



STATES OF MATTER

SLOs: After completing this lesson, the student will be able to:

1. Identify the three common states of matter, with the example of water etc.
2. Students will be able to compare the intermolecular forces between three states of matter.
3. Students will be able to describe the following properties of gases by using daily life examples:
 - (i) Diffusion
 - (ii) Effusion
 - (iii) Condensation
 - (iv) Density
 - (v) Compressibility
4. Students will be able to analyze the following properties of liquids:
 - (i) Evaporation
 - (ii) Vapor pressure
 - (iii) Boiling point
 - (iv) Freezing point
 - (v) Density
5. Students will be able to rationalize the following properties of solids:
 - (i) Melting point
 - (ii) Sublimation
 - (iii) Compressibility
 - (iv) Density
6. Differentiate between amorphous solids and crystalline solids.
7. Differentiate allotropic forms of carbon.

Matter exists in three fundamental states, i.e. the gas, the liquid and the solid state. As we know that the whole matter is made up of atoms and molecules hence in terms of molecular motion the gas is the state in which molecules have the maximum freedom for moving around, the liquids have an intermediate freedom of motion while the solids have only restricted motions of their molecules i.e. only vibrational motion. In this unit we will demonstrate an understanding of the common states of matter, properties of gasses, liquids and solids and also the gas laws. Matter can also be found in a state which is known as the plasma state. In this state matter exists in the form of ions and electrons at very high temperature. Sometimes it is called as the fourth state of matter, as at very high temperature the gas turns into plasma state but it is not the common state of matter.

7.1 COMMON STATES OF MATTER

The state of matter can be found by some properties of molecules of the matter. As all matter is made up of atoms and molecules, hence we can differentiate the states of the matter in terms of behaviour of molecular motions. In the gaseous state the molecules are spread much more and can move freely due to their random motions. Gases have neither a fix shape nor a fix volume and expand to fill any available space and get the shape of the container in which the gases are filled. In the liquid state molecules are nearly in the closed packed form but with an order less pattern. Liquids have definite volume but not the shape, as they get the shape of the container in which they are poured. Molecules in liquids can move but their motion is not as freely as in the case of gasses. Like gases the liquids can flow hence they are called the fluid.

"A substance which can flow is called the fluid".

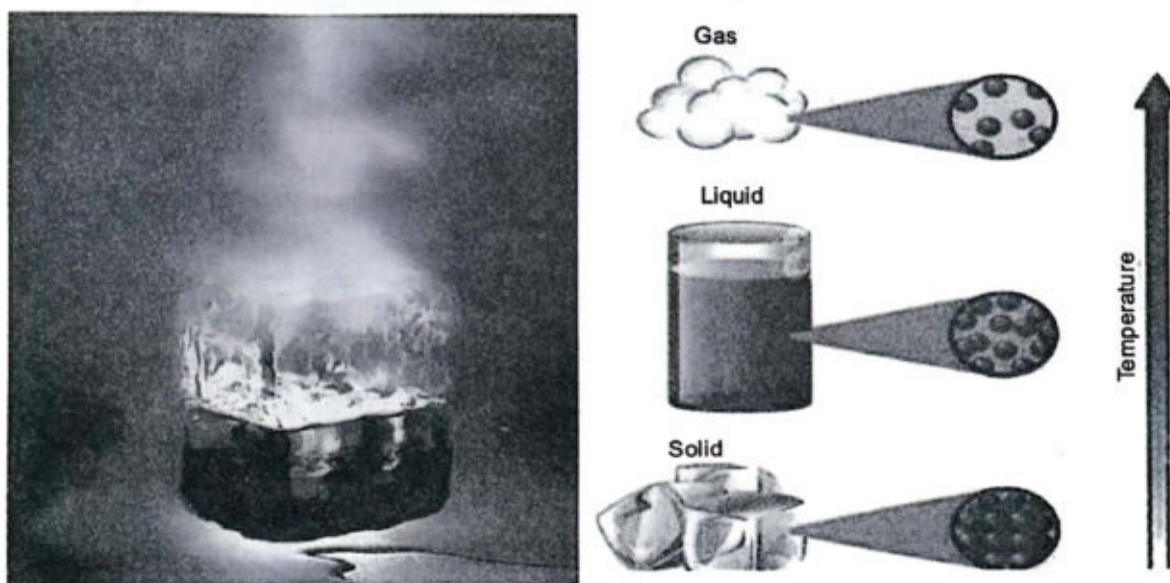


Fig. 7.1: Water in all three states

Like gases and the liquids both can be categorized as fluid. In solids the molecules are closely packed in regular pattern. They can only vibrate about some fix position. Due to the restricted

motion of molecules, solids have fix shape and fix volume. Solids usually resist against any change in their shape. Some of the properties like shape, volume, particle's motion and arrangement along with some examples of solids, liquids and gases are shown here in the table. In terms of molecular motion matter at lower temperatures usually gets the solid form as that of ice in above example upon heating the molecular motions become more rigorous and molecules get a distance from one another and transform into liquid state i.e. water. Upon further heating the molecules of water move further apart and get free from the attractive forces of other molecules and transforms into the gaseous state i.e. vapours or steam.

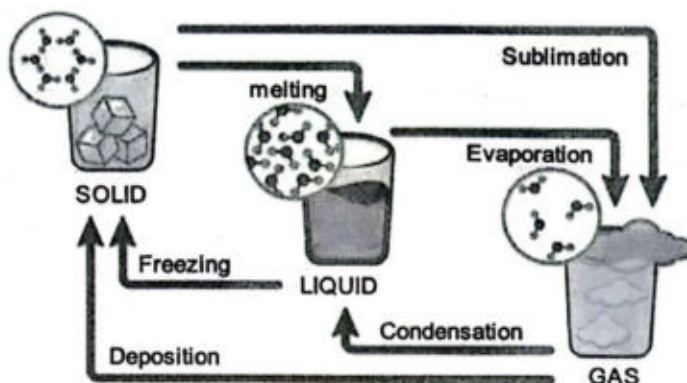


Fig. 7.2: Conversion of water in all three states

When we heat a substance this heat energy increases the molecular kinetic energy (energy associated with the motion of a body is called kinetic energy).

SCIENCE TIDBITS

Triple point of water is the temperature at which water can co-exist in all three forms i.e. solid ice, liquid water and gaseous vapors. This temperature is 273.16 K (0°C).

Table 7.1 Properties of matters

Property	Solids	Liquids	Gases
Shape	Definite shape	No definite shape, takes shape of the container	No definite shape, takes shape of the container
Volume	Definite volume	Definite volume	No fixed volume
Particle Arrangement	Tightly packed  Solid	Close together but can move  Liquid	Far apart, can move  Gas
Particle Motion	Vibrating in a fixed position	Flowing and sliding past each other	Moving rapidly and freely
Example	Ice, Wood, Stone	Water, Oil, Milk	Air, Oxygen, Nitrogen

Inter Molecular Forces

The *interatomic* forces (forces of attractions between atoms) are called chemical bond i.e. ionic and covalent bond as studied in unit-5, are responsible for the making of molecules which are also known as intra-molecular forces as shown in figure 7.3.

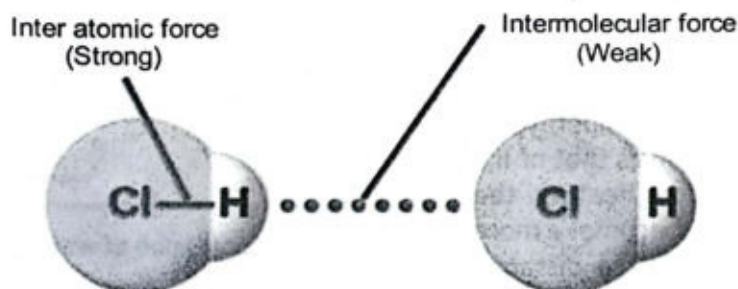


Fig. 7.3: Intra-molecular force and intermolecular force

Now for molecules there are more forces of attraction which hold the molecules together to form the large structures. Even the matter exists in the distinct forms of solid, liquid and gases are due to the difference of these intermolecular forces. Intermolecular forces act between the neighbouring molecules and are responsible for many of the physical properties of substances like solubility, density, melting point and boiling point etc.

The intermolecular forces are categorized as strong intermolecular forces and weak intermolecular forces.

- Dipole-dipole forces exist between polar molecules (molecules which have partial charges at opposite ends of the molecules). Dipole-dipole interaction is shown here in figure 7.4.

