PROPERTIES OF MATTER

Solids : The materials that have a definite shape and volume are known as solids. In solids, the intermolecular forces are very strong which hold them together in a fixed position and provide them regular shape. They are classified into two categories :

(i) **Crystalline solids :** In these solids, the atoms or molecules are arranged in a regular geometrical pattern throughout the entire three dimensional network of the crystal. They have long range order. The examples of crystalline solids are sugar, rock salt, mica, quartz, copper sulphate, alum, calcite, sulphurs, diamond etc.

(ii) **Amorphous solids :** In these solids, the atoms or molecules are not arranged according to a certain definite geometrical order. In them, long range order is absent.

The examples of amorphous solids are flour, talc powder, glass rubber, plastics etc.

Unit cell : A unit cell is defined as the smallest pattern of the atoms in a lattice, which when repeated again and again in different directions forms the full crystal lattice. The lengths of their edges are represented by $\vec{a}, \vec{b}$ and $\vec{c}$, which are called translation vectors.

Crystal lattice : Crystal lattice is defined as a regular arrangement of large number of points in space, each point representing the position of an atom or a group of atoms in a crystal. A three dimensional lattice can be represented by,

$\vec{l} = n_1\vec{a} + n_2\vec{b} + n_3\vec{c}$, where n_1, n_2, n_3 are arbitrary integers.

Inter-atomic and inter-molecular forces : A force acting between the atoms of an element is called inter-atomic force. Similarly, a force acting between two molecules is said inter-molecular force. Forces between atoms and molecules are electrical in nature. These forces are of two types :

(i) **Cohesive forces :** If inter-atomic/inter-molecular forces are acting between similar atoms/molecules, then these forces are called as forces of cohesion.

(ii) **Adhesive forces :** If inter-atomic/inter-molecular forces are acting between different atoms/molecules, then these forces are called as forces of adhesion.

Important Results

(i) Inter-atomic/inter-molecular forces are electrical in nature.

(ii) Inter-molecular forces are weaker than inter-atomic forces.

(iii) r_0 for two molecules is larger than r_0 for two atoms.

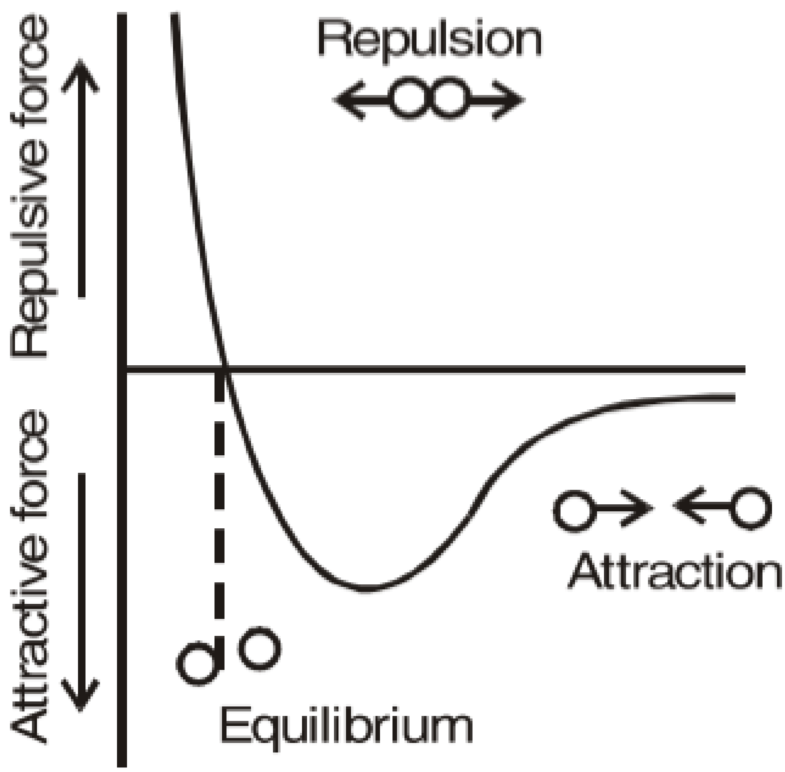

Fig. Variation of inter-atomic forces with inter-atomic separation

(iv) Inter-atomic/inter-molecular forces are short range forces.

