5
Liquids and Solids

5.1 INTRODUCTION

You are familiar with gases, liquids and solids in your daily life situation. You are aware, water can exist as a liquid, a solid (ice) or as a gas (vapour). These are called three *states of matter*. In lesson 4, you have learnt about the differences in properties of these three states of matter. You could explain the properties of gaseous state in terms of large separation of molecules and very weak intermolecular forces. In this lesson we shall study about the intermolecular forces in liquids and solids and see how their properties can be explained in terms of these forces.

5.2 OBJECTIVES

After reading this lesson, you would be able to

- explain the nature of liquid state
- correlate between the properties of liquids and nature of liquid state.
- differentiate between evaporation and boiling process
- explain the nature of solid state
- correlate between the properties of solids and nature of solid state
- differentiate between amorphous and crystalline solids
- classify the crystalline solids into four categories according to bonding between the constitutent particles in them.
- list properties of different crystalline solids
- cite examples of different types of crystalline solids

5.3 NATURE OF LIQUIDS – A CHAOTIC COMMUNITY OF MOLECULES

Look at the figure 5.1. If each circle represents a molecule, what do you notice about their arrangement in each part of the figure. In figure 5.1 a, you would find that the molecules are far apart. A gaseous state can be represented by this arrangement. In liquid state (figure 5.1 b), molecules are closer as compared to gaseous state. You would notice that these have very little space between them. However, there is no order in arrangement of molecules. Further we say that, these molecules can move about, but with lesser speeds than those in gases. They can still collide with one another as in the gaseous state. Now we consider interactions of molecules in the liquid state. You would recall that the molecules in gases have very little attaction between them. But in liquid state the attraction between the molecules is comparatively higher as compared to those in the gaseous state and strong enough to keep the molecules in aggregation. Contrary to this in solids (Fig 5.1c) you would notice that the molecules are arranged at the closest possible distance.

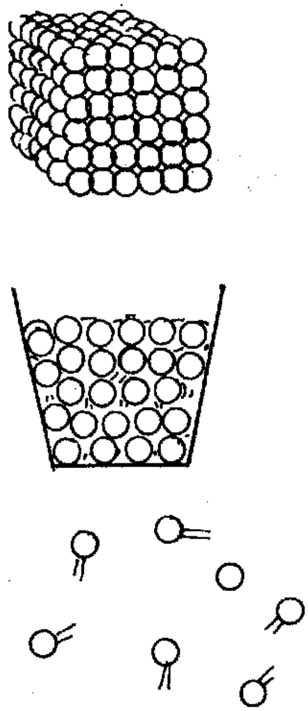

Fig. 5.1: Arrangement of molecules in Solid, liquid and gas

Solid state is a well ordered state and has very strong intermolecular forces. You would learn more about solids in section 5.5.

We would say, in a gas, there is a complete chaos due to very weak intermolecular forces, whereas in solids there is a complete order due to strong forces. Liquids falls between gases and solid state. Liquid molecules have some freedom of gases state and some order of solid state. Intermolecular forces in liquids are strong enough to keep the molecules in the bulk but not strong enough to keep them in perfect order.

5.4 PROPERTIES OF LIQUIDS

In this section you would learn how to explain the properties of liquid in terms of the molecular arrangement and intermolecular forces. We would consider a few properties of liquids as examples.

5.4.1 Volume and Shape

You would recall that the liquids (for example, water) take the shape of the container in which these are kept. The liquids flow easily. They maintain definite volume. How can you explain the properties of definite volume and variable shape? In a liquid, the attractive forces are strong enough to keep the molecules moving within a definite boundary. But these are not strong enough to keep them in definite positions. The molecules move around to allow the liquid to flow. They would take the shape of the container. If a liquid is poured on the ground, it would flow to a certain distance. This would depend upon the strength of attractive forces between the molecules in a particular type of liquid. Greater are the attractive forces between the molecules in the liquid, lesser will be the flow of the liquid.

For example the flow of vegetable oil is lesser than that of the water, because the attractive forces in vegetable oil are greater than those inwater. You can compare the flow of liquids with those of gases and explain the difference in the flow in terms of the strength of attractive forces between the molecules.

