CHAPTER 4

PROPERTIES OF MATTER

1. **Define stress and strain?**
   Stress is defined as the internal restoring force developed per unit area in a body when deforming forces are applied to it. Strain is defined as the ratio of change in dimension to the original dimension of a body.
2. **Distinguish between elasticity and plasticity.**
   The property of solids to retain its original size or shape after the removal of deforming force is called elasticity.
   The property of a material to undergo permanent deformation under applied force is called plasticity.
3. **Define elastic limit.**
   Elastic limit of a substance is defined as the maximum stress that can be applied to the substance before it becomes permanently deformed and does not return to its original state.
4. **State Hooke's law.**
   Hooke's Law states that the stress is proportional to the strain, within the elastic limit.

$$\frac{stress}{strain} = a\ constant$$

5. **Explain the terms Young's modulus, Rigidity modulus and Bulk modulus**.

Young's Modulus is defined as the ratio of longitudinal stress to the longitudinal strain under relatively small deforming force.

Consider a long bar of cross-sectional area A and initial length L that is clamped at one end. Let ΔL be the change in length produced when a force F is applied.

$$Longitudinal\ stress = \frac{F}{A}$$

$$Longitudinal\ strain = \frac{\Delta L}{L}$$

$$Young's\ Modulus = \frac{Longitudinal\ \ stress}{Longitudinal\ \ strain}$$

$$Y = \frac{\left(\frac{F}{A}\right)}{\left(\frac{\Delta L}{L}\right)}$$

$$Y = \frac{FL}{A\,\Delta L}$$

Rigidity modulus (η) is defined as the ratio of shear stress to shear strain.

Shear stress is defined as the ratio of the tangential force (F) applied to the area (A)

$$shear\ stress = \frac{tangential\ force}{area} = \frac{F}{A}$$

Shear strain is defined as the ratio of horizontal distance (Δx) that the sheared face moves to the height (h) of the object.

If the deformation is very small, shear strain can be recognized by the angular deformation (θ).

$\therefore\ shear\ strain\ = \theta$

Rigidity modulus or shear modulus (η) is defined as the ratio of shear stress to shear strain.

$$Rigidity\ Modulus = \frac{shear\ stress}{shear\ strain}$$

$$\eta = \frac{\left(\frac{F}{A}\right)}{\theta}$$

$$\eta = \frac{F}{A\theta}$$

Bulk modulus (B) is defined as the ratio of volume stress to volume strain.

The volume stress is the ratio of the magnitude of the total force (F) exerted on a surface to the area (A) of the surface. The perpendicular force per unit area is called as pressure (P).

$$volume\ stress\ = \frac{F}{A} = P$$

Under pressure, the object experiences a volume change ΔV. The volume strain or bulk strain is defined as the ratio of the change in volume to the original volume.

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

$$Bulk\ Modulus\ = \frac{Volume\ stress}{Volume\ stain}$$

$$B\ = -\frac{P}{\left(\frac{\Delta V}{V}\right)}$$

$$B\ = -\frac{PV}{\Delta V}$$

A negative sign is inserted because an increase in pressure (positive ΔP) causes a decrease in volume (negative ΔV) and vice versa.

6. Define pressure. What is its unit?

Pressure (P) is defined as the perpendicular or normal force acting per unit area of a substance.

Absolute pressure at a point is pressure measured with respect to zero pressure in absolute vacuum.

$$P\ = \frac{F}{A}$$

SI unit of pressure is N/m^2 or pascal (Pa).

7. What is hydrostatic pressure?

Hydrostatic pressure is the pressure that is exerted by a fluid at equilibrium at a given point within the fluid, due to the force of gravity or weight of the fluid.

$$hydrostatic\ pressure\ = \frac{Force\ inside\ the\ fluid}{area}$$

8. What is the difference between absolute pressure and gauge pressure?

When pressure is measured relative to a perfect vacuum, it is called absolute pressure.

When pressure is measured relative to atmospheric pressure, it is called gauge pressure.

Absolute Pressure = Gauge Pressure + Atmospheric Pressure.

