PROPERTIES OF BULK MATTER

MECHANICS OF SOLIDS AND FLUIDS.

i. ELASTICITY : It is the property of a body by virtue of which the body regains its original shape and size when the deforming force is removed.

ii. DEFORMING FORCE: The force which changes the shape and size of a body is called deforming force.

iii. RESTORING FORCE : The force which comes into play inside the body to bring it back to its original shape and size is called restoring force.

iv. ELASTIC BODIES : The bodies which regain the original shape and size after the removal of deforming force, are called elastic bodies.

v. PERFECTLY ELASTIC BODIES: A body which regains the original shape and size completely after the removal of deforming force, are said to be perfectly elastic bodies. (e.g) quartz, phosphor bronze, steel, glass etc., are nearly perfectly elastic bodies.

vi. PERFECTLY PLASTIC BODIES: A body which does not show even a tendency to regain its original shape and size even after removal of deforming force are called perfectly plastic bodies. (e.g) paraffin wax , mud, paste or flour, putty etc.,

Note: * There are no perfectly plastic or elastic bodies.
* Steel is more elastic than rubber.

STRESS: The restoring force acting per unit area of a deformed body is called stress.

Stress = restoring force/ area

SI unit = Nm^{-2} or pascal (Pa)

CGS unit = dyne/cm²

Dimensional formula for stress

Stress = force/area $= \frac{MLT^{-2}}{L^2} = [ML^{-1}T^{-2}]$

TENSILE AND COMPRESSIVE STRESS

i. If a stress causes an increase in length or volume, it is called tensile or expansive stress.

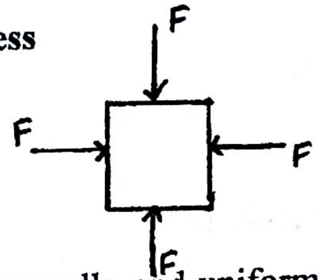
ii. If a stress causes a decreases in length or volume of a solid, it is called compressive stress.

I. ***LINEAR STRESS:***

It is a stress when there is a change in the length of a body.
If the linear stress causes an increase in length of a body it is called ***tensile stress***.

If there is a decrease in length due to the applied force then the stress is said to be ***compressive stress.***

2. Volume stress or Bulk stress

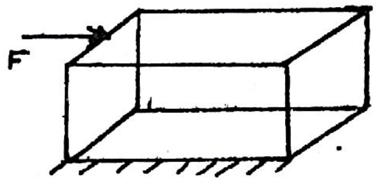


When a deforming force acts normally and uniformly all over the surface of a body, then the restoring force for unit area of the body is called volume stress or bulk stress.

Volume stress = Normal force / Area

=F/A = dp = increase in pressure.

Shearing stress



When a deforming force acts tangential on the surface of a body, there may be change in the shape of the body. When a tangential force F is applied on the upper phase, shape of the block changes without any change in the volume.

Shearing stress = tangential force/area

=F/A

Strain

Strain is defined as the ratio of change in dimension to the original dimension of the body.

i.e Strain = Change in dimension / original dimension

Since it is a ratio, it is an unitless quantity.

Strain - Types

Linear strain :- It is the ratio of change in length to the original length.

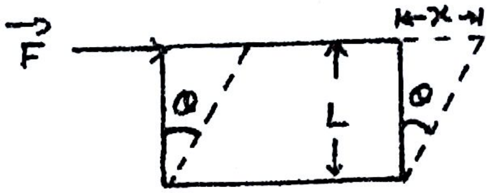
Linear strain = Change in length /original length

=ΔL / L

Volume / Bulk strain

It is the ratio of change in volume to original volume.
Volume strain = change in volume / original volume
=$\Delta V/V$

Shearing strain [Angle of shear]



When a suitable force is applied on a body, so that it produces a change in shape of the body, so that it produces a change in shape of the body, but no change in volume, it is said to be shear.

When a force F is applied on the upper surface, the vertical phases turns through an angle is known as angle of shear or shearing strain.

shearing strain

$\theta = x/L$

Elastic limit

Maximum stress upto which a body exhibits the property of elasticity is called elastic limit.