5.4.2 Compressibility

Try to compress a liquid. For example, take water in a syringe. Press the plunger while blocking the nozzle of the syringe with a finger. Does the volume of water change by pressing the plunger? You would find that it does not change. Liquids are largely incompressible, because there is very little free space between the molecules. In contrast, the gases are highly compressible.

5.4.3 Diffusion

Drop a small quantity of ink in some water taken in a transparent container, say, in a glass. When the ink is dropped, you see a 'dot' slowly spreading through the water. Why does it happen? Because the molecules in both the liquids (note that the two liquids must be miscible with each other in all proportions) are able to move throughout the container. The molecules of one liquid diffuse into the molecules of the other. You can recall that the diffusion of gases is much faster than that in liquids because the molecules in gases move very fast as compared to those in liquids.

5.4.4 Evaporation – Vapour Pressure

You know that water left in an open pan normally evaporates (vaporises) until the pan is dry. In a liquid, even at room temperature, a very small fraction of the molecules is moving with relatively high velocity. Such molecules have high kinetic energy. These can overcome the attractive forces in the liquid and can escape the liquid through the surface. We call this process as **evaporation.** Evaporation is a process by which a liquid changes into gas through the surface at temperatures well below the boiling point. Rate of evaporation of a liquid depends on a number of factors. For example, more is the surface area, faster will be the evaporation. For faster drying, we increase the surface area by spreading the wet clothes. If we supply heat to the liquid, evaporation is faster. The wet clothes dry faster in the sun. We say that the increase in temperature by supplying heat increases the kinetic energy of the molecules of the liquid and it evaporates faster. We feel cool after the bath. Why do we feel so? Evaporation of water from our body has drawn heat from the surface of our skin. As you have learnt that molecules of the liquid with high kinetic energy leave the liquid, this decreases the temperature and we feel cool.

Now let us compare the rate of evaporation of two liquids. For example, water and alcohol. Which of these two liquids evaporates faster? You must have experienced that alcohol evaporates faster. Why does this happen? The number of molecules escaping from the liquids depends upon the attractive forces in the liquid. When these forces are stronger, fewer molecule escape. In alcohol, these attractive forces are weaker than those in the water. Hence, alcohol evaporates more easily than water.

Vapour Pressure of a Liquid

You know that a liquid placed in an open vessel evaporates completely. If, however, the liquid is allowed to evaporate in a closed vessel, for example, as in stoppered bottle or bell jar, evaporation starts and after sometime the level of the liquid does not change further and remains constant. Let us understand how it happens. In the closed vessel, the molecules evaporating from the liquid surface are confined to a limited space. These molecules may