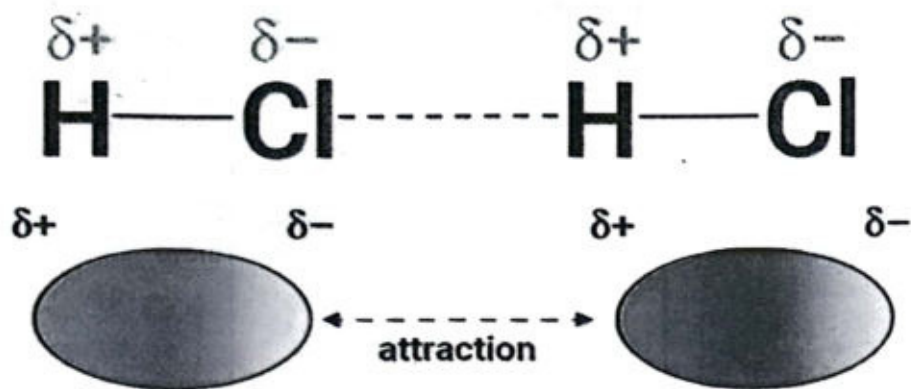


Fig. 7.4: Dipole-dipole interaction

- Dipole-induced dipole forces exist between polar and non-polar molecules (molecules which have uniform electronic distribution between all atoms in the molecules). When a non-polar molecule comes closer to a polar molecule it also induces opposite charge on its opposite ends by making the molecule as induced dipole.

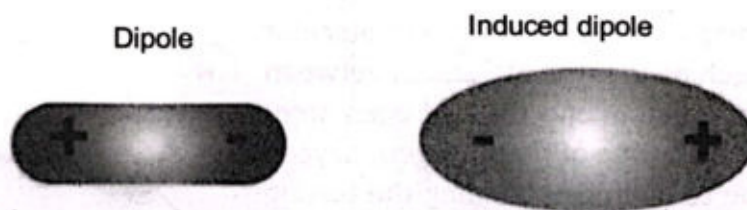


Fig. 7.5: Dipole induced-dipole interaction

- c. Ion dipole forces are between polar molecules and the free ions. In this case the negative ion (anion) is attracted by the positive end of the dipole and the positive ion (cation) is attracted by the negative end of the dipole as shown here in figure 7.6.

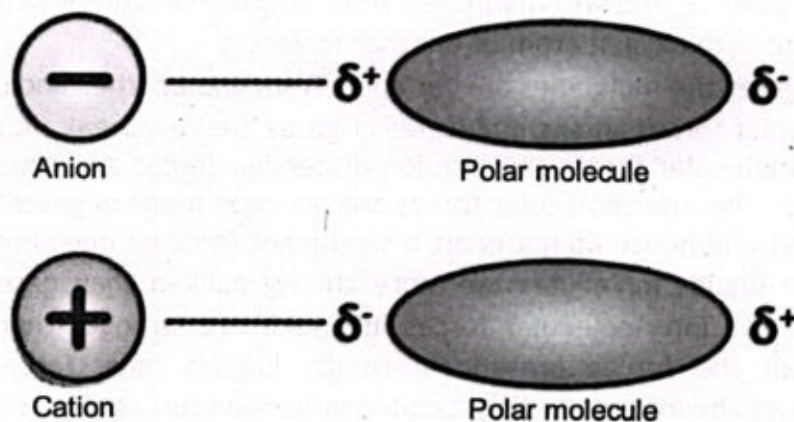


Fig.7.6: Ion-dipole interaction

- d. London dispersion forces are the weak forces among non-polar molecules which may become polar for an instant. Like in gases the electronic cloud is evenly distributed among all atoms but at any given instant the cloud may be re-distributed to form an instantaneous dipole giving rise to London dispersion forces as shown in figure 7.7 for helium molecules.

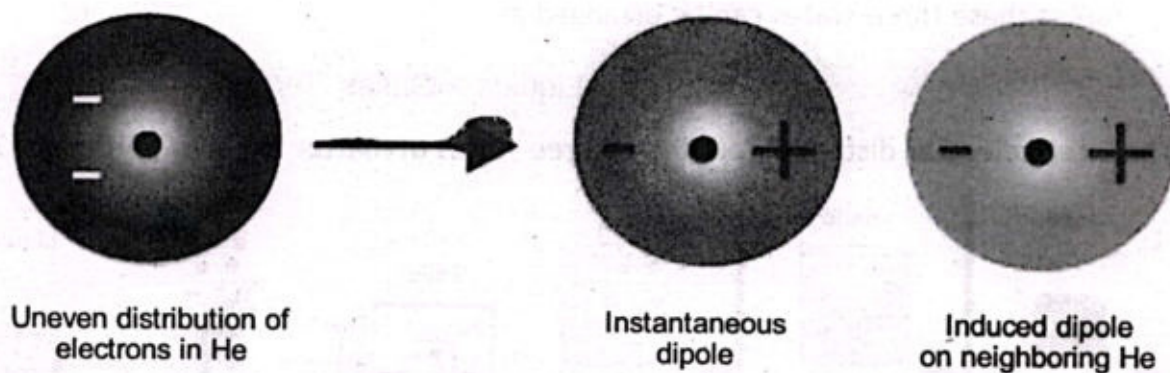


Fig. 7.7: London dispersion force

- e. **Hydrogen Bonding** is the strongest intermolecular force. A hydrogen bond is the attraction between an electronegative atom and the hydrogen atom that is bonded to any one of the nitrogen, oxygen or fluorine. Due to hydrogen bonding the boiling point and vaporization of substances occur at elevated temperatures. This is the reason that water (H_2O) has much higher boiling point than the similar molecule H_2S , because water has hydrogen bonding while H_2S has dipole-dipole interaction. The hydrogen bonding in water molecules is shown in the form of dotted line. In hydrogen bonding of water molecules, the partial positive end with hydrogen atom of one molecule is attracted by the partial negative end with oxygen atom of another molecule.

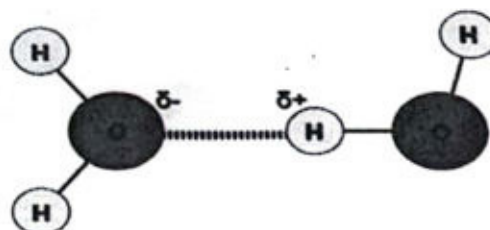


Fig.7.8: Hydrogen bonding in water molecule

- a) **Gases:** In gases the molecules are far apart from one another and can move freely. Inter molecular forces among molecules of gases are very weak. In gases we usually find weak intermolecular forces like London dispersion forces and sometimes dipole-dipole interactions. The intermolecular forces are not prominent in gases as the molecules are farther apart and hence do not exert a significant force on one another.
- b) **Liquids:** In liquids molecules are more closely packed than gases but still can have movement. The intermolecular forces in liquids are stronger than those of gases but weaker than the forces present in solids. Liquids have forces like dipole-dipole interaction and hydrogen bonding. London dispersion forces also known as Van der Waals forces are present in liquids which cause temporary fluctuations of electrons in molecules.
- c) **Solids:** In solids the molecules are closely packed together in a regular arrangement and the movement is limited to vibrations about some fixed position only. The intermolecular forces in solids are the strongest among all the states of the matter as they have the least distance among the molecules. Solids have strong intermolecular forces such as ionic bonds (in sodium chloride crystals), covalent bonds (in covalent network solids like diamond and quartz) and metallic bonds etc. In the term of strength of intermolecular forces these three states can be arranged as:

Solids > Liquids > Gases

The intermolecular distances for all the three states of matter are shown in figure 7.9.

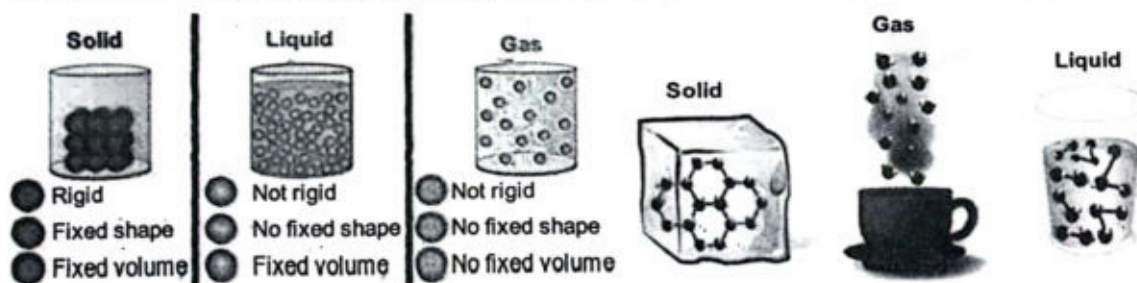


Fig. 7.9: Intermolecular distances for all three states

7.2 PROPERTIES OF GASES

In gases the molecules can move freely in random manner, like the motion of smoke particles. The molecules of gases move in straight lines until they collide with the other molecules or the walls of the container, upon collision they change their direction of motion. The molecules in gas can have translational, rotational and vibrational motion. Some of the properties of gases are given here.

Diffusion

Due to random movement of gas molecules, the movement of gas molecules from a region of high concentration to a region of low concentration is called diffusion. The spontaneous intermixing of molecules of one gas into the molecules of other gas is called diffusion provided that the temperature and pressure of both the gases remain the same. In daily life we have many examples of diffusion like,

- The fragrance of perfume when sprayed in one corner of the room it spreads into the whole room in a while due to diffusion.
- When you put some fume in one glass bottle and put upside down another bottle onto it, the fume slowly spread into the upper bottle due to diffusion. As shown in figure 7.10. Even students can do this activity in the classroom.