(v) Inter-atomic/inter-molecular forces are much stronger than inverse square forces.

(vi) At $r = r_0$, no force acts between atoms/molecules.

(vii) At $r < r_0$, the nature of forces is repulsive.

(viii) At $r > r_0$, the nature of forces is attractive.

(ix) The magnitude of the repulsive forces is much more than the magnitude of the attractive forces.

Elasticity and plasticity : The property of a body by virtue of which it recovers its original shape and size when the external force are removed, is called **elasticity**. And the property of remaining deformed even after the removal of external force is called plasticity. Those bodies which possess the property of elasticity, are called elastic bodies and those which possess the property of plasticity are called plastic bodies.

Perfectly plastic : When the bodies completely recovers its original shape and size as soon as the deforming forces are removed, it is called **perfectly elastic**, while if it completely retains its deformed force, it is said to be perfectly plastic. Actual behaviour of the bodies lie between these two limits.

Stress : When some external forces act on a body to deform it, it offers an internal resistance on account of its elasticity. This internal force per unit area of the body is called stress. This internal force is equal but opposite to the external forces and due to this only the body regains its original shape and size. Hence, stress is measured by the external force acting on unit area of the body.

Hence,

$$\text{Stress, } T = \frac{F}{A}$$

where F is the external force acting on an area A of the body.

The stress is of three types :

(i) **Normal stress :** If the force F is acting normally over an area A of the body, then stress is called normal stress.

(ii) **Hydrostatic stress :** If a pressure P is acting on the body uniformly from at the sides, then this pressure P is called hydrostatic stress.

(iii) **Tangential stress :** If a force F is acting tangentially on an area A of the body, the body gets sheared through a certain angle. The stress is now called tangential stress.

Strain : The change in dimensions of a body on the application of deforming forces per unit original dimensions is called strain. Therefore,

$$\text{Strain} = \frac{\text{change in dimensions}}{\text{original dimensions}}$$

Being a ratio of two like quantities, it has no dimensional formula and no unit.

Strain is also of three types

(i) **Longitudinal strain :** It can be defined as the change in length per unit original length of the body. Hence

$$\text{Longitudinal Strain} = \frac{\text{change in length}}{\text{original length}}$$

$$= \frac{\Delta l}{l}$$

(ii) **Volume strain :** It can be define as the change in volume per unit original volume of the body. Hence

$$\text{Volume strain} = \frac{\text{change in volume}}{\text{original volume}}$$

$$= \frac{\Delta V}{V}$$

(iii) **Shearing strain (or shear) :** It is measured by the angle θ (in radians) through which a line originally perpendicular to the fixed face is turned.

Hooke's law and modulii of elasticity : Hooke's law is a fundamental law of elasticity. It states that within elastic limit, stress is proportional to the strain, i.e.,

stress $\propto$ strain

$$\text{or} \quad \frac{\text{stress}}{\text{strain}} = \text{constant.}$$

This constant is called modulus of elasticity or simply elasticity and is represented by E. Its dimensional formula is $[ML^{-1}T^{-2}]$ and its SI unit is Nm^{-2}. Corresponding to three different type of strains, there are three modulii of elasticity, as follows :

1. Young's modulus of elasticity (Y)
2. Bulk modulus of elasticity (K), and
3. Modulus of rigidity (η).

Young's modulus of elasticity : Within elastic limit, the ratio of the longitudinal stress to the corresponding longitudinal strain is called Young's modulus of the material of the body. Thus,

$$\text{Young's modulus} = \frac{\text{longitudinal stress}}{\text{longitudinal strain}}$$

$$\text{or } Y = \frac{F/A}{\Delta l/l} = \frac{F.l}{A.\Delta l}$$

If extension is produced by a load M in a wire of radius r, then

$$F = mg \text{ and } A = \pi r^2$$

$$\text{Hence, } Y = \frac{mg}{\pi r^2} \cdot \frac{l}{\Delta l}$$

From this, if $l = 1$ m

$A = 1 \text{ m}^2$

$\Delta l = 1$ m

then, $Y = F$

Hence, Young's modulus is equal to the force required to double the length of the wire of unit area of cross section.

