(CN)_2]$ , and anode is of pure silver. The following ions are formed in the electrolytic solution.



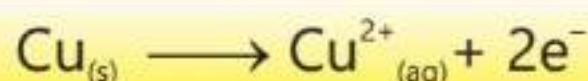


When the electric current is passed,  $\text{Ag}^+$  ions migrate towards the cathode and deposit after picking up electrons. Cyanide ions move towards the anode, where they react with silver to form  $\text{AgCN}$ , which combines with  $\text{KCN}$  to reproduce the electrolyte,  $\text{K}[\text{Ag}(\text{CN})_2]$ .

## Copper Plating

In copper plating, the anode is made of copper metal and the electrolyte is  $\text{CuSO}_4$  to which a few drops of sulphuric acid are added to prevent its hydrolysis. The article to be electroplated is made the cathode. The following electrolytic reactions take place, at the electrodes.

**At Anode:**



**At cathode:**



Chromium plating is usually done on iron or on steel. As chromium metal does not directly adhere to the iron properly, therefore, iron is first copper or nickel plated.

### 16.7 Quick Check!

1. What is the principle behind electroplating?
2. How electroplating is used to repair worn-out areas of metal objects?

## 16.16 Galvanic Cells

As described earlier, the oxidation-reduction reactions take place at the electrodes when fused ionic compounds or the aqueous solutions of ionic compounds are electrolyzed. The reverse process may also occur. In other words, oxidation-reduction reactions can be used to produce electricity. This can be understood with a very simple process. Take a plate of zinc metal and dip it in an aqueous solution of copper sulphate. After some time, a pink layer of copper metal will appear on the zinc plate and the blue colour of the solution will become lighter. If the quantity of zinc is enough and sufficient time is allowed, the solution will become colourless. In this process, electrons are transferred from zinc to copper ions. Every copper ion gets two electrons from zinc atom to get deposited as a metallic copper atom. A zinc atom goes into the aqueous solution as  $\text{Zn}^{2+}$ . The reaction can be shown as follows.



In other words, zinc is oxidized to  $\text{Zn}^{2+}_{(aq)}$  while  $\text{Cu}^{2+}_{(aq)}$  is reduced to copper

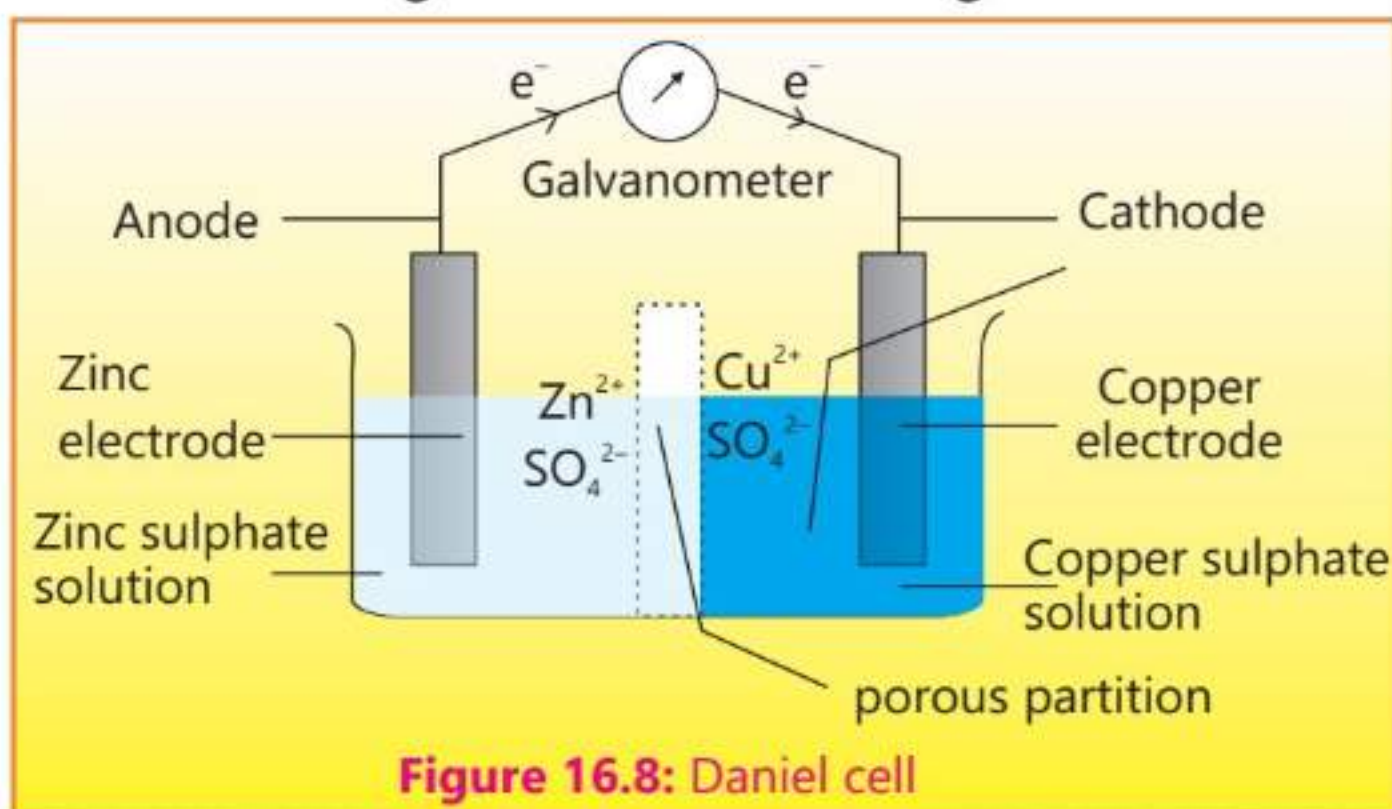




metal. This reaction can be made a basis for producing electric current in a galvanic cell which is named as Daniel cell.

Daniel cell uses oxidation-reduction reactions to produce electric current. In the above mentioned process, the oxidation-reduction reactions are taking place directly on the zinc electrode, so electricity can not be generated. However, if oxidation-reduction reactions are carried out in separate compartments, electricity can be generated. Such an arrangement is shown in Figure 16.8.

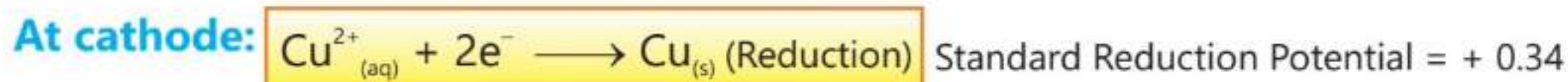
In this type of galvanic cell, a zinc plate is dipped in zinc sulphate solution while a copper plate is dipped in copper sulphate solution. The two solutions are kept separate by a porous partition through which ions can pass but the solutions cannot.



The two electrodes are connected by a wire through a galvanometer which measures the electric current.

At the surface of zinc electrode, each zinc atom loses two electrons and goes into the solution as zinc ions. These electrons travel through the external wire to copper electrode where they are used to discharge copper ions into copper atoms which are deposited at this electrode. An oxidation reaction takes place at zinc electrode and it is called anode while reduction takes place at copper electrode and it is called cathode.

The following reactions take place at the two electrodes.



Both parts of the cell are called half cells. No reaction can take place in any





isolated half cell. Both the reactions take place simultaneously at both half cells. In this cell, electrons travel in the external circuit while ions travel through the porous partition in the internal circuit. Daniel cell produces a voltage of around 1.10 volts under standard conditions.



### 16.8 Quick Check!

1. Compare an electrolytic and a galvanic cell.
2. Write down the reactions which occur in a Zn-Mg galvanic cell.

## 16.17 Order of Reactivity of Metals using Voltage Data

The reactivity of metals can be found out by using voltage data obtained from galvanic cells. According to the available data the reactivity of metals depends upon how readily it is oxidized or lose electrons to form positive ions. If a galvanic cell is established between two metals, the more reactive metal will lose electrons and form positive ions. The voltage generated by this cell measures the comparative tendencies of the metals to lose electrons. A higher voltage indicates that the difference in the tendency of one metal (more reactive metal) to lose electron is far more than the other.

If a cell is established between magnesium and copper it produces a higher voltage than a cell established between iron and copper. This will mean that magnesium is more reactive than iron because it has a tendency to lose electrons more easily.

By measuring the voltage produced when different metal pairs are used in a voltaic cell, it is possible to determine the reactivity series of metals which is called electrochemical series. Metals placed higher in this series are considered more reactive and easily lose electrons than the metals placed lower in the series.


## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

1. The oxidation number of Mn in  $K_2MnO_4$ :  
(a) +7                      (b) +5                      (c) +6                      (d) -6
2. Which element in the following reaction is being reduced?  
$$4HBr_{(aq)} + MnO_{2(s)} \longrightarrow MnBr_{2(aq)} + Br_{2(g)} + 2H_2O_{(l)}$$
  
(a) Br                      (b) Mn                      (c) H                      (d) Both Mn and H



- 
3. During electrolysis of dilute solution of  $\text{H}_2\text{SO}_4$ , using Pt electrodes, which process takes place at the cathode?
- (a) Reduction  
(b) Neither oxidation nor reduction  
(c) Oxidation  
(d) First oxidation and then reduction
4. Which product you will get at the anode when an aqueous solution of  $\text{CuSO}_4$  is electrolysed using copper electrodes?
- (a) Cu  
(b)  $\text{O}_2$   
(c)  $\text{H}_2$   
(d) No product, instead copper metal will go into the solution as  $\text{Cu}^{2+}$ .
5. Which of the following statements is NOT correct about Zn-Cu electrochemical cell?
- (a) Anode is negatively charged  
(b) Reduction occurs at anode  
(c) Cathode is positively charged  
(d) Reduction occurs at cathode
6. Which product will be obtained at the anode when a concentrated solution of NaCl will be electrolysed?
- (a)  $\text{Cl}_2$  (b)  $\text{O}_2$   
(c) More  $\text{O}_2$  and less  $\text{Cl}_2$  (d) More  $\text{Cl}_2$  and less  $\text{O}_2$
7. When a dilute aqueous solution of  $\text{ZnCl}_2$  is electrolysed which product you will get at the cathode?
- (a)  $\text{H}_2$  (b) Zn (c)  $\text{O}_2$  (d) Zn and  $\text{O}_2$
8. What is produced at the cathode in hydrogen-oxygen fuel cell?
- (a)  $\text{H}^+$  (b)  $\text{O}^{2-}$  (c)  $\text{H}_2\text{O}$  (d)  $\text{OH}^{1-}$
9. Which of the following metals is highest in the electrochemical series?
- (a) Tin (b) Iron (c) Magnesium (d) Zinc

## **B** Short Answer Questions

- 16.1 What happens when electricity is passed through an aqueous solution of NaCl?
- 16.2 What are the main objectives of electroplating?
- 16.3 Mention one difference between an electrolytic cell and a galvanic cell.



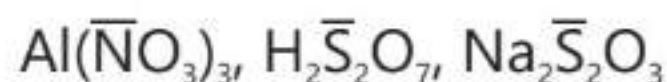
- 16.4 Through which electrode, electrons leave the electrolytic cell?
- 16.5 How does an electrolyte conduct electricity?
- 16.6 What will happen if a strip of Cu metal is dipped in  $\text{FeSO}_4$  solution?
- 16.7 Why fuel cells are regarded as environment friendly?

### **C** Constructed Response Questions

- 16.1 Calculate the oxidation number of chlorine atom in  $\text{Ca}(\text{ClO}_3)_2$ .
- 16.2 How can  $\text{H}_2\text{O}_2$  behave as an oxidizing agent?
- 16.3 Why different products are formed at the electrodes when a dilute and concentrated aqueous solutions of NaCl are electrolysed?
- 16.4 Why corrosion becomes fast during rainy season?
- 16.5 If a galvanic cell is established between Cu and Ag, what reactions do you expect at the electrodes?
- 16.6 What is the function of a porous partition in a galvanic cell?
- 16.7 How do fuel cells produce electricity?
- 16.8 How can the chemical reactivity of metals be compared by using electrochemical series?

### **D** Descriptive Questions

- 16.1 Explain with examples how the formula of ionic compound can be written using oxidation numbers.
- 16.2 Find the oxidation numbers of the indicated elements in the following compounds.



- 16.3 Write down the formulae of the following compounds using ionic charges.  
Sodium hypochlorite, calcium oxalate, ammonium phosphate and calcium nitrite
- 16.4 Describe the working of a fuel cell.
- 16.5 Discuss the electrolysis of concentrated solutions of metal halides.
- 16.6 Explain electroplating giving examples.
- 16.7 What is corrosion? Explain the reactions involved in corrosion of iron.

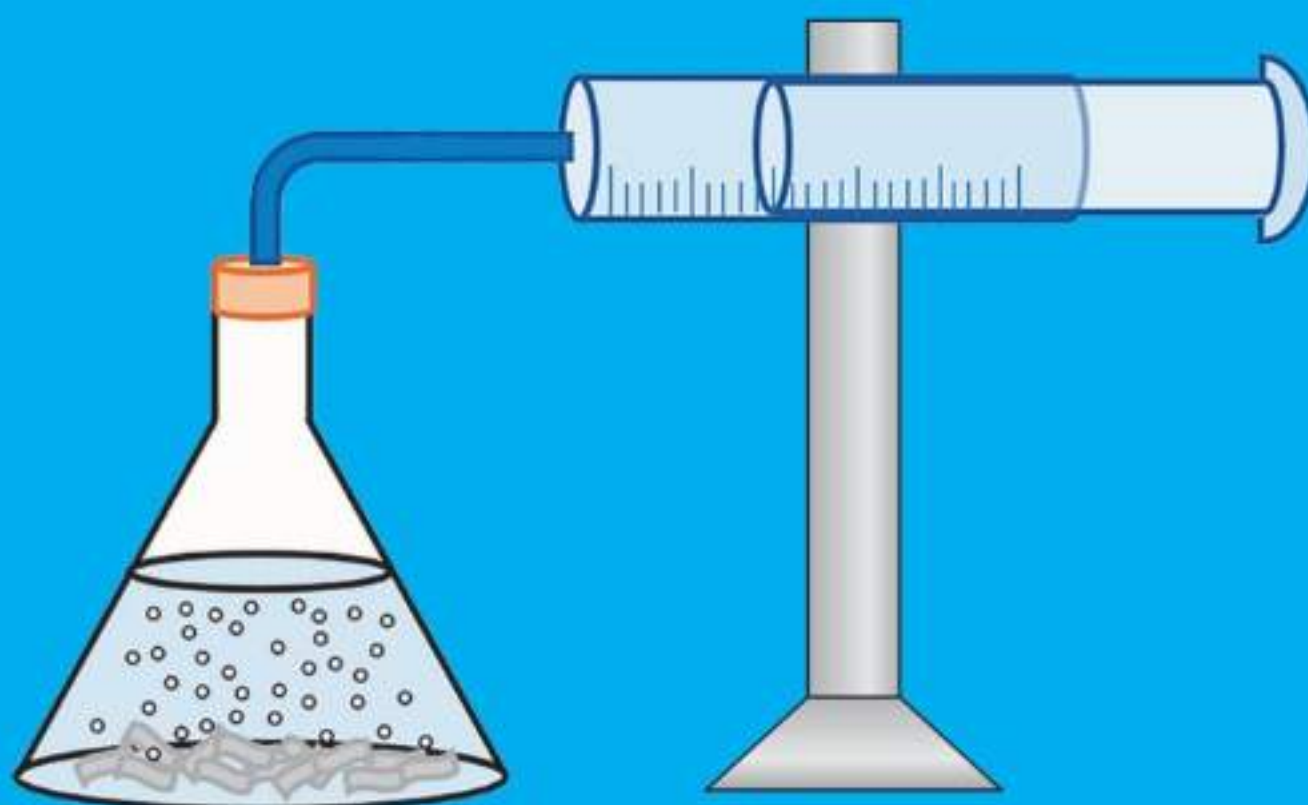


# Reaction Kinetics

## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Describe collision theory in terms of number of particles per unit volume, frequency of collisions of particles, kinetic energy of particles and activation energy
- State that catalyst increases the rate of reaction provides alternate pathway with lower activation energy, and remains unchanged at the end of a reaction
- Describe the physical parameters that may be affected by the rate of, reaction including change in mass, temperature, and formation of gas
- Interpret data, including graphs, for investigating rate of reaction
- Explain the effect on rate of reaction of changing concentration of a reactant, pressure of gases, surface area of solids, temperature, presence of catalyst (including enzymes) using collision theory
- Justify the importance of chemical kinetics in the food industry to determine ideal harvesting and transportation times for produce.





## Reaction Kinetics

Rate of reaction is the speed at which the reaction takes place. Chemical reactions are useful only when they occur at a reasonable rate. In this chapter we shall study the rates at which chemical reactions proceed. We shall also try to understand the factors that govern the rate of reaction. The studies eventually lead us to come to know how reactions occur at the molecular level.

### 17.1 Collision Theory of Reaction Rate

A reaction takes place only when the participating particles (atoms, molecules or ions) collide with one another. It has been observed that a very small fraction of collisions lead to the formation of products. In the majority of collisions the reactant particles simply bounce back without any change. Collisions which lead to reaction are called effective collisions.

The rate of a reaction depends upon the number of effective collisions which, in turn, depends upon the following factors.

#### 1. The number of particles per unit volume

The larger the number of particles per unit volume, larger is the possibility of effective collisions. In other words, higher the concentration of the reactants, more the number of molecules and hence more will be the number of collisions between them.

#### 2. The frequency of Collisions

A greater number of collisions per second will also result in the increase in the number of effective collisions. At higher temperature the velocities of the molecules increase resulting in the increase in the frequency of collisions. This increase in the frequency of collisions will also increase the number of successful collisions.

#### 3. The kinetic energy of the particles

The kinetic theory of particles says that all matter is composed of tiny constant moving particles. Their motion is due to kinetic energy they possess. As the temperature increases, the kinetic energy of the particles also increases. As a result the particles start moving fast leading to more vigorous motion. The fast moving particles will have more chances to collide with each other.



## 4. Activation energy

According to collision theory, the colliding particles will lead to effective collisions only when they possess sufficient energy to break the bonds present in the reactant molecules. This minimum energy required to start a chemical reaction is called its activation energy.

Generally, at a particular temperature, most of the molecules of the reactant possess average energy. A fraction of total molecules will, however have more than the average energy. Particles will react only when average energy of this small fraction of molecules exceeds the energy needed to activate molecules so that they can undergo a chemical reaction.

When the reactant particles come close to each other at the time of collision, they slow down and the kinetic energy they possess, is converted to increase their potential energy. This process can be understood with the help of a graph drawn between the path of reaction and the potential energy of the system as shown in

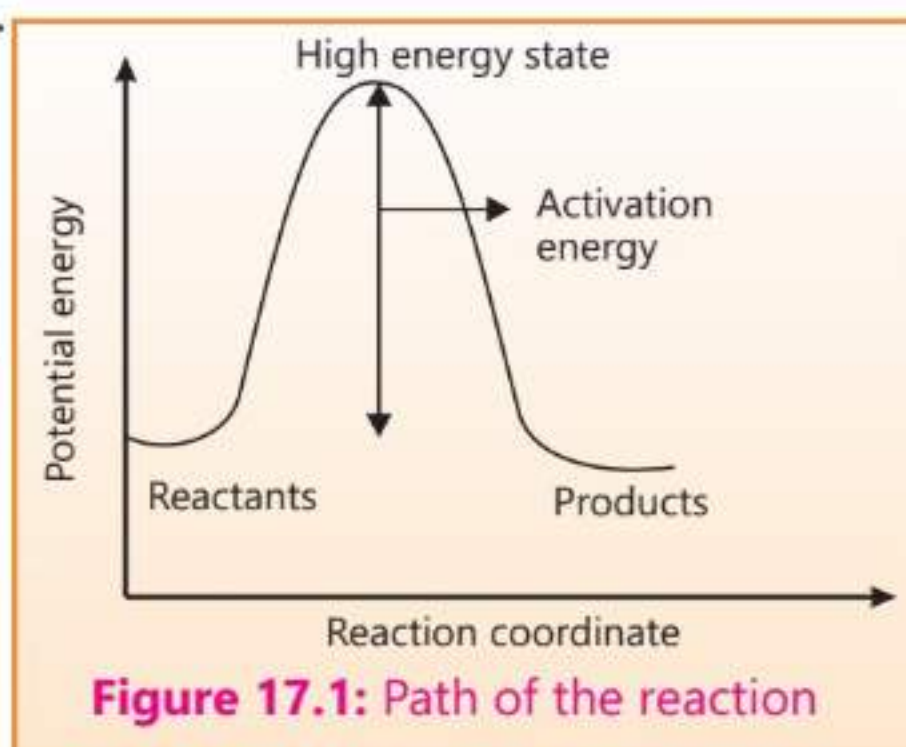


Figure 17.1. When the reactant particles possessing activation energy collide they form high energy state with the corresponding increase in the potential energy of the system. After this stage the reactants are converted into the stable products and the potential energy of the system falls down.

The information provided by the energy of activation is very important in understanding the mechanism of the reaction.



### 17.1 Quick Check!

1. How will you increase the frequency of collisions?
2. What happens to the reactant particles after collision?

## 17.2 Change in Mass during a Chemical Reaction

The total mass during a chemical reaction always remains the same. This is the requirement of the law of conservation of mass which is always obeyed. However, some reactions may appear to proceed with a change in mass which can usually be explained because a reactant or a product is a gas in such reactions.



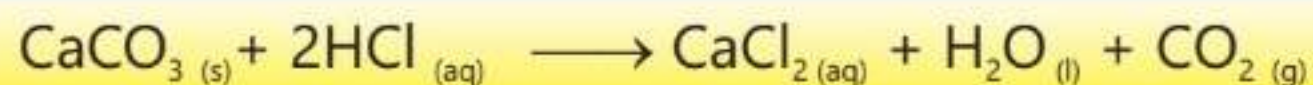


If a reaction is carried out in an open container where gases can escape or enter, the apparent mass change can occur if a gas is either absorbed or evolved. For example, if a gas is evolved, we shall observe a decrease in mass and if a gas is absorbed, the apparent mass will increase.

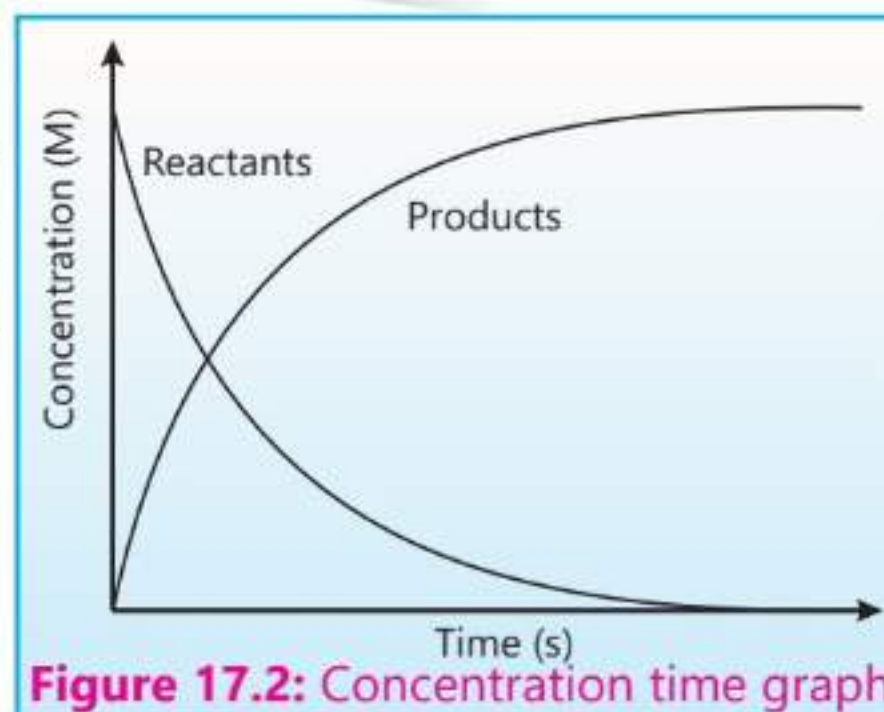
If a ribbon of magnesium is burnt in an open crucible, the mass of the product (MgO) formed will be greater than the reactant (Mg). This increase in mass has occurred due to the reaction of magnesium with oxygen present in air. However, if the two reactants (Mg and O<sub>2</sub>) are allowed to react in a closed container, the total mass will remain the same before and after the reaction.

### Formation of a gas during a chemical reaction

If a reaction is performed between marble chips and dilute hydrochloric acid in an open container, the mass of products will apparently be less than that of reactants. This apparent decrease in mass is due to evolution of CO<sub>2</sub> gas during the reaction which escapes into the atmosphere.



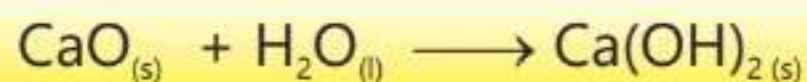
When a reaction moves ahead the concentrations of the reactants decrease until all the reactants are used up. At the same time, the concentrations of the products increase and reach the maximum value at the end of the reaction. This is shown in a graph in Figure 17.2.



### 17.3 Change in Temperature during a Chemical Reaction

Chemical reactions are quite often accompanied by the changes in the temperature indicating whether they are exothermic or endothermic. In exothermic reactions heat energy is released which is absorbed by the surrounding causing their temperature to increase.

For example, when quick lime (CaO) reacts with water slaked lime Ca(OH)<sub>2</sub> is formed and a lot of heat energy is released.





In endothermic reactions heat energy is absorbed causing the surrounding to cool down.

For example, when ammonium chloride or ammonium nitrate is dissolved in water, heat energy is absorbed causing the container to cool down.

Increasing the temperature of the reaction increases its rate. For many reactions, the rate doubles with every  $10\text{ }^{\circ}\text{C}$  rise in temperature. Cooking food uses high temperature to speed up chemical reactions that break down the components of food making it edible.

## 17.4 Factors Affecting the Rates of Reactions

According to the collision theory all those factors which change the number of successful collisions per second affect the rates of chemical reactions. Some of the important factors are explained in the following paragraphs.

### 1. Effect of Concentrations of the Reactants

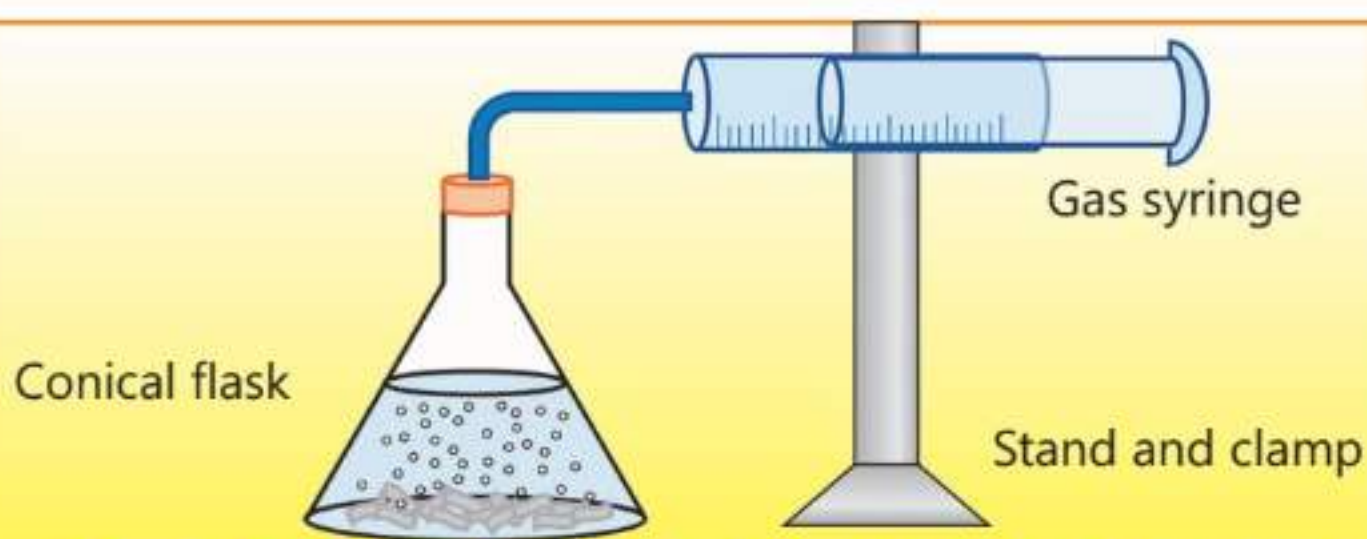
In order for the reaction to occur, the reactants must come in contact with each other. For this reason, the reactions are most often carried out in one phase, for example, in liquid solutions or in gas phase. When the reactants are present in the same phase, their particles are able to meet on the molecular level and thus are able to collide with each other easily. The higher the number of particles of the reactants per unit volume, higher will be chances of effective collisions and hence higher will be the rate of reaction. Hence an increase or decrease in concentrations of the reactants will result in increase or decrease in the rate of reaction respectively. For example, combustion of coal in air (21% oxygen) proceeds relatively slowly as compared to the reaction in pure oxygen. Similarly, lime stone reacts with different concentrations of hydrochloric acid at different rates.

#### Activity 17.1

An experiment can be performed to show the increase in the rate of reaction with the increase in the concentration of hydrochloric acid. Take a flat-bottomed conical flask fitted with a delivery tube which is connected to a syringe as shown in the Figure 17.3. The flask contains granules of lime stone taken in excess and a fixed volume of one molar hydrochloric acid. After the start of reaction carbon dioxide gas is generated which is collected in the



syringe. The scale present on the syringe directly measures the volume of carbon dioxide gas evolved. It is essential to keep all the variables constant in this experiment, for example, the volume of one molar hydrochloric acid, the temperature at which the experiment is being carried out, the mass and size of lime stone granules, and the rate of stirring. The reaction is followed by measuring the volume of carbon dioxide gas evolved. The same experiment is then repeated taking the same volume of two molar hydrochloric acid.



**Figure 17.3:** Reaction of hydrochloric acid with limestone

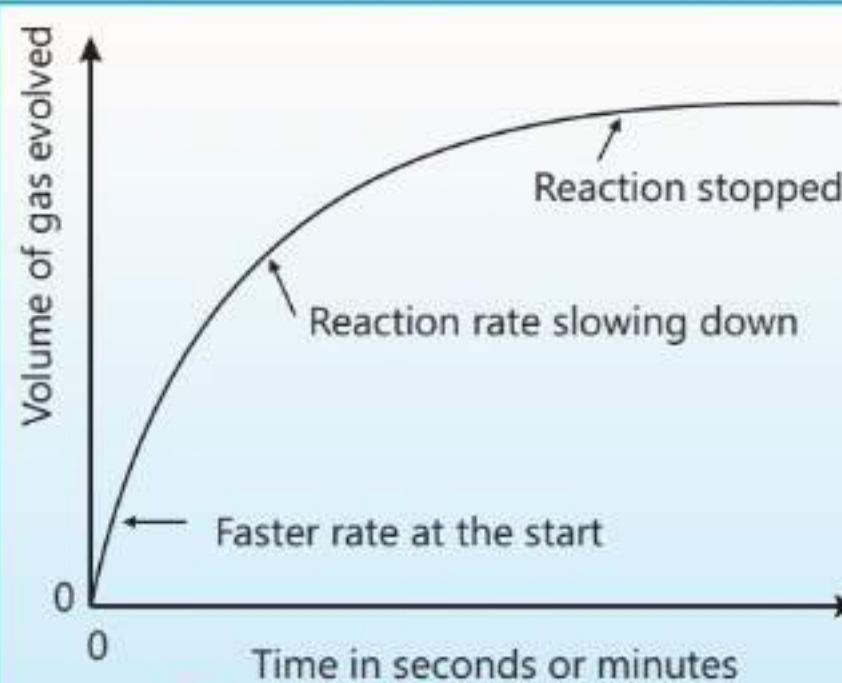


Understanding kinetics helps us to control the reaction conditions in order to speed up or slow down reactions as needed.

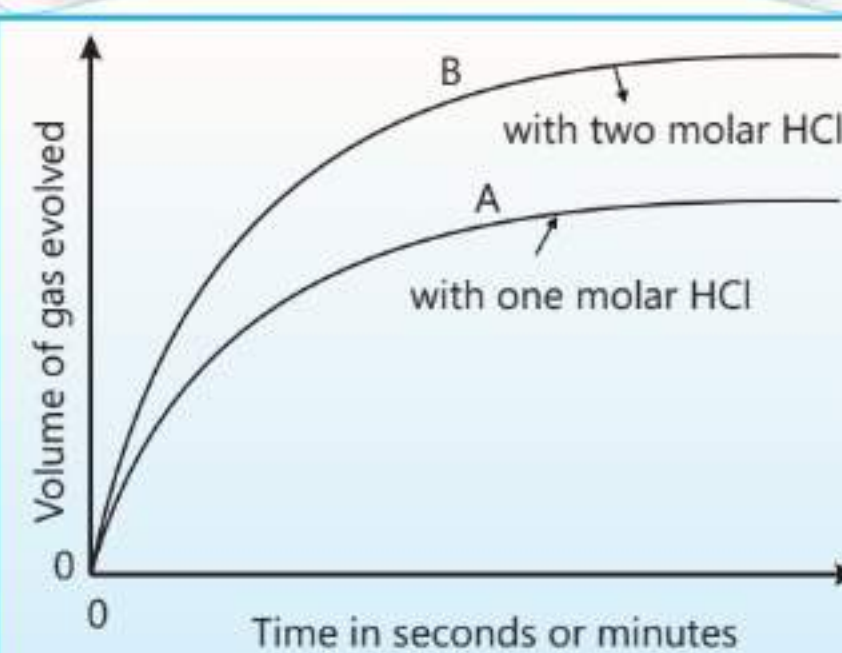
The change in the rate of reaction is then seen when a graph is drawn between the time in seconds or minutes against the volume of gas evolved as shown in Figure 17.4.

The graph obtained is in the form of a curve. We can measure the rate of reaction during a time interval by drawing a tangent on this curve. The results show that the reaction starts with a very fast rate which then progressively slows down as the concentration of hydrochloric acid decreases. After a while the reaction stops because the whole of hydrochloric acid has been utilized.

