Mr. Rohit Kumar, Dept. Of science, (Physics), YBN University, Ranchi

TEACHING MATERIAL ON

Physics

(Dept. Of Science)

1

Properties of Bulk Matter.

→ • **Deforming Force:→**

Deforming force is one which when applied changes the configuration (shape or size not state) of the body.

→ • **Elasticity:→**

The property of the body to regain its original state (configuration) when the deforming force are removed is called Elasticity.

• **Perfectly Elastic Body:→**

A body which regains its original configuration immediately and completely after the removal of deforming force from it is called perfectly elastic body. Quartz and phosphor Bronze are nearly perfectly elastic.

• **Perfectly plastic Body:→**

A body which does not regain its original configuration at all after the removal of deforming force, However, small the deforming force is called perfectly plastic body. putty, wax and mud are nearly perfectly plastic body.

- **Stress :→**

The deforming force per unit area is called stress. or Restoring force per unit area is known as stress, the S.I unit of stress is Nm^{-2}

$$\text{Stress} = \frac{\text{Restoring force}}{\text{Area}}$$

- **Types of stress**

① **Normal stress :→**

When deforming force acting perpendicular to the area. this stress is known as normal stress.

② **Tangential or Shearing stress :→**

when a deforming force acting tangentially to the surface of the body produces a change in shape without changing the volume is known as tangentially or shearing stress.

- **Strain :→**

The ratio of change in configuration to the original configuration is called strain

$$\text{Strain} = \frac{\text{Change in configuration}}{\text{original configuration}}$$

It is a dimensionless physical quantity.

• Types of Strain

① Longitudinal Strain :→

It is the ratio of change in length original length.

$$\text{Longitudinal Strain} = \frac{\text{Change in Length } (\Delta l)}{\text{Original length } (l)}$$

② Volumetric Strain :→

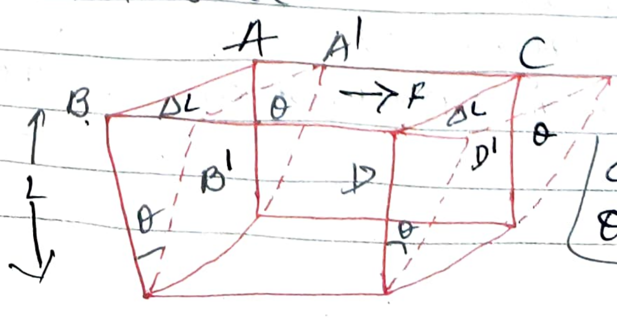
It is the ratio of change in volume to original volume

$$\text{Volumetric Strain} = \frac{\text{Change in Volume } (\Delta V)}{\text{Original Volume } (V)}$$

③ Shearing Strain :→

It is deforming force produce a change in shape of the body without changing its volume. the strain produced is called shearing strain. **OR**

It is defined as angle in the radian through which a plane perpendicular to the fixed surface of the cubical body get turn under the effect of tangential force.



Shearing Strain

$\theta = \frac{\Delta L}{L}$

- **Elastic Limit :→**

Elastic limit is the upper limit of deforming force upto which if deforming force is removed. the body regain's its original form completely and beyond which if deforming force is increased the body loses its property of elasticity and gets permanently deformed.

- **Hooke's Law :→**

Within elastic limit The stress developed is directly proportional to the strain of the body.

$$\text{stress} \propto \text{strain}$$

$$\text{stress} = E\ \text{strain}$$

$$E = \frac{\text{stress}}{\text{strain}}$$

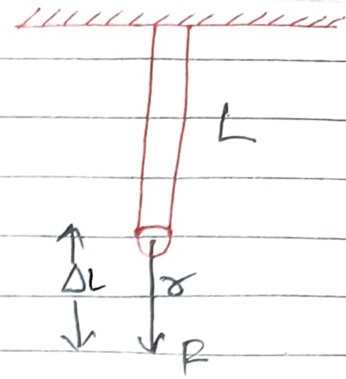
'E' is known as modules of elasticity or coefficient of elasticity.

It depends on the nature of material and the manner in which the body is deformed.