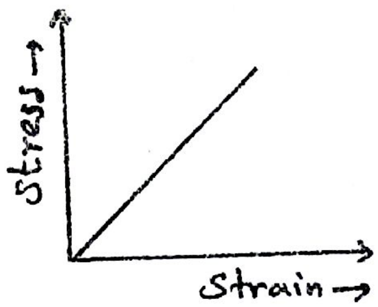
Hooke's law

Hooke's law states that within elastic limit, stress is directly proportional to strain.

Stress α strain

Stress/strain = constant (k)

K → modulus of elasticity



Modulus of elasticity

It is defined as the ratio of stress to strain within elastic limit.

i. Young's modulus:

It may be defined as the ratio of linear stress to linear strain within elastic limit.

Y = linear stress/ linear strain

$= (F/A) / (\Delta L/L)$

$= (F/A) \times (L/\Delta L)$

$= (mg/\pi r) \times (L/\Delta L)$

ii. Bulk modulus:

It may be defined as the ratio of bulk stress to bulk strain.

B = Bulk stress/ Bulk strain

$= (F/A) / (\Delta V/V)$

$= (F/A) \times (V/\Delta V) = dp\,(V/\Delta V)$

iii. Rigidity modulus

It may be defined as the ratio of shearing stress to shearing strain within elastic limit.

N = Shearing stress/Shearing strain

$= (F/A)/\theta$ $= (F/A)/(X/L)$ $= (F/A) \times (L/X)$

Note:

ELASTOMERS:

Substances which can be elastically stretched to large values of strain, are values of strain, are called elastomers.

ELASTIC FATIGUE

A substance temporarily looses its elasticity when it is continuously subjected to strain. This is called elastic fatigue.

FLUID MECHANICS

Fluid:- Fluid is a substance which can flow . Hence the term applies to both liquids and gases.

Thrust:- Total normal force acting on a surface.

Pressure:- Pressure at a point is the thrust acting on it per unit area
i.e Pressure =Thrust/Area

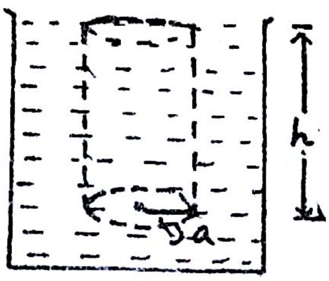
Unit = N/m^2

Dim= $[M L^{-1} T^{-2}]$

EXPRESSION FOR FLUID PRESSURE

Consider a liquid of density ρ at rest . Let O be any point inside the liquid at a depth h below the surface of the liquid. To find the pressure at O, imagine a small horizontal area 'a' around it.

Pressure at the point O,



P = Thrust/Area

= mg/a

$= \rho V g/a$ [since $\rho = m/V$]

$= \rho (ah) g/a$ [since V=ah]

Therefore $P = h\rho g$

SURFACE TENSION

The free surface of a liquid behaves like a stretched elastic membrane having a natural tendency to contract and to have the smallest possible area.

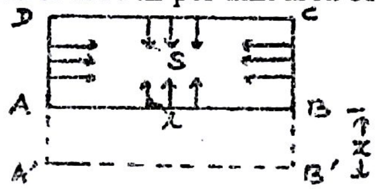
Definition:- Surface tension of a liquid is defined as the force acting tangential to the liquid surface and perpendicular to the unit length of an imaginary line drawn on the surface of the liquid.

i.e $S = F/L$

S.I Unit = N/m

TO SHOW THAT SURFACE ENERGY IS NUMERICALLY EQUAL TO SURFACE TENSION

Surface energy of a liquid is the P.E per unit area of the liquid surface.



Consider a rectangle frame ABCD, the side AB is movable. A liquid film is formed on it. Let the movable side AB be 'l' and the surface tension of the liquid = s

The force acting on AB, F = 2(sl) (since the film has 2 sides)

The work done, in order to displace the wire AB through a small distance X is given by W.D = F x X

W = 2SLX

Surface energy = P.E/Area = W.D/Area

= 2SLX/2LX = S

Hence surface energy of a liquid is numerically equal to surface tension.