Fig. 7.10: Diffusion of fumes

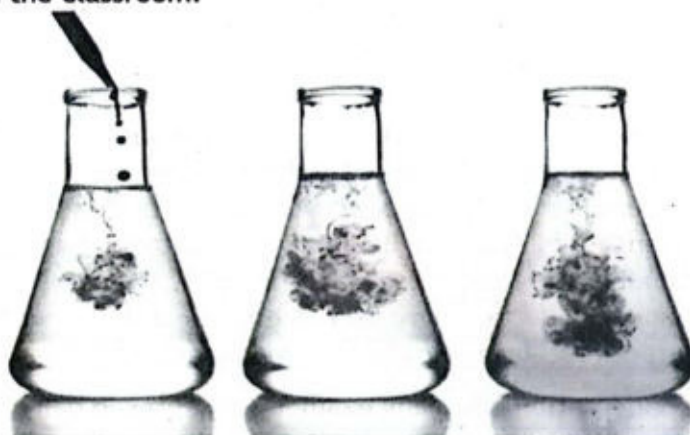


Fig. 7.11: Diffusion of ink

- The liquid ink when poured into clean water it mixes in water with time due to diffusion, as shown in figure 7.11.

Effusion

Due to pressure difference the escape of gas molecules from tiny hole is called effusion. When we bound the gas in a container which is initially sealed the gas comes to a constant pressure. When we make a small hole in the container



Fig. 7.12: Effusion of gas from small nozzle

which is comparable to the size of molecules the gas molecules start escaping through the hole to outward atmosphere where the pressure is low than the inside pressure. In effusion the molecules do not escape out from the whole due to collisions. Some of the daily life examples of effusion are as,

- The gas coming from the cylinders for cooking the food. The cylinder has a fuel gas at high pressure, with a small nozzle from which due to effusion gas molecules escape out to our stove where the fuel gas burns and gives us heat, as shown in figure 7.12.

- Effusion from an inflated balloon. Blow a balloon to its full with no leak. Put it for some time like a couple of hours. You would feel that the balloon is not as inflated as it was before two hours. This is due to the fact that some air escaped out of the balloon due to effusion, as shown in figure 7.13.

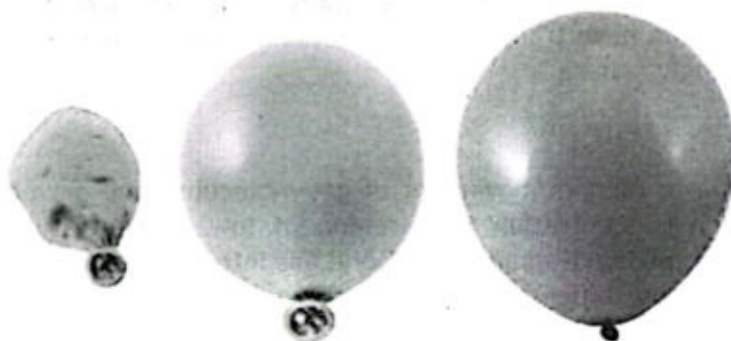


Fig. 7.13: Effusion of gas from balloon with passage of time

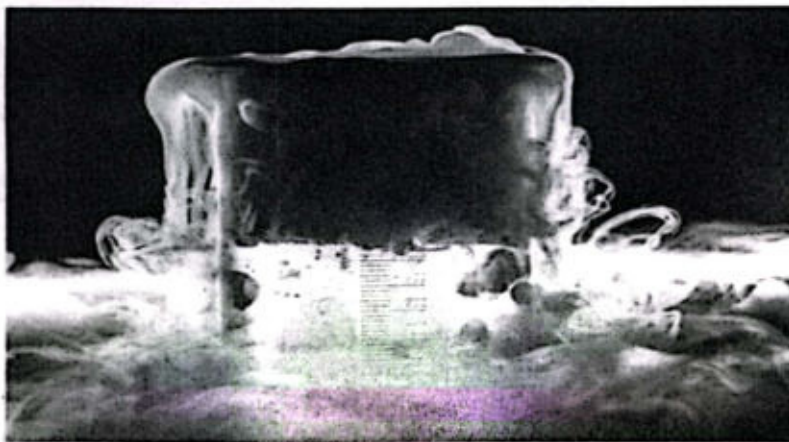
Condensation

Condensation is the process in which a gas converts into a liquid phase. This happens when the gas is cooled and it loses the heat content in it. This happens when the temperature of a gas is lowered below its condensation point. The condensation point is the temperature at which a gas changes its state to liquid. Every material has its own condensation point for example the condensation point for water is 100°C , which is also its boiling point. Condensation can also happen due to increased pressure, due to which molecules of a gas come closer and intermolecular forces become dominant to change the state from gaseous into liquid state.

Condensation has many examples and uses in daily life from which some are discussed below.

For Your Information

There is a minimum temperature below which the gas changes its state into liquid called the critical point. At temperature and pressure above critical point, the gas cannot be liquefied by pressure alone. Rather it becomes a supercritical fluid which has the properties of both gas and liquids.



- a. Cloud formation in the sky is an example of condensation. The water is present on the Earth's surface evaporates due to the Sun's heat. The vapours of water being lighter in weight rise in the atmosphere.

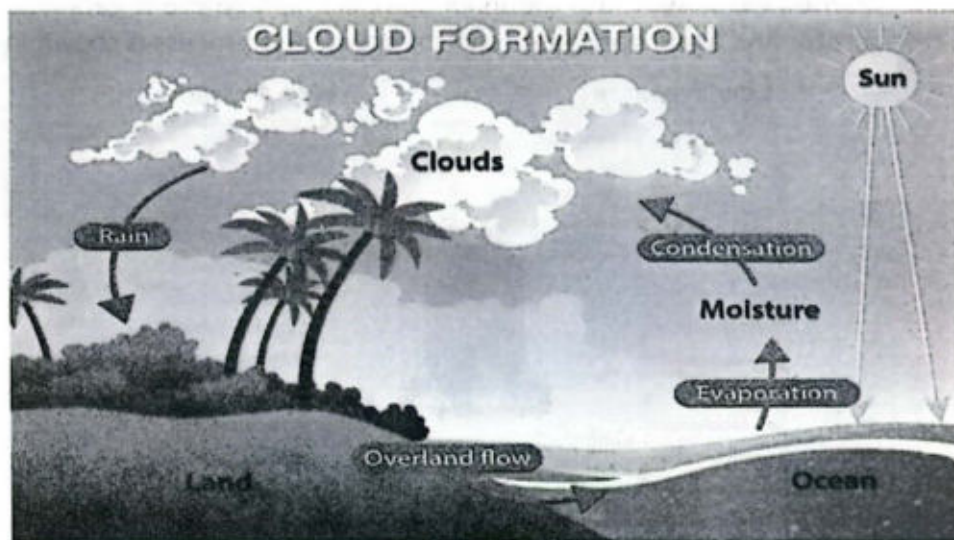


Fig. 7.14: Cloud formation

As they move up in the air they face a drop in temperature. The low temperature allows the water vapours to cool down and condensate into liquid drops. These water droplets accumulate together to form clouds in the sky. The process involve in cloud formation are shown in figure 7.14.

- b. The contrail is also an example of condensation. When an airplane flies at very high altitude the water vapours from its exhaust enter into the cold atmosphere where due to low temperature, they condensate into liquid and then into ice crystals. This process makes lines of ice or cloud like behind the airplane which are called as contrails as shown in figure 7.15.
- c. In fog fences the water is taken out from fog using a fog net which traps the water in it and due to condensation we can take pure water separated from other particles present in our atmosphere.

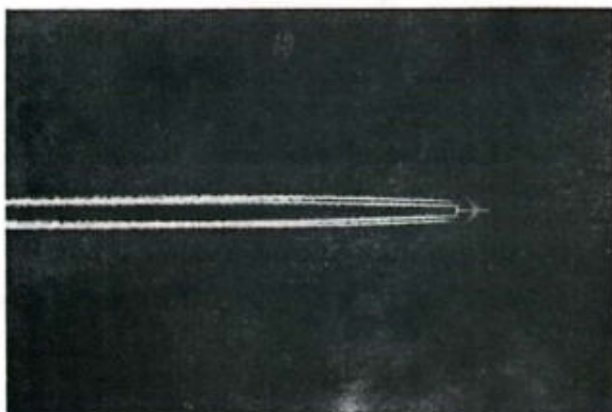


Fig. 7.15: Contrail

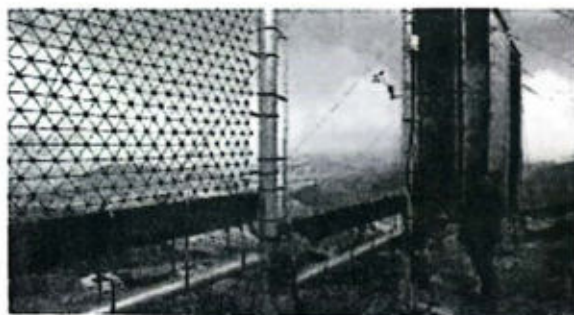


Fig. 7.16: Fog fence

- d. The compressor in refrigerator also uses the process of condensation in its working. The condenser is placed on the back side of the refrigerator. The refrigerant is cooled in the condenser, then due to condensation process the gas turns into liquid. Then this cooled liquefied gas is sent into the inner compartment where it gets heat from inside the refrigerator and again condenser cools it down. The process is shown in figure 7.17.