- **Young's Modules of Elasticity (Y)**

The ratio of normal stress to longitudinal strain is known as young's modules of elasticity (Y)

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



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

$$Y = \frac{\text{Normal stress}}{\text{long. strain}}$$

$$Y = \frac{F/A}{\Delta L/L}$$

$$Y = \frac{F/\pi r^2}{\Delta L/L}$$

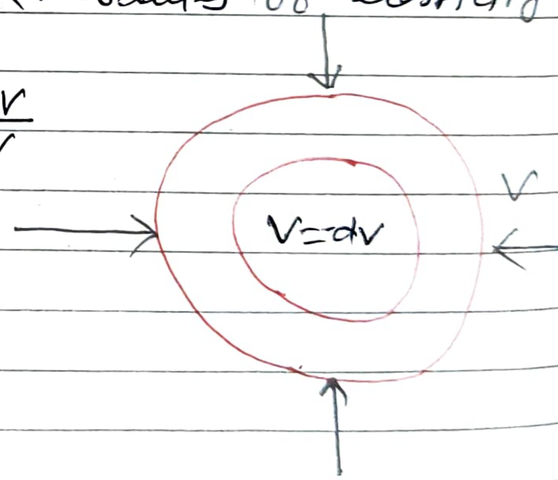
$$Y = \frac{FL}{\Delta L(\pi r^2)}$$

The S.I unit of Y is Nm^{-2}

- **Bulk Modules of Elasticity (B or K) :→**

The ratio of normal stress to volumetric strain is known as Bulk modules of elasticity (B.)

Volumetric strain $= \frac{-\Delta V}{V}$



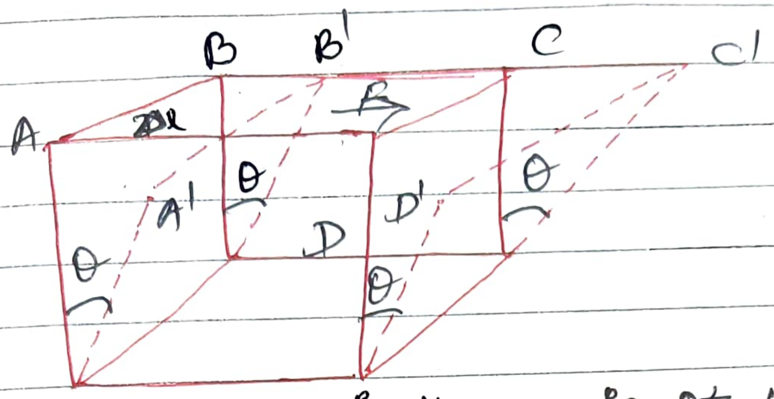
Normal stress $= F/A$

$$B = \frac{\text{Normal stress}}{\text{Volumetric strain}}$$

$$B \text{ or } K = \frac{F/A}{-\Delta V/V}$$

The S.I unit of K is Nm^{-2}

• Modules of Rigidity or Shear Modules of Elasticity (G/η) :→



It is the ratio of tangential stress to shear strain

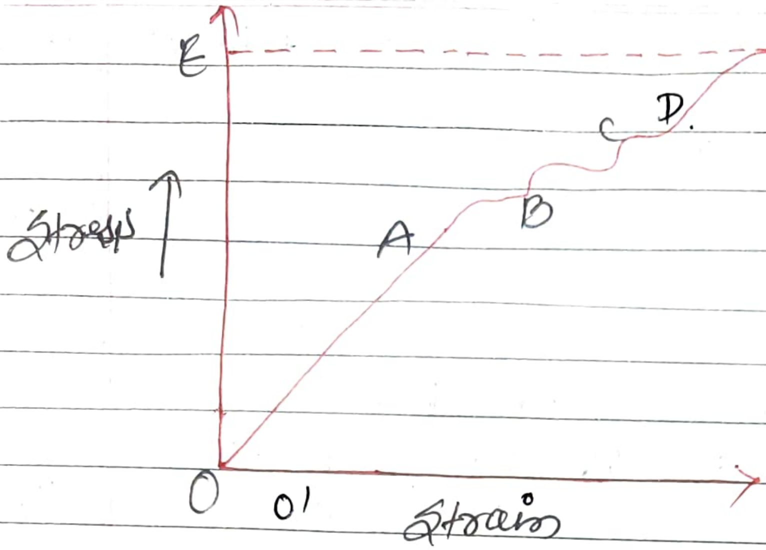
$$G = \frac{\text{Tangential stress}}{\text{Shearing strain}}$$

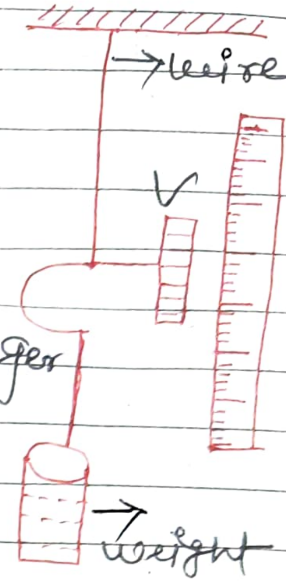
$$G = \frac{F/A}{\theta}$$

$$(or)\ G = \frac{F/A}{\Delta l/l}$$

• Stress - Strain Curve :→

Suspend a curve of uniform area of cross - section vertically from a rigid support through one end and attach a hanger at the other end of the wire on which known weight can be placed. Attach vernier scale 'V' to the lower end of the wire.