The two curves A and B shown in Figure 17.5 represent two separate experiments done with one and two molar



**Figure 17.4:** Reaction rate



**Figure 17.5:** Reaction rates at two different concentrations



concentrations of HCl respectively.

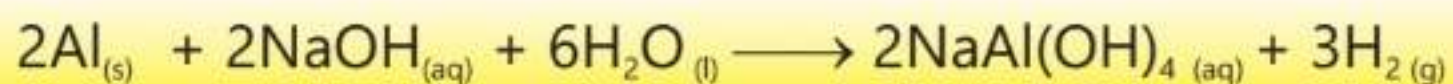
The greater the concentration, the steeper is the curve at the start of the experiment which means faster rate of reaction. The more concentrated is the acid, the more are the chances of effective collisions.

## 2. Reactants present in gas phase

If reactants in a reaction are present in gas phase, their concentrations can be changed by changing their pressure. For example, the rate of reaction between hydrogen and chlorine can be doubled if the pressure of chlorine gas is doubled provided the other component hydrogen is present in excess.

## 3. Effect of Surface Area of Solids

Reactions involving solids take place on their surfaces and the rates of their reactions depend to a great extent on the area of the surface contact between them. The larger the surface area of the solids, the more is possibility of their particles to come in contact with each other and the higher is the rate of reaction. Finely divided solids, because of the greater surface area available, react more rapidly than do large pieces of the same substances. For example, aluminum foil reacts slowly with warm sodium hydroxide but in finely divided state it reacts rapidly with even cold aqueous solution of sodium hydroxide evolving hydrogen gas.



Similarly, a large piece of wood will burn slowly while small pieces burn rapidly.

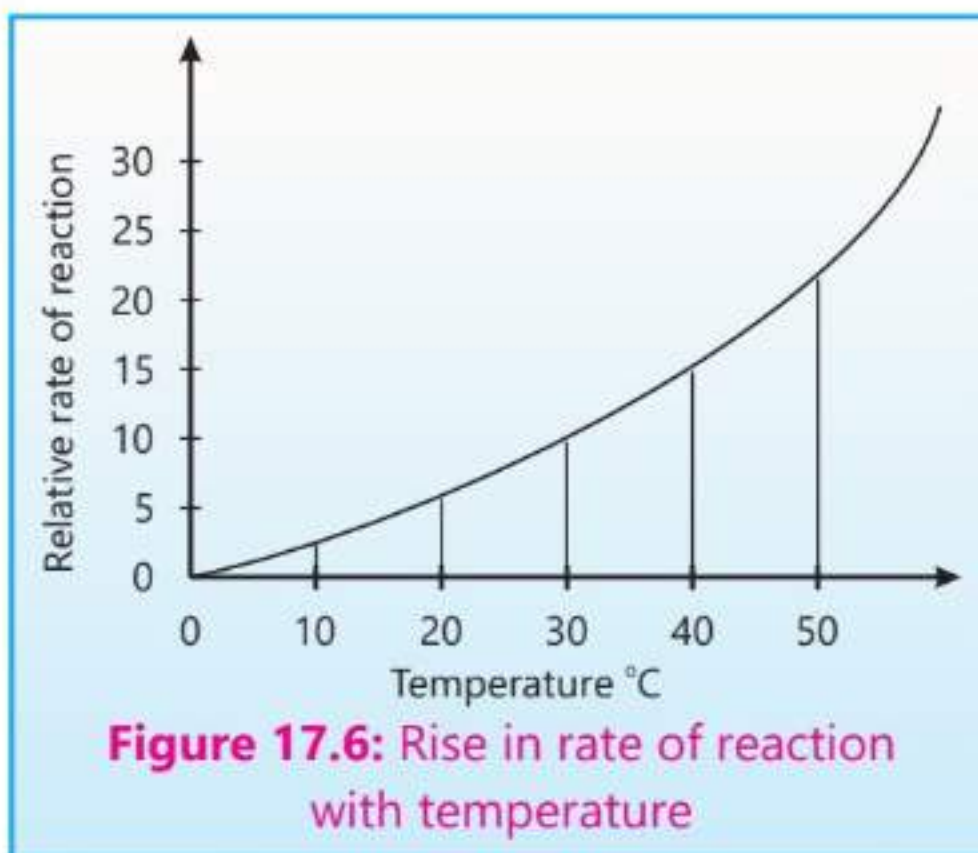
## 4. Effect of Temperature

It is an everyday observation that the rates of chemical reactions increase with increase in temperature. Food cooks faster at higher temperatures than at lower ones. Similarly, the oxidation of iron is very slow at room temperature but proceeds very fast at high temperature. In many cases the rate of reaction is nearly doubled when the temperature is increased by 10 °C. The graph shown in the Figure 17.6 explains this rapid increase in the rate of reaction with the rise in temperature.





According to the collision theory, the rate of reaction depends upon the frequency of successful collisions between reactant molecules. As the temperature of a reaction is increased, the kinetic energy of the participating reacting particles also increases. This, in turn increases the velocities of their movements. As a result the collisions which lead to the occurrence of reactions also increase, enhancing the rate of reaction.



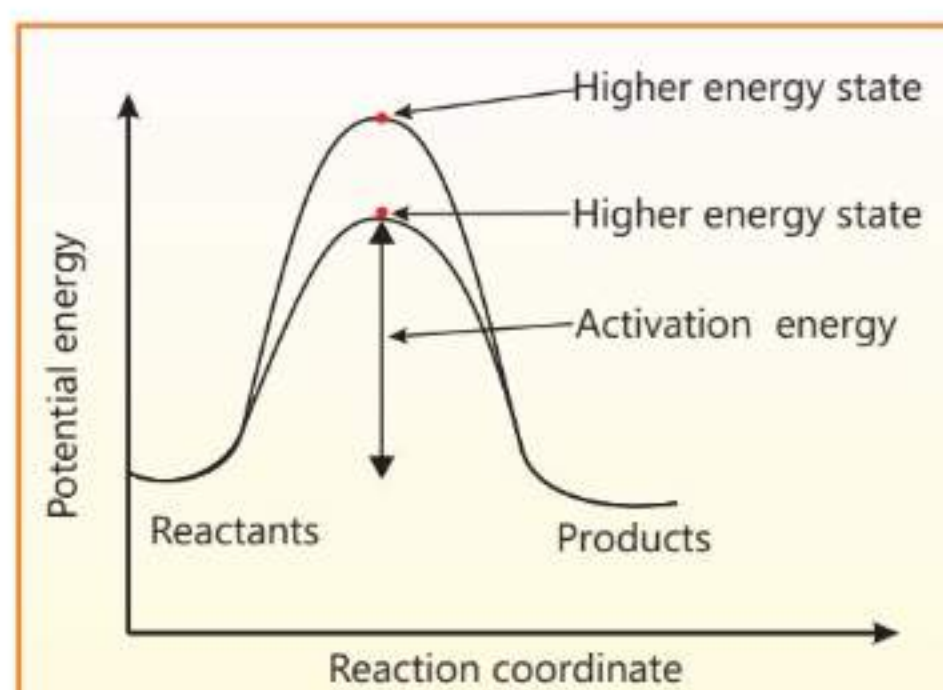
### Interesting Information

Kinetics helps us to increase the yield of a reaction and minimize the waste.

## 5. Effect of Catalyst

A catalyst is a substance which alters the rate of the reaction but it is not consumed during the course of reaction. Its role is to alter the way the reaction takes place by substantially lowering its activation energy. When the activation energy is lowered, more and more particles of the reactants will start forming the high energy state and the rate of reaction will increase. For example, platinum metal serves as a catalyst during the addition of hydrogen in ethene. Both hydrogen and ethene are known to adsorb on the surface of platinum metal and the bonds, present in them, get weakened. Thus, the surface of metal helps the reactant molecule to react together. This is shown in the Figure 17.7.

In the presence of a catalyst, the activation energy is sufficiently lowered allowing more and more molecules to react together.



## 6. Enzymes as Catalysts

Enzymes are biological catalysts. These are basically proteins which help to speed up specific chemical reactions taking place in our body. They react with the reactant molecules using the active sites present in them. Once bound with the reactant molecule the particular bonds in the reactant molecule are sufficiently weakened for the reaction to take place. The product formed then dissociates itself from enzyme which is then free to bind another reactant molecule. The active sites present in enzymes are very specific such that a particular enzyme can catalyze a specific reaction only.



### 17.2 Quick Check!

1. Why a catalyst is mostly used in finely divided form?
2. How do you increase the number of successful collisions?
3. How does the concentrations of the products change during reaction? Explain with the help of a graph.

## 17.5 Importance of Chemical Kinetics in Food Industry

The study of reaction rates and the factors which affect these rates play an important role in food industry.

The rates of chemical reactions which are involved during food ripening and food spoilage are studied for different types of fruits and vegetables. The information thus obtained is used to minimize the losses due to spoilage. Food scientists can determine the optimum conditions for harvesting, storage and transportation of food products by studying the rates of enzymatic reactions, oxidation or microbial growth.

### Interesting Information

Enzyme based biosensors are used to detect glucose in blood.

Fruits and vegetables ripen owing to the reactions which involve enzymes. These reactions convert starches into sugars, soften tissues and develop characteristics flavour and colours. With the help of rates of these enzymatic reactions, farmers can predict when the product will reach at its peak quality and ready for harvesting. For example, the rate of production of ethene during ripening can be monitored to determine the best time to harvest the fruits.





Some enzymes which are naturally present in foods can spoil the foods which then undergo changes in texture, flavour and nutritional value. Again understanding the rates of these enzymatic reactions will allow us to plan how to stop this spoilage.

For example, if a fruit is known to degrade rapidly during transportation or storage owing to high temperature, refrigeration can be employed to prevent rapid spoilage.

#### Interesting Information

Understanding the kinetics of oxidation reactions of fats helps to prevent spoilage of butter.



#### 17.3 Quick Check!

1. How would you determine the best time of fruit harvesting?
2. Why some fruits and vegetables get destroyed early during summer than during winter.


## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

1. The number of collisions per unit volume of the reaction mixture is called:  
(a) Collision energy (b) Activation energy  
(c) Collision frequency (d) Collision force
2. If the reactants possess an energy higher than the activation energy, then the reaction will be:  
(a) Slow (b) Fast  
(c) Not affected (d) Instantaneous
3. Which of the following explains the increase in rate of reaction in the presence of a catalyst?  
(a) Catalyst provides extra energy to the reactant molecules  
(b) Catalyst provides an alternative pathway which lowers the activation energy.  
(c) Catalyst increases the collision frequency  
(d) Catalyst decreases the collision frequency



- 
4. Which of the following statements is correct?
- (a) Collisions with energy equal to or greater than the activation energy lead to reaction.
  - (b) Collision frequency is not related to the reaction rate
  - (c) All collisions lead to a reaction.
  - (d) Collisions with energy less than the activation energy lead to the reaction.
5. When a reaction proceeds ahead, how the concentrations of reactants and products change?
- (a) Concentration of reactants increases and that of the products decreases.
  - (b) Concentration of reactants decreases and that of the products increases.
  - (c) Concentration of both reactants and products decreases.
  - (d) Concentration of both reactants and products increases.

## **B** Short Answer Questions

- 17.1 What is a successful collision?
- 17.2 How does increase in the temperature increase the rate of a reaction?
- 17.3 Define activation energy.
- 17.4 Why does the burning of sulphur proceed slower in air than in pure oxygen?
- 17.5 Why a catalyst used in a reaction is preferably taken in the powdered form?
- 17.6 Why is the rate of a reaction often very fast at the beginning of the reaction?
- 17.7 Magnesium does not react with air at room temperature but it reacts very fast at high temperature giving intense white light. Explain.
- 17.8 What happens to the reactants after they climb the energy hill during a reaction?



17.9 How does a catalyst lower the activation energy of a reaction?

17.10 Give any two features of the catalytic action of an enzyme.

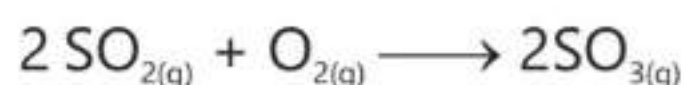
### C Constructed Response Questions

17.1 In what different ways you can increase the successful collisions between the particles of the reactants?

17.2 Give an example of a reaction which proceeds with the gain in mass.

17.3 From where do molecules get energy to attain higher energy state?

17.4 How does the presence of  $V_2O_5$  catalyst lower the activation energy of the following reaction?



17.6 Explain the catalytic action of an enzyme.

17.7 If you desire to stop a reaction going on at  $60^\circ\text{C}$ , what action you will take?

### D Descriptive Questions.

17.1 Explain the effect of surface area on the rate of a reaction.

17.2 Describe the main points of the collision theory of reaction rate.

17.3 Discuss the following factors affecting the rate of a reaction:

(a) Effect of concentrations of the reactants.

(b) Effect of temperature at which a reaction is carried out.

17.4 How does chemical kinetics play an important role in the food industry?

17.5 Write briefly about the role enzymes play in our body as biological catalysts.

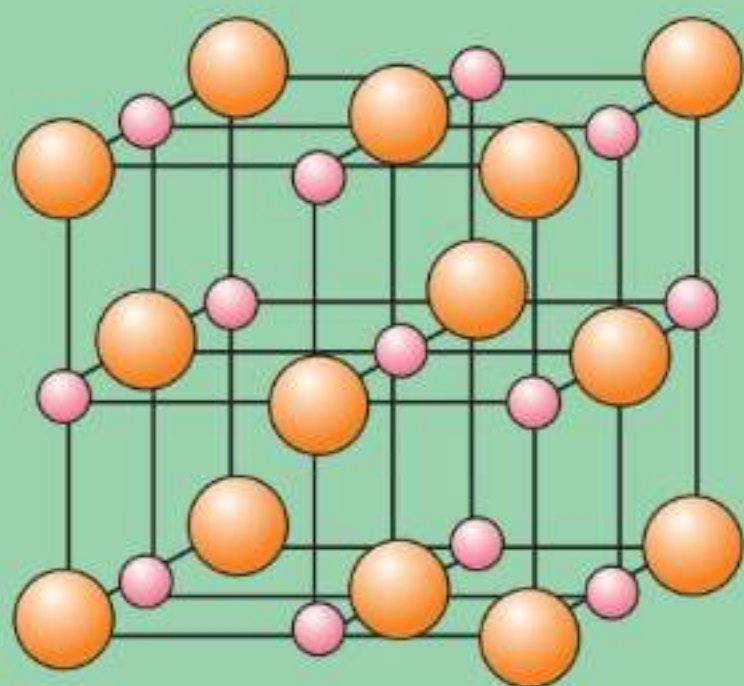


# Salts

## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Explain that salts are ionic compounds formed due to electrostatic attraction between oppositely charged ions (in which the positive ions come from bases and negative ions come from acids)
- Explain why at STP salts are solids with high melting points.
- Describe that under normal conditions, ionic compounds are usually solids with lattice structures.
- Explain why the molten and aqueous solutions of salts are good conductors of electricity by making reference to the idea of mobile ions
- Describe the general solubility rules for salts. (these are:
  - (a) sodium, nitrate, potassium and ammonium salts are soluble
  - (b) chlorides are soluble except lead and silver
  - (c) carbonates are insoluble except sodium, potassium and ammonium
  - (d) hydroxides are insoluble except sodium, potassium, ammonium and calcium (partially).
- Describe the preparation, separation and purification of soluble salts by reactions of acids with alkali (titration), excess metal, excess insoluble base, excess insoluble carbonate.



## 18.1 Arrangement of Ions in Salts

When acids neutralize bases or alkalis, salts and water are formed. For example, sodium hydroxide, an alkali, neutralizes hydrochloric acid to form sodium chloride and water. This reaction is called neutralization reaction.



A salt is a chemical combination of positive and negative ions. These oppositely charged ions are then bonded together by the electrostatic force of attraction. The strength of this attraction depends on the magnitude of the charges and the distance between the ions.

These oppositely charged ions then arrange themselves in a regular and repeating pattern to give a three dimensional network structure called a crystal lattice. The properties shown by the ionic compounds are due to the presence of this ordered structure. Under ordinary conditions of temperature and pressure ionic compounds exist as crystalline solids.

In NaCl, each sodium ion is surrounded by six chloride ions and each chloride ion, in turn, is surrounded by six sodium ions. Figure 18.1 shows how these ions are arranged in the crystal lattice having the shape of a face-centered cube. The bigger chloride ions are present at the corners and at the centre of each face of the cube while the smaller sodium ions occupy the edges of the cube.

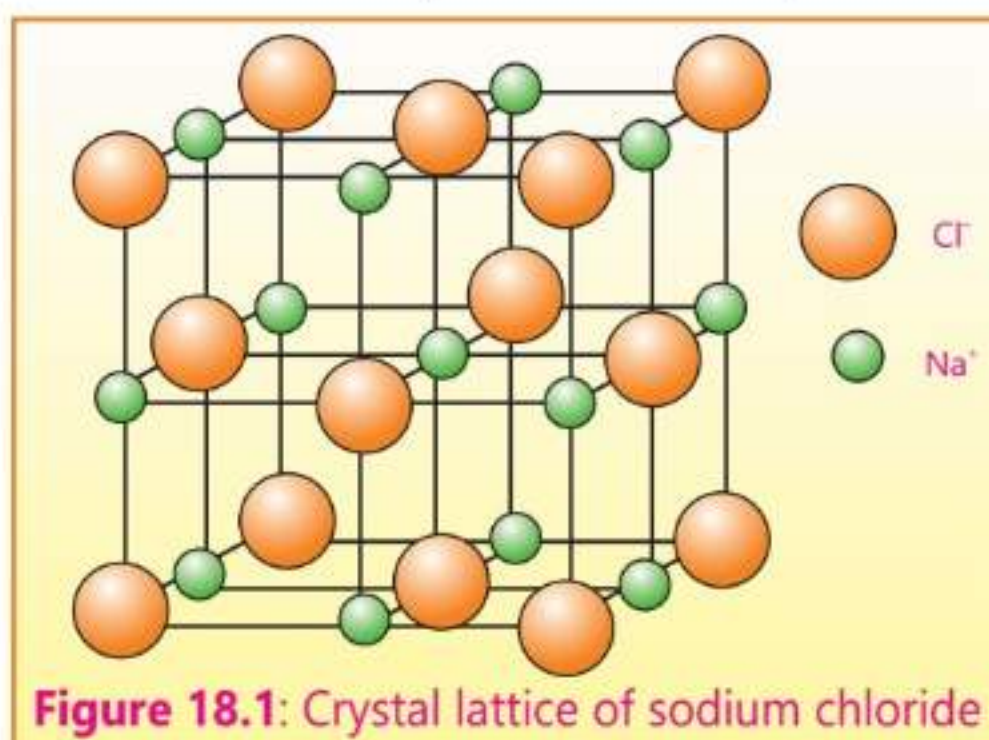


Figure 18.1: Crystal lattice of sodium chloride

### Interesting Information

Common salt was a valuable commodity in the past. It was even used as currency.

## 18.2 Melting Points of Ionic Compounds

Since very strong electrostatic forces of attraction are present between the ions within a crystal lattice, a significant amount of energy is needed to break these forces. This is the reason why the melting points of ionic compounds are generally very high. During the process of melting these attractive forces break down and let the ions move freely. The melting points of ionic compounds



depend upon the charges present on the ions and their sizes. Higher charges and smaller ion sizes lead to stronger attractions and hence the higher melting points.

## 18.3 Conduction of Electricity by Ionic Compounds

Ionic compounds do not conduct electricity in solid state, however, they start conducting electricity in molten state or when they are dissolved in water. In the solid state ions are held together by strong forces of attractions, they are not free to move and, therefore, cannot conduct electricity. When ionic compounds are heated to their melting points, their ions become free to move around and hence start conducting electricity. Similarly, when ionic compounds are dissolved in water, the forces of attraction between ions break down and the ions are again free to move independently.

Ionic compounds serve as strong electrolytes because they dissociate completely into ions when dissolved in water.



### 18.1 Quick Check!

1. How the ions present in NaCl arrange themselves to form a crystal lattice?
2. Do you expect melting point of KCl to be higher or lower than NaCl?

## 18.4 Soluble and Insoluble Salts

Several factors effect the solubility of a salt including the nature of salt and the temperature. Soluble salts include all sodium, potassium, and ammonium salts. Similarly all metallic nitrates are soluble in water and the same is true for most chlorides and sulfates. In contrast all carbonates with the exception of carbonates of sodium, potassium and ammonium are insoluble in water. Similarly, chlorides of silver and lead and sulfates of barium and lead are also insoluble in water.

Hydroxides of sodium, potassium and ammonium are soluble while calcium hydroxide is only partially soluble in water. All other hydroxides are insoluble in water.

The following table shows the pattern for the solubility of salts in water.





**Table 18.1 Solubility of salts in water**

Salts	Soluble	Insoluble
Salts of sodium, potassium and ammonium and all nitrates	All	None
Chlorides, bromides and iodides	Most soluble	Silver, Lead (II)
Sulphates	Most soluble	Barium, Lead (II), Calcium
Carbonates	Sodium, Potassium, Ammonium	Most insoluble
Hydroxides	Sodium, Potassium, Ammonium, Calcium (partially soluble)	Most insoluble

## 18.5 Preparation of Soluble Salts

Salts which are soluble in water can be prepared by adopting the following two methods.

### (a) Reaction of water soluble acid with water soluble base

This method is also called a titration method. It involves the reaction of a water soluble acid and a water soluble base. The acid and base are selected depending on the nature of salt which is to be prepared.

For the preparation of soluble potassium nitrate, appropriate volumes of potassium hydroxide and nitric acid are made to react together in a conical flask.



**Figure 18.2:** Evaporating dish

The solution present in the conical flask now contains the soluble salt and water. Transfer the solution to an evaporating dish. If the salt being prepared is stable towards heat, then evaporate the solution to dryness to get the salt. Alternatively, heat the solution gently until a thin film of crystals is

formed on the surface of the solution. Cool this solution slowly which is now saturated with salt. Filter this mixture to get the pure crystals of the salt. Dry the crystals between the folds of the filter papers.

#### Interesting Information

Copper sulphate is used as a fungicide. Other salts are used in water softening and glass manufacture.

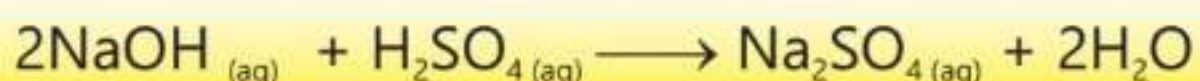


**Activity 18.1**

Prepare pure crystals of sodium sulphate.

**Method**

Add 50 cm<sup>3</sup> of 1 mol/dm<sup>3</sup> solution of sodium hydroxide in a neat conical flask with the help of a pipette. Add a few drops of phenolphthalein indicator to get a pink colour solution. Run 1 mol/dm<sup>3</sup> solution of sulphuric acid from the burette into the conical flask until the colour of solution changes from light pink to colourless. Note down the volume of sulfuric acid used to neutralize sodium hydroxide.



Repeat the experiment taking the same volumes of sodium hydroxide and sulphuric acid but without using the indicator. Transfer this neutralized solution to an evaporating dish and heat it gently until one-third of the solution is left. Dip a glass rod into this hot solution and take it out. If the immersed end of the glass rod turns cloudy, the solution is concentrated enough for crystals to form. Cool down the solution for the crystallization to occur completely. Filter and wash the crystals with a little cold distilled water to remove any soluble impurities and the acid attached. Dry the crystals within the fold of filter papers or in an oven.

**(b) Reaction of an acid with an insoluble base**

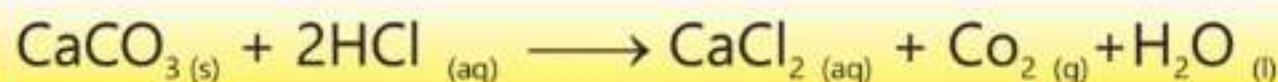
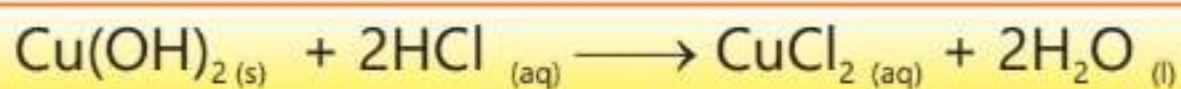
This is also a neutralization reaction between the soluble acid and an insoluble base. The insoluble base may be an appropriate metal oxide, a metal carbonate or a metal hydroxide. The acid and the insoluble base are selected depending upon the salt to be prepared. A salt is also formed when an acid reacts with a metal.

This method involves the mixing of the selected acid with the selected base or a metal with constant stirring to ensure that the acid has fully reacted with the base or the metal. The insoluble base or the metal should always be added in excess to make sure that all the acid present has reacted. Filter the mixture to remove the excess amount of the base or the metal. Evaporate the filtrate to get a saturated solution. Allow the solution to cool down when pure





crystals of the salt will start appearing. Filter and dry the crystals carefully.



### Activity 18.2

Prepare pure crystals of zinc sulphate.

#### Method

Take about 25 cm<sup>3</sup> dilute sulphuric acid in a beaker and warm it gently. Go on adding small granules of zinc metal slowly with constant stirring till the metal starts settling down at the bottom of the beaker. Filter the solution to remove undissolved zinc metal and collect the filtrate. Evaporate the filtrate in an evaporating dish by gentle heating to concentrate the solution without overheating or boiling. Cool down the solution slowly and allow the crystals to appear. Once all the crystals have formed, carefully filter the mixture to get the crystals. Allow the crystals to dry on filter paper.



#### 18.2 Quick Check!

1. Which salts of barium and calcium are soluble in water?
2. How barium sulphate is prepared in the laboratory?

## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

1. Which base is not soluble in water?  
(a) KOH  
(b) Mg(OH)<sub>2</sub>  
(c) NaOH  
(d) Na<sub>2</sub>CO<sub>3</sub>
2. The shape of the crystal of NaCl is:  
(a) Cubic  
(b) Hexagonal  
(c) Rhombic  
(d) Trigonal





3. Which salts are always soluble in water?
- (a) Chlorides (b) Sulphates  
(c) Nitrates (d) Carbonates
4. Which salt will be formed when marble pieces react with dilute nitric acid?
- (a) Sodium nitrate (b) Calcium nitrate  
(c) Potassium nitrate (d) Magnesium nitrate
5. Water insoluble salt is:
- (a) Calcium sulphate (b) Sodium sulphate  
(c) Potassium sulphate (d) Magnesium sulphate

### **B** Short Answer Questions

- 18.1. Which factors are responsible for the strength of electrostatic forces between ions?
- 18.2. Is lead (II) chloride soluble in water? Give comments.
- 18.3. Which lead salts are insoluble in water?
- 18.4. Name two insoluble carbonates.
- 18.5. What is a crystal lattice?

### **C** Constructed Response Questions

- 18.1. Why are melting points of ionic salts generally very high?
- 18.2. Why ionic salts exist in solid state?
- 18.3. How will you prepare calcium sulphate in the laboratory?
- 18.4. Compare the melting points of NaCl and MgCl<sub>2</sub>.
- 18.5. How would you prepare pure crystals of copper sulfate in the laboratory?

### **D** Descriptive Questions

- 18.1. Explain the formation of sodium chloride crystal?
- 18.2. Explain the methods of preparation of two soluble salts.
- 18.3. How are the following salts prepared?



- 18.4. Describe which salts are soluble in water and which are insoluble.

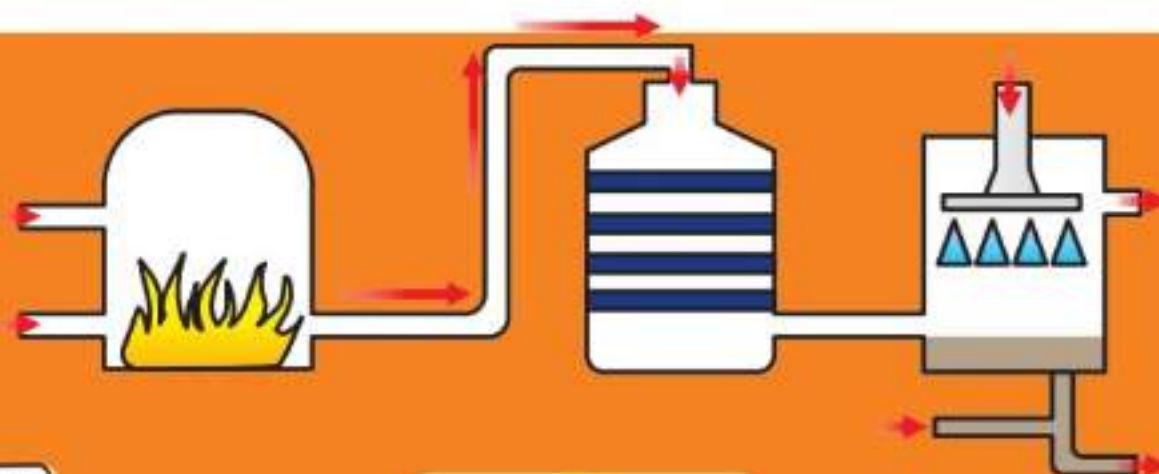


# Nitrogen and Sulphur

## Student Learning Outcomes

After studying this chapter, students will be able to:

- Recognize that atmospheric oxides of nitrogen (NO and NO<sub>2</sub>) can react with unburned hydrocarbons to form peroxyacetyl nitrate, PAN, which is a component of photochemical smog
- Describe the role of NO and NO<sub>2</sub> in the formation of acid rain both directly and in their catalytic role in the oxidation of atmospheric sulphur dioxide
- State the symbol equation for the production of ammonia in the Haber process,  $N_{2(g)} + 3H_{2(g)} \longrightarrow 2NH_{3(g)}$
- State the sources of the hydrogen (methane) and nitrogen (air) in the Haber process
- State the typical conditions in the Haber process as 450 °C, 20000kPa /20 atm and an iron catalyst
- State the symbol equation for the conversion of sulphur dioxide to sulphur trioxide in the Contact process,  $2SO_{2(g)} + O_{2(g)} \longrightarrow 2SO_{3(g)}$
- State the sources of the sulphur dioxide (burning sulphur or roasting sulphide ores) and oxygen (air) in the Contact process
- State the typical conditions for the conversion of sulphur dioxide to sulphur trioxide in the Contact process as 450 °C, 200kPa /atm and a vanadium(V) oxide catalyst
- Describe amphoteric oxides as oxides that react with acids and bases to produce a salt and water
- Classify oxides as acidic, including SO<sub>2</sub> and CO<sub>2</sub>, basic, including CuO and CaO, or amphoteric, limited to Al<sub>2</sub>O<sub>3</sub> and ZnO, related to metallic and non-metallic character.
- properties of metal
- Identify the general chemical properties of metals, limited to their reactions with dilute acids, cold water, steam and oxygen.
- Arrange metals in order of reactivity given relevant information.



## 19.1 Ammonia

Ammonia gas is one of the most important chemicals produced globally for industrial use. Urea and other ammonium salts are extensively used as fertilizers. About 80% of the ammonia produced in the industries world-wide are used to produce these fertilizers. Apart from this, ammonia is also used in the production of plastics and pharmaceuticals. It is also used as a refrigerant.

Ammonia is produced industrially by Haber process discovered by a German Chemist F.J. Haber. In this process, a mixture of nitrogen and hydrogen, in the ratio of 1:3 by volume is heated at 400-500 °C under 200 atmospheric pressure and in the presence of catalyst Fe/Al<sub>2</sub>O<sub>3</sub> to give ammonia.



The equilibrium mixture obtained in the above reaction contains 35% ammonia by volume. This mixture is cooled by refrigeration coils where ammonia gas changes to liquid ammonia at -33.4 °C and is removed from the mixture. The other components of the mixture, hydrogen and nitrogen gases, are then recycled back into the reaction chamber (Figure 19.1).

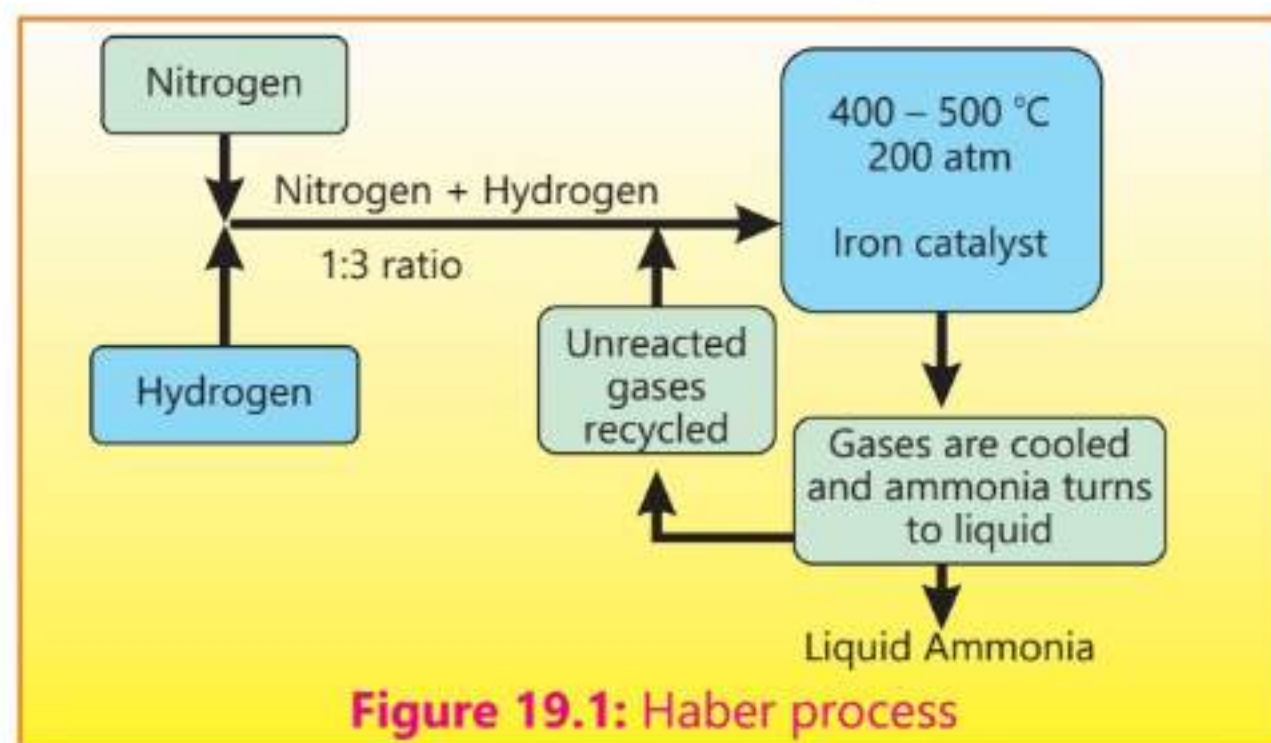


Figure 19.1: Haber process

### Source of Nitrogen

One of the raw materials used for the production of ammonia is nitrogen gas and it is obtained by the fractional distillation of air. For this purpose, first of all carbon dioxide present in air is removed and the air is subjected to about 200 atmospheric pressure. This compressed air is then cooled and allowed to pass through a spiral jet. While escaping through this jet, the air suffers sudden expansion and its temperature is decreased. This process of compression and



expansion is repeated again and again till the air is liquified.