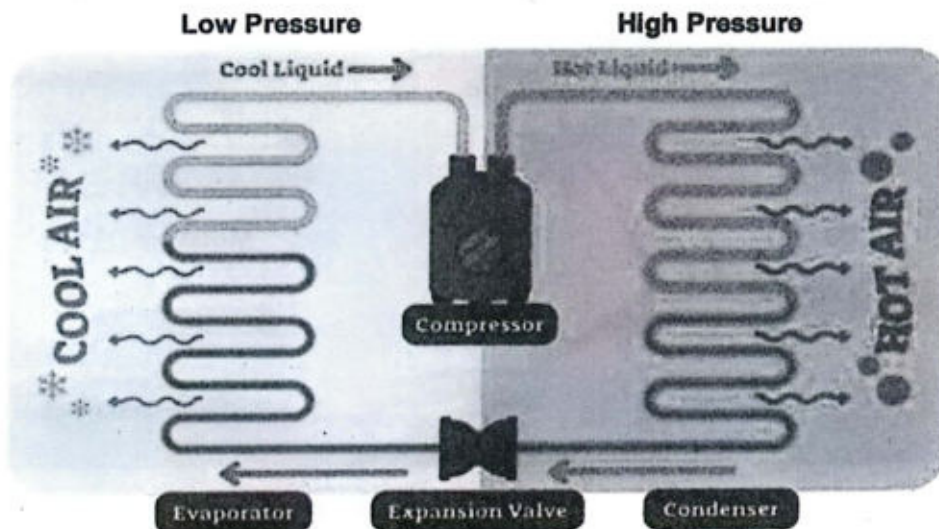
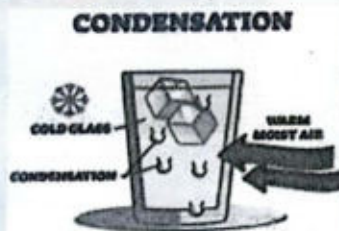


Fig. 7.17: Condensation in refrigerator

Do You Know?

The formation of dew drops outside of a glass or bottle containing chilled water is due to condensation. When the bottle or the glass containing chilled water is placed in room temperature, the water vapours present in the air around the glass or bottle condensate due to low temperature of chilled water.



Density

Density of a substance is the mass per unit volume. Density of a gas can be defined as the mass of the gas occupying a certain volume at specific pressure and temperature. Gases have the smallest value of density among all the three states of matter. The density of gases can be measured in the unit of kg/m^3 . The density of air at standard temperature and pressure (standard conditions of temperature are room temperature i.e. 25°C and that of pressure is 1 atmospheric pressure i.e. 101.325 kPa) is 1.225 kg/m^3 .

Densities of some gases at room temperature are given in table 7.1.

Table 7.1: Densities of some common gases		
Name	Formula	Density (kg/m ³)
Air	---	1.225
Carbon dioxide	CO ₂	1.842
Carbon monoxide	CO	1.165
Hydrogen	H ₂	0.089
Chlorine	Cl ₂	2.994
Oxygen	O ₂	1.331
Ozone	O ₃	2.14

- There are many examples in our daily life where density plays a vital role, like shipbuilding, designing of pipes, Helium balloons and weight distribution in an airplane.
- Knowledge of densities of different substances is used in separation techniques in chemistry and physics.
- Density is one of the major determining factors for an object that whether an object floats on water or sinks, the denser is the material the more it sinks into the medium as shown in figure 7.18.



Fig. 7.18: Floating or sinking due to difference in densities

Compressibility

The property of a gas which determines how much it can be compressed under a certain temperature, pressure and volume, is called compressibility. The value of compressibility changes for gas to gas, due to two factors i.e. the size of molecules of the gas and reaction of gas to pressure and temperature. Due to large distance among the molecules of gasses they are the most compressible among all three states. The more compressible is the gas its volume can be decreased more, provided that the gas does not liquefy. Compressibility is one of the common properties which have a wide range of applications in daily life.

- a. Natural gas is used as a fuel in homes and industries. It occupies a large volume which is difficult to transport from one place to another. To overcome this difficulty, we use to fill the cylinders with gas in compressed form. When we compress the gas, it can be filled in small space and it is easy to transport.
- b. Oxygen cylinders that are used in hospitals and for scuba diving also contain the gas in compressed form as shown in the figure 7.19.



Fig. 7.19: Compressed oxygen in cylinder for scuba diving

7.3 PROPERTIES OF LIQUIDS

In liquids the molecules can move but only restricted motions. The molecules in liquid can have restricted translational motion and rotational motion but vibrational motion is prominent in liquids due to intermolecular forces among the molecules of liquids. Liquids are less rigid than solids but more rigid than gasses. Some of the properties of liquids are given here.

Evaporation

Evaporation is the property of liquids in which a liquid turns into a gas or vapour state at temperature below the boiling point of the liquid. This transition occurs only at the surface of the liquids as the molecules taking excess energy to break the bonds by overcoming the attractive forces of the neighbouring molecules and hence escape out of the surface. Evaporation is the reverse process of the condensation where liquid turns into a gas. Evaporation takes place on the surface of liquids at every temperature. Evaporation depends upon certain factors which are given below.

- a. **Temperature:** higher temperature generally increases the rate of evaporation. As the temperature rises more and more molecules get enough energy to break the bonds and escape from the surface of the liquid.
- b. **Surface area:** as evaporation occurs only at the surface of the liquid, hence greater is the surface area greater will be the rate of evaporation. This is the reason we use a flatter pan to rapid cooling of the hot liquid for drinking.
- c. **Humidity:** the presence of water vapours in the surrounding air affects the evaporation. When the air is already saturated with water vapours, the rate of evaporation decreases.
- d. **Wind:** wind (the moving air) carries away the evaporated molecules from the liquid surface and hence it decreases the concentration of vapours above the liquid surface which increases the rate of evaporation. This is the reason that the wet clothes dry faster in windy day as compared to a still day.

Evaporation plays a vital role in water cycle in which water from the water reservoirs on the surface of Earth evaporates into the atmosphere. Upon reaching at high altitudes these vapours condense and make clouds which upon increase in precipitation cause the rain.

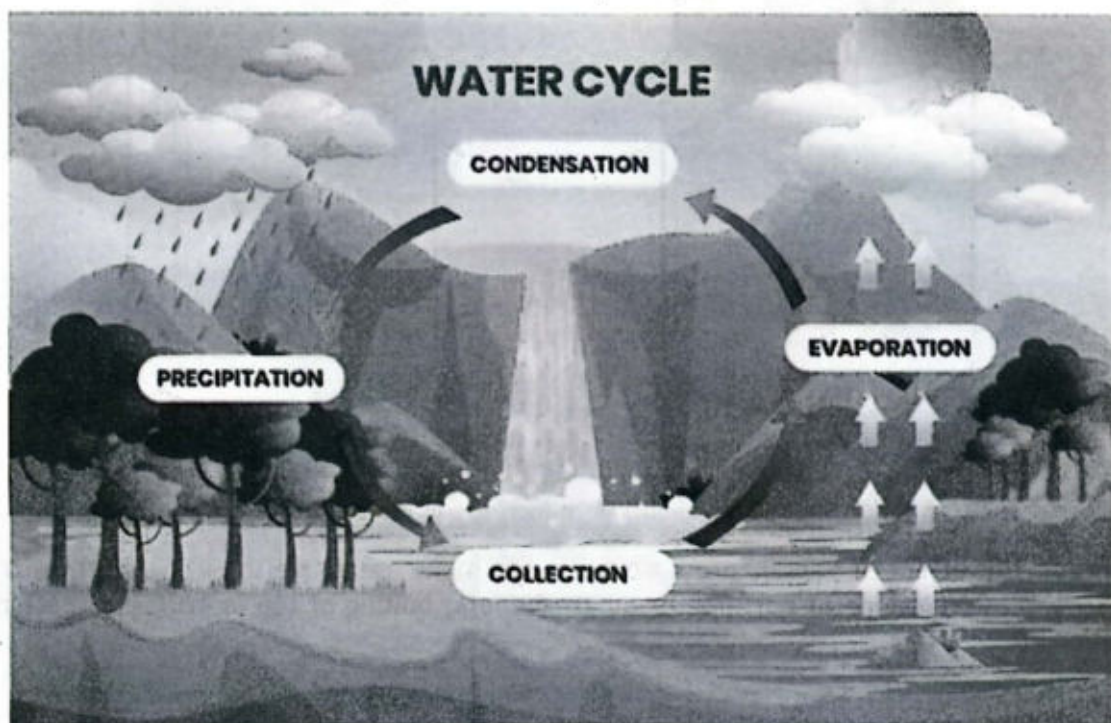


Fig. 7.20: Water cycle

Vapour Pressure

Pressure is the average force that a material (gas, liquid or solid) exerts upon the surface. When a liquid is heated, its molecules gain sufficient kinetic energy (energy associated with the motion of particles) to overcome the intermolecular forces and escape into the gaseous phase as vapours. Vapour pressure is the measure of the tendency of a material to change into the gaseous or vapour state. It increases with temperature. It can also be defined as the pressure exerted by the vapours on the surface of liquid. Vapour pressure is measured in standard units of pressure i.e. pascal (Pa). The vapours of a liquid are shown here in figure 7.21.