Pt. A Corresponds to proportional limit

Pt. B Corresponds to elastic limit

C = yield pt.

OC' = yield strength

OE' = ultimate stress

F = Breaking pt.

OO' = Permanent set.

① The portion OA of the graph is a straight line, showing that stress is directly proportional to strain upto ~~Pt.~~ point 'A' on the graph. It means Hooke's law is fully obeyed in the region OA. point A is called point of proportional limit.

② Beyond the point A, the stress-strain variation is not a straight line as indicated by the part 'AB' of the graph. If the wire is unloaded at point B then the graph follows the reverse path BAO then, the point B is called elastic limit. the portion of the graph between 'O' and 'B' is called elastic region. Hooke's law is not ~~oby.~~ obeyed between the point 'A' and B.

3. Beyond the point 'B' the curve 'BC', where the strain increases much more rapidly with the stress. the slope of the graph from point B to C becomes quite small. If the curve is unloaded at point 'C', the graph will not follow the path CBAO but traces a curve CO' it means a permanent strain OO' developed in the wire and OO' is known as permanent set. this deformation in the wire is called ~~permanent~~ Plastic Deformation. In the portion 'BC' of the graph. Hooke's law fails and the extension in the wire is partly elastic and partly plastic in behaviour.

4. Beyond point C, the wire starts showing increase in strain without any increase in stress. it means the wire begins to flow down after point 'C' upto point D. So the point C is known as yield point. the behaviour of the wire beyond point 'C' is perfectly plastic upto point D.

5. Beyond point 'D', the graph is a curved line DEF, which shows, the thinning of the wire developed and constriction developed on the wire and finally the wire breaks at point 'F'. So, 'F' is known as Breaking point DEF shows plastic behaviour.

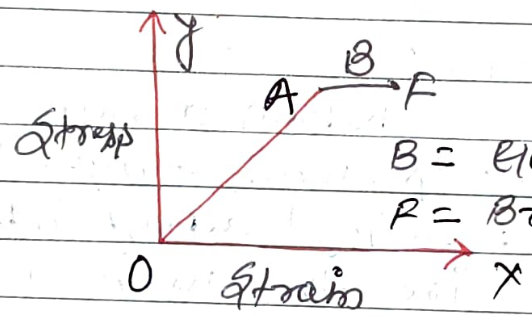
• Classification of materials from the study of stress versus strain curve :→

(1) Ductile Materials :→

These are those materials which shows large plastic range beyond elastic limit.

(2) Brittle Materials :→

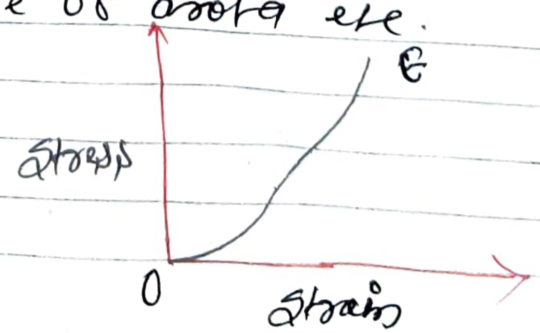
these are those materials which show very small plastic range beyond elastic limit. For such materials, the breaking point lies close to the elastic limit. e.g ⇒ cast iron, glass etc.



B = Elastic limit
F = Breaking point

(3) Elastomers :→

These are those materials for which stress and strain variation is not straight line within elastic limit. The elastic region is very large. these materials do not obey Hooke's law and such materials have no plastic range. e.g → Rubber, The elastic tissue of aorta etc.



- Elastic After Effect :→

The temporary delay in regaining the original configuration by an elastic body after the removal of a deforming force is called elastic after effect.

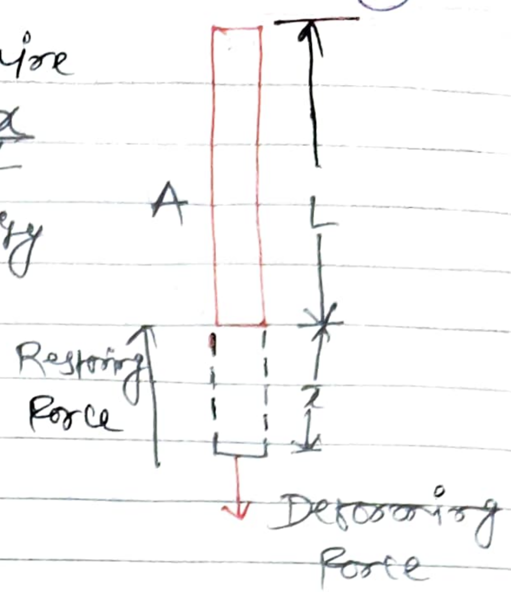
- Elastic Fatigue (थकान) :→

Elastic Fatigue is the property of an elastic body by virtue of which its behaviour becomes less elastic under the action of repeated alternating deforming forces.