9. Define surface tension. What is its unit?

Surface tension is defined as the force per unit length acting tangential to the surface of the liquid to reduce the surface area of the liquid. If 'F' is the magnitude of force acting perpendicular to the line of length 'l', then

$F \propto l$

$F = S\,l$

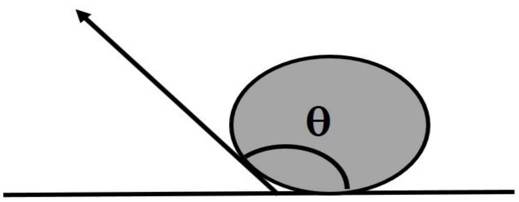
where 'S' is called surface tension.

$$S = \frac{F}{l}$$

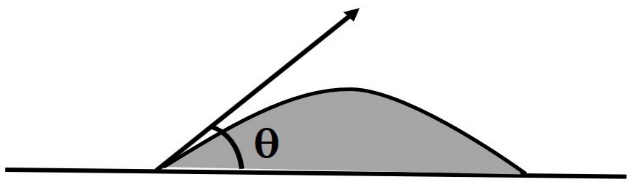
The SI unit of Surface tension is N/m.

10. Explain angle of contact.

The angle between tangent to the liquid surface at the point of contact and solid surface inside the liquid is termed as angle of contact.



Obtuse angle of Contact



Acute angle of Contact

When θ is an obtuse angle, then the molecules of liquids are attracted strongly to themselves and weakly to those of solid. The liquid does not wet the solid surface. If θ is an acute angle, the liquid molecules are strongly attracted to those of the solid and the liquid gets easily wet to the solid surface.

11. What is capillarity?

The rise or fall of liquid in the capillary tube is known as capillarity. If the angle of contact is less than 90^0 (acute angle of contact), the liquid rises in the tube and it is called capillary rise. If the angle of contact is greater than 90^0 (obtuse angle of contact), the liquid falls in the tube and it is called capillary depression.

The elevation height of liquid in a capillary tube h is given by the ascent formula.

$$h = \frac{2S\cos\theta}{r\rho g}$$

Here S is the surface tension, θ is the angle of contact between the surface of the liquid and surface of the capillary tube at the point of contact, r is the inner radius of the capillary tube, ρ is the density of the liquid rising through the capillary tube and g is the acceleration due to gravity.

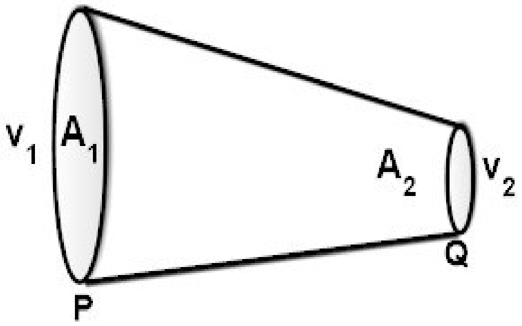
12. Distinguish between streamline flow and turbulent flow.

Streamline flow	Turbulent flow
The speed and direction of particles at a given point remains the same.	The speed and direction of the particles in the fluid at a given point varies with time.
The velocity of flow is less than critical velocity.	The velocity of flow is above the critical velocity.
Each particle follows exactly the same path and has the same velocity as its predecessors.	When the velocity exceeds the critical velocity, the flow becomes irregular or zigzag.

13. State and explain the equation of continuity.

When there is a steady flow of an incompressible and non-viscous fluid through a tube of non-uniform cross section, the product of the area of cross section and the velocity of flow remains the same at every point in the tube.

At point the point P, let velocity of the fluid be v_1 and area of cross section be A_1. At point the point Q, let velocity of the fluid be v_2 and area of cross section be A_2. If ρ is the density of the fluid and considering the flow of fluid through the pipe for a time Δt, we can write



Distance travelled by the fluid at point P = $v_1 \Delta t$

Volume of the fluid entering the tube at P = $A_1 v_1 \Delta t$

Mass of the fluid entering the tube at point P = $\rho\, A_1 v_1 \Delta t$

Mass of the fluid leaving the tube at point Q = $\rho\, A_2 v_2 \Delta t$

The total mass of the fluid entering into a pipe through any cross section should be equal to the total mass of fluid coming out of the same pipe through any other cross section in the same time. Therefore,

$$\rho\, A_1 v_1 \Delta t = \rho\, A_2 v_2 \Delta t$$

$$A_1 v_1 = A_2 v_2$$

$$Av = constant$$

14. What are three types of energies associated with a flowing liquid?

A flowing fluid possesses three types of energies – kinetic energy, potential energy and pressure energy.