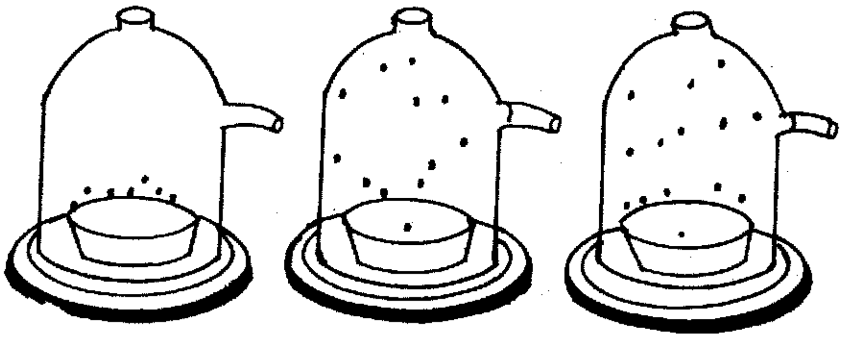

Fig. 5.2: Establishing (vapour⇌liquid) equilibrium under a evacuated jar

collide among themselves or with the molecules of air and in that process are pushed back to the surface of the liquid. This is known as **condensation.** In the beginning, rate of evaporation is greater than the rate of condensation. But as the molecules accumulate in the space above the liquid, rate of condensation gradually increases. After sometime, rate of evaporation is equal to rate of condensation and an equilibrium state is reached (Fig. 5.2) The number of molecules in the vapour above the liquid is constant. These molecules exert pressure over the surface of the liquid. This pressure is known as **equilibrium vapour pressure** or simply **vapour pressure**. The vapour pressure of a liquid has a characteristic value at a given temperature. For example, vapour pressure of water is 17.5 mm Hg and that of benzene is 75.00 mm Hg at 20°C. The vapour pressure of a liquid increases with increase in temperature. What would happen if we remove some of the vapours from the closed vessel. Would the vapour pressure of the liquid increase, decrease or remain constant? Vapour pressure of the liquid would remain constant at that temperature. In the beginning, the pressure of the vapour would decrease after the removal of the vapours, but sooner more liquid would evaporate to maintain the equilibrium. So the vapour pressure would attain a constant value at a particular temperature.

Boiling

You must have seen he formation of bubbles at the base of a vessel, when water is heated in a vessel. More bubbles form, more heat you supply. What are the bubbles made of? The first bubbles that you see are of the air, driven out of the liquid by increase in temperature. After sometime, bubbles of vapour are formed throughout the liquid. These bubbles of water vapours rise to the surface and break at the surface. The vapours escape from the liquid. When this happens, we say that the liquid is boiling. These bubbles would rise up and break only if the vapour pressure of the liquid is equal to the atmospheric pressure above the liquid, if the vessel is open.

The temperature at which boiling occurs is called the **boiling point** of the liquid. At this temperature the vapour pressure of the liquid is equal to the atmospheric pressure. The boiling point, therefore, depends on the atmospheric pressure. For example, water boils at 100°C at 760 mm Hg and at 97.7°C at 700 mm Hg.

The normal boiling point is defined as temperature at which the vapour pressure of a liquid is equal to one atmosphere or 760 mm Hg.

You can make a liquid boil at temperatures other than normal boiling point. How? Simply alter the pressure above the liquid. If you increase this pressure, you increase the boiling point and if you decrease this pressure you decrease the boiling point. On the mountains, the atmospheric pressure decreases and therefore boiling point of water also decreases. People living on hills face problem in cooking their meals. They, therefore, use pressure cooker. How food is cooked faster in it? The lid of pressure cooker does not allow water vapours to escape out. On heating the water vapours accumulate and the inside pressure increases. This makes the water boil at a higher temperature and the food is cooked faster.

Let us now compare the boiling points of different liquids. As you have learnt earlier that the rates of evaporation of liquids differ. The liquid which evaporates faster at a particular temperature would have higher vapour pressure. For example, benzene has higher vapour pressure than water, say, at 20°C. therefore, vapour pressure of benzene would become equal to atmospheric pressure at lower temperature than water. The normal boiling point of benzene and water are 80°C and 100°C respectively. Vapour pressure or boiling points of liquids give us an idea of the strength of attractive forces between molecules in the liquids. Liquids having lower boiling points have weaker attractive forces in comparision to those having higher boiling points.

INTEXT QUESTIONS 5.1

1. Match the following

Column I	Column II
(i) Liquid flows	(i) The particles in the liquid are close and have very little free volume.
(ii) Liquids have very little compressibility	(ii) the particles in a liquid move about
(iii) Liquids have definite volume and does not fill the entire volume of the container.	(iii) The particles in a liquid are closer and have larger attractions than in gases.

2. Mark *True* or *False*

   i) Evaporation can take place only at a fixed temperature

   ii) Rate of evaporation can be increased by increasing the temperature

   (iii) Surface area does not affect the rate of evaporation

3. When water in a container boils, there are large bubbles in it. What are the bubbles made up of:

   (a) Air

   (b) Steam

   (c) Hydrogen

   (d) Oxygen

4. Differentiate between evaporation and boiling.

   ....

5. If you were asked to compare the strengths of the attractive forces in liquid A with those in liquid B, what type of data would you collect?

....