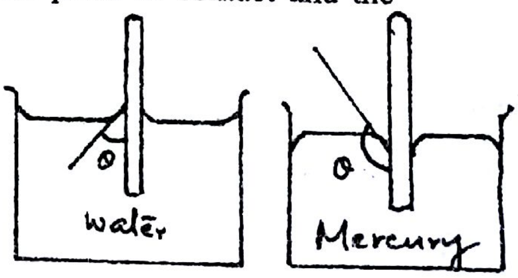
MOLECULAR FORCE:

There are two types of molecular forces

1. **Cohesive force**: Force of attraction between molecules of two similar substances.
2. **Adhesive force:** Force of attraction between molecules of two different substances.

Angle of contact:

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



Note:

For liquids like water – Angle of contact is *acute.*

For Mercury(Hg) – Angle of contact is *obtuse.*

Excess pressure

1. Inside a drop of liquid P = 2S/r

2. Inside a bubble P = 4S/r

3. Inside a bubble in a liquid P = 2S/r

CAPILLARITY

If a capillary tube is dipped in a liquid whose angle of contact is acute, the liquid rises in the tube, this is called capillary rise or capillarity.

Expression for capillary ascent

$$h = (2S\cos\theta) / r\rho g$$

Fluid flow

1. STREAMLINE FLOW: It is a steady flow in which each layer of liquid follows the same path and has the same velocity as that of its predecessor.
2. TURBULENT FLOW: When the velocity of flow of a liquid is greater than a virtual value the flow of the liquid becomes disorderly and zig – zag and is called turbulent flow.

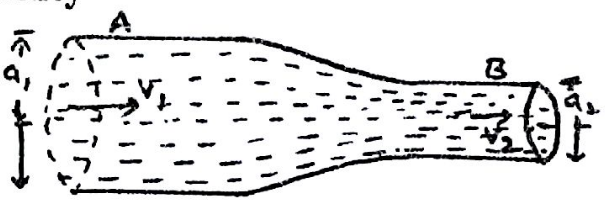
CRITICAL VELOCITY IS GIVEN BY A FORMULA

$$v = R_e \eta / \rho D$$

Where R_e = Reynold's number
η = Coefficient of viscosity of liquid
ρ = density of the liquid
D = diameter of the tube

It is found that the flow will be streamlined if R_e is less than 2000.

Equation of continuity



Consider a streamlined flow through a pipe of non- uniform area of cross section. Consider two sections A&B. Let a_1&a_2 be their areas and v_1&v_2 be their velocities of the fluids of these sections.

Quantity of fluid crossing section A/sec = $a_1 v_1 \rho$

Quantity of fluid crossing section B/sec = $a_2 v_2 \rho$

According to law of conservation of mass, there is no accumulation of mass anywhere in the tube.

$$a_1 v_1 \rho = a_2 v_2 \rho$$

$$a_1 v_1 = a_2 v_2$$

$$av = \text{constant}$$

BERNOULLI'S THEOREM

Bernoulli's theorem states that in a streamlined flow of liquid, the total energy of small amount of liquid flowing without any friction remains constant throughout its flow.

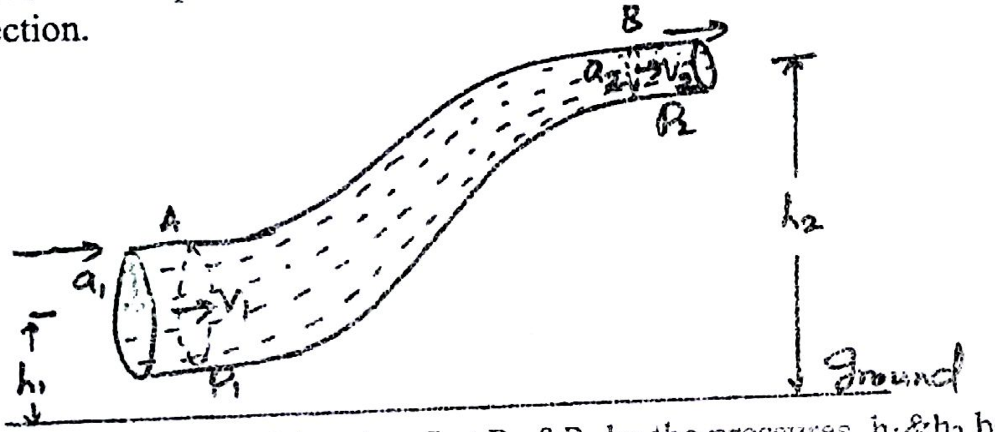
Pressure energy + P.E + K.E = a constant.