Bulk modulus of elasticity : Within elastic limit, the ratio of the normal stress to the corresponding volume strain is called Bulk modulus of the material of the body. Hence,

$$\text{Bulk modulus} = \frac{\text{Pressure}}{\text{Volume strain}}$$

$$\text{or } K = -\frac{\Delta P}{\Delta V/V} = -V\frac{\Delta P}{\Delta V}$$

The negative sign indicates that increase in pressure (ΔP) causes decreases in volume ($-\Delta V$) and vice-versa.

It should be noted that the reciprocal of Bulk modulus is called compressibility.

$$\therefore \text{ Compressibility} = \frac{1}{K} = -\frac{1}{V} \times \frac{\Delta V}{\Delta P}$$

Elastic limit : It is defined as the maximum stress from which an elastic body will regain its original shape or size on removing the deforming forces.

Modulus of rigidity : Within elastic limit, the ratio of the tangential stress to the corresponding shearing strain is called modulus of rigidity of the material of the body. Thus

$$\text{Modulus of rigidity} = \frac{\text{tangential stress}}{\text{shearing strain}}$$

$$\text{or } \eta = \frac{F/A}{\theta} = \frac{F}{A\theta}$$

Poisson's ratio : Within elastic limit, the ratio of lateral strain (the change in lateral dimension per unit lateral dimension is called **lateral strain**) to longitudinal strain is called as Poisson's ratio.

$$\text{Hence, Poisson's Ratio} = \frac{\text{lateral strain}}{\text{longitudinal strain}}$$

$$\text{or, } \sigma = \frac{\beta}{\alpha}$$

If l be the length of the wire, D its diameter, Δl the change in length and ΔD corresponding change in diameter, then

$$\alpha = \frac{\Delta l}{l}$$

$$\text{and } \beta = \frac{\Delta D}{D}$$

$$\therefore \quad \sigma = \frac{\Delta D/D}{\Delta l/l} = \frac{l}{D} \cdot \frac{\Delta D}{\Delta l}$$

Kinetic Theory of Gases : The kinetic theory of gases is based on the following fundamental assumptions :

(i) The gas is composed of small indivisible particles called molecules.

(ii) The molecules of a gas are considered to be perfectly elastic solid rigid spheres. All of them are also identical in all regards, i.e., size, shape, mass, etc.

(*iii*) The size of the molecules is taken negligible as compared with the large distance between the two molecules. Thus the force of attraction between two molecules is considered to be negligible.

(*iv*) The molecules are continuously in motion with varying velocities and the path of their motion between any two consecutive collision is straight line. There is no change in the number of molecules present in a unit volume of the gas.

(*v*) The molecules during their motion collide with one another as well as with the walls of the container. During the collision process the velocities of the molecules change in magnitude and direction.

(*vi*) The time taken in a collision is negligible as compared to the time taken by a molecule in moving independently from one point to another inside the container.

(*vii*) The collision between the molecules of the gas are perfectly elastic and there are no force of attraction or repulsion between the molecules, which implies that the mean energy of the gas is all kinetic.

Expression for the pressure :

$$P = \frac{1}{3}\rho c^2$$

where ρ = density of the gas

c = root mean square (RMS) velocity of the gas

Some Important Deduction :

(i) The pressure of a gas is equal to two-third of the mean kinetic energy of translation per unit volume of the molecules.

(ii) Mean square velocity of the molecules is also directly proportional to the absolute temperature.

(iii) Average kinetic energy per molecule is proportional to the absolute temperature of the gas.