The liquid air is then fractionally distilled. Since the boiling point of nitrogen is less than oxygen, nitrogen evaporates first at  $-196^{\circ}\text{C}$  leaving behind the oxygen. The separated nitrogen is reliquified and stored in specially designed cylinders.

## Source of Hydrogen

The second raw material, hydrogen, is produced by heating methane in the limited amount of oxygen that is not enough to completely oxidize methane to carbon dioxide and water. With less oxygen available, the reaction products contain primarily hydrogen and carbon monoxide and a relatively small amount of carbon dioxide. The carbon monoxide obtained is then reacted with water to form carbon dioxide and more hydrogen gas.



### Interesting Information

13% of total Nitrogen fixation in the environment is contributed by the Haber process.

### 19.1 Quick Check!

1. Why is ammonia gas turned into a liquid after its production?
2. Why high pressure is maintained in the production of ammonia?

## 19.2 Sulphuric Acid

Sulphuric acid is one of the most important chemical compounds known. It is very commonly used in the laboratory and almost every manufacturing process makes use of this acid directly or indirectly at some stage.

Sulphuric acid is prepared industrially by the contact process. The process involves the following steps.

### (1) Preparation of Sulphur dioxide gas

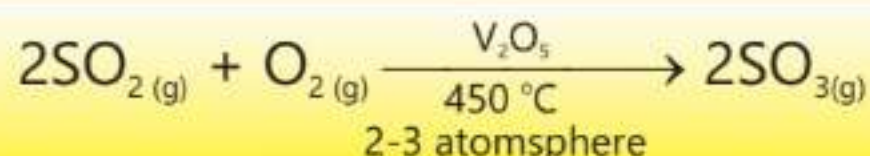
Sulphur dioxide gas is produced either by burning elemental sulphur in air or roasting a sulphur ore, iron pyrite, in excess of air.



Sulphur dioxide produced above is then passed through purifying chambers and sprayed with steam. This process removes dust impurities as well as arsenic compounds present in the gas. This step is important because arsenic compounds poison the catalyst used later on. The moist gases ( $\text{SO}_2$  and  $\text{O}_2$ ) are then dried by passing through a drying tower in which concentrated sulphuric acid is being sprayed. Oxygen used in this reaction is obtained by the fractional distillation of air.

## (2) Oxidation of Sulphur dioxide

The clean and dry gases ( $\text{SO}_2$  and  $\text{O}_2$ ) are then passed over vanadium (V) oxide catalyst at  $450^\circ\text{C}$  and 2-3 atmospheric pressure through a contact chamber. Although the reaction is reversible yet under these conditions 98%  $\text{SO}_2$  gas is converted to  $\text{SO}_3$  (Figure 19.2).



### Interesting Information

Sulphuric acid is called the "king of chemicals" because it is used in almost every industry.

3. Sulphur trioxide gas formed in the contact chamber is then absorbed into 98% sulphuric acid to give oleum.

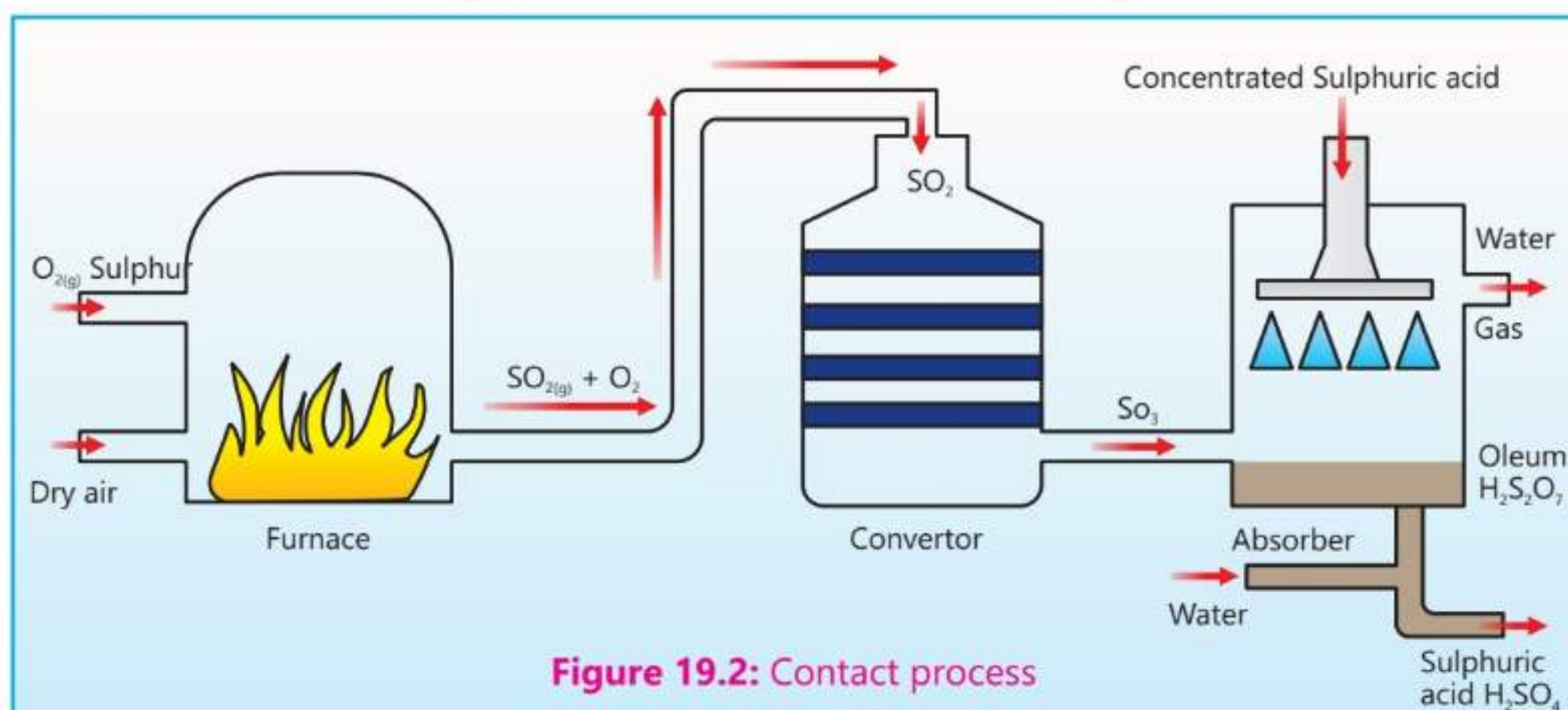


Figure 19.2: Contact process

4. The oleum is then mixed with an appropriate amount of water to produce sulphuric acid with desired concentration.



### 19.2 Quick Check!

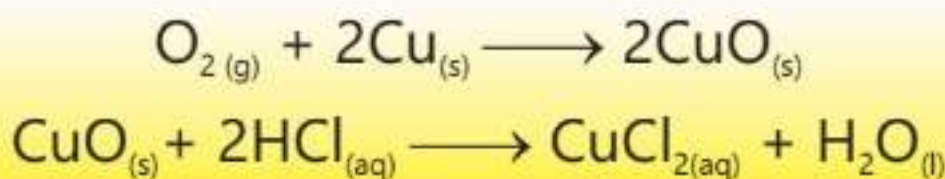
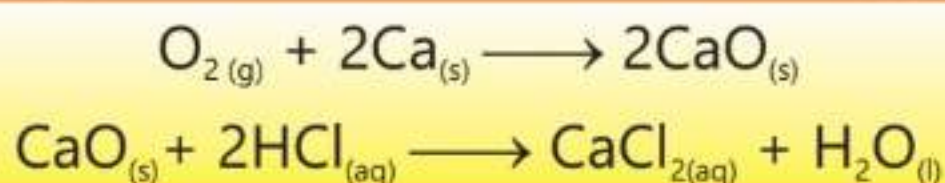
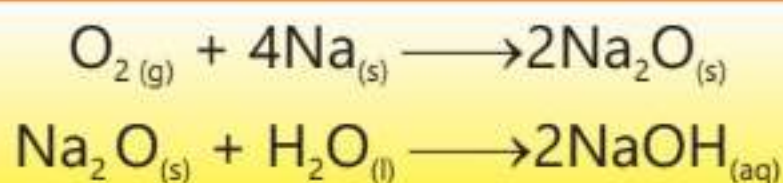
1. How  $\text{SO}_2$  is prepared from  $\text{FeS}_2$ ?
2. Why  $\text{SO}_2$  and oxygen are purified before they react to produce  $\text{SO}_3$ .

## 19.3 Oxides

Binary compounds of elements with oxygen are called oxides. Oxygen shows an oxidation state of -2 in these oxides. Metal oxides are commonly basic and amphoteric while non-metallic oxides are acidic in nature. Both basic and acidic oxides are formed when metals and non-metals are heated respectively in the presence of air or oxygen. Metal oxides are typically ionic compounds in which electrons are transferred from metals to oxygen. Non-metal oxides are covalent compounds where electrons are shared between non-metals and oxygen atom.

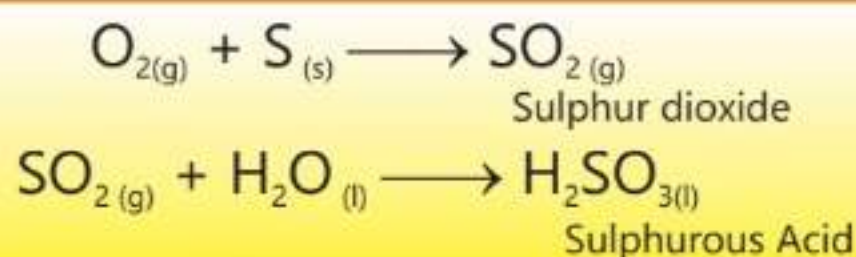
### (i) Basic Oxides

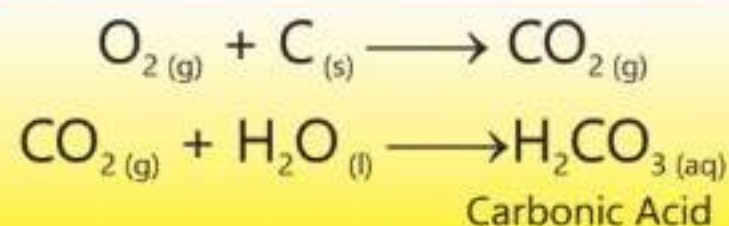
Oxygen reacts with metals to give oxides which when dissolved in water produce hydroxides. They change red litmus blue. When treated with acids they give salts.



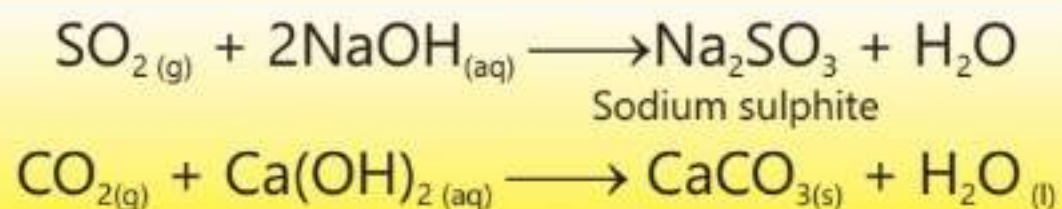
### (ii) Acidic Oxides

Oxygen combines with non metals (S, C, N) to give acidic oxides. These oxides react with water to give acids which turn blue litmus red.





Acidic oxides react with bases to give salts.

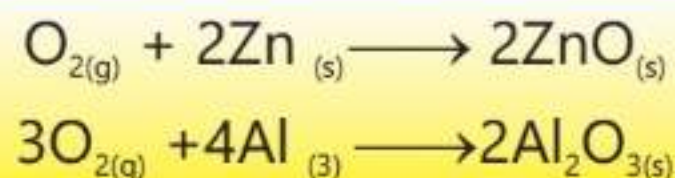


### (iii) Neutral Oxides

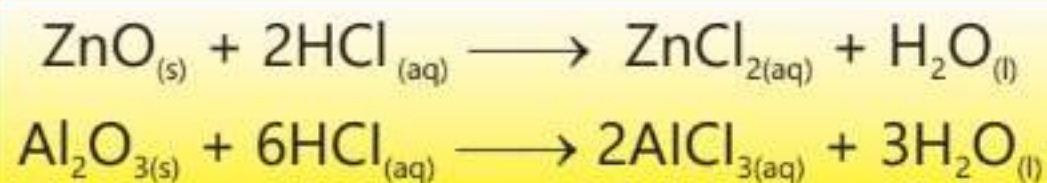
Neutral oxides are those oxides which on contact with water produce neither an acid nor a base. Their aqueous solutions have no action on blue or red litmus paper. Examples are carbon monoxide (CO), nitric oxide (NO) and nitrous oxide (N<sub>2</sub>O).

### (iv) Amphoteric Oxide

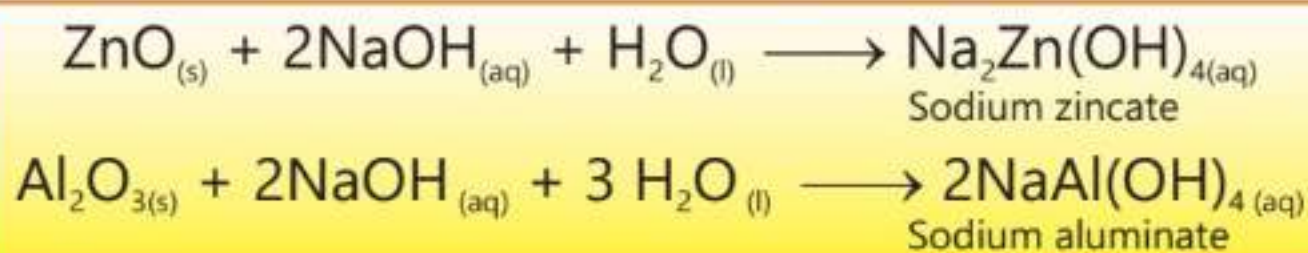
Amphoteric oxides are usually formed when oxygen reacts with less electropositive metals.



These oxides behave both as an acid and a base. Zinc oxide and aluminium oxide behave as bases in the presence of an acid.



These oxides behave as acids in the presence of an alkali.



#### Interesting Information

Water is an amphoteric substance. It can act as both an acid and a base, depending on the other substance it reacts with.

These oxides are insoluble in water and have no action on litmus paper.





### 19.3 Quick Check!

1. Why lead oxide is called an amphoteric oxide?
2. Why non-metals form covalent oxides?

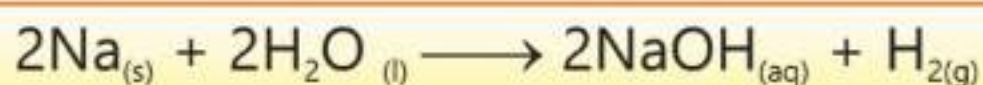
## 19.4 Metals

Nearly three fourth elements shown in the periodic table are called metals. Metals show remarkable properties. Mostly metals occur in earth crust in the form of their oxides, hydroxides, carbonates and sulphides, etc.

Metals have a tendency to lose electrons and form cations. Usually they form ionic bonds with other elements.

### Reactions of metals with cold water

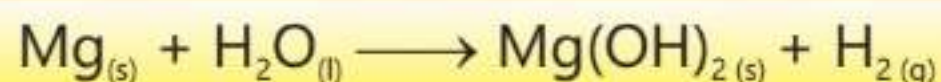
Most of the elements present in the first and second group of the periodic table react vigorously with cold water producing their respective hydroxides and hydrogen gas.



#### Interesting Information

If two pieces of uncoated metal touch in space, they become permanently stuck together. It does not happen on Earth because the atmosphere puts a thin layer of oxide between the surfaces which acts as a barrier preventing adhesion.

Magnesium, however, reacts with cold water slowly giving magnesium hydroxide and hydrogen gas.



### Reactions of metals with steam

The more reactive the metal, the more readily it reacts with steam. Reactive metals like lithium, sodium, potassium and calcium react violently with steam and the reaction can be dangerous.

Beryllium and aluminum react with steam at high temperatures (around 700 °C) to give their respective oxides and hydrogen.





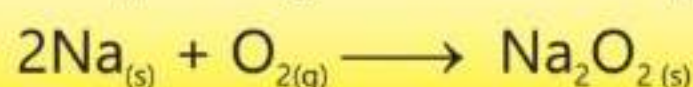
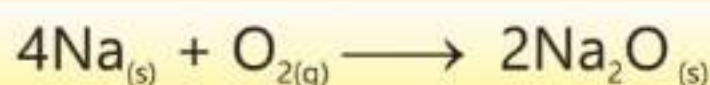
Magnesium, iron and Zn have a moderate reaction with steam producing their respective oxides and hydrogen gas.



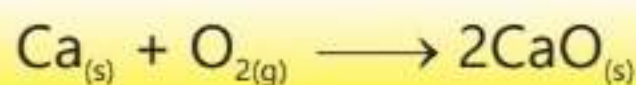
## Reactions of metals with Oxygen

Metals react with oxygen to give metal oxides. The ease of reaction and the type of oxide which is formed, depends upon the reactivity of metals and the conditions used.

Sodium burns in air with yellow flame producing both sodium oxide and sodium per oxide.



Magnesium, calcium, strontium and barium burn in oxygen with colour of the flame characteristic to each metal giving their respective oxides.



Metal	Colour of flame
Mg	Intense white flame
Ca	White flame with a tinge of red
Sr	Crimson flame
Ba	A pale green flame

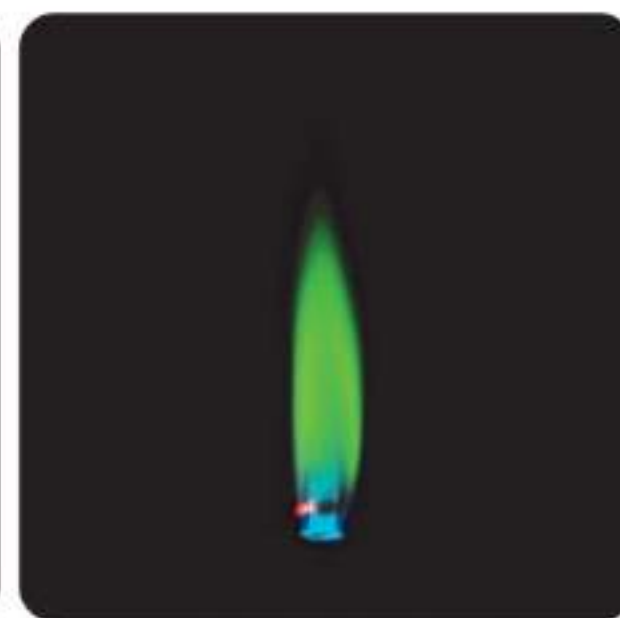
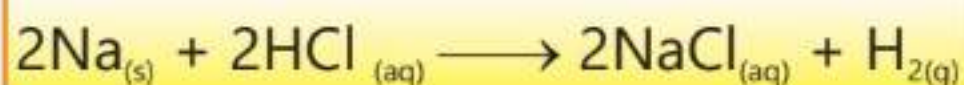


Figure 19.3: Strontium flame Figure 19.4: Barium flame

## Reactions of metals with dilute acids

The more reactive the metal the more vigorous is its reaction with dilute acids. Sodium and potassium are very dangerous and react violently with dilute acids giving their respective salts and hydrogen gas.



All group 2 elements react with dilute acids giving their salts, and



hydrogen gas. The reaction generally becomes more vigorous as we move down the group.



## 19.5 Reactivity Series of metals

Based on their reactions with water and acids, the metals can be arranged in decreasing order of their reactivities. Such an arrangement is shown in Table 19.1 and it is called the reactivity series of metals.

According to this reactivity series, calcium and metals above it react with cold water to give metal hydroxides and hydrogen gas. The metals below calcium do not react with cold water, instead they react with steam to give metal oxides and hydrogen gas.

Only metals above hydrogen will be able to liberate  $\text{H}_2$  upon reacting with dilute acids. Unreactive metals below hydrogen do not react with dilute acids. The more reactive the metal, the more vigorous its reaction will be with dilute acids. Similarly reactive metals, like potassium and sodium, react with oxygen easily whereas the less reactive metals like silver, copper and iron react with oxygen much more slowly.

The metals at the top of the series are powerful reducing agents since they are easily oxidized. However, the reducing ability of metals decreases going down the series.



## 19.6 Role of oxides of nitrogen in spreading air pollution

The primary pollutants in the atmosphere include oxides of nitrogen, sulphur and carbon and various hydrocarbons etc.

These primary pollutants are then converted into secondary pollutants

### 19.4 Quick Check!

1. Write the equation for the reaction between Ba and  $\text{H}_2\text{O}$ .
2. How do aluminum and zinc react with water.

**Table 19.1 Reactivity Series of Metals**

Most Reactive
K
Na
Li
Ba
Sr
Ca
Mg
Al
C
Mn
Zn
Fe
<b>H</b>
Cu
Ag
Au
Least Ractive

### 19.5 Quick Check!

1. Which will react faster with HCl, Zn or Fe?
2. Name one metal which will displace Zn from its salt.



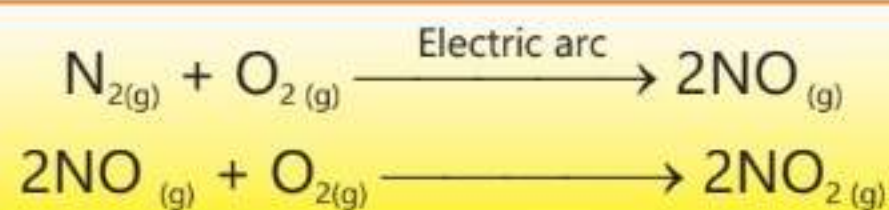
through various reactions going on in the atmosphere. The main secondary pollutants are ozone, per oxyacetyl nitrate (PAN), sulphuric acid etc. All these compounds are toxic and their concentration in the atmosphere must be controlled.

### Interesting Information

Air pollution is responsible for about seven to eight million deaths annually. It is a significant risk to child health.

Oxides of nitrogen which are harmful when present in the atmosphere include NO and NO<sub>2</sub>, collectively represented by NO<sub>x</sub>. They are generated in the atmosphere through both natural and man-made sources.

Natural sources for the production of NO<sub>x</sub> include electrical discharges



during lightning which can cause atmospheric nitrogen and oxygen to react forming nitric oxide. This nitric oxide is rapidly converted into nitrogen dioxide by oxygen present in air.

Combustion of fossil fuels in vehicles, various industrial processes and electricity power plants are the main man-made sources which generate NO<sub>x</sub> in the atmosphere. Apart from these, agricultural activities and fertilizers also contribute to NO<sub>x</sub> emission.

Heavy traffic during morning and evening hours together with industrial processes emit a huge amount of oxides of nitrogen (NO<sub>x</sub>) and most volatile organic compounds (VOCs) in the atmosphere.

Ultraviolet radiation present in sunlight interacts with the oxides of nitrogen and VOCs through a complex series of chemical reactions to produce secondary pollutants like ozone, aldehydes and peroxyacetyl nitrate (PAN).

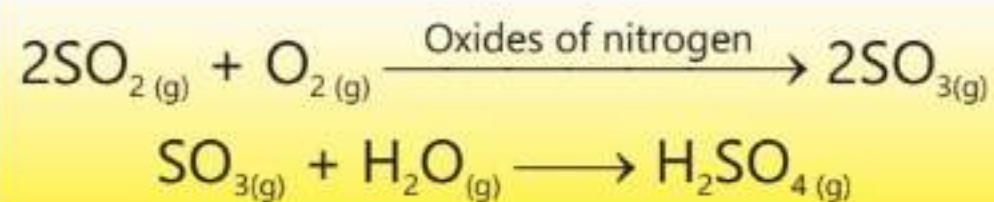
Oxides of nitrogen are also responsible for the formation of another type of pollutant called acid rain. Especially NO<sub>2</sub> reacts with water and other chemicals presents in air, to produce vapours of nitric acid and nitrous acid.





These acidic vapours then mix with water vapours present in air and fall to earth as acid rain.

Oxides of nitrogen ( $\text{NO}_x$ ) can also act as catalyst to convert, another primary pollutant, sulphur dioxide present in air, to sulphuric acid which is another major component of acid rain.



### 19.6 Quick Check!

1. What are the harmful effects of oxides of nitrogen on human health?
2. How do oxides of nitrogen pollute environment?

Acid rain has a pH less than 5.6. Acid rain is damaging for the ecosystem, it can corrode materials and can lead to respiratory problems.

## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

1. The reason for maintaining higher temperature for the production of ammonia is:
  - (a) activation energy of the reaction is very high.
  - (b) activation energy of the reaction is very low.
  - (c) nitrogen and hydrogen are both gases.
  - (d) at low temperature nitrogen and hydrogen change into liquids.
2. The contact process used for the industrial production of  $\text{H}_2\text{SO}_4$  is sensitive to the impurities present in  $\text{SO}_2$  and  $\text{O}_2$  because the impurities:
  - (a) affect the capability of the catalyst
  - (b) affect the purity of  $\text{H}_2\text{SO}_4$
  - (c) do not let  $\text{SO}_2$  to react with oxygen
  - (d) decrease the rate of reaction appreciably
3. Which of the following oxides is neutral in character?

(a) $\text{Al}_2\text{O}_3$	(b) $\text{SO}_2$
(c) $\text{CO}_2$	(d) $\text{NO}$





4. Sodium is considered more reactive than magnesium because:
- It is more electropositive than magnesium
  - It reacts with water slowly.
  - It is present in second group
  - It is the less metallic
5. Secondary pollutants present in the atmosphere are:
- Oxides of nitrogen
  - Oxides of Sulphur
  - Ozone and PAN
  - Oxides of Carbon
6.  $\text{SO}_3$  is absorbed in  $\text{H}_2\text{SO}_4$  rather than  $\text{H}_2\text{O}$  during the production of sulphuric acid because:
- $\text{SO}_3$  does not react with  $\text{H}_2\text{O}$
  - reaction of  $\text{SO}_3$  with  $\text{H}_2\text{O}$  is highly exothermic producing mist of  $\text{H}_2\text{SO}_4$  which is difficult to condense.
  - It gives better yield of  $\text{H}_2\text{SO}_4$
  - reaction of  $\text{SO}_3$  with  $\text{H}_2\text{O}$  can cause explosion.
7. Oxides formed when oxygen reacts with metals:
- Acidic
  - Basic
  - Both basic and amphoteric
  - Neutral
8. Major components of acid rain are:
- $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$
  - $\text{H}_2\text{SO}_3$  and  $\text{HNO}_2$
  - $\text{H}_2\text{SO}_4$  and  $\text{HCl}$
  - Acetic acid and  $\text{HNO}_3$

## B Short Answer Questions

- 19.1 How is nitrogen obtained from air?
- 19.2 How is hydrogen produced from methane?
- 19.3 Which conditions are used to oxidize  $\text{SO}_2$  to  $\text{SO}_3$ ?
- 19.4 Why  $\text{CO}_2$  is called an acidic oxide while  $\text{CO}$  is called a neutral oxide?
- 19.5 How do magnesium and calcium differ with each other towards their reactions with water?





- 19.6 How are the reactivities of metals determined?
- 19.7 Which secondary pollutants are produced by oxides of nitrogen?

### **C** Constructed Response Questions

- 19.1 Why ammonia is regarded as an important chemical?
- 19.2 How  $\text{SO}_2$  present in the atmosphere is converted to  $\text{SO}_3$ ?
- 19.3 The burning of fossil fuels in a car engine is responsible for the production of oxides of nitrogen. Explain.
- 19.4 The metals present at the top of the reactivity series are regarded as more reactive than those present at the bottom. Comment on this statement.
- 19.5 How fossil fuels produce  $\text{SO}_2$ ?

### **D** Descriptive Questions

- 19.1 Explain the production of ammonia on industrial scale.
- 19.2 Describe the contact process for the production of sulphuric acid.
- 19.3 Explain the formation and properties of acidic and basic oxides.
- 19.4 Differentiate between first and second group metals based on their reactivities with oxygen and water.
- 19.5 Describe the role of oxides of nitrogen in the formation of PAN and the acid rain.



## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Investigate chemical tests for the presence of water using anhydrous copper (II) sulphate.
- Explain how to test the purity of water using melting point and boiling point.
- Distinguish between Distilled water and tap water with their applications in practical chemistry.
- State that water from natural sources may contain useful and harmful substances. (Some examples include:
  - a. Dissolved oxygen
  - b. metal compounds
  - c. plastics
  - d. sewage
  - e. harmful microbes
  - f. nitrates from fertilizers
  - g. phosphates from fertilizers and detergents
- Recognize that some naturally occurring substances in water are potentially harmful (some examples include:
  - a. some metal compounds that are toxic
  - b. some plastics that harm aquatic life
  - c. sewage that contains harmful microbes which cause disease
  - d. nitrates and phosphates that lead to deoxygenation of water and damage to aquatic life (details of the eutrophication process are not required)
- Explain the treatment of the domestic water supply; (some examples of this includes:
  - a. sedimentation and filtration to remove solids.
  - b. Use of carbon to remove tastes and odours
  - c. Chlorination to kill microbes
- Describe various water-borne diseases and the steps that can be taken to avoid them
- Identify the negative effects of water pollutants on life and the ways to avoid them.
- Explain water scarcity as an important issue faced by Pakistan and the ways in which it can be resolved.
- State that urea, ammonium salts and nitrates are used as fertilizers.
- Explain the use of NPK fertilizers to provide the elements nitrogen, phosphorus and potassium for improved plant growth.

## 20.1 Water

Water is essential for all forms of life on earth. All living organisms contain plenty of water in them. They also need water every day to support life.

Identifying the presence of water has many important applications which include determining the purity of substances and analyzing chemical reactions.

### Test for Water

Testing water is important for food and pharmaceutical industries where the presence of water can affect the product quality and safety.

Hydrated copper(II) sulphate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ) is blue in colour but when it is heated, it loses water molecules to become anhydrous copper(II) sulphate which is white in colour. A drop of water on anhydrous sample of copper(II) sulphate changes its colour from white to blue Figure 20.1.



Figure 20.1: Water test

It is a very sensitive test and can detect even a small amount of water.

## 20.2 Purity of Water

Pure water boils at  $100^\circ\text{C}$  and freezes at  $0^\circ\text{C}$  under standard conditions of temperature and pressure. The impurities present in water will change both these physical constants.

1. The purity of a sample of water can be checked by determining its boiling point at STP. If it boils at  $100^\circ\text{C}$  it is pure sample of water. The presence of impurities in water will slightly increase its boiling point.
2. Another test to check the purity of water is to determine melting point of the sample. For this purpose, cool the sample of water until it freezes. Observe and record the temperature at which the ice begins to melt. If its melting point is  $0^\circ\text{C}$  it is pure water. A melting point below  $0^\circ\text{C}$  suggests the presence of impurities in the sample.



The impurities present in water raise the boiling point but lowers the melting point. Both these constants are specific to standard conditions. At high altitudes or lower pressure, these values will change.

### 20.1 Quick Check!

How purity of water can be checked by determining its freezing point.

## 20.3 Difference between distilled water and tap water

Water which is supplied to our homes, shops and offices comes through taps and is readily available for any usage. This water may either come from rivers, lakes and ponds or from underground sources.

Tap water contains minerals like salts of calcium and magnesium depending upon the source from where it is obtained. It also contains chlorine and fluoride salt which are mixed with it during treatment. It is a conductor of electricity due to the presence of free ions from dissolved minerals. Its pH has the range of 6.5 to 8.5 depending upon its source.

Water obtained after the process of distillation is called distilled water. The process involves heating water to get steam and then condensing this steam back into liquid water. This process effectively removes all the dissolved minerals, microorganisms and contaminants from water leaving behind only pure water.

The purity of distilled water makes it ideal for use in the laboratories, medical procedures and pharmaceutical industry. Its purity ensures accurate scientific measurements, sterilization of medical equipments and to prevent corrosion.

Distilled water contains only water molecules without any bacteria, ions, gases or other contaminants. Its pH is 7. Although it is safe to drink but it may not have the necessary minerals needed for the body. It is also a bad conductor of electricity due to absence of ions.

### 20.2 Quick Check!

Why tap water is a conductor of electricity whereas distilled water is not?

## 20.4 Substances present in water obtained from natural sources

Water from natural sources such as rivers, lakes and aquifers contains a number of substances which maybe useful or harmful for our health.





## Useful Substances

### Dissolved Oxygen

Oxygen enters the natural water from the atmosphere through the process of diffusion. It is also produced by aquatic plants and algae in the process called photosynthesis.

This absorbed oxygen is then used by the aquatic organisms including fish to breathe and survive. The health and diversity of an ecosystem directly depends upon the amount of dissolved oxygen in a water body.

## Harmful substances and their effects on the quality of water

### (i) Harmful Microbes

Both surface and ground water which are vital sources of fresh water can be contaminated by various human activities. Harmful microorganisms like bacteria, viruses and parasites enter into natural water through human and animal wastes, landfills, agricultural runoff and waste water from industries. Sewage from wastewater treatment plants or from faulty septic tanks can release pathogens directly into nearby water body. These bacterial contents can cause such infectious diseases as dysentery, typhoid, hepatitis and cholera.