For unit mass of fluid,

$$P/\rho + gh + \frac{1}{2} v^2 = \text{constant}$$

Proof:

Consider a liquid of density ρ flowing through a pipe of non – uniform area of cross section.



A&B are two sections of the pipe. Let P_1 &P_2 be the pressures, h_1&h_2 be mean heights , a_1&a_2 the areas of cross section and v_1 &v_2 be the velocities of flow at the sections A&B respectively.

Work done on unit mass if liquid through the section A = $P_1 V_1 / m$
$= P_1 / \rho$

Work done by unit mass of liquid through the section B = $P_2 V_2 / m$
$= P_2 / \rho$

Therefore the net work done per unit mass of the liquid from A to B = $P_1 / \rho - P_2 / \rho$

The increase in P.E per unit mass when the liquid flows from A to B= $gh_2 - gh_1$

The increase in K.E per unit mass when the liquid flows from A to B = $\frac{1}{2} v_2^2 - \frac{1}{2} v_1^2$

According to work – energy principle,

Net work done = increase in P.E + increase in K.E

$$P_1 / \rho - P_2 / \rho = gh_2 - gh_1 + \frac{1}{2} v_2^2 - \frac{1}{2} v_1^2$$

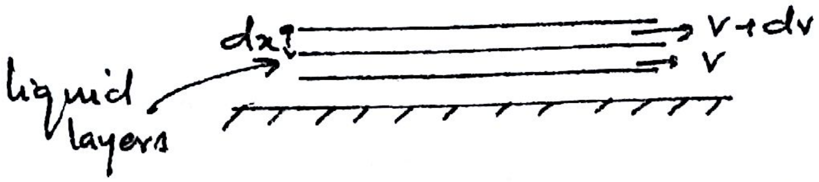
$$P_1 / \rho + gh_1 + \frac{1}{2} v_1^2 = P_2 / \rho + gh_2 + \frac{1}{2} v_2^2$$

$$P/ \rho + gh + \frac{1}{2} v^2 = \text{constant}$$

Hence Bernoulli's theorem is proved.

APPLICATIONS OF BERNOULLI'S THEOREM
1. Venturimeter
2. Atomiser
3. Lift of an air craft.

Viscosity:- It is the property of a fluid by which it apposes the relative motion between its successive layers.



Velocity Gradient :- Rate of change of velocity with respect to distance

Viscous force $F \alpha A\, dv/dx$

$$\mathbf{F = \eta A\, dv/dx}$$

Where η is a constant known as coefficient of viscosity of the liquid.

$\eta = F$ if $A = 1$ unit & $dv/dx = 1$ unit

Hence , coefficient of viscosity of a liquid is defined as a tangential viscous force per unit area required to maintain unit velocity gradient.

S.I unit of η : Ns/m^2

STOKE'S LAW

It gives an expression for the viscous force experienced by spherical ball of radius moving through a viscous medium of coefficient of viscosity η, with a terminal velocity v_t

i.e $\mathbf{F = 6\pi\eta r v_t}$

This is called Stoke's law / formula.

TERMINAL VELOCITY

When a ball of density d falls through a liquid of density ρ at first its velocity increases then the upward viscous force also increases. A stage will be reached where the force of gravity is balanced by up thrust and viscous force. Thus it moves down with a uniform velocity known as ***terminal velocity.***

When a ball attains a terminal velocity ,

Weight of a ball = upthrust + viscous force

$$4/3\,\pi r^3 d g = 4/3\,\pi r^3 \rho g + 6\pi\eta r v_t$$

$$6\pi\eta r v_t = 4/3\,\pi r^3 (d - \rho) g$$

$$\mathbf{v_t = (2/9\eta)\, r^2 (d - \rho) g}$$