(iv) **Boyle's law :** When temperature of a given mass of a gas is constant, its pressure is inversely proportional to its volume, or

$$PV = \text{constant}$$

(v) **Charles' law :** If pressure of a given mass of a gas is kept constant, its volume is directly proportional to absolute temperature of the gas, or

$$V \propto T$$

(*vi*) **Gay Lussac's law :** If volume of a given mass of a gas is kept constant, its pressure is directly proportional to its absolute temperature, or

$$P \propto T$$

(*vii*) **Avogadro's hypothesis :** Equal volumes of all gases under similar conditions of temperature and pressure contain equal number of molecules.

(*viii*) **Grahm's law of diffusion :** Root mean square velocity of the molecules of a gas is inversely proportional to the square root of its density.

(*ix*) **Perfect gas equation :** PV = RT.

(*x*) **Dalton's law of partial pressure :** If a number of gases having no chemical affinity for one another are completely mixed together, then the total pressure exerted by then is equal to the sum of their partial pressures.

Thrust and Pressure : The force exerted by a liquid on any surface in contact with it is called *thrust* of the liquid.

The thrust exerted by a liquid per unit area of the surface in contact with the liquid is called pressure exerted by the liquid.

Pressure exerted by the liquid at a depth $h = h\rho g$

Where ρ = density of the liquid

SI unit of pressure is Nm^{-2}. It is also called as pascal (p_a).

Pascal law : According to this law, the pressure exerted at any point on a fluid contained in a vessel is transmitted equally in all possible directions.

Archimedes' principle : According to this law, when a solid body is immersed completely or partly in a fluid, it looses its weight which is exactly equal to the weight of the fluid displaced by the solid body.

Density and Relative density : Density of a substance is defined as its mass per unit volume, i.e.,

$$\text{Density, } \rho = \frac{M}{V}$$

Its unit in SI system is Kg m^{-3}.

Relative density : It is defined as the ratio of the mass of any volume of the substance to the mass of an equal volume of water at 4°C temperature. i.e.,

Relative density, ρ_r

$$= \frac{\text{mass of any volume of substance}}{\text{mass of equal volume of water at } 4°\text{C}}$$

Law of floatation : The weight of the body acts downwards through its centre of gravity but upthrust acts upwards through the centre of buoyancy. It simply implies that the centre of gravity of the body and the centre of buoyancy must lie on the same vertical line passing through these two centres. This law is called as the law of floatation.

A body can only float in a liquid when the weight of the liquid displaced is greater than the weight of the body.

Stream line flow : When a liquid flows in such a manner that each molecule of the fluid travels regularly along the same path as its preceding molecule and also all the particles crossing a particular point have the same speed in same direction, the motion is called *streamline flow*.

Turbulent flow : When the velocity of the liquid is increased beyond a certain limit (called as critical velocity), the flow of the liquid becomes zig-zag is called as turbulent flow.

Reynold's number : According to Reynold, the critical velocity (V_c) of a liquid flow can be expressed as ,

$$V_c = k\frac{\eta}{\rho r}$$

Where k = Reynold's number

η = coefficient of viscosity of the liquid

ρ = density of the liquid

r = radius of the tube through which the liquid is flowing.

Av

Hence, $k = \frac{\rho r V_c}{\eta}$

Equation of Continuity : Equation of continuity for the steady flow of an incompressible fluid is given by,

Av = constant

Where A = area of cross-section of the tube

v = speed of flow.

Viscosity : Viscosity is the property of a fluid by virtue of which it opposes the relative motion between its different layers.

The tangential viscous force action on a layer of fluid is given by,

$$F = -\eta A \frac{dv}{dx}$$

where η = coefficient of viscosity of the fluid

A = area of the layer

$\frac{dv}{dx}$ = velocity gradient

If A = 1,

$\frac{dv}{dx}$ = 1

then η = $-F$

Coefficient of Viscosity : The coefficient of viscosity of a fluid is defined as the backward viscous force acting per unit area of a fluid layer moving with unit velocity gradient.

Poise : 1 poise = coeff. of viscosity of a fluid in which a tangential force of one dyne acting per sq. cm maintains a velocity gradient of 1 per sec. under streamline flow.

Bernoulli's theorem : According to this theorem, total energy at different points in an ideal liquid, undergoing streamline flow, remains constant.