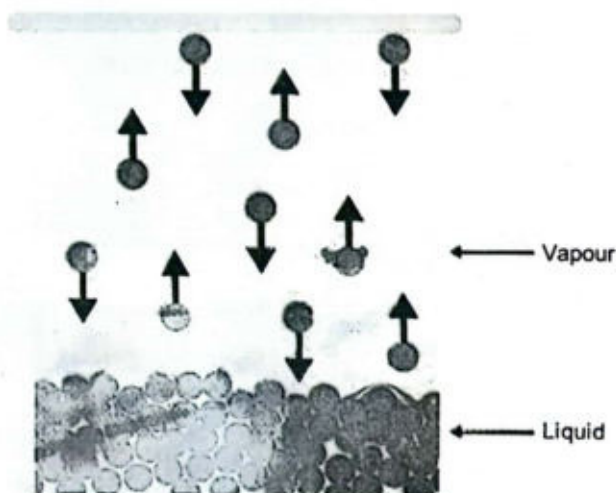


Fig. 7.21: Liquid and its vapours

The vapour's pressure increases with increase in temperature, as shown here in figure 7.22 that at $T_1 = 20^\circ\text{C}$ there is low vapour pressure as compared to vapour pressure at $T_2 = 37^\circ\text{C}$.

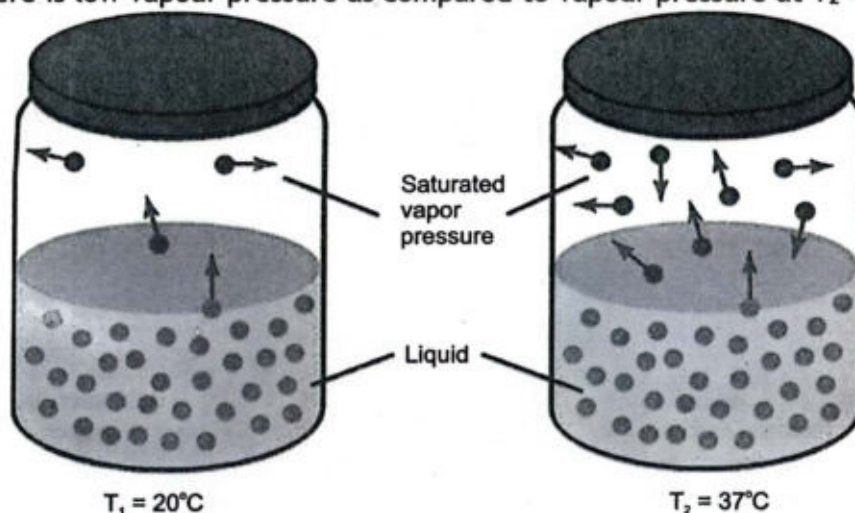


Fig. 7.22: Vapours with increase in temperature

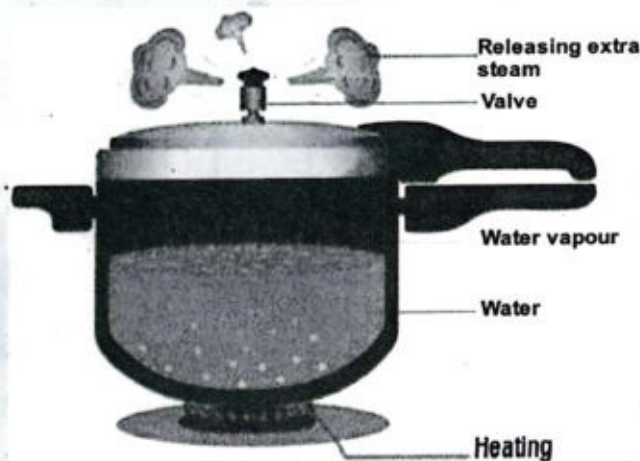
In daily life the effect of vapour pressure is used in many areas like in drying clothes, cooking food, spread of fragrance of perfume or air fresheners, boiling of tea or coffee, breathing and hair dryer etc.

Boiling Point

The temperature at which a liquid's vapour pressure becomes equal to the atmospheric pressure surrounding it is called boiling point of that liquid.

SCIENCE TIDBITS

In cooking food rapidly we use pressure cookers. In pressure cooker the pressure above the liquid surface in closed container is higher than the atmospheric pressure which raises the boiling point of the liquid. This enables the water to boil at 120°C instead of 100°C which adds more heat to cook food evenly and rapidly.



Boiling point for any liquid material is the temperature at which the material transforms into gaseous state. The normal boiling point of a liquid is the temperature at which its vapour pressure becomes equal to unit atmospheric pressure (760 torr). Boiling point of liquids depends upon temperature, atmospheric pressure and vapour pressure of liquid. The greater is the atmospheric pressure the higher will be the boiling point of the liquid.

Boiling point of liquid depends upon the volume of liquid more the volume of liquid greater is the boiling point of the liquid.

Boiling of liquids play a major role in daily life applications, like in steam engines and power generation the energy of boiling water is used, in cooking, sterilizing, cleaning, disinfecting, removing stain and preserving. Boiling point of water also depends upon the altitude, as with altitude the atmospheric pressure decreases and hence lowers the boiling points.

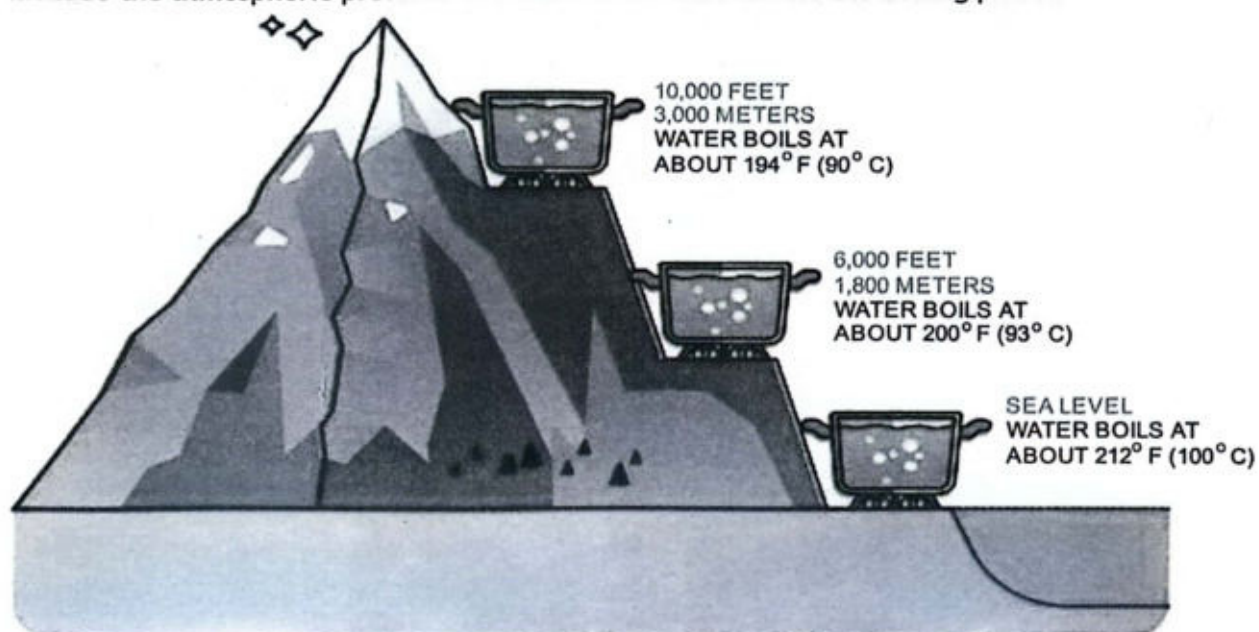


Fig. 7.23: Boiling point of water with altitude

Freezing Point

The temperature, at which a liquid becomes a solid at normal atmospheric pressure, is called freezing point. It occurs when the particles in the liquid lose energy, usually due to a drop in temperature. With decrease in temperature the motions of particles (molecules) decrease and hence molecules come closer to one another. Due to decrease in the distance between the molecules intermolecular forces become dominant and liquid turns into solid. Freezing point depends upon the factors like,

- Intermolecular forces: freezing point depends directly upon the strength of intermolecular force. If the intermolecular forces are high then the freezing point is also high. If the forces are weak the freezing point will be low.
- Pressure: freezing point depends directly upon the pressure. With increase in pressure, the freezing point also increases.

- c. Contamination: the liquids alter their freezing point with impurities in it. Due to added impurities in liquids their freezing point lowers. As in hilly areas when there is snow on roads we use salt to melt the snow to clear the roads. As adding salts decreases the freezing point of water and hence the snow melts. The saltation to melt the snow is shown in figure 7.24.