### (ii) Heavy metals and their compounds

Heavy metals like lead, mercury, cadmium and chromium and their compounds can enter in natural water through many routes. Waste water from factories may contain heavy metals and their compounds, which are eventually released into rivers and other water bodies. Similarly, mining operations and use of fertilizers and pesticides can contaminate both ground and surface water with heavy metals and their compounds.

Heavy metals and their compounds not only damage vital organs like liver and kidney, they can also lead to neurological problems. Arsenic and cadmium are known to increase the risk of certain cancers.

### (iii) Plastics

Very small particles of plastics called microplastics are present in both tap





and bottled water. These tiny particles can enter water through wastewater, rainwater when it carries plastic debris to water sources, and by degradation of plastic waste. Plastic tiny particles have been found in some human organs like lungs and blood. These particles can disturb the immune and reproductive systems.

#### **(iv) Nitrates and Phosphates**

Nitrates and phosphates enter natural waters through weathering of rocks. They can also enter in water through human sources such as agriculture fertilizers, detergents and industrial wastewater. They are essential nutrients for plant and animal life. However, if amounts of these compounds exceed a limit they can affect the quality of water and cause eutrophication. Eutrophication is the name of the process which starts in a water body containing excess of phosphorus and nitrogen nutrients. The excessive amounts of these nutrients cause algae and other aquatic plants to grow excessively. This overgrowth of algae, in turn, can decrease the dissolved oxygen level in water which is not only harmful for aquatic life but can also disrupt the entire ecosystem.

## **20.5 Treatment of Domestic Water Supply**

Three types of impurities are mostly present in water obtained from natural sources.

1. Dissolved impurities
2. Suspended impurities
3. Microorganisms

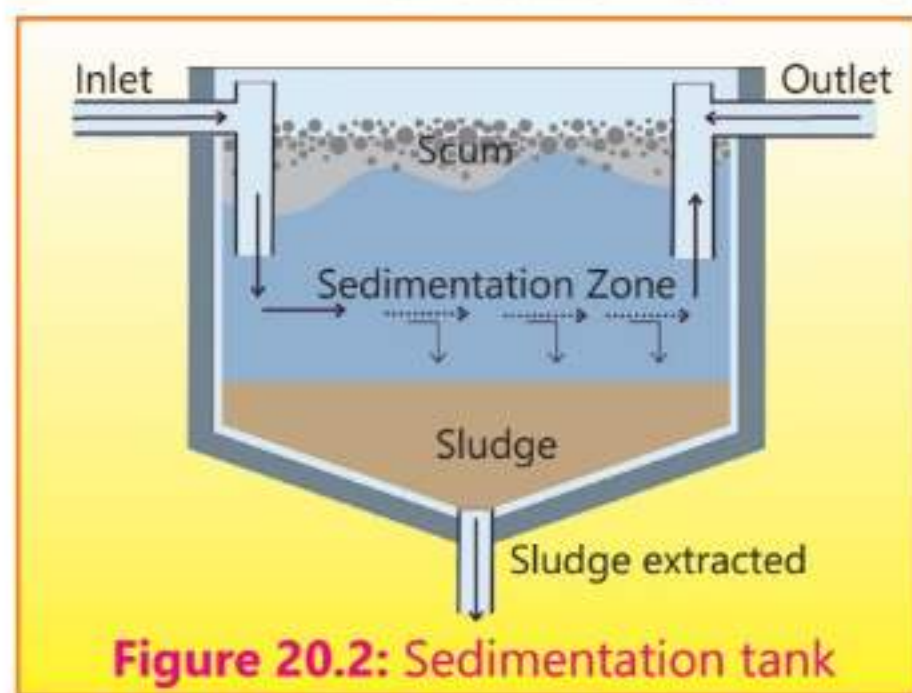
In order to remove these impurities different methods are applied which include sedimentation, filtration, distillation and treatment with liquid chlorine etc.

### **(1) Sedimentation**

Insoluble impurities present in natural water include soil, pieces of plants and other organic matter and sand. These impurities are bigger in size and are often removed by the process called sedimentation. In this process water



obtained from natural sources is pumped into sedimentation tanks (Figure 20.2) where water is allowed to stand for a few hours. The suspended particles present in water settle down at the bottom of the tank due to gravity and form a layer of sediment. The cleaner water at the top can then be extracted for the next stage.



**Figure 20.2:** Sedimentation tank

## (2) Filtration

This process is used to remove suspended particles of smaller size which are generally not removed in the sedimentation process. For this purpose water is allowed to trickle through layer of sand and gravel filters which trap these solid particles.

## (3) Chlorination

Water must be sterilized before humans can use it. For this purpose all harmful bacteria and other microbes, must be killed.

Mostly a small amount of liquid chlorine is added which has the power to kill all these germs.



Water from different sources requires different treatment methods.

## (4) Removal of odours

Water is passed through powdered activated carbon in the form of charcoal to remove tastes and odours. Activated carbon removes a wide range of organic compounds responsible for taste and odour through absorption. Odour can also be removed by exposing water to air in a process called aeration.

## 20.6 Effects of pollutants present in water

Water pollution affects human health, ecosystems, aquatic organisms and industries that are dependent on good water quality.

### How to Control the Negative effects of Pollutants

Water Pollutants can disrupt aquatic ecosystems through eutrophication and destruction of habitats. Polluted water can also lower crop yields and



contaminate food sources.

Negative effects due to water pollution can be controlled by taking a number of steps:

1. Sewage and industrial wastewater should be treated before it is discharged into water bodies.
2. Plastics must be reused or recycled to minimize their production.
3. Chemical cleaners, fats or oils and grease should never be thrown down the drain.
4. Minimize the use of pesticides and fertilizers in agriculture.
5. General public should be made aware of the harmful effects of water pollution through public campaigns.
6. Implement and enforce laws for the strict control of all types of water pollution.



### 20.3 Quick Check!

1. Which pollutants are harmful for aquatic life?
2. How to identify if water is polluted?

## Water-borne Diseases

The World Health Organization (WHO) has estimated that 80% of the sickness and diseases in the world are caused by polluted water and lack of sanitation. Water-borne diseases include cholera, typhoid, malaria, nausea and leprosy. In all nearly 500 million people suffer from water-borne diseases every year in the world. For example, millions of persons are suffering from a disease called 'trachoma' which often causes blindness. This disease is particularly prevalent among babies and children in developing countries. The liver diseases particularly viral hepatitis is also caused by drinking contaminated water.

## Prevention of water-borne diseases

Water-borne diseases can be avoided if we strictly follow the following instructions.

1. Drink clean water after removing impurities and boiling to kill the germs.
2. Practice hygiene by keeping your body especially hands clean. Ensure proper sanitation facilities are available.



## 20.7 Water Scarcity in Pakistan

Our world is divided into different regions depending upon the annual rainfall which they receive every year. Pakistan is included in a semi-arid region and hence receives a low rainfall annually. Northern Pakistan including Punjab generally receives rainfall within the range 250-600 mm per year mostly during monsoon season. In southern Pakistan precipitation is scarce, below 200mm per year.

Pakistan, at present, is facing a severe water scarcity crisis due to a number of different factors. Less rainfall, growth in population, flood irrigation, climate change, depleting aquifers and poor water management are some of the reasons responsible for this scarcity. If the current situation continues then Pakistan could face very serious challenges in coming years.

The problem can be addressed by taking a number of steps which are as follows:

1. Collecting rain water especially during monsoon season by constructing water reservoirs and other water storage facilities.
2. Using better crop irrigation techniques.
3. Taking appropriate measures to face effects of climate change.
4. Effective management of water resources.

### 20.4 Quick Check!

How can we conserve water at home?

## 20.8 Elements Essential for Plant Growth

Plants need nutrients from the soil for a healthy growth. The elements essential for the plant growth can be classified as micro-nutrients and macro-nutrients.

### Micro-nutrients (Trace elements)

The nutrients which are required in a very small amount for the growth of plants are called micro-nutrients. These include boron, copper, iron, manganese, zinc, molybdenum and chlorine. Only minute amounts of these elements are needed for healthy plant growth and it may be dangerous to add too much quantity because they are poisonous in larger quantities. These are generally required in quantities ranging from 6 grams to 200 grams per acre.



## Macro-nutrients

The nutrients which are required in a large amount for the growth of plants, are called macro-nutrients. These include nitrogen, phosphorous, potassium, calcium, magnesium, sulphur, carbon, hydrogen and oxygen. These are generally required in quantities ranging from 5 Kg to 200 Kg per acre.

## 20.9 Fertilizers

Fertilizers are the substances added to the soil to make up the deficiency of essential elements like nitrogen, phosphorus and potassium (NPK) required for the proper growth of plants. Fertilizers enhance the natural fertility of the soil and provide the chemical elements taken up from soil by the previous crops.

### Requirements of a Fertilizer

Every compound of the desired elements cannot be a fertilizer. The desired elements should be present in the compound in a water soluble form readily available to the plants. The compound employed as fertilizer should be stable in soil as well as in storage e.g., it should not absorb moisture or set to hard stony materials with time. Above all it should be cheap to manufacture.

### Essential Qualities of a Good Fertilizer

The essential requisites of a good fertilizer are:

- (i) The nutrient elements present in it must be readily available to the plants.
- (ii) It must be fairly soluble in water so that it thoroughly mixes with the soil.
- (iii) It should not be injurious to plants.
- (iv) It should be inexpensive.
- (v) It must be stable so that it is available for a longer time to the growing plants.
- (vi) It should not alter the pH of the soil.
- (vii) By rain or water, it should be converted into a form, which the plant can absorb easily.



## 20.10 Classification of Fertilizers

Fertilizers are classified according to the nature of the elements like nitrogen, phosphorus and potassium which they provide to the soil. This classification gives the following types of fertilizers.

- (i) Nitrogenous fertilizers
- (ii) Phosphatic fertilizers
- (iii) Potassium fertilizers

### Interesting Information

Biofertilizers are environment friendly. They provide the soil essential nutrients as well as microbes required for the growth of plants. Biofertilizers improve soil health and structure. They also increase biodiversity and reduce the need for harmful chemicals. They also prevent soil degradation.

### Nitrogenous Fertilizers

These fertilizers supply nitrogen to the plants or soil. Nitrogen is required during the early stage of plant growth for the development of stem and leaves. It is the main constituent of proteins, imparts green colour to the leaves and enhance the yield and quality of the plants. Some examples of nitrogen fertilizers are: ammonium sulphate, calcium cyanamide, ammonia, ammonium nitrate, ammonium phosphate, ammonium chloride and urea.

Urea is a high quality nitrogenous fertilizer. It contains about 46% nitrogen and is the most concentrated solid nitrogen fertilizer. It is the most widely used nitrogen fertilizer in Pakistan.

Ammonium nitrate is a useful fertilizer for many crops except paddy rice because the microbial bacteria in flooded fields decompose it to nitrogen gas. It is also used in combination with limestone. It is hygroscopic in nature.

### Phosphatic Fertilizers

These fertilizers provide phosphorus to the plants or soil. Phosphorus is required to stimulate early growth and to accelerate the seed and fruit formation during the later stages of growth. It also increases resistance to diseases. The various phosphatic fertilizers have different compositions, due to which they have different solubilities. The two most important water soluble fertilizers are super phosphate (calcium super phosphate)  $\text{Ca}(\text{H}_2\text{PO}_4)_2$ , and triple phosphate (diammonium-phosphate  $(\text{NH}_4)_2\text{HPO}_4$ ).

## Potassium Fertilizers

These fertilizers provide potassium to the plant or soil. Potassium is required for the formation of starch, sugar and the fibrous material of the plants. They increase resistance to diseases and make the plants strong by helping in healthy root development. They also help in ripening of seeds, fruits and cereals. Potassium fertilizers are especially useful for tobacco, coffee, potato and corn.

Some common examples of potassium fertilizers are potassium chloride, potassium sulphate and potassium nitrate.



### 20.5 Quick Check!

1. Which is the most concentrated solid nitrogen fertilizer?


## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

- The pH of distilled water is:  
(a) 6.5 (b) 8.5  
(c) 7 (d) 7.5
- The unpleasant odours in water can be removed by:  
(a) adding chlorine (b) treating it with activated charcoal  
(c) sedimentation (d) filtration
- The source of harmful microbes in natural water:  
(a) human and animal wastes (b) fertilizers used for crops  
(c) industrial waste-water (d) microbes in rocks
- Which gases are dissolved in natural water from the atmosphere through diffusion?  
(a)  $O_2$  and  $CO_2$  (b)  $N_2$  and  $CO_2$   
(c)  $O_2$  and  $N_2$  (d)  $O_2$ ,  $N_2$  and  $CO_2$
- The fertilizer harmful to paddy rice is:  
(a) Super phosphate (b) Ammonium nitrate  
(c) Urea (d) Potassium sulphate





6. Fertilizers which increase the resistant of plants towards diseases and make plants strong by healthy root development are:

- (a) Nitrogenous fertilizers      (b) Phosphate fertilizers  
(c) Potassium fertilizers      (d) Magnesium fertilizers

### **B** Short Answer Questions

- 20.1 Name two methods to check the purity of water.  
20.2 What is the main difference between tap water and distilled water?  
20.3 How water is distilled in the laboratory?  
20.4 Name useful and harmful substances present in water.  
20.5 How would you remove harmful bacteria and other microbes present in water?  
20.6 What is the difference between sedimentation and filtration?  
20.7 Name any three water-borne diseases.  
20.8 Why fertilizers containing nitrogen element are added into the soil?  
20.8 What is trachoma disease?

### **C** Constructed Response Questions

- 20.1 Describe the negative effects of using plastics in every day life.  
20.2 Explain one method to remove dissolved impurities present in water.  
20.3 Why urea is regarded as a good nitrogenous fertilizer?  
20.4 Why Pakistan is facing a severe shortage of water?

### **D** Descriptive Questions

- 20.1 How domestic water supply can be made fit for drinking?  
20.2 Which measures should be taken to avoid water-borne disease?  
20.3 What are fertilizers? Mention the essential qualities of a good fertilizer.  
20.4 What are the main functions of nitrogenous, phosphatic and potassium fertilizers?  
20.5 How can you avoid the negative effects of pollutants present in water?

## Student Learning Outcomes

After studying this chapter, students will be able to:

- Describe organic molecules as either straight-chained, branched or cyclic.
- State that a structural formula is an unambiguous description of the way the atoms in molecules are arranged, including  $\text{CH}_2=\text{CH}_2$ ,  $\text{CH}_3\text{CH}_2\text{OH}$ ,  $\text{CH}_3\text{COOCH}_3$
- Identify and draw structural formulae for molecules.
- Interpret general formulae of compounds in the same homologous series including alkanes, alkenes, alkynes, alcohols and carboxylic acids.
- Define structural isomers as compounds with the same molecular formula, but different structural formulae, including  $\text{C}_4\text{H}_{10}$  as  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$  and  $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_3$  and  $\text{C}_4\text{H}_8$  as  $\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2$  and  $\text{CH}_3\text{CH}=\text{CHCH}_3$ .
- Identify a functional group as an atom or group of atoms that determine the chemical properties of a homologous series including that for alcohols, aldehydes, ketones, phenols, carboxylic acids, amine, esters, and amide.
- Describe the general characteristics of homologous series. These can include:
  - a. Having the same functional group
  - b. Having the same general formula
  - c. Differing from one member to the next by a  $\text{CH}_2$  – Unit.
  - d. Displaying a trend in physical properties.
  - e. Sharing similar chemical properties
- State that a saturated compound has molecules in which all carbon-carbon bonds are single bonds.
- State that an unsaturated compound has molecules in which one or more carbon-carbon bonds are not single bonds.
- Name and draw the structural and displayed formulae of unbranched alkanes, alkenes, alcohols, and carboxylic acids. (Include but-1-ene and but-2-ene, propan-1-ol, propan-2-ol, butan-1-ol and butan-2-ol.
- State the type of compound present given the chemical name ending in –ane, -ene, -yne, -ol, or -oic acid or from a molecular, structural or displayed formula.
- Name and draw the displayed formulae of the unbranched esters which can be made from unbranched alcohols and carboxylic acids, each containing up to four carbon atoms.

# Organic Chemistry

An organic compound is a chemical compound primarily composed of carbon atoms that are covalently bonded to each other or to other elements. Apart from carbon, majority of organic compounds also contain hydrogen. Other elements which may also be present include oxygen, nitrogen, sulphur and halogens etc. For historical and conventional reasons a few of the carbon compounds such as its oxides, carbonates and hydrogen carbonates, etc. are studied as inorganic compounds. Organic chemistry is defined as that branch of chemistry in which we study compounds of carbon and hydrogen (hydrocarbons) and their derivatives.

## 21.1 Classifications of Organic Compounds

There are millions of organic compounds. It is practically not possible to study each individual compound. To facilitate their study, organic compounds are classified into various groups and sub-groups. They may be broadly classified into the following classes:

- Open chain or Acyclic compounds.
- Closed chain or Cyclic (or ring) compounds

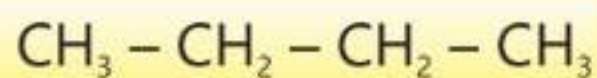
### Interesting Information

Organic chemistry plays a vital role in developing new materials with specific properties, such as polymers and drugs.

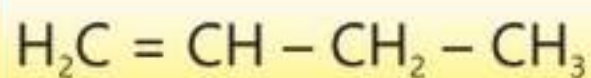
### (i) Open Chain or Acyclic Compounds

This type of compounds contains an open chain of carbon atoms. The chains may be branched or non-branched (straight chain). Open chain compounds alongwith certain cyclic compounds are also called aliphatic compounds.

### Straight chain (or non-branched) compounds



Butane

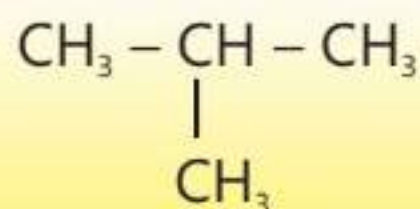


But-1-ene

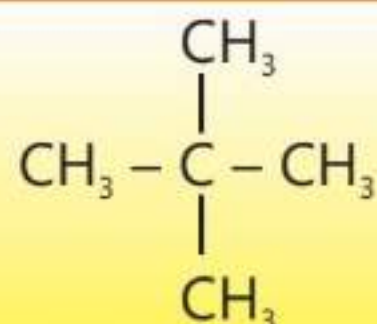


Butan-1-ol

### Branched chain compounds



2-Methylpropane



2,2-Dimethylpropane

## (ii) Closed Chain or cyclic Compounds

These compounds contain one or more closed chains (cyclic) of atoms and are known as closed chain or ring compounds.

### Interesting Information

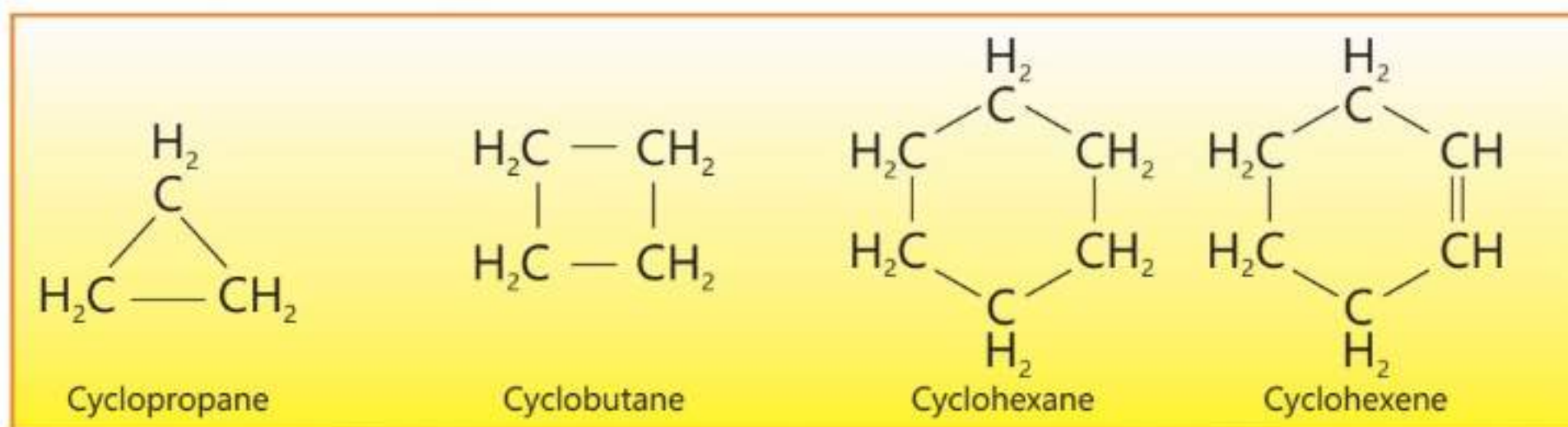
The ability of carbon atom to form four bonds creates an almost infinite variety of molecules which make organic chemistry very useful.

When the ring contains carbon atoms only, the compounds are called carbocyclic compounds. However, if the ring contains other atoms alongwith carbon atoms, the compounds are called heterocyclic compounds. Carbocyclic compounds are further classified as;

- (1) Alicyclic compounds      (2) Aromatic compounds

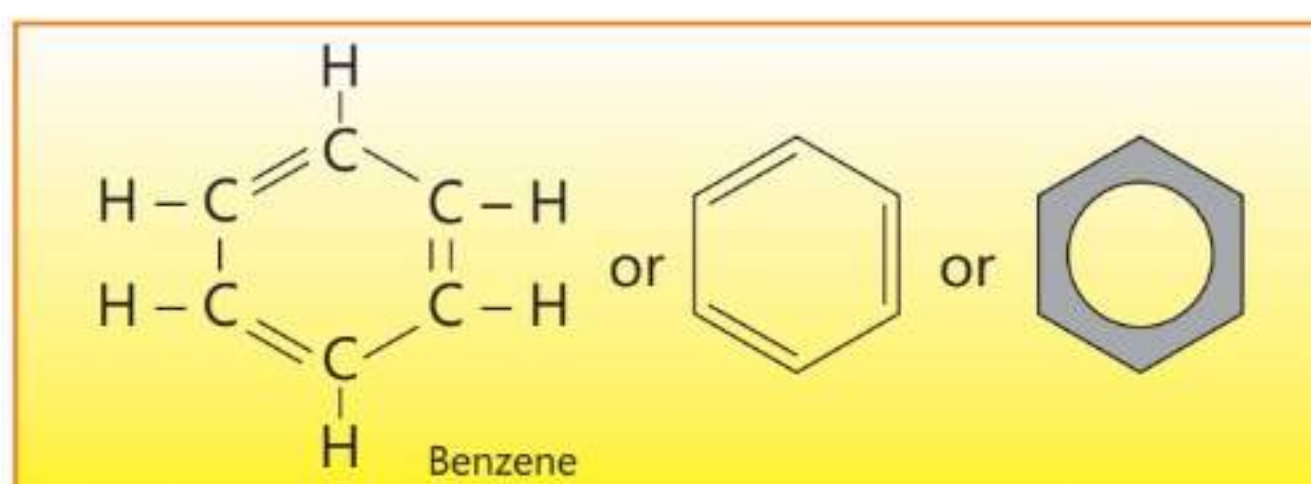
### (1) Alicyclic compounds

The carbocyclic compounds which contain a ring of three or more carbon atoms and resemble aliphatic compounds are called alicyclic compounds. The saturated alicyclic hydrocarbons have the general formula  $C_nH_{2n}$ . A few typical alicyclic compounds are given below.



### (2) Aromatic compounds

Aromatic compounds are of many types. The simplest among them are those which contain one benzene ring. A benzene ring has six carbon atoms with three alternate double and single bonds. These bonds are usually shown in the form of a circle. Some other cyclic compounds having alternate double bonds are also included in aromatic compounds.





### 21.1 Quick Check!

1. What is the difference between cyclohexane and benzene?
2. Give two examples of branched chain compounds.

## 21.2 Structural Formula

The structural formula of a compound shows the arrangement of atoms and bonds present in that compound. It gives enough information to understand the structure of a molecule clearly. While showing the arrangement of atoms in a molecule, it is usual to omit most of the single covalent bonds present in the molecule. Only important bonds such as double and triple bonds are shown. Identical groups present in the molecules can be bracketed together while some other groups are also shown using brackets.

There are various ways of drawing the structural formula of organic compounds and the students should familiarize with all of them.

### Displayed Formula or Full Structural Formula

This formula shows the detailed structure of a molecule showing the relative position of atoms, the number and type of bonds between them. The bonds are represented by lines.

### Condensed Structural Formula

This formula still uses lines between bonded atoms, but it omits the carbon to hydrogen bonds.

Table 21.1 Condensed Structural Formulae

Compound	Displayed Formula	Condensed Structural Formula
Ethane	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H} - \text{C} - \text{C} - \text{H} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$	$\text{CH}_3 - \text{CH}_3$
Ethene	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H} - \text{C} = \text{C} - \text{H} \end{array}$	$\text{CH}_2 = \text{CH}_2$
Ethyne	$\text{H} - \text{C} \equiv \text{C} - \text{H}$	$\text{HC} \equiv \text{CH}$
Propane	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ \text{H} - \text{C} - \text{C} - \text{C} - \text{H} \\   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\text{CH}_3 - \text{CH}_2 - \text{CH}_3$



Compound	Displayed Formula	Condensed Structural Formula
Butane	$  \begin{array}{cccc}  & \text{H} & \text{H} & \text{H} & \text{H} \\  &   &   &   &   \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{H} \\  &   &   &   &   \\  & \text{H} & \text{H} & \text{H} & \text{H}  \end{array}  $	$\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3$
But-1-ene	$  \begin{array}{cccc}  & & & \text{H} & \text{H} \\  & & &   &   \\  \text{H} & & & \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{H} \\  & & & // &   &   &   \\  & & & \text{H} & \text{H} & \text{H} & \text{H}  \end{array}  $	$\text{CH}_2 = \text{CH} - \text{CH}_2 - \text{CH}_3$
But-2-ene	$  \begin{array}{cccc}  & & & & \text{H} \\  & & & &   \\  \text{H} & & & & \text{C} & - \text{C} & = \text{C} & - \text{C} & - \text{H} \\  & & & &   &   &   &   \\  & & & & \text{H} & \text{H} & \text{H} & \text{H}  \end{array}  $	$\text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_3$
Ethanol	$  \begin{array}{ccc}  & \text{H} & \text{H} \\  &   &   \\  \text{H} & - \text{C} & - \text{C} & - \text{O} & - \text{H} \\  &   &   \\  & \text{H} & \text{H}  \end{array}  $	$\text{CH}_3 - \text{CH}_2 - \text{OH}$
Propanol	$  \begin{array}{ccc}  & \text{H} & \text{H} & \text{H} \\  &   &   &   \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{H} \\  &   &   &   \\  & \text{O} & \text{H} & \text{H} \\  &   \\  & \text{H}  \end{array}  $	$  \begin{array}{c}  \text{CH}_2 - \text{CH}_2 - \text{CH}_3 \\    \\  \text{OH}  \end{array}  $
Propan-2-ol	$  \begin{array}{ccc}  & \text{H} & \text{H} & \text{H} \\  &   &   &   \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{H} \\  &   &   &   \\  & \text{H} & \text{O} & \text{H} \\  & &   \\  & & \text{H}  \end{array}  $	$  \begin{array}{c}  \text{CH}_2 - \text{CH} - \text{CH}_3 \\    \\  \text{OH}  \end{array}  $
Butanol	$  \begin{array}{ccc}  & \text{H} & \text{H} & \text{H} & \text{H} \\  &   &   &   &   \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{H} \\  &   &   &   &   \\  & \text{O} & \text{H} & \text{H} & \text{H} \\  &   \\  & \text{H}  \end{array}  $	$  \begin{array}{c}  \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3 \\    \\  \text{OH}  \end{array}  $
Butan-2-ol	$  \begin{array}{ccc}  & \text{H} & \text{H} & \text{H} & \text{H} \\  &   &   &   &   \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{H} \\  &   &   &   &   \\  & \text{H} & \text{O} & \text{H} & \text{H} \\  & &   \\  & & \text{H}  \end{array}  $	$  \begin{array}{c}  \text{CH}_3 - \text{CH} - \text{CH}_2 - \text{CH}_3 \\    \\  \text{OH}  \end{array}  $
Ethanoic acid	$  \begin{array}{ccc}  & \text{H} & \text{O} \\  &   &    \\  \text{H} & - \text{C} & - \text{C} & - \text{O} & - \text{H} \\  &   \\  & \text{H}  \end{array}  $	$  \begin{array}{c}  \text{O} \\     \\  \text{CH}_3 - \text{C} - \text{OH}  \end{array}  $
Propanoic acid	$  \begin{array}{ccc}  & \text{H} & \text{H} & \text{O} \\  &   &   &    \\  \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{O} & - \text{H} \\  &   &   \\  & \text{H} & \text{H}  \end{array}  $	$  \begin{array}{c}  \text{O} \\     \\  \text{CH}_3 - \text{CH}_2 - \text{C} - \text{OH}  \end{array}  $



Compound	Displayed Formula	Condensed Structural Formula
Methyl ethanoate	$  \begin{array}{ccccccc}  & \text{H} & & \text{O} & & \text{H} & \\  &   & &    & &   & \\  \text{H} & - \text{C} & - & \text{C} & - \text{O} & - \text{C} & - \text{H} \\  &   & & & &   & \\  & \text{H} & & & & \text{H} &   \end{array}  $	$  \begin{array}{c}  \text{O} \\     \\  \text{CH}_3 - \text{C} - \text{O} - \text{CH}_3  \end{array}  $



### 21.2 Quick Check!

Write down the displayed and condensed formulae of butan-2-ol, ethyl ethanoate, 2-methylpropane, but-2-ene and pentane.

## 21.3 Homologous Series

Organic compounds have also been classified into various families. Each family contains closely related organic compounds, as their structure and chemical properties are similar. The different families are known as homologous series.

### Characteristics of a Homologous Series

The common characteristics of the members of a homologous series are:

- (i) All the members of the series can be represented by a general formula. For example, the general formula for the series of saturated hydrocarbons called alkanes is  $C_nH_{2n+2}$  where  $n$  represents the number of carbon atoms present in a member. The general formula of some other families are given below.

Series	General formula
Alkenes	$C_nH_{2n}$
Alkynes	$C_nH_{2n-2}$
Alcohols	$C_nH_{2n+1}OH$
Carboxyl acids	$C_nH_{2n+1}COOH$




### 21.3 Quick Check!

- Write down the molecular formula of a carboxylic acid having three carbon atoms.
- Write down the molecular formula of an alcohol containing four carbon atoms.

- (ii) Successive members of the series differ by  $CH_2$  group and 14 units in their relative molecular masses.
- (iii) Different members in a family have common functional group e.g. all the members of carboxylic acid family have  $-COOH$  group as the functional group.
- (iv) The members in any particular family have almost identical chemical properties due to the presence of the same functional group.



- 
- (v) The physical properties such as melting point, boiling point, density and solubility show a regular change with the increase in the molecular masses.
- (vi) All members of a series can be prepared by similar methods.

## 21.4 Isomerism

Two or more compounds having the same molecular formula but different structural formulae and properties are said to be isomers and the phenomenon is called structural isomerism.

The simplest hydrocarbon to have structural isomers is butane ( $C_4H_{10}$ ). Methane, ethane and propane do not show the phenomenon of isomerism because each exists in one structural form only. If we study the structural formula of butane or other higher hydrocarbons of the alkane family, we will observe that it is possible to arrange the atoms present in the molecule in more than one way to satisfy all valencies. This means that it is possible to have two or more different arrangements for the same molecular formula. For example, butane molecule can have two different arrangements as represented by the following structural formulae:



This fact has been supported by an experimental evidence that there are two compounds with different physical properties but with the same molecular formula of  $C_4H_{10}$ .

As the number of carbon atoms in a hydrocarbon increases, the number of possible isomers increase very rapidly. The five carbon compounds, pentane, has three isomers. When the number of carbon atoms increases to thirty, the number of isomers are over four billions.

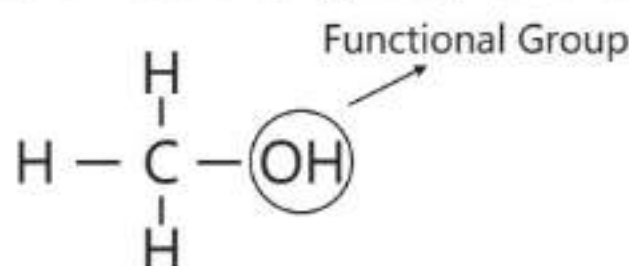
Structural isomerism is not confined to saturated hydrocarbons only. In fact, all classes of organic compounds and their derivatives show the phenomenon of structural isomerism.

Butene ( $C_4H_8$ ) has two structural isomers.



## 21.5 Functional Group

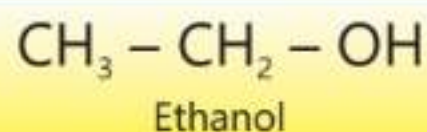
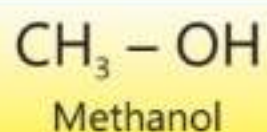
A functional group may be defined as an atom or group of atoms that determines the characteristic properties of an organic compound. For example, the family of alcohols have its characteristic properties due to the presence of -OH (hydroxyl) group, called the functional group of alcohols.



Some important functional groups are described below.

### (a) Hydroxyl group (-OH)

This group is present in the family of compounds called alcohols.

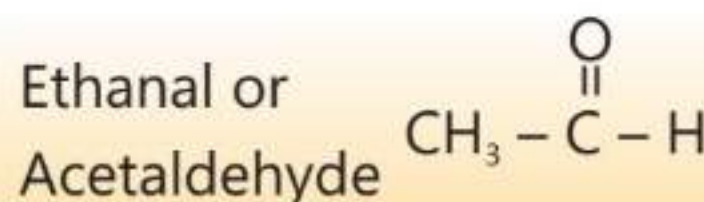
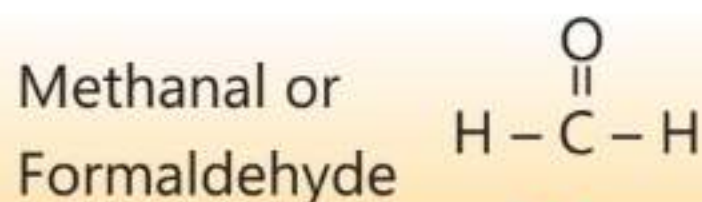


If hydroxyl (-OH) group is attached to benzene ring the compound is a member of a series which is named as phenols.