5.5 SOLIDS – A WELL ORDERED STATE

If we stack the molecules in a regular arrangement as the mason builds wall, brick by brick, then we obtain solids. The molecules are closest in the solid state and are held in fixed positions by strong intermolecular attractions. The molecules, however, vibrate about their fixed positions. We would now consider some of the properties of the solids and explain their behaviour in terms of the molecular arrangement and attraction between them.

5.5.1 Rigidity, Definite Volume and Diffusion

The solids are rigid and do not take the shape of the container. They have a definite volume. Diffusion in solids is negligible because the particles have fixed positions and are held by strong attractive forces.

5.5.2 Melting

You know when a solid like wax is heated, it changes into liquid state. When it is heated, its particles get more energy and vibrate more. This makes the solid expand (exception of ice changing into water, where volume contracts). Eventually the energy of the particles becomes sufficiently large to overcome the binding forces and the solid melts to form a liquid as shown in figure 5.3.

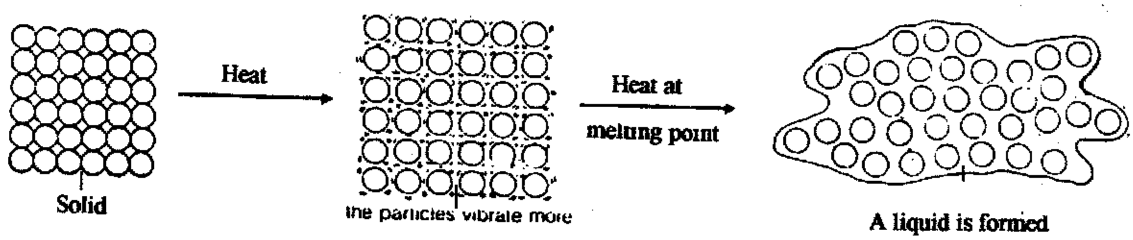

Fig. 5.3: The process of melting

The temperature at which a solid mets at normal pressure is called its melting point.

The melting point of a solid gives a rough idea about the nature of the binding forces between the particles of the solid. Sodium chloride has high melting point because of strong attractive forces between sodium ions and chloride ions. Wax has low melting point because of weak attractive forces. We will study about the different types of bonding in solids in the next section.

Many solids have highly ordered arrangement of the particles. These solids have definite shapes and sharp melting points. This type of solids is called **crystalline solids.**

All solids need not be crystalline. There are many solids which do not have ordered arrangement of the particles. Glass, for example, is rigid, but there is only short range order in the arrangement of particles. These are called **amorphous solids**. These do not have sharp melting points. Fig. 5.4 (a) shows the long range order in crystalline structure and

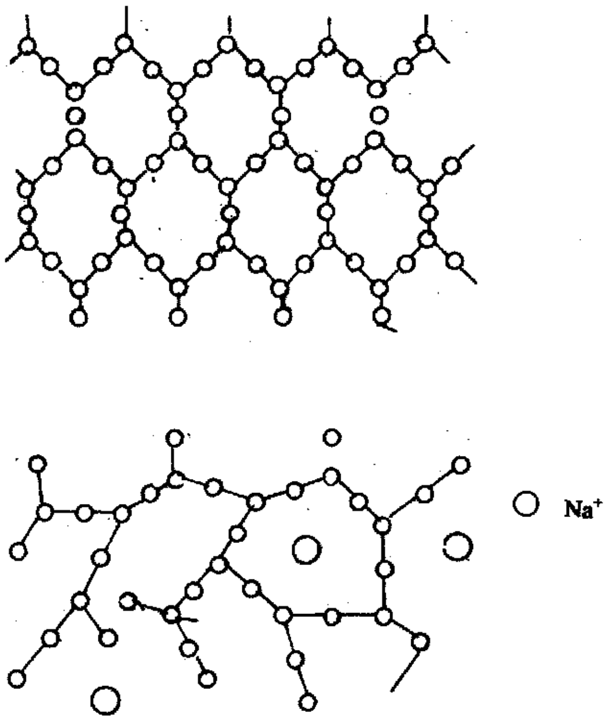

Fig. 5.4: Two dimensional representations of the silica structure. In (a), the structure is crystalline and in (b) the structure is amorphous containing a modifying ion such as Na^+

Fig. 5.4 (b) shows there is no long range order in amorphous solids. We can differentiate between these two types in the following table:

Crystalline solids	**Amorphous solids**
1. These have long range as well as short range order.	1. These don't have long range order but have short range order.
2. These have sharp m.p	These don't have sharp m.p

INTEXT QUESTION 5.2

I. Using the idea of particles explain why?

a) A solid expands when it is heated.