Fig. 7.24: Saltation to melt the snow

SCIENCE TIDBITS

Antifreeze is used in automobiles in cold areas to prevent the water to freeze in engine's radiator. It is a solution which lowers the freezing point of water or other coolant such that they may not freeze even at very low temperature. Such coolant remains in a liquid state even in the freezing conditions, preventing damage to the engine.



Density

Density of the liquid can be defined as the mass of the liquid occupying a certain volume at specific pressure and temperature. Liquids have the intermediate values of density between the gases and solids i.e. they are denser than the gases but rarer than the solids. The density of liquids can be measured in the unit of kg/m^3 . The density of water at standard temperature and pressure (standard conditions of temperature are room temperature i.e. 25°C and that of pressure is 1 atmospheric pressure i.e. 101.325 kPa) is 1000 kg/m^3 .

Densities of some liquids at given temperature are given in table 7.2.

Name	Temperature (°C)	Density (kg/m ³)
Pure water	4	1000
Sea water	25	1022
Turpentine	25	868.2
Petrol	16	711
Mercury	---	13590
Kerosene	15	820
Oxygen (liquid)	-183	1140
Milk	15	1020-1050

Densities of liquids can be used in daily life in many ways, some are given here.

- Density measurements are utilized in medical diagnostics like in analysing body fluids, blood components and pharmaceutical formulations.
- Knowledge of densities of different substances is used in separation techniques in chemistry and physics.
- In aviation and automobile industries, the density of liquid fuels is critical for fuel efficiency calculations.
- On the basis of difference of densities of the composition of blood, different parts of blood can be separated in centrifuge for finding the concentration and other medical aspects of these components. The red blood cells having highest density accumulate at the bottom while the least dense component plasma goes to the top, as shown in figure 7.25.

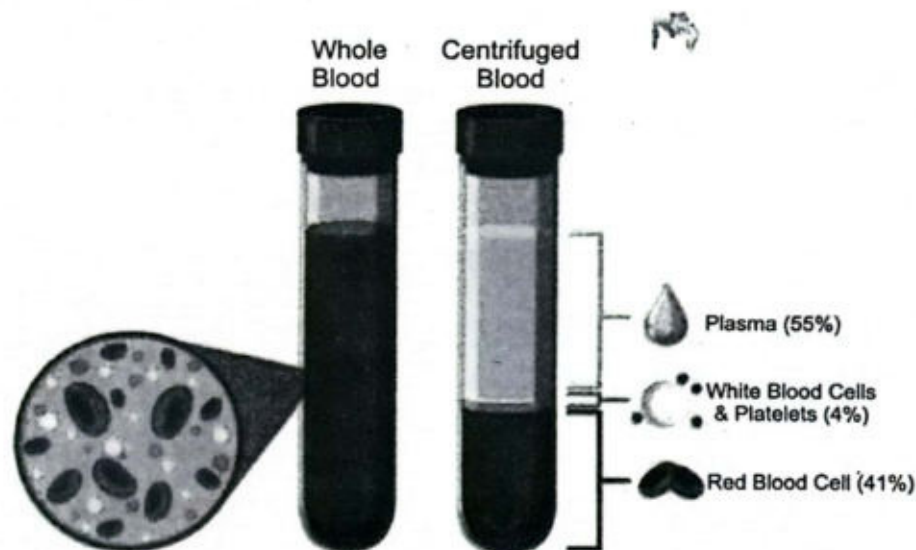


Fig. 7.25: Composition of blood

7.4 PROPERTIES OF SOLIDS

In solids the molecules cannot move along the body of solids rather they can only vibrate about their fixed positions only. The molecules in solids are closely packed together due to very strong intermolecular forces among them. All solids have rigid structures that tend to resist any external forces applied to them. Solids have fixed definite shape and volume. Some of the properties of solids are given here.

Melting Point

The temperature, at which the solid turns into liquid state at atmospheric pressure, is called the melting point of the solid. Melting point is the physical property which may depend upon some factors like pressure and the purity of the substance. In daily life we use this phenomenon for various reasons. Some are given below.

- Cooking:** knowing the melting points of solid ingredients in food is essential for cooking as we have to heat the food for cooking which depends upon melting of some foods like sugar, butter and chocolate etc. as shown in figure 7.26.
- Industries:** in industries we need to melt many substances for moulding them to desired shapes. Like metals, glass and plastics are moulded in their molten state as shown in figure 7.27.
- Pharmaceuticals:** in drug formulation we must understand the melting points of ingredients, like capsule covers such that they can melt in stomach under body temperature.
- Temperature controls:** melting points are also relevant in temperature control applications, like melting points of plastic and wax which are used in products such as thermostats and temperature sensitive switches as shown in figure 7.28.



Fig. 7.26: Melting of solid



Fig. 7.27: Moulding of molten glass

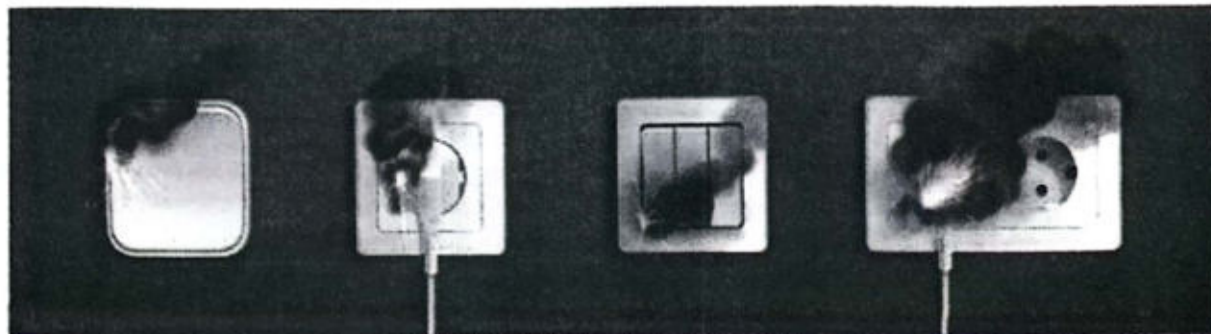


Fig. 7.28: Melting of plastic switches

Sublimation

A transformation, in which a solid substance transforms into vapours directly without melting first, is called sublimation. In this process a solid substance directly converts into gaseous state under normal atmospheric pressure. This phenomenon is the result of vapour pressure and temperature relationship. Solids which have weak intermolecular forces have higher vapour pressure. This property changes them to a gaseous state directly without melting. Sublimation depends upon temperature, surface area, humidity and the wind speed. Some of the daily life applications of sublimation are listed below.

- Dry ice: solid CO_2 sublimates at atmospheric pressure and temperature, producing dry ice. It is used for cooling purposes in food preservation and transportation of perishable goods.
- Some air fresheners use sublimation to release the fragrance into the air as shown in figure 7.29.
- Camphor: The solid mothball and other insect repellent are used in homes to avoid insect to spoil household item are used. These solid sublime at room temperature and pressure to an insect repelling gas.
- Freeze drying: in food industries this process is done which involves sublimation to remove the moisture from food products before packing.
- Printing and dyeing: sublimation printing involves in sublimation of solid paint or dye directly into gas state which then bonds with the fabric. This process is used in textile industries, ceramics and other materials providing long lasting colours. The sublimation printing is shown in figure 7.30.



Fig. 7.29: Sublimating fragrance



Fig. 7.30: Sublimation printing

Compressibility

The compressibility of a solid determines their ability to undergo change in volume under the changed pressure. Solids are least compressible than gases and liquids as they have strong intermolecular forces and their molecules are closely packed. When a pressure is applied to the solid its molecules are forced to move close to one another, causing decrease in volume. The degree of decrease in volume depends upon many factors like the structure of solid, bonding type and conditions of temperature and pressure. For most of the solids compressibility is low still it is major field of study in material science where we study the behaviour of solids under the applied stress. As the behaviour of solids under applied stress is important to know about strength and other like properties.

Compressibility is one of the common properties which have a wide range of applications in daily life.

- a. Engineering: in engineering the compressibility of solids have great deal, like in construction and building design. Engineers must take into account the compressibility of material used and requirement. In bridges the compressibility of material is necessary for safe design, as shown in figure 7.31.
- b. In automobile industries the compressibility of tyres and metal parts is important for a safe and comfortable ride. The compressibility of metals in engine components like piston and cylinders affects the performance and efficiency of an automobile.
- c. The compressibility of construction materials like foam and insulation is important for providing thermal and sound insulation in buildings. These materials should be able to compress under applied pressure to fill gaps effectively.