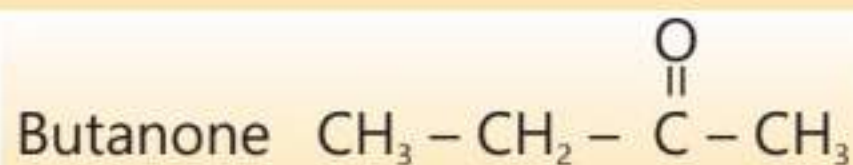
### (b) Aldehyde Group ( $-\overset{\text{O}}{\parallel}{\text{C}}-\text{H}$ )

This group is present in the family called aldehydes. For example,



### (c) Ketone Group ( $\begin{array}{l} \text{R} \\ \diagup \\ \text{C} = \text{O} \\ \diagdown \\ \text{R} \end{array}$ where R is an alkyl group)

The homologous series which contains a ketonic functional group is called ketones.





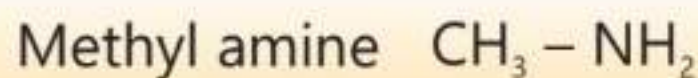
### (d) Carboxyl Group $(-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH})$

This group is present in the family of compounds called carboxylic acids.



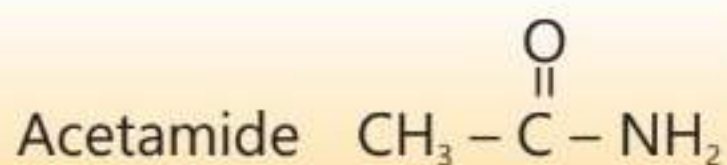
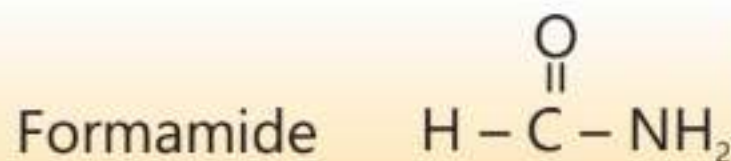
### (e) Amino Group $(-\text{NH}_2)$

This group is present in a series of compounds called amines.



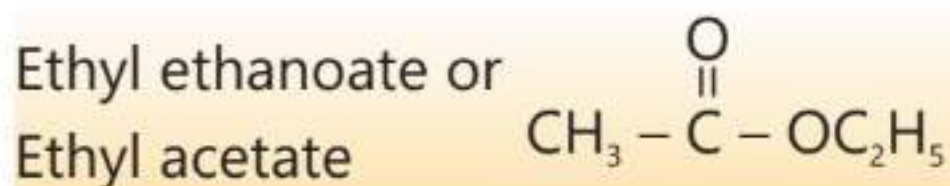
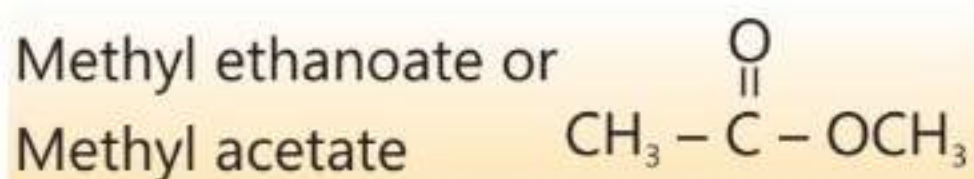
### (f) Amide Group $(-\overset{\text{O}}{\parallel}{\text{C}}-\text{NH}_2)$

Amide functional group is present in a family called acid amides.



### (g) Ester Group $(-\overset{\text{O}}{\parallel}{\text{C}}-\text{OR})$

Ester group is present in a family called carboxylic esters.



#### 21.4 Quick Check!

1. How phenols are different from alcohols?
2. What is common between the formula of aldehydic and ketonic functional groups.



## 21.6 Naming Organic Compounds

The early organic chemists prepared many organic compounds and gave them names which are called common or trivial names. These names are quite often used because they are very simple and easy to use. However, due to existence of a large number of organic compounds and their complexity, it is not possible to give common name to every compound individually. To deal with this problem, the International Union of Pure and Applied Chemistry (IUPAC) has introduced a systematic way of naming organic compounds called IUPAC nomenclature.

### 1 Alkanes

The organic compounds containing carbon and hydrogen only are called hydrocarbons. The hydrocarbons in which all the four valencies of carbon are utilized using single bonds only are called saturated hydrocarbons or alkanes. While those containing at least one double or triple bond are called unsaturated hydrocarbons. The saturated hydrocarbons or alkanes may contain one or more carbon atoms and they may have a straight chain or a branched chain.

Methane ( $\text{CH}_4$ ) is the simplest member of saturated hydrocarbons.

According to IUPAC system of nomenclature, the entire name of an organic compound has three parts.

1. **Root:** It tells us the number of carbon atoms in the longest continuous chain present in the molecule. The roots up to ten carbon atoms are shown in Table 21.2.
2. **Suffix:** It is added after the root and tells us about the class of organic compound.
3. **Prefix:** It is indicated before the root and tells us about the group or groups attached to the longest chain.

The molecular formulae, the displayed formulae or the condensed structural formulae of some alkanes are given in Table 21.3:

Table 21.2 Roots used for IUPAC Names

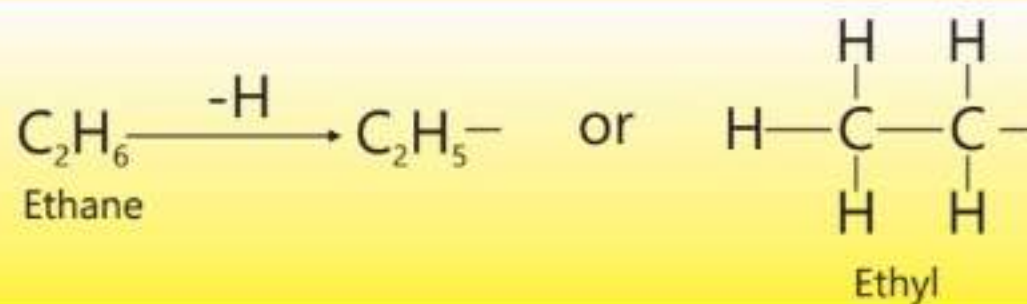
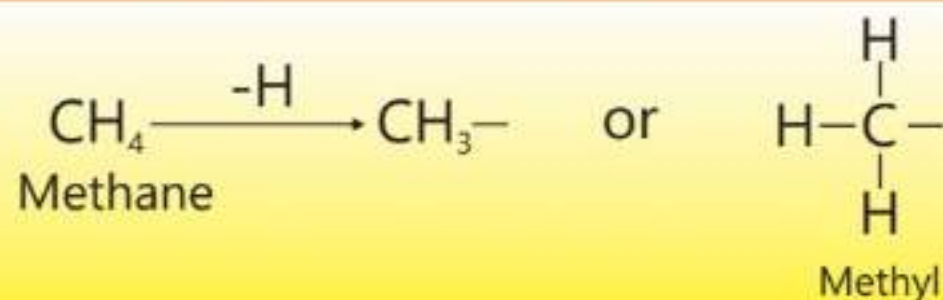
Root	No. of Carbon atoms
Meth-	1
Eth-	2
Prop-	3
But-	4
Pent-	5
Hex-	6
Hept-	7
Oct-	8
Non-	9
Dec-	10

Table 21.3 Formulae of Alkanes

Methane	CH <sub>4</sub>	$\begin{array}{c} \text{H} \\   \\ \text{H}-\text{C}-\text{H} \\   \\ \text{H} \end{array}$
Ethane	C <sub>2</sub> H <sub>6</sub> CH <sub>3</sub> -CH <sub>3</sub>	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}-\text{C}-\text{H} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$
Propane	C <sub>3</sub> H <sub>8</sub> CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>3</sub>	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$
Butane	C <sub>4</sub> H <sub>10</sub> CH <sub>3</sub> -(CH <sub>2</sub> ) <sub>2</sub> -CH <sub>3</sub>	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$
Pentane	C <sub>5</sub> H <sub>12</sub>	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>
Hexane	C <sub>6</sub> H <sub>14</sub>	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>
Heptane	C <sub>7</sub> H <sub>16</sub>	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>
Octane	C <sub>8</sub> H <sub>18</sub>	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>
Nonane	C <sub>9</sub> H <sub>20</sub>	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>
Decane	C <sub>10</sub> H <sub>22</sub>	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>

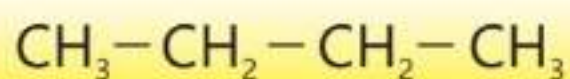
## 2 Alkyl Group

An alkyl is formed when an alkane molecule loses one of its many hydrogen atoms. For example,



Generally, an alkane is represented by RH and an alkyl group is represented by R-.

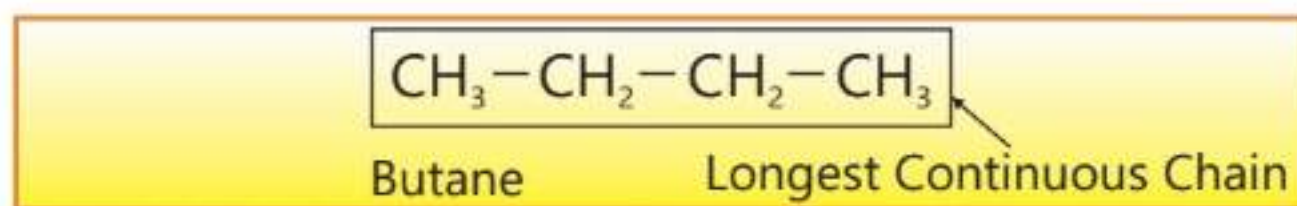
To explain the IUPAC system, let us name the following compound.





- Identify the longest continuous chain present in the compound.
- Identify the class of organic compound.

The organic compound contains four carbon atoms in the longest continuous carbon chain and it belongs to the family of hydrocarbons called Alkanes. The root is, therefore, But- and the suffix -ane is added to this. The organic compound will, thus, be given the name Butane.



### 21.5 Quick Check!

Name the following compounds according to IUPAC system of nomenclature.

- $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3$
- $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2$

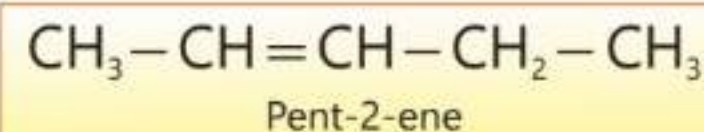
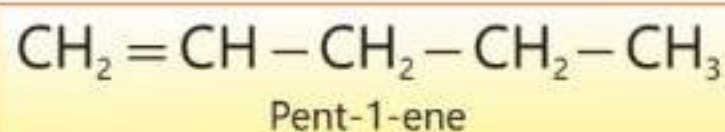
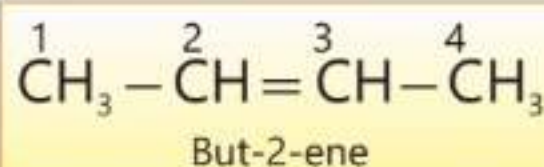
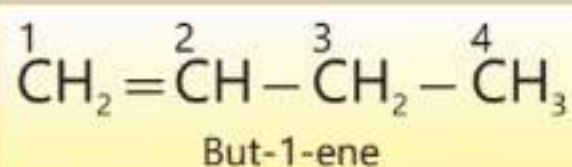
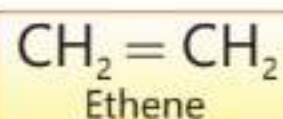
## 3. Alkenes

Hydrocarbons containing at least one carbon to carbon double bond are called Alkenes.

Alkenes are named in the same way as alkanes except the suffix used is -ene. The rules for naming alkenes are as follows.

- Count the number of carbon atoms in the longest continuous chain that contains both the carbon atoms of the double bond.
- Number the chain starting from the end nearest to the double bond carbon atom.
- Write the root, then position of double bond and finally the suffix -ene.

Examples of alkenes are as follows:



## 4. Alcohols

Monohydroxy derivatives of alkanes are also called alcohols. General formula for alcohol is ROH. According to IUPAC system, alcohols are named observing the following rules.

- The longest chain of carbon atoms containing the hydroxyl group is taken as a parent hydrocarbon. The ending 'e' of alkane is replaced by 'ol'.
- The longest carbon chain is numbered, starting from the end where carbon atom attached with hydroxyl group gets the lowest possible number.
- The position of hydroxyl group is indicated by a number placed before the **-ol**.

Names and condensed formulae of some simple alcohols are given in the Table 21.4:

**Table 21.4 Names and formulas of Alcohols**

Alcohol	CH <sub>3</sub> OH	CH <sub>3</sub> CH <sub>2</sub> OH	<sup>3</sup> CH <sub>3</sub> — <sup>2</sup> CH <sub>2</sub> — <sup>1</sup> CH <sub>2</sub> —OH
Common Name	Methyl Alcohol	Ethyl Alcohol	Propyl alcohol
IUPAC Name	Methanol	Ethanol	Propan-1-ol
Alcohol	$\begin{array}{c} \text{CH}_3 - \text{CH} - \text{CH}_3 \\   \\ \text{OH} \end{array}$	$\begin{array}{c} \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3 \\   \\ \text{OH} \end{array}$	$\begin{array}{c} \text{CH}_3 - \text{CH} - \text{CH}_2 - \text{CH}_3 \\   \\ \text{OH} \end{array}$
Common Name	Iso-Propyl Alcohol	n-Butyl Alcohol	Sec-Butyl Alcohol
IUPAC Name	Propan-2-ol	Butan-1-ol	Butan-2-ol

## 5. Carboxylic Acids

Organic compounds containing a carboxyl group (–COOH) as a functional group are called carboxylic acids. They are also commonly called fatty acids because some carboxylic acids are obtained from fats. They are represented by the general formula RCOOH.

The IUPAC names of carboxylic acids are derived from the names of alkanes containing the same number of carbon atoms as the acid. The ending 'e' of the alkane name is replaced by '-oic' acid.

The common and IUPAC names of some common carboxylic acids are shown in Table 21.5.

### Interesting Information

The common names of carboxylic acids are derived from the source from which they were first isolated. Formic acid was first isolated from red ants. The Latin word Formica means ant. Similarly acetic acid was isolated from vinegar. The Latin word for vinegar is acetum.



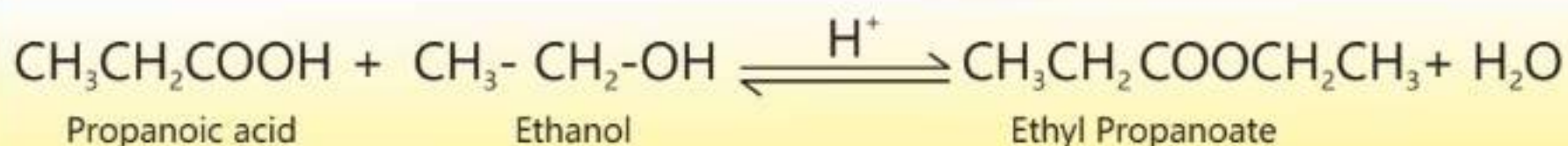
**Table (21.5) Names of Carboxylic Acids**

Carboxylic Acids	HCOOH	CH <sub>3</sub> COOH	CH <sub>3</sub> CH <sub>2</sub> COOH	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> COOH
Common Name	Formic acid	Acetic acid	Propionic acid	Butyric acid
IUPAC Name	Methanoic acid	Ethanoic acid	Propanoic acid	Butanoic acid

## 6. Esters

Esters are sweet smelling compounds. They are commonly used as flavouring agents in certain food items. They are represented by a general formula RCOOR.

Esters can be prepared by reacting an alcohol with a carboxylic acid in the presence of an acid catalyst.



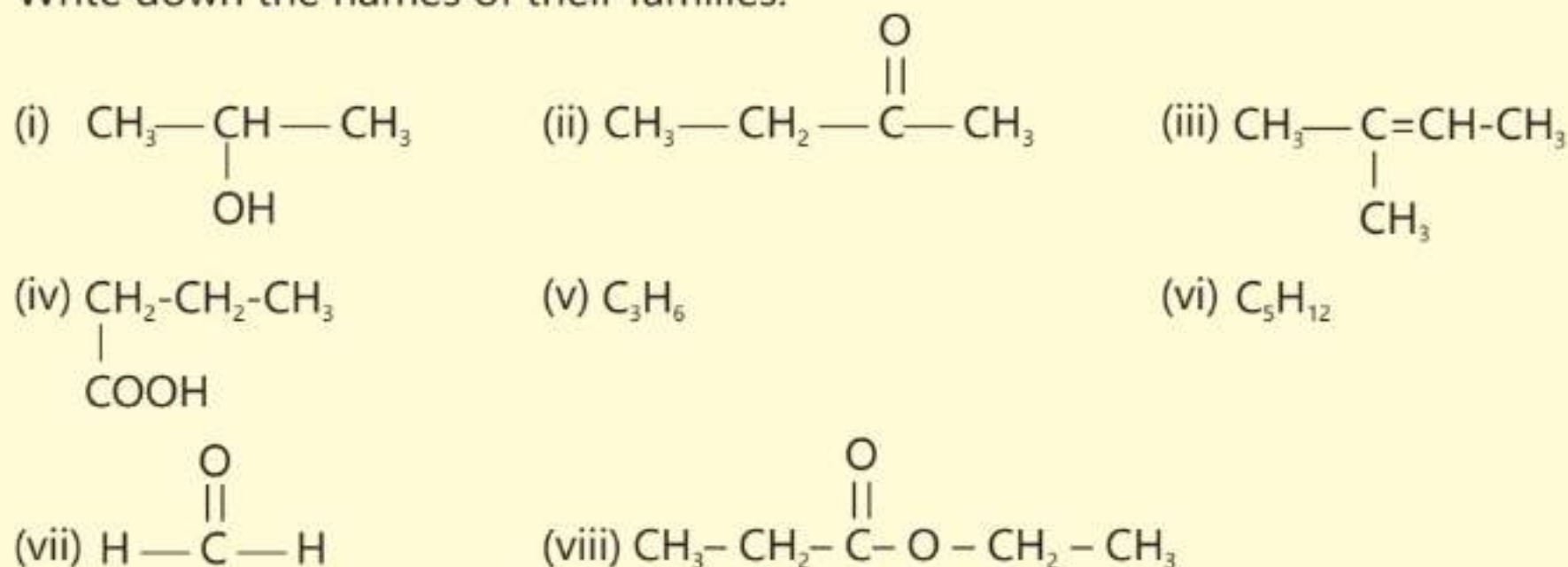
Common and IUPAC names of esters are shown in Table 21.6.

**Table 21.6 Common Names of some Esters**

Esters	CH <sub>3</sub> COOCH <sub>3</sub>	CH <sub>3</sub> COOCH <sub>2</sub> CH <sub>3</sub>	HCOOCH <sub>2</sub> CH <sub>3</sub>
Common Name	Methyl acetate	Ethyl acetate	Ethyl formate
IUPAC Name	Methyl ethanoate	Ethyl ethanoate	Ethyl methanoate
Esters	CH <sub>3</sub> CH <sub>2</sub> COOC <sub>2</sub> H <sub>5</sub>	CH <sub>3</sub> CH <sub>2</sub> COOCH <sub>3</sub>	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> COOCH <sub>3</sub>
Common Name	Ethyl Propionate	Methyl Propionate	Methyl butyrate
IUPAC Name	Ethyl propanoate	Methyl propanoate	Methyl butanoate

## 21.6 Quick Check!

- Condensed structural formulae of some organic compounds are given below. Write down the names of their families.



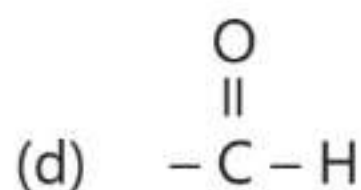
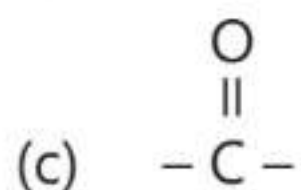
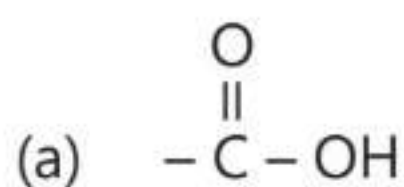
## EXERCISE

### A Multiple Choice Questions

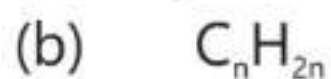
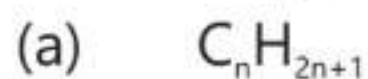
Choose and tick the correct answer from the given choices.

1. Choose the correct IUPAC name for the compound  $\text{HC} = \text{CH}_2 - \text{CH}_2 - \text{CH}_3$ .
- (a) But-3-ene      (b) But-1-ene  
(c) But-2-ene      (d) Butene
2. Select a branched chain compound.
- (a)  $\text{CH}_2 = \text{CH} - \text{CH}_2 - \text{CH}_3$       (b)  $\text{CH}_2 = \underset{\text{CH}_3}{\text{C}} - \text{CH} - \text{CH}_3$   
(c)  $\text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_3$       (d)  $\text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3$
3. Which is the displayed formula of ethanol?
- (a)  $\text{C}_2\text{H}_5\text{OH}$       (b)  $\text{CH}_3 - \text{CH}_2 - \text{OH}$   
(c)  $\text{H} - \underset{\text{H}}{\overset{\text{H}}{\text{C}}} - \underset{\text{H}}{\overset{\text{H}}{\text{C}}} - \text{OH}$       (d)  $\text{H} - \underset{\text{H}}{\overset{\text{H}}{\text{C}}} - \underset{\text{H}}{\overset{\text{H}}{\text{C}}} - \text{O} - \text{H}$

4. Identify the aldehydic functional group among the following:



5. Select the general formula of alkyne family.



6. How many structural isomers will be there for a saturated hydrocarbon having five carbon atoms?

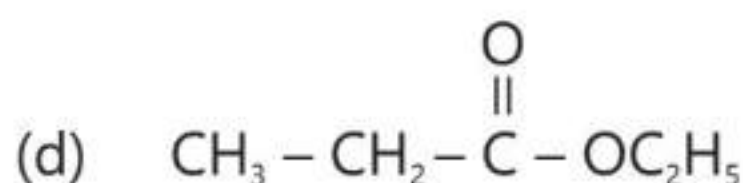
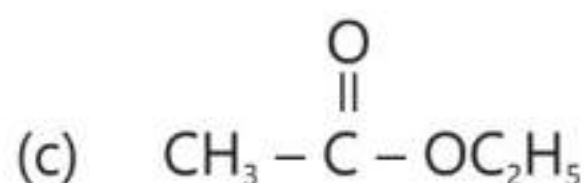
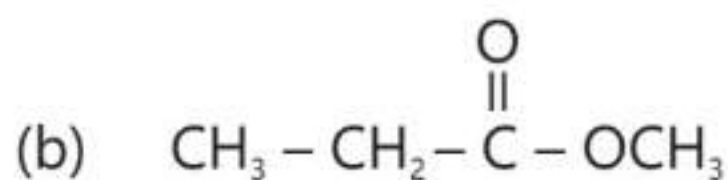
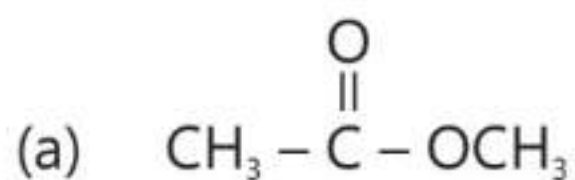
(a) 2

(b) 3

(c) 4

(d) 5

7. Which ester among the following will be called ethyl propanoate?



8. Which functional group is present in alkenes?

(a) No functional group

(b) Carbon-carbon triple bond

(c) Carbon-carbon double bond

(d) Carbon-carbon single bond

## B Short Answer Questions

21.1 What is the difference between saturated and unsaturated hydrocarbons?

21.2 Write down the structural formula of Butan-2-ol.



- 21.3 Why is ethylamine  $\text{CH}_3 - \text{CH}_2 - \text{NH}_2$  called an organic compound?
- 21.4 Write down the formula of an ester called ethyl methanoate.
- 21.5 Define structural isomerism.
- 21.6 Give IUPAC name to  $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3$
- 21.7 What is common in carboxyl group, amide functional group and ester functional group?

### **C** Constructed Response Questions

- 21.1 Why the members of a homologous series have similar chemical properties?
- 21.2 How are the properties of 2-methylpropane different from n-butane, both containing the same number of carbon atoms?
- 21.3 Write down the structural formulae of isomers shown by saturated hydrocarbon containing five carbon atoms.
- 21.4 Write down the structural formulae of the isomers shown by butene.
- 21.5 Explain the difference among functional groups present in aldehyde, ketone and carboxylic acid.

### **D** Descriptive Questions

- 21.1 What is an organic compound? How organic compounds are classified based on the type of carbon chain present in them?
- 21.2 Explain structural formula giving examples.
- 21.3 Write down five characteristics of a homologous series.
- 21.4 Give IUPAC rules for naming alcohols.
- 21.5 Name the following compounds.
- $\text{CH}_3 - \text{CH}_2 - \text{CH}_2\text{OH}$
  - $\text{CH}_3 - \text{CH}_2 - \text{CHO}$
  - $\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{COOH}$
  - $\text{CH}_3 - \text{CH}_2 - \text{CO} - \text{O} - \text{CH}_3$



## Student Learning Outcomes

### After studying this chapter, students will be able to:

- State that the bonding in alkenes includes a double carbon-carbon covalent bond and that alkenes are unsaturated hydrocarbons.
- Describe the manufacture of alkenes by the cracking of large alkane molecules using a high temperature and a catalyst.
- Describe the reasons for the cracking of large alkane molecules.
- Describe the test to distinguish between saturated and unsaturated hydrocarbons by their reaction with aqueous bromine and  $\text{KMnO}_4$ .
- Describe the properties of alkenes in terms of addition reactions with:
  - o bromine or aqueous bromine
  - o hydrogen in the presence of a nickel catalyst
  - o steam in the presence of an acid catalyst and draw the structural or displayed formulae of the products
- Describe, using symbol equations, preparation of alkenes by elimination reaction in halogenoalkanes and alcohols.
- Identify alkynes as hydrocarbons containing triple carbon-carbon covalent bond and that alkynes are unsaturated hydrocarbons.
- Describe the use of ethyne as fuel for welding and in artificially ripening fruits.
- Describe separation of petroleum into useful fraction by fractional distillation.
- Describe how the properties of fractions obtained from petroleum change from the bottom to the top of the fractionating column, limited to:
  - o decreasing chain length
  - o higher volatility
  - o lower boiling points
  - o lower viscosity
- Name the uses of the fractions as:
  - o refinery gas fraction for gas used in heating and cooking
  - o gasoline/petrol fraction for fuel used in cars
  - o naphtha fraction as a chemical feedstock
  - o kerosene /paraffin fraction for jet fuel
  - o diesel oil/ gas oil fraction for fuel used in diesel engines.
  - o fuel oil fraction for fuel used in ships and home heating systems
  - o lubricating oil fraction for lubricants, waxes and polishes
  - o bitumen fraction for making roads
- Name fossil fuels; coal, natural gas and petroleum
- Name methane as main constituent of natural gas
- State that petroleum is a mixture of hydrocarbons, compounds containing hydrogen and carbon only

## 22.1 Alkenes

Alkenes are unsaturated hydrocarbons containing one or more carbon-carbon double bond. They are also called olefins. General formula for alkenes is  $C_nH_{2n}$ . They are known for their unique physical and chemical properties. They are widely used in the synthesis of various products, like plastics and fuels.

### Preparation

Alkenes may be prepared either by dehydration of alcohols or dehydrohalogenation of alkyl halides. Dehydration means removal of water molecule while in dehydrohalogenation a molecule of hydrogen halide (HX) is removed from a molecule of alkyl halide. Alkenes can also be prepared by cracking of Alkanes.

#### 1. By Dehydration of Alcohols

Dehydration of alcohols is carried out with a dehydrating agent like concentrated sulphuric acid.



#### 2. By Dehydrohalogenation of Alkyl Halides

Dehydrohalogenation of alkyl halides is done with potassium hydroxide dissolved in ethanol.



This is an example of Elimination reactions. These reactions occur when a molecule is removed from a saturated compound to produce an unsaturated compound.

#### Interesting Information

Alkenes occur abundantly in nature. Ethylene, for example, is a plant hormone that induces ripening in fruit. An alkene  $\beta$ -carotene is an orange pigment responsible for the colour of carrots.



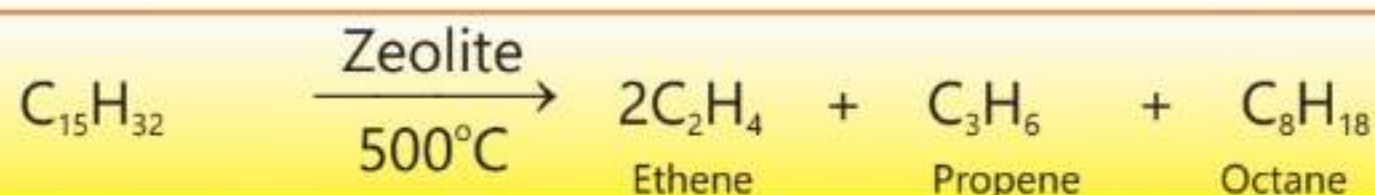
#### 3. By Cracking of Alkanes to Alkenes

Cracking is a process which is carried out to convert high molecular mass alkanes to lower alkanes and alkenes. The process is carried out by heating

alkanes at high temperature in the absence of oxygen and in the presence of zeolites as catalysts.

Cracking is important commercially because it produces smaller alkanes which are useful as fuel as well as alkenes (ethene and propene) which are useful starting materials to produce many commercially important chemicals.

For example, kerosene oil and diesel oil which contain higher molecular mass alkanes are often cracked to give petrol, alkenes and hydrogen gas.

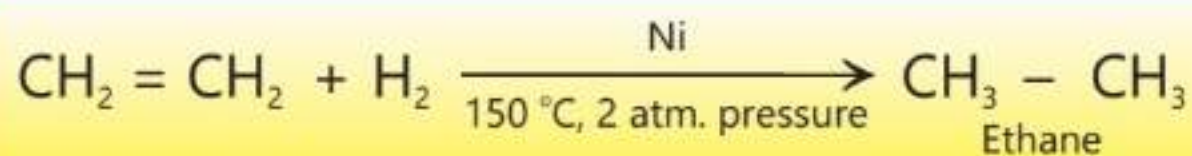


## 22.2 Important Reactions of Alkenes

Alkenes are very reactive compounds. Their chemical reactivity is due to the presence of a carbon-carbon double bond. They undergo addition reactions. Addition reactions are those reactions in which reactants combine to form a single new product.

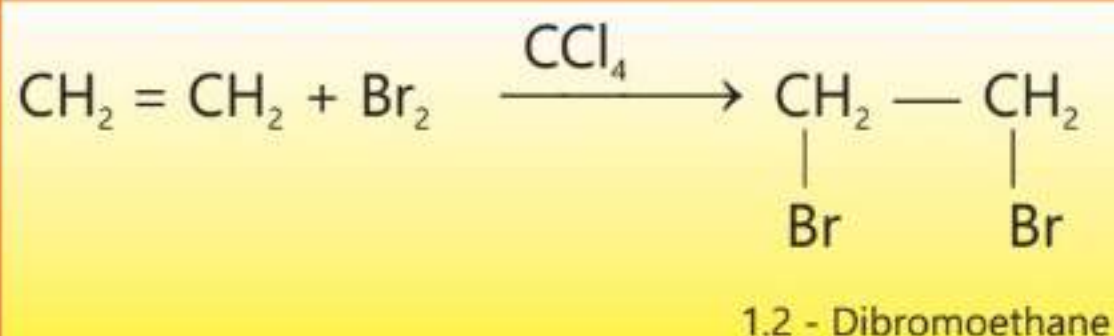
### 1. Addition of Hydrogen

Hydrogen is added to alkenes in the presence of nickel metal as a catalyst to give alkanes as the products. This reaction is called catalytic hydrogenation or catalytic reduction.



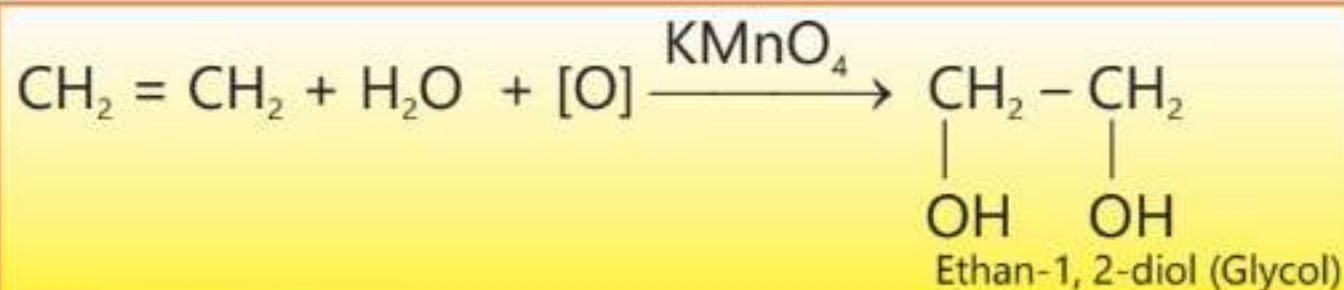
### 2. Addition of Halogens

Halogens are readily added to alkenes in the presence of a non-polar solvent to give alkyl dihalides.



### 3. Oxidation with $\text{KMnO}_4$

Alkenes can also react with cold and dilute alkaline potassium permanganate to give an important compound called ethylene glycol or ethane-1,2-diol.