1. Kinetic energy

The kinetic energy is due to the motion of fluid particles.

If *m* mass of the fluid flows with a velocity *v*, then kinetic energy is given by

$$Kinetic\ Energy = \frac{1}{2}\, mv^2$$

For unit volume, we can rewrite this equation with density of fluid ρ as

$$Kinetic\ Energy = \frac{1}{2}\rho v^2$$

2. Potential energy

The energy of the fluid by virtue of its position is called potential energy.

$Potential\ Energy = mgh$

In terms of density of fluid,

$Potential\ Energy = \rho gh$

3. Pressure energy

Pressure energy is the energy stored in a fluid due to the force per unit area applied onto it.

If P is the pressure, m is the mass of fluid and ρ is the density of fluid, the pressure energy is given by

$$Pressure\ Energy = \frac{mP}{\rho}$$

For unit volume, we can rewrite this equation as

$$Pressure\ Energy = P$$

15. State and explain Bernoulli's theorem.

Bernoulli's theorem states that the sum of kinetic energy, potential energy and pressure energy of an ideal fluid in streamline flow remains a constant throughout the flow.

If $\frac{P_1}{d}$, gh_1, $\frac{{v_1}^2}{2}$ and $\frac{P_2}{d}$, gh_2, $\frac{{v_2}^2}{2}$ are the pressure energy, potential energy and kinetic energy respectively of unit mass of the liquid flowing through a tube at two different positions,

$$\frac{P_1}{d} + gh_1 + \frac{{v_1}^2}{2} = \frac{P_2}{d} + gh_2 + \frac{{v_2}^2}{2}$$

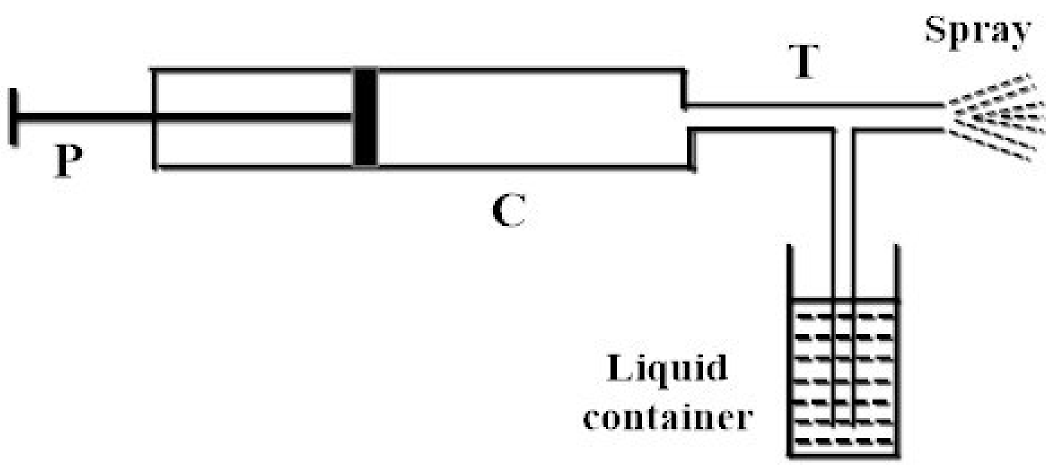
For a horizontal tube, h remains constant, or $h_1 = h_2$. In that case Bernoulli's theorem can be expressed as

$$\frac{P_1}{d} + \frac{{v_1}^2}{2} = \frac{P_2}{d} + \frac{{v_2}^2}{2}$$

This equation shows that where the velocity is larger, the pressure is small.