....

b) A solid has a definite shape and does not flow.

....

2. Name two chracteristics of crystalline solids.

....

3. List two differences between crystalline solids and amorphous solids.

....

5.6 TYPES OF CRYSTALLINE SOLIDS

The solids have different characteristic melting points. Some conduct electricity, while others do not. Some are soft, some are hard, metallic etc. These characteristic properties are the result of the highly ordered arrangement and nature of binding forces between the constituent particles. In this section, we would classify the crystalline solids into four types: ionic solid, covalent solids, metallic solids and molecular solids based on the nature of forces between the constituent particles in them. We would now discuss these types of crystalline solids in detail.

5.6.1 Ionic Solids

Ionic solids are ordered arrangement of ions (cations and anions) held together by strong ionic bonds. Ionic bonds do not have perferred direction in contrast with covalent bonds which have preferred direction. For example in sodium chloride, the ionic bond between Na^+ ions and Cl^- ions do not have any preferred direction, whereas in methene (CH_4), the C–H bonds have preferred direction. Because ionic bonds are strong, ionic crystals tend to be hard and have high melting points, for example, sodium chloride melts at 801°C. Examples of some other ionic solids are AgCl, LiF, ZnO. These are electrically insulator, but they conduct electricity in molten state and in their solutions. Under such conditions the ions are free to move about.

5.6.2 Covalent Solids

In a covalent solid, the atoms are connected to one another by covalent linkages froming a giant network. Diamond (an allotrop of carbon), silicon and silicon carbide are examples of covalent solids. In diamond, each carbon atom is linked to four other tetrahedrally oriented carbon atoms (carbon being sp^3 hybridized about which you shall study in later lessons) forming a three-dimensional covalent network.

In graphite, the other allotropic form of carbon, the carbon atoms are linked in two dimensional network (carbon being sp^2 hybridized) and these two dimensional sheets are held together by weak attractive forces (van der Waals forces). Since covalent bonds are strong and directional, these types of solids are fairly hard and have high melting points. These are generally non-conducting (graphite is an exception and is a good conductor of electricity). Fig. 5.5 and 5.6 show structures of graphite and diamond respectively.

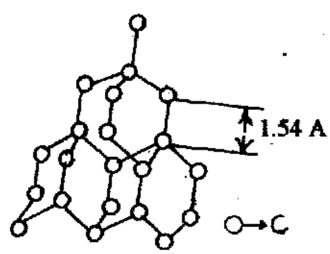

Fig. 5.:5 Structure of diamond showing the tetrahedral valency bonds

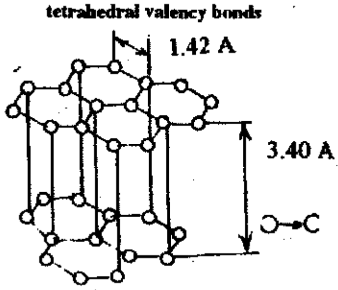

Fig. 5.6: Structure of graphite

5.6.3 Metallic Solids

The positive ions of metals are held together by their valence electrons (Fig. 5.4). These electrons are free to move throughout the crystal and form a sort of sea of electrons in which positive ions are embedded just like cherries in a cake. For example, Cu, Fe, etc are metallic solids. These conduct electricity due to free movement of electrons. Melting points of metallic solids depend ont he strength of the attractive forces between the electrons and positive metal ions. Greater is the attractive force, higher will be the melting point.