Both halogenation and oxidation reactions may be used to detect the presence of an alkene. The reddish brown colour of bromine or purple colour of potassium permanganate is rapidly discharged when either of two reacts with an alkene. Similarly alkenes also discharge the violet colour of iodine.

These reactions are not given by saturated compounds or alkanes. Thus they are used to distinguish between saturated and unsaturated compounds (alkenes).

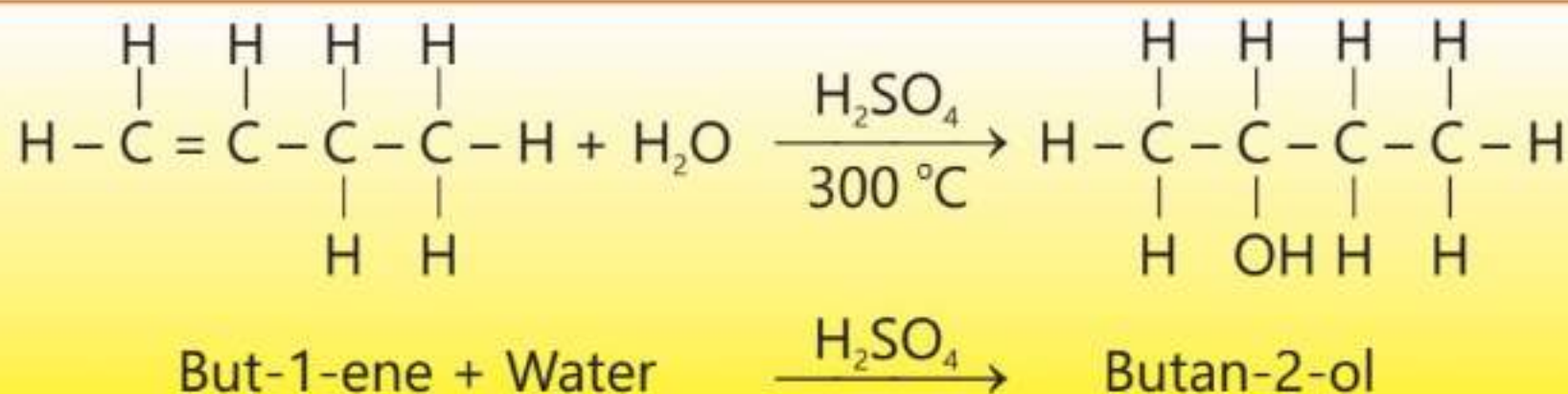
### 4. Addition of Hydrogen Halides

Like halogens, hydrogen halides can also be added to a double bond of an alkene. These reactions are known as hydrohalogenation of alkenes.



### 5. Addition of Water (Steam)

Alkenes react with water in the presence of sulphuric acid. The reaction takes place at around  $300^\circ\text{C}$ . This is also called hydration reaction.

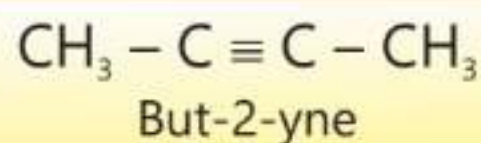
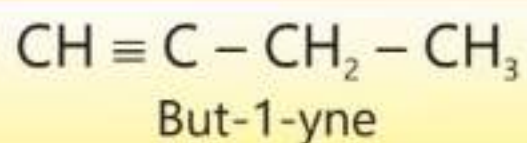
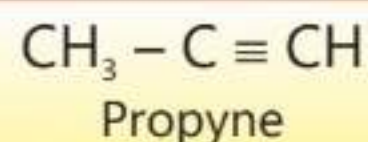
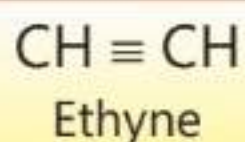


## 22.3 Alkynes

Alkynes are unsaturated hydrocarbons which contain at least one  $-\text{C} \equiv \text{C}-$  bond. They are represented by the general formula  $\text{C}_n\text{H}_{2n-2}$ . Just like alkenes,



alkynes are also named by counting the number of carbon atoms present in the longest continuous chain that contains the triple bond.



The simplest unsaturated hydrocarbon containing a triple bond is called ethyne or acetylene gas. It is commonly used for welding and cutting purposes because it produces a large amount of heat when it is ignited in the presence of oxygen or air.



Figure 22.1: Acetylene torch



In the acetylene torch, acetylene gas burns in oxygen to produce  $\text{CO}_2$  and  $\text{H}_2\text{O}$ . The high temperature of the oxy-acetylene flame speeds up the cutting and welding processes.

Acetylene gas is also used for ripening of green fruits. When solid calcium carbide reacts with moisture present in the air it produces acetylene gas which accelerates the ripening of the green fruits and induces a colour change.

#### Do You Know?

The use of calcium carbide in our country is prohibited because it is known to cause serious health problems like dizziness, vomiting and skin ulcer.

## 22.4 Sources of organic compounds

Organic compounds can be obtained from many sources. Coal, petroleum and natural gas are, however, three major sources of organic compounds. Natural gas and petroleum are chief sources of aliphatic hydrocarbons while coal is a major source of aromatic hydrocarbons. Natural gas is a mixture of many hydrocarbon gases, with methane ( $\text{CH}_4$ ) being the largest component.





**Petroleum:** Petroleum and natural gas are mostly found together, held between the layers of non-porous rocks underground. When a well is drilled through the rock, the gas is released carrying with it some of more volatile liquids. After the flow of gases ceases, the liquid petroleum is then taken out with the help of pumps.

Liquid petroleum is a complex mixture of mainly aliphatic hydrocarbons. It has been estimated that when petroleum is boiled upto  $400^{\circ}\text{C}$ , at least 500 compounds can be obtained.

Although the principal products of petroleum refining are various types of fuels, yet a large number of other important chemicals can also be produced from these fuels. For example, petroleum products produce alkenes which are starting material to prepare plastics. Similarly, benzene, an aromatic hydrocarbon, may be produced from n-hexane. Benzene may be used to produce thousands of useful aromatic compounds like perfumes, drugs, dyes and photographic developers etc.

## 22.5 Refining of Petroleum

Petroleum in a crude state is a mixture of many hydrocarbons which do not burn easily. To make it useful, petroleum must be separated into different fractions by a process called refining of petroleum.

Refining process involves the fractional distillation of petroleum at about  $400^{\circ}\text{C}$  whereby it is separated into many useful fractions.

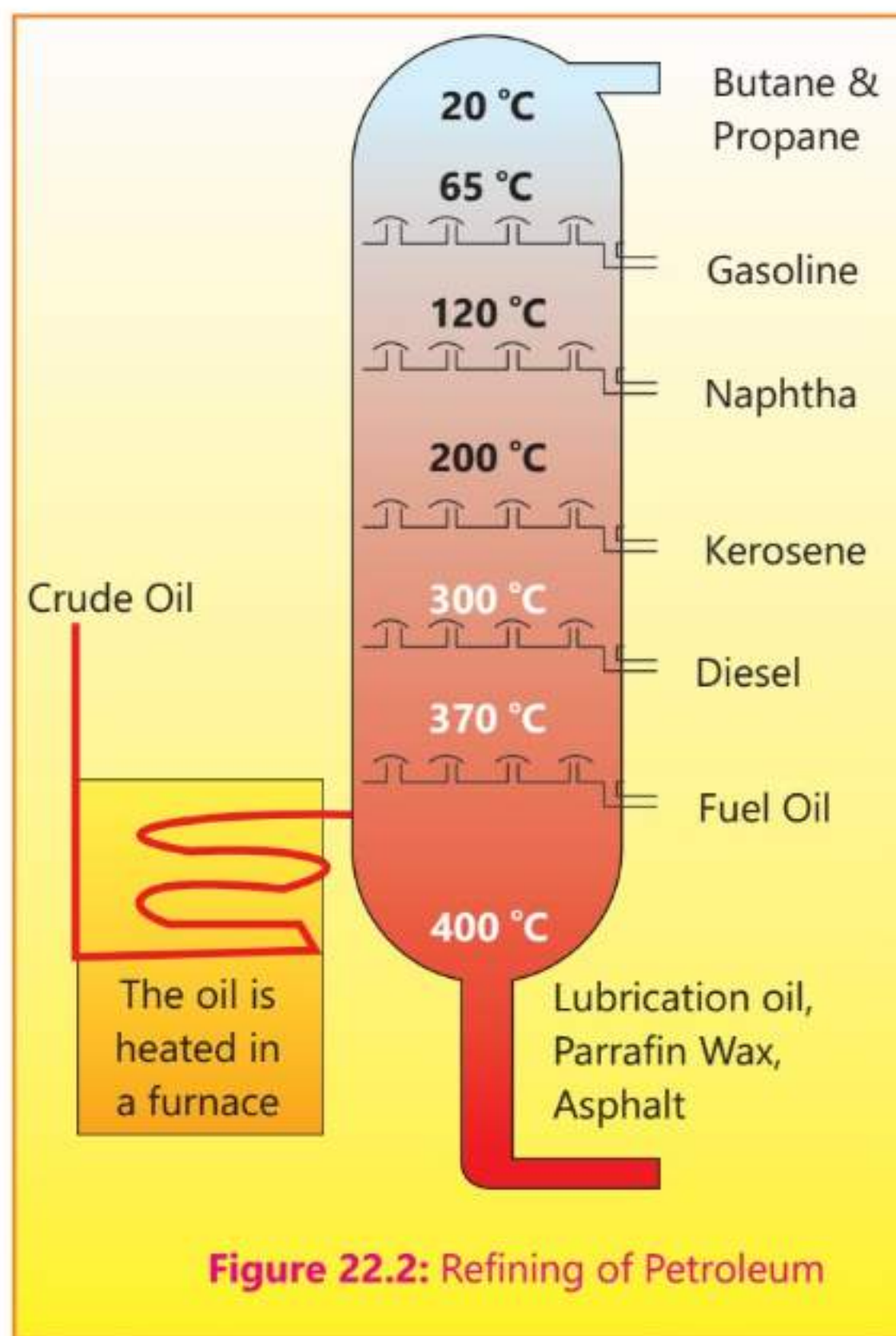
The first step in the refining process is neutralization of the crude oil by washing with acidic or basic solution as required. The neutralized oil is then heated in an electric furnace above  $400^{\circ}\text{C}$  and the resulting gases and vapours are allowed to pass into a tall fractionating column as shown in the Figure, 22.2. The column has a number of compartments divided into shelves having holes in them. These holes are covered with bubble caps.

When the oil is heated, the dissolved gases known as the refinery gases first go at the top of the fractionating column and escape there from the outlet shown in the Figure, 22.2. As the temperature rises, the vapour start going up in the column where the hydrocarbon fractions which have high boiling points are





easily condensed to liquids in the lower part of the column. The fraction which have lower boiling point ranges rise up near the top of the column as vapours, which are then condensed into liquid state. These condensed liquid fractions are collected on the various shelves from where they can be drained off into separate storage tanks. The fractions thus separated are not without impurities from the other fractions. They are then redistilled to have a better separation of hydrocarbons. Various fractions obtained in this process along with their boiling ranges are shown in the Table (22.1). The table gives the detailed information about the petroleum fractions and their uses for a variety of purposes.



**Table 22.1: Fractions of petroleum and their uses.**

Name of the Fraction	Appropriate boiling range (°C)	Range of carbon atoms in each Fraction	Uses
Refinery gases	Below 0	1-4	Refinery gases are liquified and sold as fuels for stoves
Gasoline (petrol)	0-65	5-6	Used to drive automobiles
Naphtha	65-170	6-10	It is used as source of many useful hydrocarbons
Kerosene oil	170-250	10-14	It is a fuel used in jet engines.
Diesel oil	250-340	14-19	Used to run cars, buses and trucks



Name of the Fraction	Appropriate boiling range (°C)	Range of carbon atoms in each Fraction	Uses
Lubricating oil	340-500	19-35	Used in cars, buses and truck as lubricant, waxes and polishes
Fuel oil	340-500	Above 20	Used in ships and to run power plants
Bitumen	Above 500	Above 35	Used to construct roads and to water proof roofs and pipes.

## 1. Physical Properties of different Petroleum Fractions

Each petroleum fraction contains a mixture of hydrocarbons. They have similar physical properties which depend upon the following factors:

1. Number of carbon and hydrogen atoms present in the molecule of a fraction.
2. Volatility
3. Boiling point range
4. Viscosity

As the number of carbon and hydrogen atoms in the molecule of a hydrocarbon increases so does their molecular masses. This changes the strength of intermolecular forces between the molecules. Higher the molecular mass of a hydrocarbon stronger the intermolecular forces between its molecules. This fact affects the physical properties of hydrocarbons as well. Lower hydrocarbons have high volatility, low boiling points and lower viscosities. As the chain length increases their properties also show upward trends. So the fractions of the petroleum obtained at the top of the column have high volatilities, lower boiling ranges, lower viscosities and they are highly inflammable.



## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

1. Which of the following compounds is expected to give addition reaction?

- (a)  $\text{CH}_3 - \text{CH}_3$  (b)  $\text{CH}_2 = \text{CH}_2$   
(c)  $\text{CH}_4$  (d)  $\text{CH}_3 - \text{CH}_2 - \text{CH}_3$

2. Which of the followings is not used as a fuel?

- (a) LPG (b) CNG  
(c) Diesel (d) Asphalt

3. Indicate the type of the following reaction.



- (a) Substitution (b) Oxidation  
(c) Reduction (d) Addition

4. Which species acts as a reducing agent in the reaction between ethene and  $\text{KMnO}_4$ ?

- (a)  $\text{H}_2\text{O}$  (b)  $\text{CH}_2 = \text{CH}_2$   
(c)  $\text{KMnO}_4$  (d)  $\text{NaOH}$

5. The product which will be formed when propene reacts with bromine molecule.

- (a) 1,2-Dibromopropane (b) 1,1-Dibromopropane  
(c) 2,3-Dibromopropane (d) 1,3-Dibromopropane

6. Select the name of the petroleum fraction which generates electricity in power plants.


- (a) Bitumen (b) Lubricating oil  
(c) Kerosene oil (d) Fuel oil

7. The molecule eliminated in the following reaction is:



- (a)  $\text{Br}_2$  (b)  $\text{H}_2$   
(c)  $\text{HBr}$  (d)  $\text{H}_2\text{O}$



- 
8. Fractional distillation of petroleum is based on:
- (a) Viscosity (b) Boiling point range  
(c) Flammability (d) Melting point range

## **B** Short Answer Questions

- 22.1 Give two examples of addition reactions.
- 22.2 Give the names of the compounds obtained from coal tar and petroleum.
- 22.3 How ethene is oxidized by cold aqueous solution of potassium permanganate.
- 22.4 Differentiate between elimination and addition reactions.
- 22.5 Name the starting materials used to generate oxyacetylene flame:
- 22.6 How can an alkene be identified?

## **C** Constructed Response Questions

- 22.1 What is the difference between the terms dehydration and dehydrohalogenation?
- 22.2 You have got two test tubes A and B containing a saturated and unsaturated compound (Alkene). How will you identify the two?
- 22.3 Why is oxyacetylene flame so hot?
- 22.4 Do you expect ethyne to decolourize a cold solution of  $\text{KMnO}_4$ ?
- 22.5 How do chlorine and hydrogen chloride add to ethene?

## **D** Descriptive Questions

- 22.1 Describe two methods of preparation for ethene.
- 22.2 Describe the fractional distillation of petroleum.
- 22.3 Which properties of petroleum fractions change with their boiling points?
- 22.4 Explain with examples the cracking of alkanes.
- 22.5 Give uses of acetylene.

# Monohydroxy Alkanes or Alcohols

## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Describe the manufacture of ethanol  
(This can be done by discussing fermentation of aqueous glucose at 25-35 °C in the presence of yeast and in the absence of oxygen catalytic addition of steam to ethene at 300°C and 6000kPa /6 atm in the presence of an acid catalyst including a comparison of the advantages and disadvantages of the two methods)
- Describe the combustion of alcohols
- Discuss the applications of alcohols as fuels, including their advantages and disadvantages over fossil fuels.
- Explain the role of alcohols in various industries such as pharmaceuticals, cosmetics, and fuel production.
- Discuss the impact of alcohols on daily life, including their use as solvents and disinfectants.





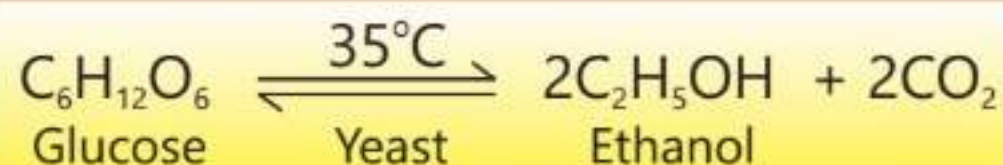
Monohydroxy alkanes or alcohols are an important class of organic compounds. Some of these alcohols can be obtained by the reactions in which living organisms are used as catalysts. They can also be synthesized in the laboratory.

Ethyl alcohol or ethanol is a very important member of this homologous series. It is manufactured on large scale by the following processes:

## 23.1 Manufacture of Ethyl Alcohol ( $\text{CH}_3\text{-CH}_2\text{-OH}$ )

### Fermentation of Glucose by Yeast

Fermentation is a reaction in which a substance breaks down into simpler substances in the presence of enzymes present in yeast. Preparation of yogurt, bread and ethyl alcohol are some examples of the fermentation reactions. Glucose can be converted to ethyl alcohol in the presence of yeast at around  $35^\circ\text{C}$  and in a neutral or acidic solution. This fermentation reaction must be carried out in the absence of air (anaerobic conditions) to obtain ethanol. Yeast contains an enzyme which acts as a catalyst in this reaction. The balanced chemical equation for the fermentation of glucose is as follows:



Carbon dioxide gas comes out of the reaction mixture leaving behind a mixture of ethanol and water.

The temperature of the process must be kept around  $35^\circ\text{C}$  to get the maximum yield of the product. A lower temperature decreases the rate of the reaction whereas the higher temperature makes the enzyme inactive in anaerobic conditions. Oxygen is excluded from the reaction because it converts the resulting ethanol into ethanoic acid. Since ethanol is toxic to yeast in high concentration, yeast is made inactive when the concentration of ethanol in the reaction mixture exceeds 15%.



#### 23.1 Quick Check!

- What is the role of yeast in fermentation reaction?
- At which temperature enzymes present in yeast get inactive?

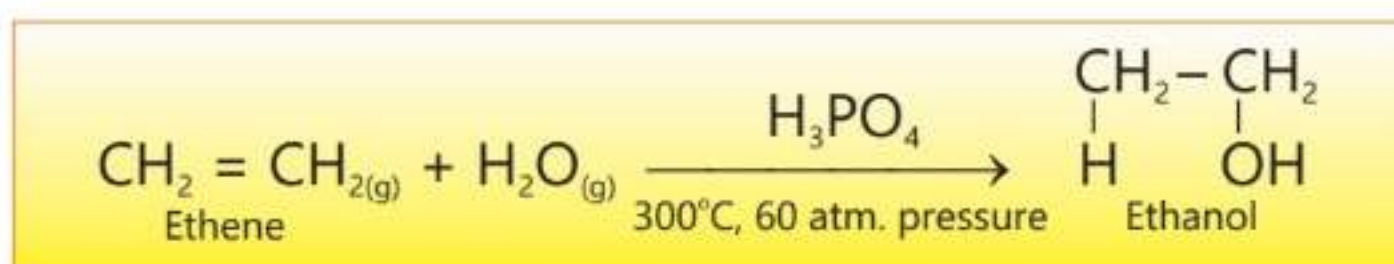




## Hydration of Ethene or Ethylene

Hydration of ethene is an addition reaction. In this reaction water is added across the double bond of the ethene. The reaction is carried out by passing a mixture of ethene and steam over hot phosphoric acid ( $\text{H}_3\text{PO}_4$ ), which acts as a catalyst.

Hydrogen atom of  $\text{H}_2\text{O}$  attaches itself to one carbon atom of ethene and the hydroxyl group to other atom. During this addition the double bond breaks down to give a saturated compound, ethanol.



Gaseous ethanol obtained is then condensed into its liquid form. Hydration of ethene is an important industrial process because ethanol is a versatile compound. It has a wide range of applications from alcoholic drinks to fuels and as a solvent.

A comparison of methods of production of ethanol is given in the following table 23.1.

**Table 23.1 Comparison of methods of production of ethanol**

Hydration of Ethene	Fermentation
Reaction is performed at high temperature and at high pressure.	It takes place at around $35^\circ\text{C}$ and at atmospheric pressure.
Starting material for the process is obtained from crude oil, which is a non-renewable source.	Starting material for this method is a renewable source, such as cane-sugar.
Rate of reaction is high.	Rate of reaction is low. It may take days to complete.
The reaction produces relatively pure alcohol.	The reaction produces 15% alcohol which needs further distillation to increase the concentration. Distillation requires energy.
Ethanol produced in this method is expensive.	Ethanol produced in this process is cheap.



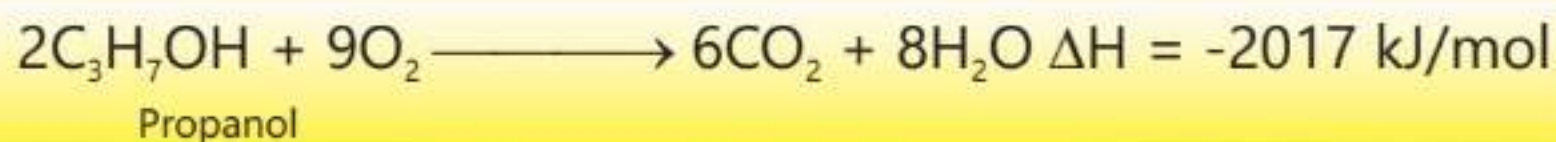
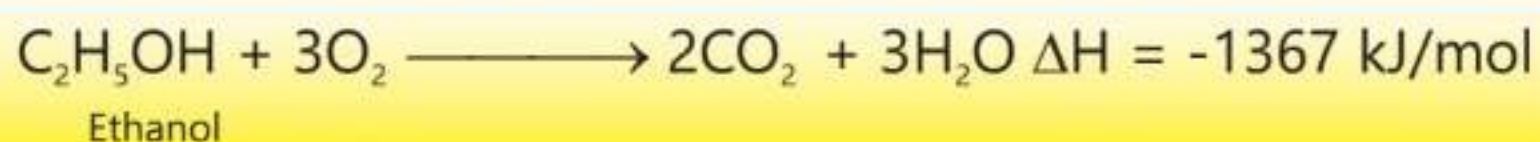
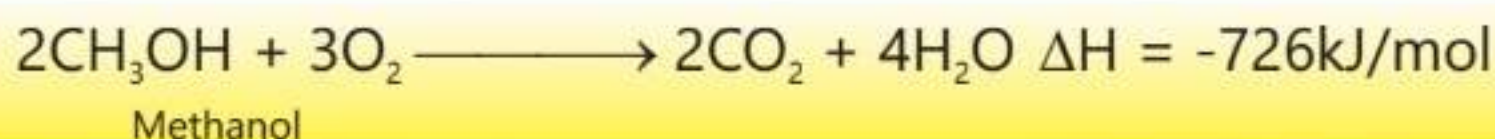


### 23.2 Quick Check!

1. Why oxygen is excluded when the fermentation reaction is carried out?
2. Which method for the preparation of ethene involves renewable source?

## 23.2 Combustion of Alcohols

Alcohols are flammable, therefore, burn in air to produce  $\text{CO}_2$  and  $\text{H}_2\text{O}$  evolving a large amount of heat. Methanol, ethanol and 1-propanol, all burn completely in excess of air because they contain a hydrocarbon chain. The balanced equations for the combustion of alcohols are given below:



During combustion of alcohols the weaker C-H bonds in  $-\text{CH}_2$  groups break and the stronger C=O and O-H bonds are formed in  $\text{CO}_2$  and  $\text{H}_2\text{O}$  respectively. This explains why the amount of heat evolved increases with the addition of a  $-\text{CH}_2$  group in the alcohol homologous series.

### 23.3 Quick Check!

Why does butanol evolve a higher amount of heat than propanol when burnt in oxygen?

## 23.3 Applications of Alcohols as Fuels

Alcohols are also used as fuels instead of petrol and diesel to run an automobile. The first four aliphatic alcohols namely methanol, ethanol, propanol and butanol have such properties which make them suitable to be used in internal combustion engines.



## Advantages of Alcohols as Fuels

1. Alcohols are obtained from renewable sources.
2. Burning of alcohols does not produce oxides of sulphur which makes them environmental friendly as compared to fossil fuels.
3. Alcohols have higher fuel efficiency as compared to petrol or diesel fuels.

### Interesting Information!

Alcohols are produced from plant materials which, in turn, are the result of the photosynthesis process using  $\text{CO}_2$  of the atmosphere. The same  $\text{CO}_2$  is generated when these bioalcohols are burnt in internal combustion engine. The overall process is considered to be carbon neutral because it does not increase the concentration of carbon dioxide gas in the atmosphere.

## Disadvantages of Alcohols as Fuels

1. Alcohols have less energy per volume than gasoline. It means more fuel is needed to travel the same distance.
2. Alcohols can increase wear and tear on engine components.
3. Land is utilized to grow crops which then yield alcohols. This fact affects the cultivation of food crops.

### 23.4 Quick Check!

1. Why does the amount of heat evolved during burning of alcohols go on increasing from lower to higher alcohols?
2. Why burning of alcohols does not produce oxides of sulphur unlike fossil fuels?

## 23.4 Role of Ethanol in Industries

### Pharmaceutical Industry

Ethyl alcohol serves as a very common ingredient in a variety of manufacturing processes in pharmaceutical industry. It possesses bactericidal activity and it is often used as a disinfectant in hand sanitizer and methylated spirit. It is also commonly used as a solvent and preservative in many pharmaceutical preparations including vaccines.

Ethanol and isopropanol are found as an active ingredient in certain oral and topical drug products. They help solubilize many drugs.

### Interesting Information!

Ethanol as a fuel reduces greenhouse gas emissions by 44 to 52% as compared to petrol. Besides this, ethanol also cuts down on other harmful pollutants like  $\text{CO}_x$ ,  $\text{NO}_x$  and particulate matter.





## Cosmetic Industry

Ethyl alcohol plays an important role in cosmetic industry because of its following properties:

1. Being highly volatile it evaporates in a very short time.
2. Deodorizing and anti-inflammatory properties.
3. Refreshing and antimicrobial properties.

Ethanol is an important part of such cosmetic and hygiene products as hair styling products, foundation creams, perfumes, deodorants and after shave lotions.

## 23.5 Impact of Alcohols on Daily life

Ethyl alcohol is an essential part of first aid kit in every home in the form of methylated spirit. Methylated spirit is used as an antiseptic, for dressing of wounds and as an antidote for snake bites. In many parts of the world, ethanol is used as high efficiency fuel to drive vehicles. Ethanol is widely used as a solvent in perfumes. It is relatively safe and can be used to dissolve many organic compounds which are insoluble in water.

### Do You Know?

Ethyl alcohol as a drink can cause hangover, alcohol poisoning, accidents and risky behaviour. Long-term use of alcohol is known to cause more than 200 different diseases.

## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

1. Which conditions are considered best for the fermentation of glucose?
  - (a) 35 °C, fresh yeast, absence of oxygen
  - (b) 45 °C, yeast
  - (c) 45 °C, absence of oxygen
  - (d) 35 °C, fresh yeast



2. Which catalyst other than  $\text{H}_3\text{PO}_4$  can also be used for hydration of alkenes?
- (a)  $\text{NaOH}$  (b)  $\text{H}_2\text{SO}_4$   
(c)  $\text{CH}_3\text{COOH}$  (d)  $\text{Ni}$
3. Alcohol which has the maximum heat of combustion is:
- (a)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$  (b)  $\text{CH}_3\text{CH}_2\text{OH}$   
(c)  $\text{CH}_3\text{OH}$  (d)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$
4. The most environment friendly fuel is:
- (a) coal (b) kerosene oil  
(c) ethanol (d) wood
5. Which property or properties of ethanol make it suitable to be used in cosmetic industry?
- (a) Easily Flammable  
(b) Highly volatile and deodorizing  
(c) Antipyretic  
(d) Sedative
6. Which is the correct name of the following alcohol:
- $$\begin{array}{ccccccc} \text{CH}_3 & - & \text{CH} & - & \text{CH}_2 & - & \text{CH} & - & \text{CH}_3 \\ & & | & & & & | & & \\ & & \text{OH} & & & & \text{CH}_3 & & \end{array}$$
- (a) 2-Methylpentan-4-ol (b) 4-Methylpentan-2-ol  
(c) Hexan-2-ol (d) Hexan-4-ol
7. Which property of ethanol makes it suitable for cleaning wounds?
- (a) Good solvent (b) Volatility  
(c) Antiseptic (d) Deodorizing
8. Which alcohol is used to accomplish all the following tasks:  
It is added in petrol to improve combustion. It serves as a feed stock to prepare vinegar and many other organic compounds.
- (a) Propanol (b) Propan-2-ol  
(c) Ethanol (d) Methanol





## **B** Short Answer Questions

- 23.1 Give two advantages of burning of alcohols over the burning of fossil fuel?
- 23.2 Which properties of ethyl alcohol make it useful for cosmetic industry?
- 23.3 How is ethyl alcohol important for pharmaceutical industry?
- 23.4 Give any two disadvantages of fermentation reactions.
- 23.5 Write the conditions involved in the hydration of ethene.

## **C** Constructed Response Questions

- 23.1 How ethanol is obtained as a by-product in sugar industry?
- 23.2 Why do we get relatively impure alcohol in the fermentation process?
- 23.3 How do properties of ethyl alcohol help us to utilize it as fuel?

## **D** Descriptive Questions

- 23.1 Give a comparison of fermentation reaction and catalytic hydration of ethene for the preparation of ethanol.
- 23.2 Describe the preparation of ethanol by fermentation process.
- 23.3 Describe the applications of ethanol in pharmaceutical and cosmetic industries?



# Carboxylic Acids

## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Describe the reactions of carboxylic acids with metals, bases and carbonates including names and formulae of the salts produced.
- Describe the formation of ethanoic acid by the oxidation of ethanol; with acidified aqueous potassium manganate (VII) & by bacterial oxidation during vinegar production
- Describe the reaction of a carboxylic acid with an alcohol using an acid catalyst to form an ester
- Describe the industrial applications of carboxylic acids and esters, including their use as solvents, flavours, fragrances, and plastics.
- Explain the role of carboxylic acids and esters in daily life, including their use in food preservation, cosmetics, and pharmaceuticals.



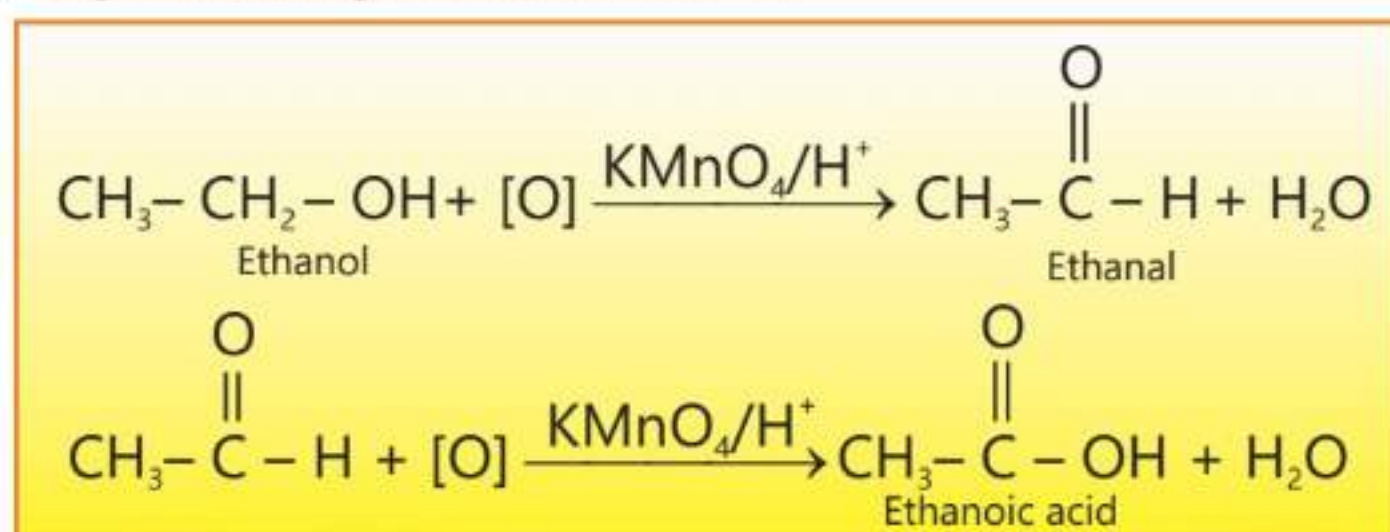
Organic acids or carboxylic acids are the class of organic compounds containing a carboxyl group (-COOH) attached to an alkyl group or hydrogen. They are generally weak acids as compared to the mineral acids because they do not give proton easily. They occur naturally in living organisms and they can also be synthesized.

## 24.1 Preparation of Acetic Acid or Ethanoic Acid

### Oxidation of Ethanol

Ethanol is oxidized by the acidified potassium manganate (VII) to first ethanal which then further undergoes oxidation under the reaction conditions to give ethanoic acid.

Hot acidified potassium manganate (VII) acts as a very efficient oxidizing agent and oxidizes ethanol to ethanoic acid and during this reaction the purple colour of the reagent changes to colourless.



### Preparation of Ethanoic acid by Oxidative Fermentation

Alcoholic foodstuffs like grain, malt, rice or potato mesh are converted to vinegar when they undergo fermentation reaction in the presence of bacteria. These bacteria can produce vinegar from alcoholic foodstuffs if sufficient oxygen is provided. The overall chemical reaction in this fermentation process is:



In this process, alcohol is fermented to vinegar in a tank provided with a continuous supply of oxygen. The liquid present in the tank is stirred continuously when the oxygen is bubbled through it. In this method, vinegar containing 15% ethanoic acid can be prepared in only 24 hours.





### 24.1 Quick Check!

1. Can you oxidize methanol with  $\text{KMnO}_4$  just like ethanol?
2. Explain the difference between a fermentation reaction and a chemical reaction.