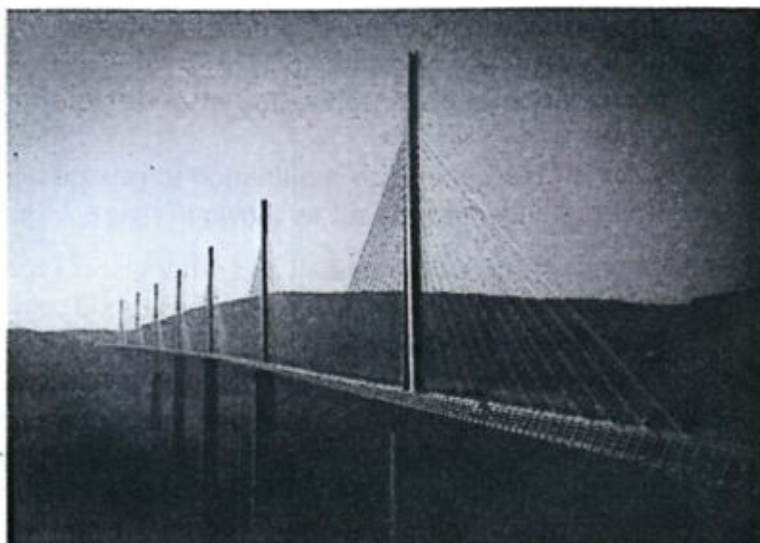


Fig. 7.31: Safe design of a bridge

Density

Density of the solids can be defined as the mass of the solid occupying a certain volume at specific pressure and temperature. Solids have the highest value of density than the gases and liquids. The density of solids can be measured in the unit of kg/m^3 . The density of solids depends upon molecular packing. For solids the density along with temperature and volume depends upon the crystal structure. The general density of wood at standard temperature and pressure (standard conditions of temperature are room temperature i.e. 25°C and that of pressure is 1 atmospheric pressure i.e. 101.325 kPa) is 1500 kg/m^3 .

Densities of some solids at room temperature are given in table 7.3.

Table 7.3: Densities of some common solids	
Name	Density $10^3 \text{ (kg/m}^3\text{)}$
Aluminium	2.7
Bone	1.7 - 2.0
Sand	2.32
Cork	0 - 0.25
Cotton	0.08
Diamond	3.5
Glass	2.9 - 5.9
Lead	11.35

Densities of solids can be used in daily life in many ways, some are given here.

- Density plays a vital role in construction material like bricks, concrete and metals. Engineers use density to determine the strength and stability of structures, like dense material i.e. concrete is used in the foundation to provide stability to the structure.
- In engineering the engineers use density measurements to select the materials for specific applications based on their strength to weight ratio. The light weight high density alloys might be used in aerospace and automobile applications to reduce the fuel consumption. The composition of an airplane's body is shown in figure 7.32.



Fig. 7.32: Composition of airplane's body

- c. In medical diagnostics like CT scans and MRI densities are used for investigations. Different tissues of the body have different densities which absorb different amount of radiations this shows the doctors the exact location of abnormalities.
- d. In jewellery making density play a vital role. As every metal and gemstone has unique density in its pure form. Jewellers use the values of density to find the purity and quality of the gold and other items. The common method for finding the density of jewellery items is the water immersion method as shown in figure 7.33.

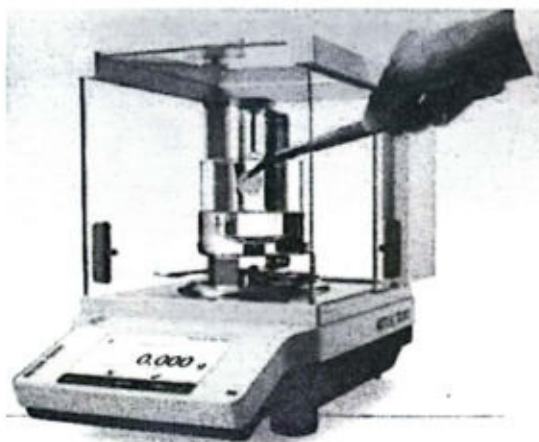


Fig. 7.33: Water immersion method to find density

7.5 AMORPHOUS AND CRYSTALLINE SOLIDS

Solids are those materials, which are incompressible and have fixed shape and volume. On the basis of atomic arrangement (the structure), solids may be classified into three types, i.e. crystalline, polycrystalline (polymeric) and amorphous (glassy) solids. Among these we will discuss only amorphous and crystalline solids here.

Crystalline Solids

In solids, particles are closely packed together but their packing may have different pattern. Among those, solids which have a regular and three-dimensional arrangements of constituent particles are called crystalline solids. The arrangement of particles can be studied by various x-rays techniques. Crystalline solid with structure is shown in figure 7.34.

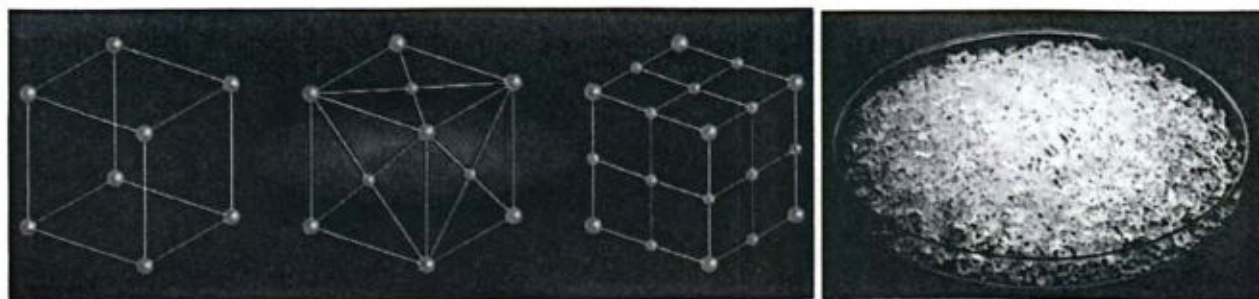


Fig. 7.34: Crystalline solids

“Crystalline solids are those solids in which the atoms, ions or molecules, which make up the solid, exist in a regular and well-defined arrangement”.

On cutting, they give sharp edges. Crystalline substances can be described by the type of particles in them and type of bonding that takes place between the particles.

Examples of crystalline solids include salts (sodium chloride, and potassium chloride), metals (copper, iron and zinc), non-metals (diamond, sulphur and mica), ionic compounds (NaCl and

copper sulphate), ceramic (zirconium), sand and quartz. Crystalline solids have sharp edges and sharp melting points, as the particles of solids are not static, on gaining thermal energy, particles of crystalline solids vibrate about their mean positions with greater amplitude, resulted in melting of material at a sharp temperature.

Amorphous Solids

Unlike crystalline solids, amorphous solids do not have a regular structure. Amorphous means without form or structure.

“Solid materials, whose constituent particles are arranged in a random manner, are called amorphous solids”.

Amorphous solids also called glassy solids, having structure like frozen liquids. They have fix volume but not definite regular geometrical shape, as shown in figure 7.35.

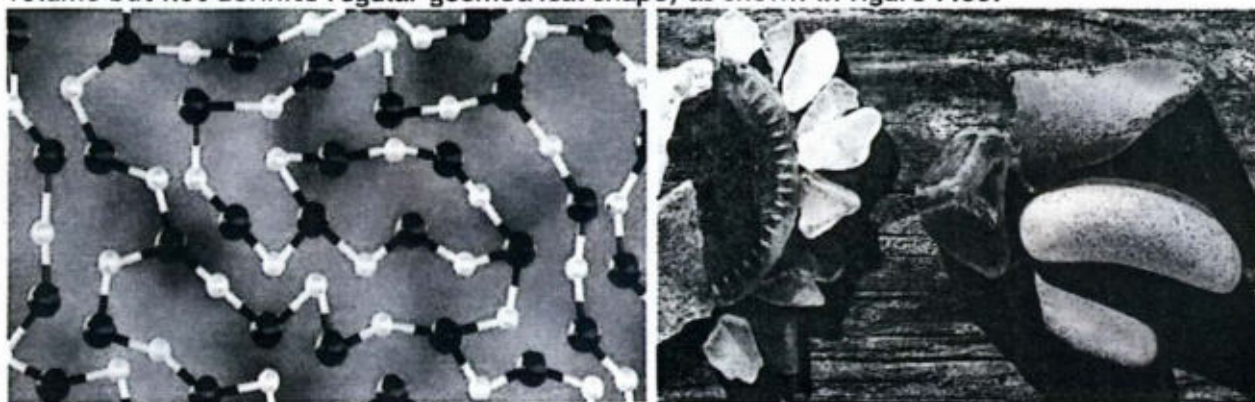


Fig. 7.35: Amorphous solids

Latest technique of 3-D imaging showed 85% of atoms were in a disorder arrangement. They have a range of temperature as melting temperature, i.e. if we heat a glass rod it gradually softens into a paste like state before it becomes viscous liquid at 800°C . The difference between crystalline and amorphous solids is that of arrangement of molecules, as shown in figure 7.36.

As from above figure that in crystalline solids the atoms or molecules are arranged in a regular manner while in case of amorphous solids the atoms or molecules of solid are not arranged in regular manner rather they are in random positions. The differences between crystalline and amorphous solids are given here in table 7.4.