Energy equation for the flow of unit mass of an ideal fluid through a pipe is given by,

$$p + \rho g h + \frac{1}{2}\rho v^2 = \text{constant}$$

where energies refer to unit volume.

This theorem also states that, at all points along a streamline of an ideal fluid, the sum of the pressure head, the gravitational head and the velocity head remains constant.

For a fluid moving horizontally (h = constant),

$$p + \frac{1}{2}\rho v^2 = \text{constant}$$

i.e., for an ideal fluid moving horizontally, the sum of the static and dynamic pressures is constant.

Torricelli's theorem : According to this theorem, the velocity of efflux of a liquid through an orifice is the same as a body would attain in falling freely from the free surface of the liquid to the orifice. The velocity of efflux is given by,

$$v = \sqrt{2gh}$$

Where, h = height of the free surface of the liquid above the orifice.

Stoke's law : According to stoke's law,

$$F = 6\pi\eta r v$$

Where, F = retarding force

η = coefficient of viscosity of the fluid

r = radius of the sphere

v = uniform velocity of the sphere.

Poiseuille's formula :

$$v = \frac{\pi p r^4}{8\eta l}$$

where v = volume of the liquid flowing per second.

r = radius of the capillary tube

$\frac{p}{l}$ = pressure gradient.

Surface tension : The surface tension of a liquid is defined as the force per unit length in the plane of the liquid surface, acting at right angles to either side of an imaginary line drawn on that surface.

Hence, $T = \frac{F}{l}$

Its SI unit is Nm^{-1}.

Terminal velocity : If a body is dropped in a viscous fluid, in the beginning it is found to be accelerated but very soon its acceleration becomes zero and it attains a constant velocity. This constant speed with which the body now moves is called the terminal velocity. This happens when the pull due to gravity on the body is exactly balanced by the uptrust of the fluid and its viscus drag. It is given by,

$$v = \frac{2}{9} \cdot \frac{r^2 g(\rho_1 - \rho_2)}{\eta}$$

Where r = radius of the sphere

ρ_1 = density of the material of the sphere

ρ_2 = density of the fluid.

Surface energy : The surface energy of a liquid can be defined as the excess potential energy per unit area of the liquid surface. Mathematically, it can be expressed as the work done on the liquid surface in increasing its surface area by unity.

Hence, Surface energy

$$= \frac{\text{work done in increasing the surface area}}{\text{increase in surface area}}$$

Variation in Surface tension :

(i) For solutes that undergo dissociation surface tension increases with concentration.

(ii) Surface tension of a liquid varies with the presence of impurities on its surface.

(iii) Surface tension of a liquid decreases with rise of temperature.

(iv) Surface tension of solutions is always less than that of the pure solvents.

Range of molecular attraction (σ) : The maximum distance upto which a molecule can exert some appreciable force of attraction on another molecule, is called as range of molecular attraction. It is of the order of 10^{-9} m in liquids. It is denoted by σ.

Sphere of influence : If an imaginary sphere of radius σ is drawn round a molecule as centre, then obviously this molecule attracts and is also attracted by only those molecules which are enclosed within this sphere of radius σ. This sphere is known as the sphere of molecular attraction or sphere of influence.

Capillarity : A glass tube of very fine bore is called as the capillary. The phenomenon of rise or fall of a liquid in a capillary when dipped in a liquid is known as capillarity. The narrower the area of cross-section of the tube, the greater is the rise or fall of the liquid in the tube.

Expression for capillary rise :

$$T = \frac{r\rho g}{2\cos\theta}\left(h + \frac{r}{3}\right)$$

where r = radius of the capillary tube at the height of the meniscus

ρ = density of the liquid

θ = angle of contact

h = height of the capillary rise from the horizontal part of the free surface outside to the bottom of the meniscus.

Special Cases

(i) For very fine tube, $\frac{r}{3} << h$

$$\text{Hence, } T = \frac{rh\rho g}{2\cos\theta}$$

(ii) If the liquid wets the tube, $\theta \approx 0°$ or $\cos\theta \approx 1$

$$\text{Hence, } T = \frac{1}{2}rh\rho g.$$