## 24.2 Reactions of Carboxylic Acids as Acids

### Reaction with Metals

Generally carboxylic acids are much weaker acids than the mineral acids. However, some carboxylic acids react with more reactive metals rather slowly to give a salt evolving hydrogen gas. For example, dilute ethanoic acid reacts with magnesium metal to give magnesium ethanoate and hydrogen gas.



### Reaction with bases

Reactions of carboxylic acids with bases like metal hydroxides are simple neutralization reactions. Ethanoic acid reacts with sodium hydroxide to give sodium ethanoate and water.

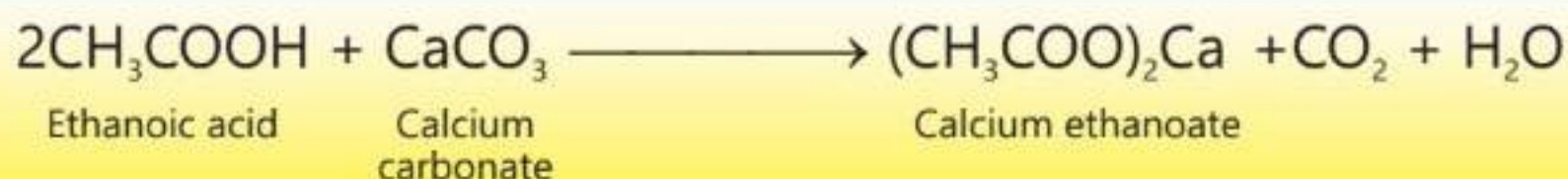


### Reaction of Carboxylic Acids with Carbonates

When solid sodium carbonate is mixed with an aqueous solution of ethanoic acid, effervescence takes place due to evolution of  $\text{CO}_2$  gas and sodium ethanoate is formed in the solution.

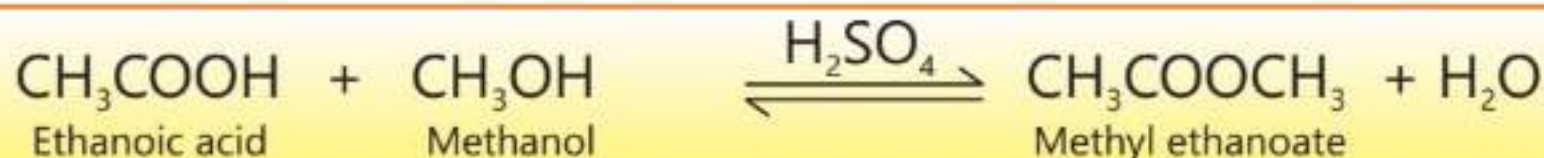
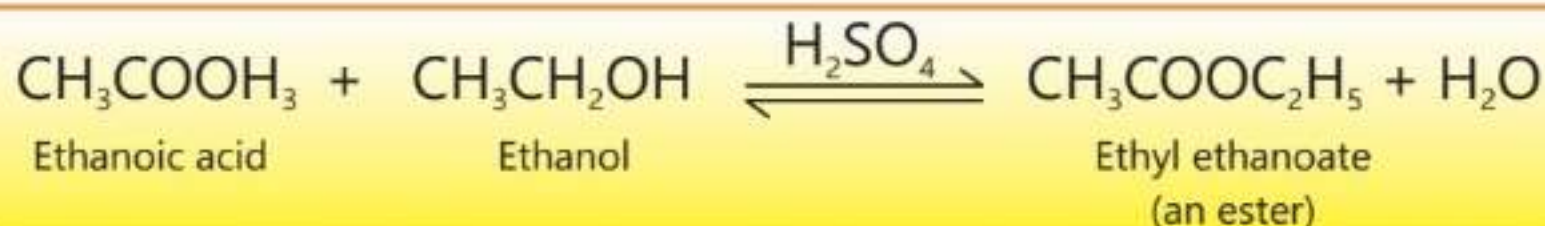


Reaction proceeds slowly with marble chips ( $\text{CaCO}_3$ ).



## 24.3 Reaction of Carboxylic Acids with Alcohols (Esterification)

Carboxylic acids form esters when they are heated with excess of alcohols in the presence of concentrated  $\text{H}_2\text{SO}_4$ , as a catalyst. Reaction is called esterification reaction.



### 24.2 Quick Check!

1. Is ethanoic acid a weak acid?
2. How will calcium carbonate react with ethanoic acid?

## 24.4 Industrial Applications of Carboxylic Acids and Esters

### Carboxylic acids and Esters as Solvents

Acetic acid dissolves many compounds such as oils, sulphur, iodine and water. In industry, acetic acid is used as a solvent for resins, paints and lacquers.

Esters are also commonly used as solvents. Ethyl acetate is used to extract caffeine from coffee. It is also used as nail polish and paint remover. Some volatile esters are used as solvents for coatings, paints, varnishes, plastics, resins and lacquers.

### Interesting Information

Pure acetic acid is also called glacial acetic acid. It is a corrosive and colourless solid, completely miscible with water.



### Carboxylic acids and Esters as Flavouring agents

Flavouring agents are substances added to give an additional taste or flavour to a substance. They also help in masking unpleasant tastes of drugs especially used by children. Organic acids like tartaric acid, citric acid and malic acid are very commonly used as flavour enhancers in food industry. The sour taste of foods is largely due to these acids. They are also responsible to improve the taste of some food and beverage products especially soft drinks.

Esters have pleasant odours and flavours. They are added to food





products to improve their smell or taste.

## Carboxylic Acid and Esters as Synthetic Fibers

Esters have also an important role to play in the production of synthetic polymers. A very important polymer, polyester is made by reacting diols and dicarboxylic acids. Esters are also important in the manufacture of soaps and detergents.

Carboxylic acids and their derivatives are very commonly used to give different types of plastics. For example, acetic acid is used in the production of cellulose acetate plastic. Palmitic and stearic acids are extensively used in the production of soaps, cosmetics, pharmaceuticals, candles and protective coatings. Oleic acid is used in the manufacture of soaps and detergents. Acrylic acid is a starting reagent to prepare many long-chain polymers called acrylates.



Figure 24.1: Uses of carboxylic acids in daily life

## 24.5 Carboxylic Acids and Esters in Daily Life

Food preservatives are chemical compounds which are added in food stuff to prevent or retard the growth of microorganisms, for example, benzoic acid, acetic acid, propionic acid and methyl and ethyl esters of 4-hydroxy benzoic acid. The presence of these preservatives helps to maintain the quality of food and extend shelf-life. The foods which are preserved include jams, juices, fruit juices, milk and many other drinks. Acetic acid is very widely used as preservative in pickles.



Figure 24.2: Jam, Juices and pickles





Carboxylic acids and the compounds obtained from them are very commonly used as medicines such as aspirin and ibuprofen. Addition of some carboxylic acids during preparation of medicines help to improve drug delivery, absorption, and overall performance.

Citric acid esters are primarily plasticizers which are used in many industries. Polymethyl methacrylate is used as a substitute of glass and it is named as Plexiglass.



**Figure 24.3:** Polyester



**Figure 24.4:** Plexiglass

Carboxylic acids occur in many common household fragrant items. A list of such items is given in the Table 24.1:

**Table 24.1 Carboxylic Acids in House hold items**

Item	Carboxylic Acid
Vitamin C	Ascorbic acid
Lemons	Citric acid
Vinegar	Acetic acid
Apple, grapes, carrots	Malic acid

Esters are an important component of many fruits and are responsible to enhance their flavours. They generally have a pleasant smell and they are commonly used as fragrances in many food products used in daily life. The following table shows the names of the esters and the flavours attached with them.

**Table 24.2. Esters and their Flavours**

Esters	Flavour
Methyl butyrate	Apple
Ethyl butyrate	Pine apple
n-Amyl acetate	Pears, Bananas
n-Octyl acetate	Orange
Methyl salicylate	Apricot

**24.3 Quick Check!**

- Explain the function of a preservative.
- Give examples of some citrus fruits.





## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

- Identify the ester functional group:  
(a)  $-\text{COOR}$  (b)  $-\text{COOH}$   
(c)  $>\text{C}=\text{O}$  (d)  $-\text{CH}_2-\text{OH}$
- During the oxidation of ethanol by acidified  $\text{KMnO}_4$ , which element is reduced?  
(a) K (b) O  
(c) Mn (d) H
- Fermentation of foodstuff in the presence of acetic acid bacteria needs a sufficient supply of oxygen. What is the role of oxygen in this process?  
(a) It enhances the reactivity of bacteria  
(b) It oxidizes ethanol which is formed during the reaction  
(c) It inhibits the destruction of bacteria  
(d) It inhibits the oxidation of acetic acid
- Which organic acid is used as a component of food?  
(a) Formic acid (b) Oxalic acid  
(c) Propanoic acid (d) Acetic acid
- Which of the following acids is present in apples?  
(a) Citric acid (b) Tartaric acid  
(c) Acetic acid (d) Malic acid
- Which substances will react to produce  $\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{COOC}_2\text{H}_5$ ?  
(a)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  and  $\text{CH}_3\text{OH}$   
(b)  $\text{CH}_3\text{CH}_2\text{COOH}$  and  $\text{CH}_3\text{CH}_2\text{OH}$   
(c)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  and  $\text{CH}_3\text{CH}_2\text{OH}$   
(d)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{COOH}$  and  $\text{CH}_3\text{OH}$
- What is the formula of ester formed by the reaction of methanol with propanoic acid?  
(a)  $\text{CH}_3\text{COOCH}_2\text{CH}_3$  (b)  $\text{CH}_3\text{CH}_2\text{COCH}_3$   
(c)  $\text{CH}_3\text{CH}_2\text{COOCH}_3$  (d)  $\text{CH}_3\text{CH}_2\text{OCOCH}_3$



8. Which polymer is made by reacting a diol and a dicarboxylic acid?

- (a) Polyethene (b) Polyester  
(c) Polystyrene (d) Polyamide

9. Which compound is used as a synthetic fiber?

- (a) Methyl acetate (b) Polyester  
(c) Resin (d) n-Amyl acetate

### **B** Short Answer Questions

24.1 What is an esterification reaction?

24.2 Name an oxidizing agent used to oxidize alcohols.

24.3 Why sufficient oxygen is provided during fermentation to prepare acetic acid from ethanol?

24.4 What is the role of carboxylic acids in the preparation of beverages?

24.5 Give a practical example in which an acid or an ester is used as a flavouring agent.

24.6 Which carboxylic acids are very often used as flavour enhancers?

24.7 Which property of acetic acid does make it suitable to act as preservative in pickle?

### **C** Constructed Response Questions

24.1 How does ethanol react with propanoic acid?

24.2 How does acetic acid react with Mg and  $\text{MgCO}_3$ ?

24.3 How carboxylic acids are used as solvents?

24.4 How carboxylic acid are used in daily life?

### **D** Descriptive Questions

24.1 Explain fermentation reaction which is used to prepare acetic acid on commercial scale.

24.2 Describe the industrial applications of carboxylic acids and esters.

24.3 What are flavouring agents? Which carboxylic acids are used as flavouring agents?

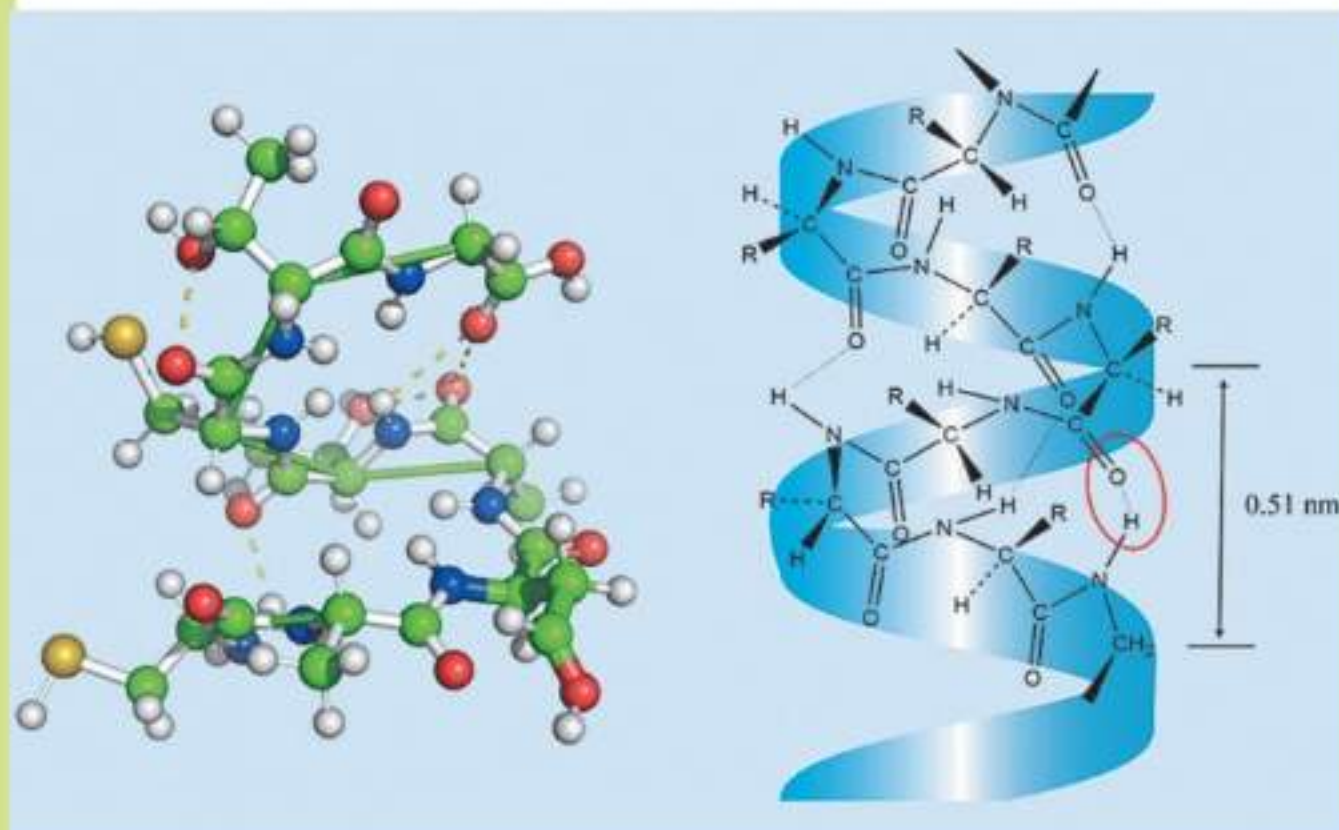
24.4 Explain the reactions of carboxylic acids with metals and carbonates.

24.5 Describe applications of esters in daily life.

## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Explain the importance and basics of nutrition and healthy eating
- Recognize the main biomolecules; carbohydrates, proteins, lipids and nucleic acids. their sources along-with the required daily intake for young adults
- Identify carbohydrates as a source of energy
- Describe proteins as natural polyamides and that they are formed from amino acid monomers with the general structure
- Draw the general structure of proteins
- Explain the sources, use and structure of proteins, lipids and carbohydrates
- Describe the importance of nucleic acids
- Explain vitamins, their sources and their importance to health
- Identify applications of biochemistry in testing (blood test, pregnancy test, cancer screening, parental genetic testing), genetic engineering, gene therapy and cloning





Biochemistry is the study of chemical substances which play a vital role in the processes taking place in living organisms.

Carbohydrates, lipids or fats and proteins are the three classes of foods which not only provide energy to human beings but are also responsible for their body structures. Lipids provide, on the average, twice as much energy as provided by carbohydrates or proteins.

Proteins are present in all living organisms. They form skin, hair, muscle, blood and almost all the organs of animals. They also play a very important role in all life processes.

Fats and oils come from a variety of natural sources like animals, plants and marine organisms. Animal fats are particularly located in tissues cells. Butter and ghee are a special type of animal fats which are made from milk.



### 25.1 Quick Check!

1. Which two functions are performed by proteins?
2. Is milk a fat, a protein or both?

## 25.1 The Importance of Nutrition

Nutrition is the study of the nutrients present in food and how they maintain a healthy body. Nutrients are the components of food that are needed on regular basis to maintain health and prevent diseases. A healthy human body needs the following nutrients.

### 1. Carbohydrates

They are the main source of energy for the human body. They also help body to use protein and fat efficiently.

A healthy adult needs 225 to 325 grams of carbohydrates per day for a standard 2000 calorie diet. However, individuals with higher activity levels may need more carbohydrates to meet their daily needs.


### 2. Lipids

They are also essential nutrients because they act as major energy reserves for our body. They also provide insulation and protection for vital organs of our body. A daily intake of fats for an adult is roughly between 44 to 78 grams.

### 3. Proteins

They also supply energy to our body. They are needed to build new cells and repair the injured ones. An adult should consume 60 grams of proteins per day.





## 4. Vitamins and Minerals

They help in growth, reproduction, the operation and maintenance of the body. A balanced diet rich in fruits, vegetables and grains can provide most of the vitamins and minerals needed daily.

### 25.1.1 Basics of Healthy Eating

The following are basics of healthy eating:

1. Consume a wide range of foods including fruits, vegetables, whole grains, lean proteins, and healthy fats.
2. They are full of nutrients which are required by our body.
3. Eat less and stay hydrated.
4. Reduce intake of saturated fats, sugar, and sodium.
5. Avoid eating processed and poor quality foods.

### 25.1.2 Healthy Eating

A healthy and balanced diet performs the following functions:

1. It prevents diseases like heart disease, diabetes, some cancers and osteoporosis.
2. Adequate nutrition provides fuel for healthy growth and development, leading to maintain a healthy weight.
3. A balanced diet can positively impact brain function and supports a strong immune system.

#### 25.2 Quick Check!

1. What is a balanced diet?
2. Name any three nutrients.

## 25.2 Carbohydrates

Carbohydrates are the most abundant naturally occurring compounds on earth. They contain the elements carbon, hydrogen and oxygen. Because of the sweet taste of some carbohydrates, they are commonly called "sugars". Apart from a number of hydroxyl groups, they also contain aldehyde or ketonic functional groups.

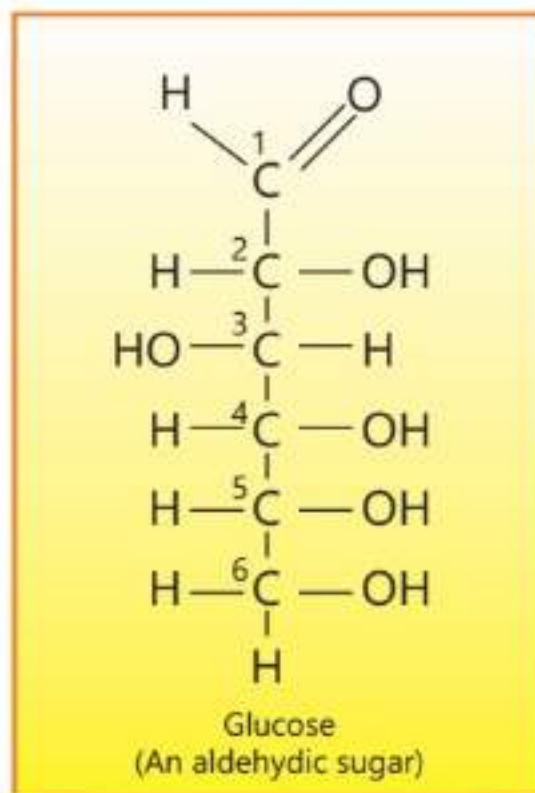
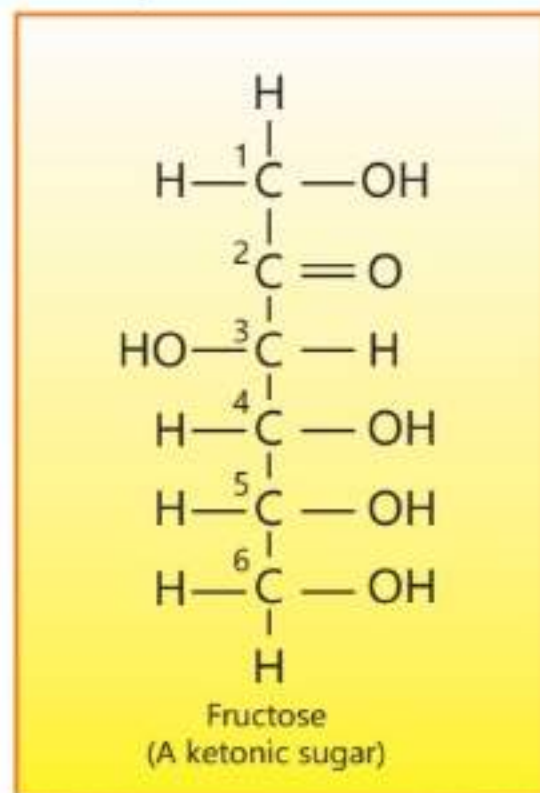
Carbohydrates can be classified into three groups (monosaccharide, oligosaccharides and polysaccharides) based on the difference in their properties.

Glucose, the most abundant carbohydrate, is also called grape sugar or

dextrose. It is present in fruits such as grapes, in honey and also in the sap of plants. It is the main source of energy for all animals and is thus present in their blood and urine.

Fructose is another carbohydrate which is present in sweet fruit juices and honey.

Both glucose and fructose have the same molecular formula,  $C_6H_{12}O_6$ . Their open chain structures are shown here.



### Interesting Information!

Acesulfame potassium is the most recently approved sweetener. It is used in soft drinks.



Sucrose, lactose and maltose are other important carbohydrates. All these carbohydrates have the same molecular formula  $C_{12}H_{22}O_{11}$ . Sucrose is present in sugar cane and sugar beets. Maltose is found in breads and other cereals while lactose is present in milk.

### Interesting Information

Lactose is widely used in baking and in commercial milk used for infants. Unlike sucrose, it is a reducing sugar.

Starch and cellulose are the two examples of important polymeric carbohydrates, they have a common formula  $(C_6H_{10}O_5)_n$ . Starch is found in foods like potatoes, rice and grains whereas cellulose sources include plant materials like wood, cotton etc.



### 25.3 Quick Check!

1. Name any two sources of starch.
2. Are all carbohydrates equally beneficial for our health?

### Interesting Information

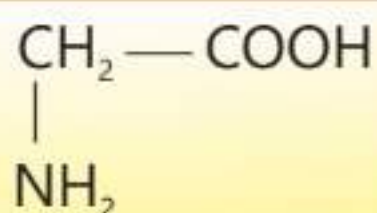
Glycogen is a carbohydrate that serves the same energy storage function in animals that starch serves in plants.



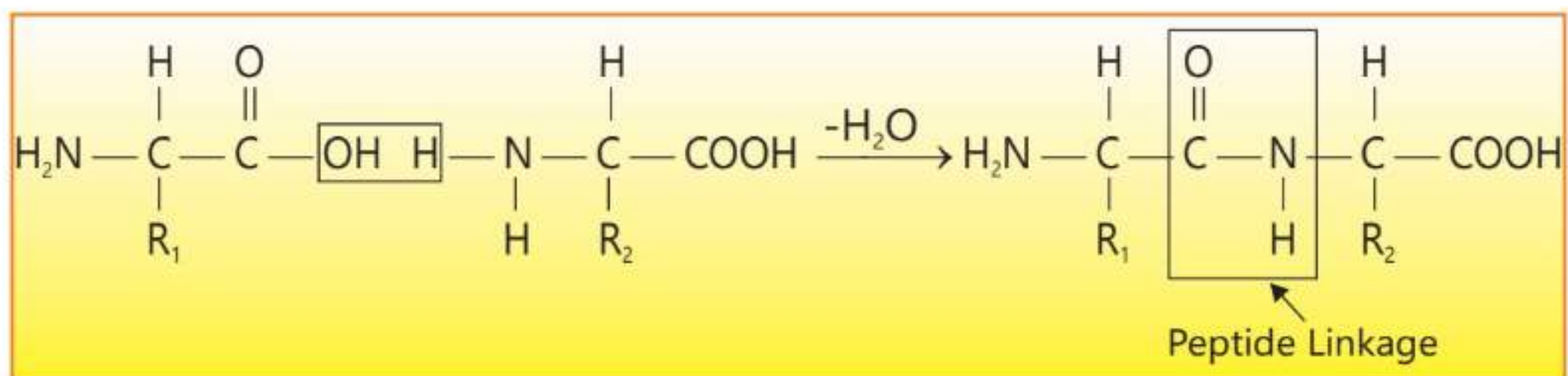
## 25.3 Proteins

Proteins are very large molecules containing C, H, O, N and sulphur atoms. The human body contains thousands of different type of proteins where they perform a large number of functions. There are fibrous proteins that are found in muscles, hair, nails, skin and connective tissues. Besides these, hormones and enzymes are also protein in nature. For example, the hormone insulin controls the level of sugar in the blood stream. Enzymes are the catalysts which speed up the biochemical reactions taking place in our body. Hemoglobin which carries oxygen in the blood stream and delivers to different parts of the body is also a protein.

Despite their wide range of functions, all proteins are formed by linking together molecules called amino acids. An amino acid has two functional groups, a carboxyl group - COOH and an amino group -NH<sub>2</sub>. The simplest amino acid is called glycine and its structural formula is:



Although the number of proteins present in the human body runs into thousands, they are all formed by linking together only twenty amino acids. The basic reaction which leads to the formation of long chains of proteins involves the elimination of water from two molecules of same or different amino acids.

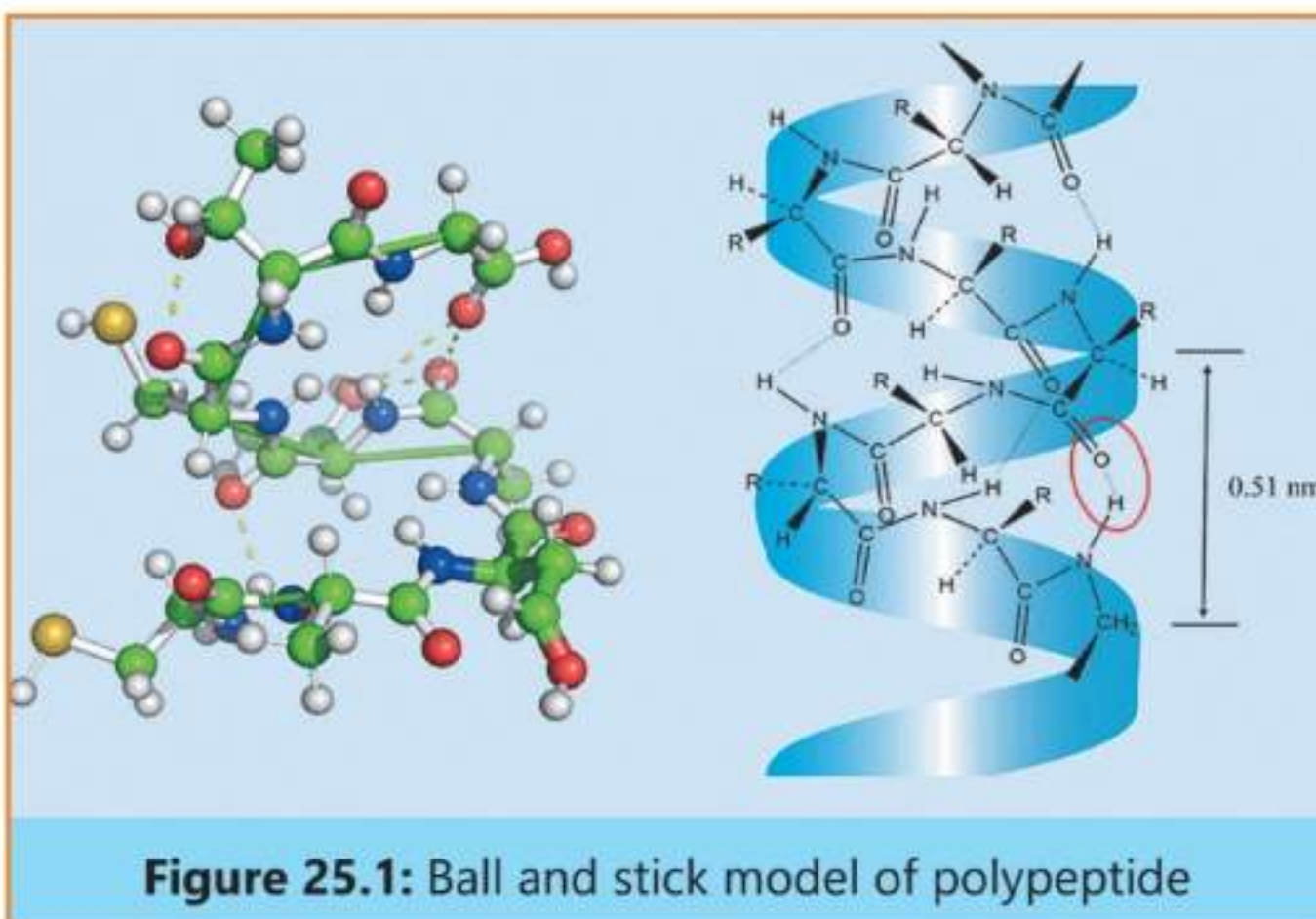


The molecule which is formed as a result of this reaction is called a peptide and it contains a peptide linkage as shown above. This peptide molecule has a carboxyl group and an amino group at its two ends. It is capable of reacting further with two molecules of amino acids to give ultimately a long chain composed of many acid molecules called a polypeptide. This polypeptide chain then undergoes twists and turns and assumes a three dimensional structure



shown in the following Figure 25.1.

Complex changes in proteins occur when they are subjected to heat, a change in pH or an attack by oxidizing and reducing agents. The phenomenon is called denaturation of proteins. A familiar example is the frying or boiling of an egg which involves the denaturation of egg albumin (protein), the principal component of egg white.



**Figure 25.1:** Ball and stick model of polypeptide

### Interesting Information!

Everyone, from infants to adult, needs protein. Children need large amounts of proteins for proper growth, and adults need protein to replace what is lost each day by the body's normal biochemical reactions.

### 25.4 Quick Check!

1. What are hormones made of?
2. What is denaturation of protein?

## 25.4 Lipids

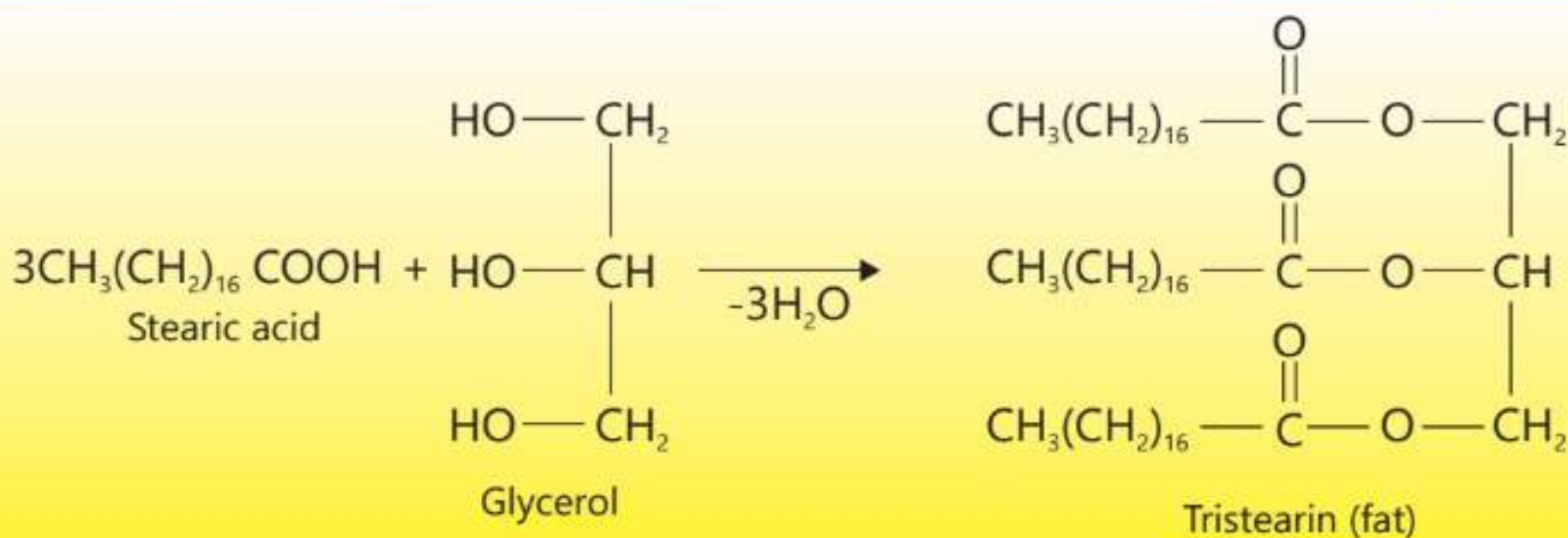
Most lipids are composed of simpler substances called fatty acids which serve as their building blocks. Fatty acids are long chain carboxylic acids containing from 12 to 28 carbon atoms. Examples of simple fatty acids along with their sources are as given in Table 25.1.

**Table 25.1 Some Simple fatty acids.**

Fatty acid	Source	Structure
Lauric acid	Coconut oil	$\text{CH}_3(\text{CH}_2)_{10}\text{COOH}$
Stearic acid	Animal fats	$\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$
Palmitic acid	Palm oil	$\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$
Oleic acid	Olive oil	$\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$

Fatty acids react with an alcohol called glycerol to give triester which are called fats. For example, stearic acid reacts with glycerol to form tristearin which is a fat. A triester of glycerol is also called triglyceride.





Animal fats are located particularly in adipose tissue cells whereas vegetable oils are present in seeds and roots of plants. Lipids mainly serve as energy rich source in animals.

### Interesting Information!

Soap has been known since at least 600BC when it was prepared by boiling goat fat with extracts of wood ash. The cleansing properties of soap did not become widespread until the 18<sup>th</sup> century. Chemically, soap is a mixture of sodium salts of the long chain fatty acids produced by hydrolysis of animal fat with alkali.