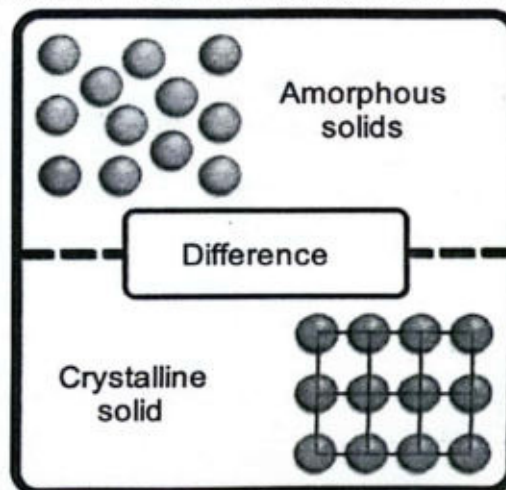


Fig. 7.36: Difference between crystalline and amorphous solids

Table 7.4: Difference between crystalline and amorphous solids

Properties	Crystalline solids	Amorphous solids
Geometry	Definite geometrical shape due to ordered arrangement	Indefinite geometrical shape due to irregular arrangement
Symmetry	Have symmetry (plane, center and axis symmetry)	Do not have any type of symmetry
Directional nature	Anisotropic, properties are direction dependent	Isotropic, properties are direction independent
Melting point	Have sharp melting point	Have a range of temperature as melting point
Physical state	Hard and rigid	Soft
Cleavage	On cutting they give sharp and smooth edges	On cutting they give irregular and diffused edges
Examples	Quartz, diamond, NaCl, ZnS	Rubber, plastic, glass

7.6 ALLOTROPIC FORMS OF CARBON

Carbon is the most unique element in the universe as it has the largest number of molecules due to its property of making large chains. There are three main types of allotropic forms of carbon i.e. diamond, graphite and Bucky balls.

Diamond

Diamond is one the of hardest materials on Earth which is made up of carbon atoms.



Fig. 7.37: Diamond

In diamond each carbon atom is surrounded by the four other carbon atoms which are linked together by the covalent bonds. Diamond has two types of structures i.e. crystallographic and cubic structure as shown in figure 7.37. In diamond molecules form a three-dimensional network of strong covalent bonds. It has a very high melting point of about 3843 K and a high density of 3150 to 3530 kg/m³. It is a poor conductor of electricity. Some of the applications of diamond are:

- It is used in making of tools for using in grinding, drilling and cutting the hard metals.
- It is used in the manufacture of filament made of tungsten used for light bulbs.
- It is used in making jewellery.
- It is used to remove cataracts from the eye as a high precision instrument.

Graphite

A soft black form of carbon that conducts electricity and is used in lead pencils and electrolytic anodes is the graphite. It is black to dark grey, opaque and very soft material. Graphite is composed of layers of carbon atoms that are arranged in 6 membered hexagonal rings. The rings have many layers of particles as shown in figure 7.38.



Fig. 7.38: Graphite

Graphite has good electrical conductivity and density about 2260 kg/m^3 . Graphite has many daily life uses and applications, some of which are given here.

- Graphite powder is used as a lubricant in the form of dispersion material.
- Graphite is widely used in lead pencils.
- It is used in the manufacture of electrodes of carbon used in electrolytic cells.
- It has high melting point.
- It is used to make crucibles due to its resistance towards heat.
- It is used in nuclear reactors as moderator.

Bucky Ball

Bucky balls composed of carbon atoms linked to three other carbon atoms by covalent bonds. However, the carbon atoms are connected in the same pattern of hexagons and pentagons like the pattern found on a soccer ball, giving the bucky balls a spherical shape, its structural formula is C_{20} , as shown in figure 7.39.



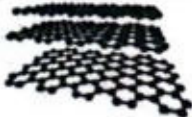
Fig. 7.39: Bucky ball

Some of the properties of bucky ball are listed here.

- Its behaviour and structure depends on the temperature, as the temperature increased it can convert into C_{70} .
- Its structure can be changed under different values of pressure.
- Its electron affinity (capacity to accept an electron) is 2.6 electron volts.

- d. It is stable but not totally non-reactive.
- e. It is ferromagnetic (materials having strongest magnetic fields).

7.5 Comparison of allotropes of carbon

Allotrope	Structure	General Strength	Heat Resistivity	Electrical Conductivity
Graphite		Low	Very low	Very high
Diamond		Very high	Moderate	None
Bucky Balls		Moderate	High	Low

SUMMARY

1. A substance which can flow is called the fluid.
2. Water can be found in all the three states at the same time at 0°C .
3. The forces of attraction between the molecules of a substance are called inter molecular forces.
4. Dipole-dipole forces exist between the polar molecules.
5. Dipole-induced dipole forces exist between polar and non-polar molecules.
6. Ion dipole forces exist between molecules and the free ions.
7. London dispersion forces are weak forces which exist between non-polar molecules.
8. Hydrogen bonding is the strongest intermolecular force which exists between hydrogen and one of oxygen, nitrogen or fluorine.
9. Gases are those substances which have neither fix shape nor fix volume.
10. Liquids are those substances which have fix volume but not fix shape.
11. Solids are those substances which have fix volume and fix shape.
12. Diffusion of gases is the property in which due to random movement gas molecules transfer from high concentration region to low concentration region.
13. Due to pressure difference the escape of gas molecules from tiny hole is called effusion.
14. Condensation is the process in which a gas converts into a liquid phase.
15. Density of a substance is the mass per unit volume.
16. The property of a gas which determines how much it can be compressed under a certain temperature, pressure and volume, is called compressibility.
17. Evaporation is the property of liquids in which a liquid turns into a gas or vapour state at temperature below the boiling point of the liquid.
18. Vapour pressure is the measure of the tendency of a material to change into the gaseous or vapour state.
19. The temperature at which a liquid's vapour pressure becomes equal to the atmospheric pressure surrounding it is called boiling point of that liquid.

20. The temperature, at which a liquid becomes a solid at normal atmospheric pressure, is called freezing point.
21. The temperature, at which the solid turns into liquid state at atmospheric pressure, is called the melting point of the solid.
22. The transformation, in which a solid substance transforms into vapours directly without melting first, is called sublimation.
23. The compressibility of a solid determines their ability to undergo change in volume under the changed pressure.
24. Solids which have a regular and three-dimensional arrangements of constituent particles are called crystalline solids.
25. Solid materials, whose constituent particles are arranged in a random manner, are called amorphous solids.
26. Carbon has three allotropic forms i.e. diamond, graphite and bucky ball.

EXERCISE

Section I: Multiple Choice Questions

Select the correct answer:

1. Which of the following is not the characteristic of a solid?
A) high rigidity
B) regular Shape
C) high density
D) high compressibility
2. One litre of water is cooled from 4°C to 0°C , its volume:
A) decreases then increases
B) remains same
C) increases
D) decreases
3. The formation of clouds in the sky is due to the process of:
A) melting
B) sublimation
C) condensation
D) boiling
4. The best conductor of heat among following liquids is:
A) water
B) ether
C) alcohol
D) mercury
5. The process which involves the transformation between gas and solid is:
A) melting
B) freezing
C) evaporation
D) sublimation
6. Glue is an example of _____ solid:
A) crystalline
B) amorphous
C) liquid-solid
D) ductile
7. Which of the following is the formula of bucky ball?
A) C
B) C_3
C) C_{12}
D) C_{60}

8. Wood charcoal is an allotrope of:
- | | |
|-------------|------------|
| A) silicon | B) carbon |
| C) nitrogen | D) mercury |
9. Which of the following is an amorphous allotrope of carbon?
- | | |
|-------------|---------------|
| A) diamond | B) bucky ball |
| C) graphite | D) lampblack |
10. What type of intermolecular forces holds liquid N_2 together?
- | | |
|------------------|----------------------------|
| A) Ionic bond | B) London dispersion force |
| C) hydrogen bond | D) dipole-dipole force |

Section II: Short Response Questions

1. Define pressure of a gas. Also give its different units.
2. Why lighter gasses diffuse more rapidly than heavier gasses?
3. Ice occupies more space than water. Give reason.
4. The boiling point of water is greater than HF. Why?
5. Why boiling point of water is different at sea level and on high altitude mountain?
6. Due to its molecular mass, at standard conditions water should be a gas. But we find water as liquid, why?
7. Why intermolecular interactions are more important in liquids and solids than for gasses?
8. We found a water droplet round. Explain why?
9. Diamond and graphite are made up of the same element (carbon), then why are they different is properties?
10. What is the reason that most of the solids prefer to be in crystalline state?
11. Enlist some daily life uses of condensation, effusion and compressibility of gases.
12. How the vapour pressure, boiling point and freezing point of water can be elevated?
13. Discuss some daily life applications of sublimation and compressibility of solids.

Section III: Extensive Response Questions

1. Matter can be categorized in different states define and explain them.
2. Water can exist in all three states? Explain.
3. Discuss the significance of intermolecular forces in case of solids, liquids and gasses.
4. What role the density plays in solids, liquids and gasses?
5. Differentiate between the compressibility of gases and solids.
6. Phenomenon like diffusion, effusion and condensation play vital role in gases. Elaborate.
7. Evaporation, vapour pressure, boiling point and freezing point are some common terms related to liquids. Justify the statement with examples.
8. Solids can transform into liquids and gases through the processes like melting and sublimation. Describe these processes for solids.
9. Amorphous and crystalline are two types of solids. Justify the classification of solids in these two types.
10. Why carbon has different allotropic forms? Differentiate between different allotropic forms of carbon.