5.6.4 Molecular Solids

In these, either molecules or atoms of noble elements which do not have a net charge are bound by weak attractive forces. The forces are due to attraction of nuclei in one molecule for electrons of other. These are called *van der Waals forces*. For example naphthalene, iodine, solid CO_2, ice, Ar, Xe, Cl_2, CH_4 in solid state are examples of molecular solids.

Since attractive forces in these solids are weaker, it is easier to separate individual molecules/atoms. These have low melting point and are volatile. These are soft, fragile, easily distorted and, in general, do not conduct electricity.

INTEXT QUESTION 5.3

1. Classify the following crystalline solids according to the type of bonding in them

   (i) diamond (ii) zinc oxide (iii) solid CO_2 (iv) lead (v) silver (vi) silicon carbide (vii) silver chloride (viii) iodine

   ....

2. Which of the following is a good conductor of electricity

   (i) copper (ii) diamond (iii) mica sheets (iv) sodium chloride

   ....

3. Why do the molecular crystals have low melting point?

   ....

5.7 WHAT YOU HAVE LEARNT

- Liquids have arrangment of particles in between completely chaotic arrangement of particles in gases and completely ordered arrangment of particles in solids. The particles in liquid are held by fairly strong attractive forces.
- Properties of liquids like evaporation, boiling, variable shape, flow, etc could be explained on the basis of randomly moving particles held by attractive forces.
- Solids have highly ordered repetitive arrangement of particles, fixed in positions and held by very strong attractive forces.
- Properties like rigidity, definite shape and volume, melting, etc could be explained on the basis of particles having closest distances, fixed in positions and held by very strong attractive forces. Crystalline solids based on the type of bonding forces can be classified as ionic solid, covalent solid, metallic solid and molecular solid.

5.8 TERMINAL EXERCISE

1. How would your explain:

   (a) Why it takes longer to cook foods at high altitudes?

   ....

   (b) Why do you feel cool after a bath?

   ....

(c) Diamond is bad conductor of electricity.

....

(d) Metals are good conductors of electricity.

....

2. Classify the crystalline solids giving two examples of each,

....

3. Draw a diagram to show arrangement of particles in gases, liquids and solids.

....

4. Indicate to which category of solids (ionic, covalent etc) each of the following belong

(a) $O_2(s)$ (b) Pt (c) KCl (d) Ge

....

5. Define boiling point, melting point and vapour pressure.

....

5.8 CHECK YOURS ANSWERS

INTEXT QUESTION 5.1

1. i) Liquids flow — i) The particles in a liquid move about

   ii) Liquids have very2 little compressibility — ii) The particles in the liquid are close and have very little free volume.

   iii) Liquids have definite volume and do not fill the entire volume of the container — iii) The particles in a liquid are closer and have larger attractions than in gases.

2. i) F

   ii) T

   iii) F

3. (b)

4. Evaporation is a process in which the liquid changes into vapours which escape from the surface of the liquid at all temperatures below boiling point.

   Boiling is a process in which vapour bubbles form throughout the liquid and escape from the surface when the vapour pressure is equal to the atmopsheric pressure.

5. i) Vapour pressure of liquids

   ii) Boiling points of liquid

INTEXT QUESTION 5.2

1. a) A solid expands on heating, because the particles vibrate more and more away from each other.

   b) A solid has definite shape and does not flow, because particles in a solid are held in fixed positions by very strong forces.

2. i) Crystalline solids have highly ordered arrangement of the particles
   ii) Crystalline solids have sharp melting points.

3.

	Crystalline solids	**Amosphous solids**
i)	These have highly ordered arrangement of the particles	These have little order of the particles
ii)	These have sharp melting points	These do not have sharp melting points.

INTEXT QUESTION 5.3

1. i) Diamond — Covalent Solid
   ii) Zinc oxide — Ionic Solid
   iii) Solid CO_2 — Molecular Solid
   iv) Lead — Metallic Solid
   vi) Silicon Carbide — Covalent solid
   vii) Silver Chloride — Ionic Solid
   viii) Solid Iodine — Molecular solid
2. Copper is a good Conductor of electricity.
3. Moelcular solids have low melting points, because the molecules are held by weak inter molecular forces in the solid.