Applications of Bernoulli's theorem

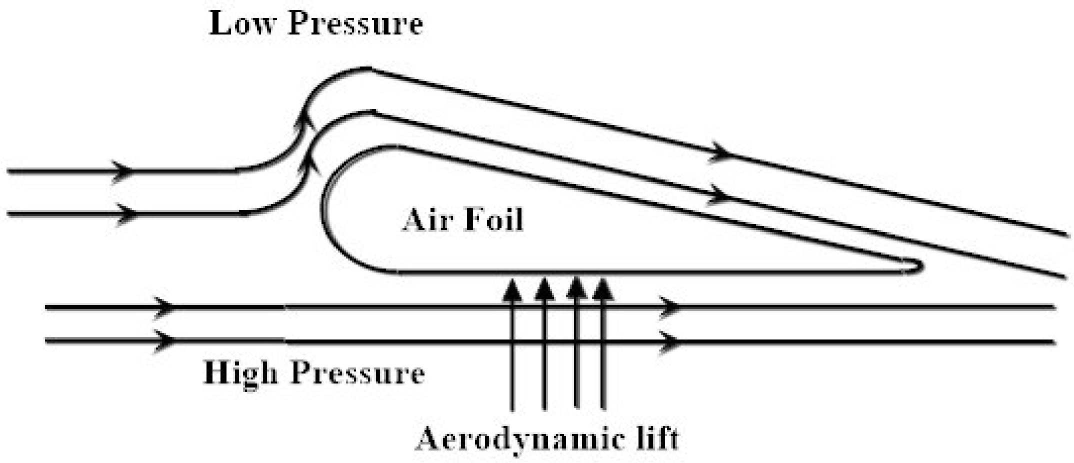
1. Atomizer



Atomizer is a device to spray a liquid or make a liquid into a jet of tiny droplets. The schematic diagram of an atomizer is shown in the figure. The essential parts of atomizer are a cylinder C with a piston P, a narrow T section pipe and a container to fill the liquid to be sprayed. As we push the piston rapidly , the air in the cylinder begins to move towards the T section pipe. Since the area of cross-section of the cylinder is larger than the area of cross section of the T section pipe, as a consequence of continuity equation the velocity of air moving through the T section pipe is greater than the velocity of air in the cylinder. According to Bernoulli's theorem, the pressure in the T section pipe must be lower than the pressure at the surface of liquid in the container. Because of this pressure difference, the liquid in the container rises up and reaches the T junction pipe. The liquid mixes with high-speed air to form a spray.

Air foil

Air foil is a special shape of solid objects which produces a lifting effect while moving in a streamlined fluid or air. The characteristic air foil shape has a rounded leading edge followed by a sharp trialing edge and curved surfaces as shown in figure. When the air foil is moving against the streamlined air, because of this special shape the streamlines might have a speed difference at the upper and lower surfaces. If the air streams are moving with different speeds, so with different kinetic energy, then according to Bernoulli's theorem there will be pressure difference.



Since the number of stream lines are more at the upper surfaces, the velocity of air is higher at the upper surface of air foil. Therefore, the kinetic energy of air at the upper side is higher. Then by Bernoulli's theorem the pressure energy should be lesser at the upper side of air foil than the lower side. That means there is a lifting force from the lower side of the air foil, which tries to float the air foil while it is in motion.

16. Explain the terms viscosity? And coefficient of viscosity.

It is the property of a fluid by virtue of which it tends to resist the relative motion between the layers of the fluid is called viscosity.

The viscous force (F) acting between two layers of the liquid is directly proportional to the area of liquid layers and velocity gradient between the layers (v_2 - v_1 / d). Combining these proportionalities,

$$F \, \alpha \, \frac{A(v2 - v1)}{d}$$

$$F = \eta \frac{A(v2 - v2)}{d}$$

The constant of proportionality η, is called as coefficient of viscosity of fluid.

The co-efficient of viscosity η, can be defined as that much resistive force developed between the liquid layers of unit area when they are moving with a unit velocity gradient.

17.What is Stoke's formula?

When a body falls through a fluid, it drags the layer of the fluid in contact with it. The body under motion through the fluid experiences a retarding force. It is observed that the viscous force is proportional to the velocity of the object and is opposite to the direction of motion. The viscus drag force F is given by

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

Where, η is the co-efficient of viscosity of the medium, r is the radius of the spherical body and v is the uniform velocity after equilibrium or terminal velocity.