### 25.5 Quick Check!

1. What is the role of lipids in our body?
2. Which is an unsaturated fatty acid?

## 25.5 Vitamins

These are organic substances which do not directly serve the purpose of providing energy and building cells of our body like carbohydrates, lipids and proteins. They are, however, necessary to maintain normal health and growth of our body. These compounds are known to function as catalysts for the biological processes going on in our body. Since the first such compound discovered was an amine, so they were named vital amines or vitamins. Over the years, scientists have prepared 13 vitamins needed by the human body.

### Importance of Vitamins

Vitamin A is present in milk, egg, fish and liver and its deficiency causes night blindness and dry skin.

Vitamin D may be obtained from butter and fish liver oils. Our skin can also prepare vitamin D directly in the presence of sunlight. This vitamin is related to normal teeth and bone development and its deficiency causes a disease called





rickets.

Vitamin C, also called ascorbic acid, is found in citrus fruits, green pepper and tomatoes. Its deficiency in our body causes scurvy.

Vitamins B<sub>1</sub> and B<sub>2</sub> are distributed widely in nature. They are present in red meat, nuts and leafy vegetables. Deficiency of vitamin B<sub>1</sub> leads to fatigue and depression whereas lack of vitamin B<sub>2</sub> causes inflammation of the lips and dryness and burning of eyes.



### 25.6 Quick Check!

1. Which vitamin is present in lemon?
2. Compare the roles played by vitamins and carbohydrates in our body?

## 25.6 Nucleic Acids

Carbohydrates, proteins and fats together with water constitute about 99% of the most living organisms. The remaining 1% represents some compounds of vital importance which include two nucleic acids deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). These compounds are responsible for the existence, development and reproduction of all forms of life.

Both DNA and RNA are chemically similar compounds which play different roles within the cell. Molecules of DNA are very large as compared to those of RNA. A DNA molecule may have molecular mass of up to 660 Da and lengths of up to 12 cm when stretched out. They are mostly found in the nucleus of the cells. RNA molecules, on the other hand, are much smaller, (molecular mass 340 Da) and are mostly found outside the cell nucleus.

The function of DNA is to store information and pass it on to RNA, at the proper time. The function of RNA, in turn, is to read, decode and use the information to make proteins.



### 25.7 Quick Check!

1. What is the function of RNA?
2. What are the basic differences between DNA and RNA?

### Interesting Information!

Molecular mass of polymers are often expressed in millions or billions of Daltons (Da).

## 25.7 Applications of Biochemistry

### Blood Tests

Doctors use the blood tests to identify various health conditions including infections, diabetes, anemia, organ failure and much more. Basic blood





chemistry tests check the amount of electrolytes, fats, proteins, glucose and enzymes. These tests give important information about how well a person's kidneys, liver, and other organs are working.

## **Pregnancy Test**

A pregnancy test checks the urine or blood to see if a woman is pregnant or not. HCG is a hormone produced in the body when a woman gets pregnant. Doctors usually perform two tests to check pregnancy. Quantitative blood tests can measure the exact amount of HCG present in the blood. It can also give information about how far along the pregnancy has progressed.

## **Blood Test for Cancer Screening**

A specific type of blood test called the Galleri test is performed to detect cancer in early stages. It uses DNA sequencing to find the characteristic patterns which may tell whether a person is suffering from cancer or not.

## **Parental Genetic Testing**

Genetic tests are often performed by taking a sample of blood or saliva. Persons get genetic testing to know if they have genetic changes themselves or if they can pass on genetic changes to their children.

## **Genetic Engineering**

Genetic engineering is a method for changing an organism's genome. This can involve changing one single DNA base or can involve deleting or inserting a whole region of DNA. It is done to modify the genes to enhance the capabilities of the organism beyond what is normal. Plants can be made to fight diseases or pollution by changing them through genetic engineering.

## **Gene Therapy**

In gene therapy a doctor fixes a faulty gene or replaces it with a healthy gene in order to cure a disease or enable the body to fight the disease in a better way. This technique may be helpful in future to fight with a wide range of diseases like diabetes, AIDS, cancer and haemophilia.





## Cloning

Cloning describes the methods used to create an exact genetic replica of a cell, a tissue or the whole organism. The copied material is called a clone and it will have the same genetic characteristics as the original one.

### EXERCISE

#### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

- Functional groups present in fructose are:  
(a) Hydroxyl and aldehyde      (b) Hydroxyl and Ketone  
(c) Hydroxyl and ester      (d) Hydroxyl and amide
- Which functional group is present in a fat?  
(a) Carboxyl group      (b) Ester group  
(c) Carbonyl group      (d) Hydroxyl group
- Which function is not performed by proteins in our body?  
(a) They serve as chemical messengers.  
(b) They serve as storage of energy-rich fuel.  
(c) They store genetic information.  
(d) They serve as catalysts for biochemical reactions.
- Which functional groups react to produce a peptide linkage in proteins?  
(a) Carboxyl group and hydroxyl group  
(b) Carboxyl group and amino group  
(c) Hydroxyl group and amino group  
(d) Ester group and amino group
- The test performed to detect cancer in early stages is:  
(a) Genetic test      (b) Urine test  
(c) Galleri test      (d) Electrolyte test
- Fatigue and depression are caused by deficiency of:  
(a) Vitamin A      (b) Vitamin C  
(c) Vitamin D      (d) Vitamin B1





## **B** Short Answer Questions

- 25.1 What is the difference between glucose and fructose?
- 25.2 Give two examples of denaturation of proteins.
- 25.3 What are the sources of vitamin D?
- 25.4 What is the role of enzymes in our body?
- 25.5 Which commercial products are obtained from oils and fats?
- 25.6 Which vitamin helps in blood clotting?

## **C** Constructed Response Questions

- 25.1 What is the function of DNA?
- 25.2 Write down three important functions played by of proteins in our body.
- 25.3 Fatty acids serve as building blocks of lipids just like amino acids are for proteins. Comment on this statement.
- 25.4 Write down about the sources of vitamin C. Which diseases are caused by its deficiency?
- 25.5 Write down the names of two polymeric carbohydrates.

## **D** Descriptive Questions

- 25.1 What are the sources of fructose, maltose and lactose?
- 25.2 Draw open chain structures of glucose and fructose.
- 25.3 Construct peptide linkage and explain the structure of a polypeptide.
- 25.4 What are DNA and RNA? Describe the role played by them in our body.
- 25.5 Compare the roles played by carbohydrates, proteins and lipids in our body.



# Polymers

## Student Learning Outcomes

**After studying this chapter, students will be able to:**

- Define polymers as large molecules built up from many smaller molecules called monomers.
- Identify the repeating units and / or linkages in addition polymers and in condensation polymers.
- Deduce the structure or repeating unit of a condensation polymer from given monomers and vice versa, limited to:
  - a. polyamides from a dicarboxylic acid and a diamine
  - b. polyesters from a dicarboxylic acid and a diol.
- Describe the differences between addition and condensation polymerization.
- State that plastics are made from polymers.
- Describe how the properties of plastics have implications for their disposal.
- Describe the environmental challenges. caused by plastics, limited to:
  - o disposal in landfill sites
  - o accumulation in oceans
  - o formation of toxic gases from burning
- Describe the structure of:
  - o nylon, a polyamide
  - o PET, a polyester The full name for PET, polyethylene terephthalate, is not required.
- State that PET can be converted back into monomers and repolymerised
- Outline the importance of polymers in the textile industry. (Examples for polymers being used may be given along with their specific properties).



Polymers or macromolecules are extremely large molecules which are formed by linking together a very large number of simple molecular units called monomers. The process of formation of a polymer from a monomer is called polymerization. Carbohydrates, proteins and nucleic acids are the everyday examples of polymers which exist naturally. Whereas plastics, synthetic fibers, and natural rubber are the examples of man-made polymers. One of the most significant changes which has occurred throughout the world, has been the gradual replacement of metals, wood and cotton with man-made synthetic polymers. Polymers are important in our daily life due to their high strength, flexibility and resistance to heat and chemicals. These properties make them useful for a wide range of applications.

## 26.1 Types of Polymers

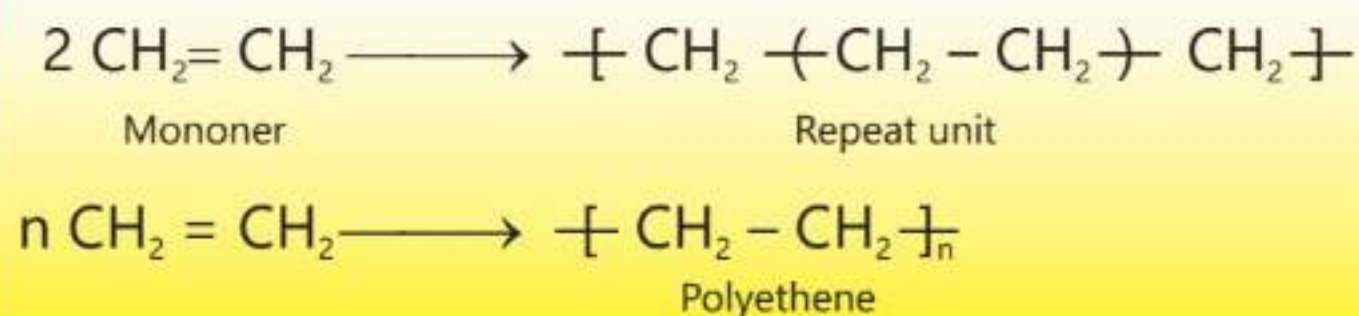
There are two main types of polymers.

- Addition Polymers
- Condensation Polymers

### (a) Addition Polymers

Addition polymers are formed when monomer molecules containing a double bond combine together through a covalent bond to give a very large molecule. For example, a large number of ethene molecules add together to give one very big molecule which is called polyethene or polythene. During this reaction, the C=C double bond in ethene breaks down to allow ethene molecules to join together. Polymerization reactions usually take place at high pressure and in the presence of a catalyst.

In addition polymerization, no molecule is eliminated and no by-product is formed.

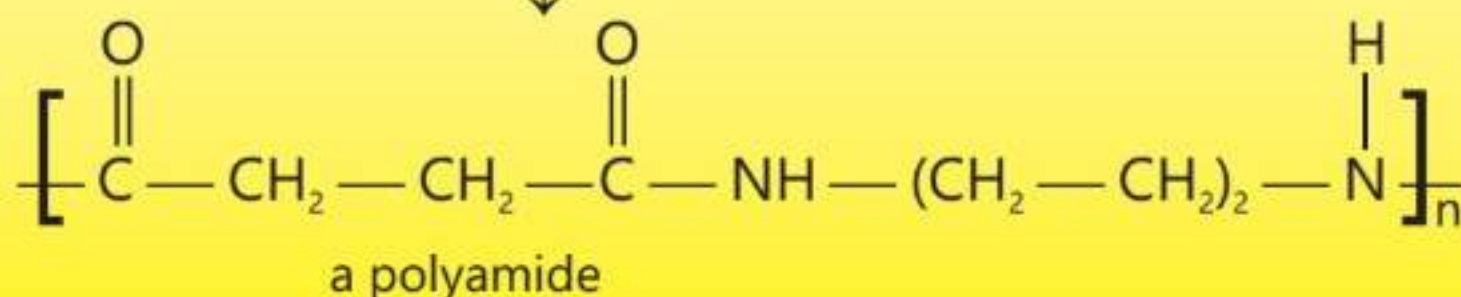
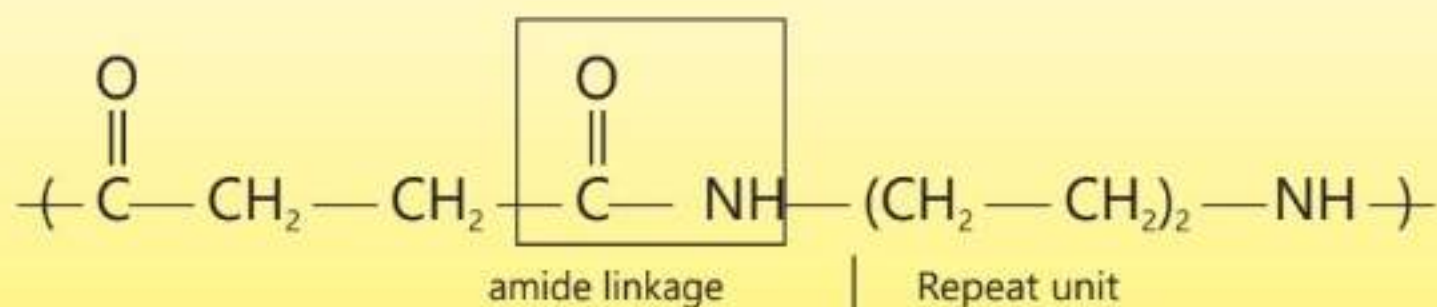
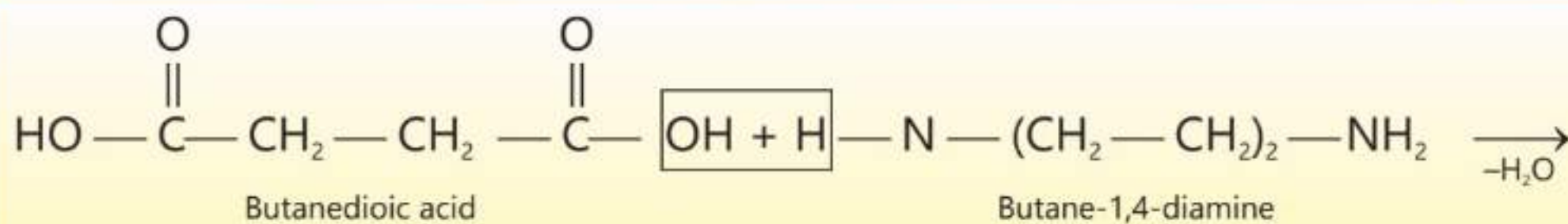


### 26.1 Quick Check!

- Give an example of a commercial product which is formed using polyethene.
- Write three properties of synthetic polymers.







### 26.2 Quick Check!

- How an ester linkage between two monomers is formed?
- How does condensation polymerization occur?

### Interesting Information!

Properties of polymers can be changed through careful control of their chemical structure and composition enabling their use in highly specific application like non-stick coating (Teflon).



### Differences between Addition and Condensation Polymerizations.

Addition Polymerization	Condensation Polymerization
A single monomer is used which should have a double or a triple bond.	This polymerization takes place between two monomers. The monomer molecules have two functional groups present one on each end of the molecule.
It involves an addition reaction and only a single product is formed.	It involves the condensation between two monomers with the elimination of a small molecule like H <sub>2</sub> O, HCl or NH <sub>3</sub> .
The molecular mass of the product polymer can be found by adding the molecular masses of all the monomers used.	The molecular mass of the polymer cannot be found by adding the molecular masses of all the monomers.



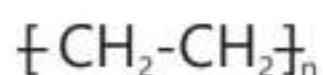


Addition Polymerization	Condensation Polymerization
The polymer formed contains only the single bonds along the polymer backbone chain.	The polymer formed contains a specific linkage, e.g. ester linkage or amide linkage.
Examples of addition polymers are polyethene, polystyrene, polyvinylchloride (PVC), etc.	Examples of condensation polymers are polyester, nylon, bakelite, etc.

## 26.2 Structure of Monomer from Polymer

### Addition Polymer

- Write down the structure of addition polymer.



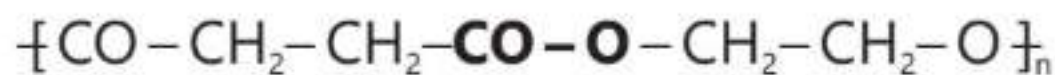
- Identify the repeating unit in the polymer. Remove the brackets, the extended bonds from each side and the subscript n. Change the single bond to a double bond.



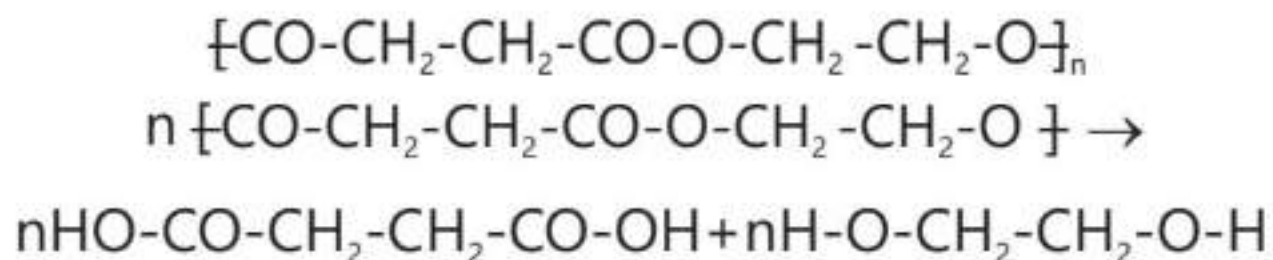
### Condensation Polymer

#### 26.1 Example:

- Write down the structure of a condensation polymer, polyester.



- Identify the repeating unit in the polymer. Remove the brackets, the extended bonds at both the ends and the subscript n. Break the bond between CO and O of the ester linkage. Add OH to the each end of the dicarboxylic acid monomer. Add H to each end of the diol monomer.



#### 26.2 Example:

- Write down the structure of a condensation polymer, a polyamide.

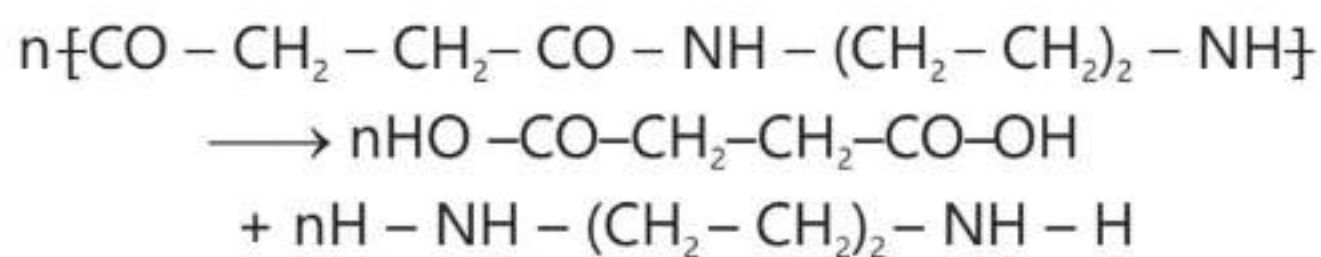


- Identify the repeating unit in the polymer. Remove the brackets, remove the extended linkage at both the ends and subscript n. Break the bond between the CO and NH of the amide linkage. Add OH to the each end of dicarboxylic acid





monomer. Add H to each end of the diamine monomer.



### 26.3 Quick Check!

- What do you understand by the term repeating unit?
- Draw the structure of a polyamide linkage.

### Interesting Information!

By varying the type and proportion of monomers, chemists can make such polymers which show specific properties, such as flexibility, strength and thermal stability to meet specific application requirements.

## 26.3 Plastics

Polymerization of monomers like ethylene, propylene and styrene gives polyethylene (PE), polypropylene (PP) and polystyrene (PS) respectively. All these polymers are a few examples of compounds called Plastics. These plastics are used to make all types of carry-home food containers, eg, soft drink bottles, water bottles, juice bottles etc. They are also used to manufacture shopping bags, kitchen-wares, buckets, tables, chairs, food wrappers, cups and plates etc. Plastics are light weight, flexible and durable. They can be easily moulded into solid objects of almost any desired shape. All these properties have led to their widespread use in almost any sphere of our daily life. Starting from early 20<sup>th</sup> century millions of tons of plastics are made every year (Figure 26.1).



Figure 26.1: Plastic products

## 26.4 Importance of Polymers in Textile Industry

Polymers which are used in the textile industry are called synthetic fibers. Examples of synthetic fibers are nylon, polyester, rayon, acrylic etc. The





properties of synthetic fibers which enable them to be used in textile industry are as follows:

1. They are cheaper in cost than natural fibers like cotton and silk.
2. They are stronger and more durable than natural fiber.
3. They do not shrink.
4. They resist wrinkling.
5. They are light weight and quick drying.
6. They are moth and insect resistant.



**Figure 26.2:** Plastic in textile

The polyesters and nylon are the two common polymers which account for 69% of all the material used in clothing industry worldwide. Polyester is an important fiber for its strength and resistance to shrinking. It is commonly used in sportswear and hosiery. Acrylic is light weight, soft and provides warmth (Figure 26.2).

## 26.5 Adverse Effects of Plastics

Unlike other materials, plastics do not undergo biodegradation. When articles made of plastics are discarded, they can take upto 1000 years to break down. This fact has led to build up of huge amounts of plastics in the environment. Accumulation of such a huge amount of different articles made of plastics has caused widespread environmental problems. Plastic pollution is found almost everywhere on lands, in air and in all the water bodies: rivers, ponds, lakes, seas and oceans. This pollution has reached to an extremely alarming level and has led to cause serious health problems.

Discarded plastic articles we put in the bins are disposed of through burning, dumping in the landfill, thrown in the drains from where they make their



**Figure 26.3:** Plastic pollution



way to rivers and oceans. Burning of discarded plastic articles in town, creates a hazardous environmental condition because this releases dangerous gases in air (Figure 26.3).

### Interesting Information!

Polymers can be 3D printed using a variety of techniques. These techniques involve layer-by-layer deposition of the polymer material to create three-dimensional objects.

## EXERCISE

### A Multiple Choice Questions

Choose and tick the correct answer from the given choices.

1. Which of the following polymer is a synthetic polymer:

- (a) Starch (b) Cellulose  
(c) Animal fat (d) Polyester

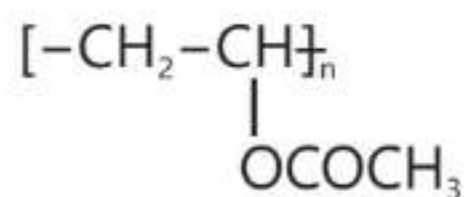
2. Which polymer has an amide linkage:

- (a) Polyester (b) Polyamide  
(c) Polyethene (d) Polystyrene

3. Identify an ester linkage:

- (a)  $\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{R}$  (b)  $\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{R}$   
(c)  $\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{NH}-\text{R}$  (d)  $\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{NH}-\text{R}$

4. The structure of the monomer of the following polymer is:



- (a)  $\text{CH}_2=\text{CH}_2$  (b)  $\text{CH}_2=\text{CH}-\text{CH}_3$   
(c)  $\text{CH}_2=\text{CH}-\text{OCOCH}_3$  (d)  $\text{CH}_2=\text{CH}-\text{CO}-\text{O}-\text{CH}_3$

5. Which of the following polymers can be recycled?

- (a) PET (b) Polystyrene  
(c) PVC (d) Epoxy

6. Which of the following polymers is biodegradable?

- (a) Polyamide (b) Polyester  
(c) Starch (d) PET



# Pairing Scheme / Instructions for Preparation of Exam Paper of Chemistry for Class-10

## ESSENTIAL INSTRUCTIONS FOR PAPER SETTERS

The paper of Chemistry (General) for class 10 will consist of 60 marks. Timing of the paper will be two hours. The paper will be made as per following details:

### Objective:

#### Q-1:

12 Multiple Choice Questions

$1 \times 12 = 12$

The detail is as follows:

Chapter	14	15	16	17	18	19	20	21	22	23	24	26
No. of Short Questions	1	1	1	1	1	1	1	1	1	1	1	1

### Subjective:

#### Q-2:

##### Part-I:

5 short answer questions have to be answered out of 8.

$2 \times 5 = 10$

The detail is as follows:

Chapter	14	15	16	17	18
No. of Short Questions	2	1	1	2	2

#### Q-3:

Five (5) short answer questions have to be answered out of Eight (8). The detail is as follows:

$2 \times 5 = 10$

Chapter	19	20	21	22
No. of Short Questions	2	2	2	2

#### Q-4:

Five (5) short answer questions have to be answered out of Eight (8). The detail is as follows:

$2 \times 5 = 10$

Chapter	23	24	25	26
No. of Short Questions	2	2	2	2

### Subjective:

This section will contain three detailed questions bifurcated in two-part **a & b** (carrying 5 & 4 marks each) and students have to attempt 2 questions The detail is as follows:

$2 \times 9 = 18$

##### Part-II:

#### Q-5:

Chapter	14	15
Part	a	b

#### Q-6:

Chapter	20	22
Part	a	b

#### Q-7:

Chapter	23	25
Part	a	b



# MODEL PAPER OF CHEMISTRY FOR CLASS-10

## Objective Type

Max. Marks: 12

Time allowed: 15 Min.

کل نمبر: 12

وقت: 15 منٹ

**Note:** Four possible answers A, B, C and D to each question are given. The choice which you think is correct, fill that circle with marker or pen ink in the answer-book. Cutting or filling two or more circles will result in zero mark in that question.

نوٹ: ہر سوال کے چار ممکنہ جوابات A، B، C اور D دیے گئے ہیں۔ جو انتخاب آپ کے خیال میں درست ہے، اس سوال کے سامنے والے دائرے کو مار کر یا پین کی سیاہی سے بھریں۔ دو یا دو سے زیادہ دائروں کو کاٹنے یا بھرنے کی صورت میں جواب غلط تصور ہوگا۔

**Q.1. Select the correct answer.**

(1×12=12)

1- درست جواب کا انتخاب کریں۔

- (i) Which gas will diffuse at the fastest rate? کون سی گیس سب سے زیادہ تیز ڈیفیوز ہوگی۔ (i)
- (a) HCl (b) SO<sub>2</sub> (c) H<sub>2</sub>S (d) CO<sub>2</sub>
- (ii) Volume occupied by 15 moles of ammonia gas at RTP پر RTP کے 15 مولز کا والیوم امونیا گیس کے (ii)
- (a) 224 dm<sup>3</sup> (b) 160 dm<sup>3</sup>
- (c) 360 dm<sup>3</sup> (d) 265 dm<sup>3</sup>
- (iii) Which of the following metal is the highest in the electrochemical series? الیکٹروکیمیکل سیریز میں کون سی میٹل کی پوزیشن سب سے اوپر ہے؟ (iii)
- (a) Tin ٹن (b) Iron آئرن
- (c) Magnesium میگنیشیم (d) Zinc زنک
- (iv) The shape of the crystal of NaCl is: سوڈیم کلورائیڈ کے کرسٹل کی شکل و صورت ہے: (iv)
- (a) Cubic کیوبک (b) Hexagonal ہیکزاگونل
- (c) Rhombic رومبک (d) Trigonal ٹرائیگونل
- (v) The oxide that is neutral in character: ایک ایسا آکسائیڈ جس کی خاصیت نیوٹرل ہے: (v)
- (a) Al<sub>2</sub>O<sub>3</sub> (b) SO<sub>2</sub> (c) CO<sub>2</sub> (d) NO
- (vi) The pH of distilled water is: ڈسٹلڈ واٹر کی pH ہے: (vi)
- (a) 6.5 (b) 8.5 (c) 7 (d) 7.5
- (vii) Select the general formula of alkyne family. الکائین فیملی کا جنرل فارمولا بتائیں: (vii)
- (a) C<sub>n</sub>H<sub>2n+1</sub> (b) C<sub>n</sub>H<sub>2n</sub> (c) C<sub>n</sub>H<sub>2n-1</sub> (d) C<sub>n</sub>H<sub>2n-2</sub>
- (viii) Which of the following is not used as a fuel? مندرجہ ذیل میں سے کون سا بطور ایندھن استعمال نہیں ہوتا: (viii)
- (a) LPG ایل۔ پی۔ جی (b) CNG سی۔ این۔ جی
- (c) Diesel ڈیزل (d) Asphalt اسفالٹ
- (ix) Which of the following acids is present in apple? سیب میں درج ذیل میں سے کون سا ایسڈ موجود ہوتا ہے: (ix)
- (a) Citric acid سٹرک ایسڈ (b) Tartaric acid ٹارٹارک ایسڈ
- (c) Acetic acid ایسٹک ایسڈ (d) Malic acid میلک ایسڈ
- (x) If the reactants possess an energy higher than the activation energy, then the reaction will be: اگر ری ایکشنز کی انرجی ایکٹیویشن انرجی سے زیادہ ہو تو ری ایکشن کیسے وقوع پذیر ہوگا؟ (x)
- (a) Slow سست (b) Fast تیز
- (c) Not affected اثر نہیں ہوگا (d) Instantaneous فوری





- (xi) Which polymer can be recycled? (xi) درج ذیل میں کونسا پولیمر ری سائیکل کیا جاسکتا ہے؟  
 (a) PET پی۔ای۔ٹی (b) Polystyrene پولی سٹائرین  
 (c) PVC پی۔وی۔سی (d) Epoxy ایپوکسی  
 (xii) Which catalyst other than  $H_3PO_4$  can also be used for hydration of alkenes. (xii)  $H_3PO_4$  کے علاوہ کون سا کیٹالسٹ الکینز کی ہائیڈریشن کے لیے استعمال کیا جاسکتا ہے؟  
 (a) NaOH (b)  $H_2SO_4$   
 (c)  $CH_3COOH$  (d) Ni

## Subjective Type (Part I)

Time allowed: 1:45 Hrs.

Max. Marks: 30

### Q. 2: Write short answers to any five (05) questions:

کوئی سے پانچ (5) سوالات کے مختصر جوابات لکھیے:

- (i) Is condensation an endothermic process? (i) کیا کنڈن سیشن حرارت جذب کرنے والا عمل ہے؟  
 (ii) Why ice melts when the pressure is exerted on it? (ii) جب برف پر دباؤ بڑھایا جاتا ہے تو وہ کیوں پگھلتی ہے؟  
 (iii) Why is percentage yield important? (iii) پرنسٹیج ییلڈ کیوں اہم ہے؟  
 (iv) What are the main objectives of electroplating? (iv) الیکٹرو پلیننگ کے بنیادی مقاصد کیا ہیں؟  
 (v) Give any two features of the catalytic action of an enzyme. (v) کسی انزائم کے بطور کیٹالسٹ عمل کرنے کی کوئی سی دو خصوصیات بتائیں۔  
 (vi) From where do molecules get energy to attain higher energy state? (vi) ہائر انرجی سٹیٹ حاصل کرنے کے لیے مالیکیولز انرجی کہاں سے حاصل کرتے ہیں؟  
 (vii) Name two insoluble carbonates. (vii) کوئی سے دو نا حل پذیر کاربونیٹس کے نام بتائیں۔  
 (viii) What is crystal lattice? (viii) کرسٹل لیٹس کسے کہتے ہیں؟

### Q. 3: Write short answers to any five (05) questions:

کوئی سے پانچ (5) سوالات کے مختصر جوابات لکھیے:

- (i) How nitrogen is obtained from air? (i) نائٹروجن ہوا سے کیسے حاصل کی جاتی ہے؟  
 (ii) How fossil fuels produce  $SO_2$ ? (ii) فوسل فیولز  $SO_2$  کیسے پیدا کرتے ہیں؟  
 (iii) What is trachoma disease? (iii) ٹراکوما کون سی بیماری ہے؟  
 (iv) What is the difference between sedimentation and filtration? (iv) سیڈیمینٹیشن اور فلٹریشن میں کیا فرق ہے؟  
 (v) Define structural isomerism. (v) سٹرکچرل آئسومرزم کی تعریف کریں۔  
 (vi) Write down the structural formula of Butan-2-ol. (vi) بیوٹین-2-اول کا سٹرکچرل فارمولہ تحریر کریں۔  
 (vii) How an alkene can be identified? (vii) الکیئن کو کیسے شناخت کیا جاتا ہے؟  
 (viii) Why is oxyacetylene flam so hot? (viii) آکسی ایسٹائلین شعلہ بہت گرم کیوں ہوتا ہے؟





### Q. 4: Write short answers to any five (05) questions:

کوئی سے پانچ (5) سوالات کے مختصر جوابات لکھیے:

- (i) Give any two disadvantages of fermentation reaction. - فرمٹیشن ری ایکشن کے دو نقصانات بتائیں۔ (i)
- (ii) How ethanol is prepared from ethene? - اتھنول سے ایٹھانول کیسے تیار کی جاتی ہے؟ (ii)
- (iii) What is esterification reaction? - ایسٹیریفیکیشن ری ایکشن کسے کہتے ہیں؟ (iii)
- (iv) How does ethanol react with propanoic acid? - ایٹھانول، پروپینوئک ایسڈ کے ساتھ کیسے ری ایکشن کرتا ہے؟ (iv)
- (v) What is the role of enzyme in our body? - ہمارے جسم میں انزائمز کیا کردار ادا کرتے ہیں؟ (v)
- (vi) What is glycoside linkage? - گلائکوسائیڈ لنکیج کسے کہتے ہیں؟ (vi)
- (vii) What is the role of catalyst in addition polymerization? - ایڈیشن پولیمرائزیشن میں کیٹالسٹ کیا کردار ادا کرتا ہے؟ (vii)
- (viii) How does condensation polymerization reaction occur? - کنڈنسیشن پولیمرائزیشن ری ایکشن کیسے وقوع پذیر ہوتا ہے؟ (viii)

### Subjective Type (Part II)

**Note: Attempt any two questions.** کوئی سے دو سوالات کے جوابات لکھیے۔

- Q5:** (a) Differentiate between evaporation and boiling. - ایوپوریشن اور بوائیڈنگ میں فرق واضح کریں۔ (5)
- (b) How would you identify the limiting reactant in a chemical reaction? - ایک کیمیکل ری ایکشن میں لیملٹنگ ری ایکٹنٹ کو کس طرح شناخت کیا جاسکتا ہے؟ (4)
- Q6:** (a) What is fertilizer? Mention the essential qualities of a good fertilizer. - کھاد کسے کہتے ہیں؟ اچھی کھاد کی اہم خصوصیات کا ذکر کریں۔ (5)
- (b) Describe two methods of preparation for ethene. - اتھین کی تیاری کے لیے دو طریقے بیان کریں۔ (4)
- Q7:** (a) Describe the applications of ethanol in pharmaceutical and cosmetic industries. - فارماسیوٹیکل اور کاسمیٹک انڈسٹری میں اتھنول کے استعمال کی وضاحت کریں۔ (5)
- (b) What are carbohydrates? Describe their classification with examples. - کاربوہائیڈریٹس کسے کہتے ہیں؟ مثالوں کے ساتھ اس کی کلاسیفیکیشن کی وضاحت کریں۔ (4)