TERMINAL EXERCISE

1. a) Lower atmospheric pressure lowers the boiling point which slows down cooling process.
   b) Evaporation of water from the body lowers the temperature and makes us feel cool.
   c) Because there are no free electrons to move about.
   d) There are free electrons to move about in the solid.

2.

Name	**Example**
Ionic Solids	NaCl, MgO
Molecular Solids	Solid CO_2 and I_2
Covalent Solids	Graphite and Silicon carbide
Metallic Solids	Cu and Fe

3. Refer text
4. a) $O_2(s) \rightarrow$ Molecular Solid
   b) Pt $\rightarrow$ Metallic Solid
   c) KCl $\rightarrow$ Ionic Solid
   d) Ge $\rightarrow$ Covalent Solid

TERMS YOU SHOULD KNOW

Acceleration due to gravity: Acceleration with which a body would fall freely under the action of gravity in vacuum.

Amorphus solid: That solid in which particles have only short range order.

Ampere: SI unit of electric current. it is the current which, if maintained in two parallel conductors of infinite length, of negligible cross-section, and placed 1 metre apart in vacuum, would produce between the conductors a force equal to 2×10^{-7} newtons per metre of length.

Atom: The smallest portion of an element that can take part in a chemical reaction.

Avogadro's constant: Number of atoms or molecules in a mole of a substance. It is equal to 6.022×10^{23} mol^{-1}.

Boiling Point: That temperature at which the vapour pressure of a liquid is equal to the atmsopheric pressure is known as the boiling point of the liquid. Boiling point at one atmosphere; 760 torr, or 760 mm Hg is referred to as normal boiling point.

Candela: Fundamental SI unit of luminous intensity.

Condensation : The change of vapour into liquid.

Covalent solids: Those solids which have ordered arrangment of atoms held by continous covalent bonds.

Critical temperature: The temperature above which a given gass cannot be liquified.

Crystalline solid: That solid which has repetitive well-ordered arrangement of particles.

Density: The mass of unit volume of a substance, usually expressed in kg/m^3.

Diffusion: General transport of matter where by molecules or ions mix through normal thermal agitation.

Effusion: The passage of gasses through small apertures under pressure.

Empirical Formula: Formula deduced from the results of analysis which is the simplest expression of the ratio of the atoms in a substance.

Energy: The capacity of a body for doing work.

Evaporation: The conversion of a liquid into vapour, at temperatures below the boiling point.

Frequency: Number of oscillation in unit time, usually one second. SI unit of frequency is hertz.

Gas: A state of matter in which the molecules move freely, thereby causing the matter to expand indefinitely, occupying the total volume of any vessel in which it is contained.

Ideal Gas: Gas with molecules of negligible size and exerting no intermolecular forces. Such a gas is a hypothetical gas which would obey the ideal gas law under all conditions.

Intermolecular forces: The forces binding one molecule to another.

Ion: Any atom or molecule which has a resultant electric charge due to loss or gain of valence electrons.

Ionic solid: These solids have ordered arrangement of ions bonded by strong electrostatic forces.

Kelvin: Thermodynamic scale of temperature.

Liquid: A state of matter between a solid and a gas, in which the shape of a given mass depends on the containing vessel, the volume being independent.

Mass: Quantity of matter in a body.

Melting Point: That temperature at which the solid melts at normal pressure.

Mole: The amount of substance that contains as many entities (atoms, molecules, ions, electrons etc) as there are atoms in 12 g of ^{12}C.

Metallic solid: Those solids which have ordered arrangement of positive ions embeded in the valence electrons belonging to the crystal as a whole instead of any single atom.

Molecular solid: Those solids which have ordered arrangement of molecule or atoms held by weak van der Waals forces.

Molecule: The smallest portion of a substance capable of existing independently and retaining the properties of the original substance.

Vapour Pressure: The pressure exerted by the quantity of vapour above the liquid, when equilibirum is established is called the vapour pressure of the liquid.

Weight: gravitational force acting on a body at the earth's surface. Weight = mass × acceleration due to gravity.