- Elastic Potential Energy in A Stressed wire :→

When a wire is stretched, some work is done against the ~~initial~~ internal forces (Restoring) acting between particles of the wire. this work done appears as elastic potential energy in the wire.

Let the original length of the wire is 'L'. After applying the deforming force (F) the elongation is 'x'. the cross-sectional area of the wire is 'A' and young's modulus of the wire is Y.



Stress produced in the wire

Stress $= \frac{F}{A}$, Strain $= \frac{x}{L}$

young's modulus of Elasticity

$= \frac{\text{Stress}}{\text{Strain}}$

$$Y = \frac{F/A}{x/L}$$

$$F = \frac{YAx}{L} \quad \text{— (1)}$$

$\because$ This force is a variables force. So, work done by variable force to elongate the wire by amount x,

$$W = \int_0^x F\,dx$$

$$W = \int_0^x \frac{YAx}{L}\,dx$$

$$W = \frac{YA}{L}\int_0^x x\,dx$$

$$W = \frac{YA}{L}\left[\frac{x^2}{2}\right]_0^x$$

$$W = \frac{YAx^2}{2L}$$

this work is stored as elastic potential energy

$$\therefore \boxed{U = \frac{YAx^2}{2L}}$$

$$U = \frac{1}{2}\left(\frac{Yx}{L}\right)\cdot Ax \qquad \because Y = \frac{\text{stress}}{\text{strain}}$$

$U = \frac{1}{2}(\text{Stress}) A x$ —— (ii) Stress = Y strain
Stress = $Y \times \frac{x}{L}$

Multiplying & dividing eqn (ii) by L

$U = \frac{1}{2}(\text{Stress})\left(\frac{AL}{L}\right)x$

$$\boxed{U = \frac{1}{2}(\text{Stress}) \times \text{Volume} \times \text{Strain}} \quad \text{—— (iii)}$$

$U = \frac{1}{2}(Y\,\text{strain}) \times \text{volume} \times \text{Strain}$

$$\boxed{U = \frac{Y}{2}(\text{Strain})^2\ \text{Volume}} \quad \text{—— (iv)}$$

$U = \frac{1}{2}\ \text{Stress} \times \text{Volume} \times \left(\frac{\text{Stress}}{Y}\right) \left(\because Y = \frac{\text{Stress}}{\text{Strain}}\right)$

$$\boxed{U = \frac{(\text{Stress})^2 \times \text{Volume}}{2Y}} \quad \text{—— (v)}$$

- Energy Density of the wire :→

Elastic potential energy per unit volume is known as energy density

Energy Density, $u = \frac{U}{\text{Volume}}$

$$\boxed{u = \frac{\text{Stress} \times \text{Strain}}{2}}$$

$$\boxed{U = \frac{Y}{2}(\text{Strain})^2}$$

$$\boxed{U = \frac{(\text{Stress})^2}{2Y}}$$

• Poisson's Ratio (σ) :→

When a deforming force is applied at the free end of a suspended wire of length 'l' and radius 'R', then its length increases by 'dl' but its radius decreases by dR. Now two types of strains are produced by a single force.

(i) Longitudinal strain $= \Delta l / l$
(ii) Lateral strain $= -\Delta R / R$.

The ratio of lateral strain to the longitudinal strain is known as ~~pos~~ poisson's Ratio.
It is denoted by σ.

poisson's Ratio $= \dfrac{\text{Lateral Strain}}{\text{Longitudinal strain}}$

$$\boxed{\sigma = \frac{-\Delta R/R}{\Delta l/l}}$$

~~Theoretic~~ theoretical value :→ -1 and $+0.5$ (B/H)
Practical value :→ 0 and 0.5 (B/H)

Formula 1:→ $Y = \frac{\text{Stress}}{\text{Longitudinal Strain}}$

Longitudinal strain $= \frac{\text{Stress}}{Y}$

$$\frac{\Delta l}{l} = \frac{\text{Stress}}{Y}$$

$$\Delta l = \frac{l(\text{Stress})}{Y}$$

$$\Delta l = \frac{(\text{Original Length}) \times \text{Stress}}{Y} \quad \text{—(1)}$$

Formula 2:→

$$\sigma = \frac{\text{Lateral Strain}}{\text{Longitudinal Strain}}$$

Lateral Strain $= \sigma \times$ Long. Strain

Lateral Strain $= \sigma \times \frac{\text{Stress}}{Y}$

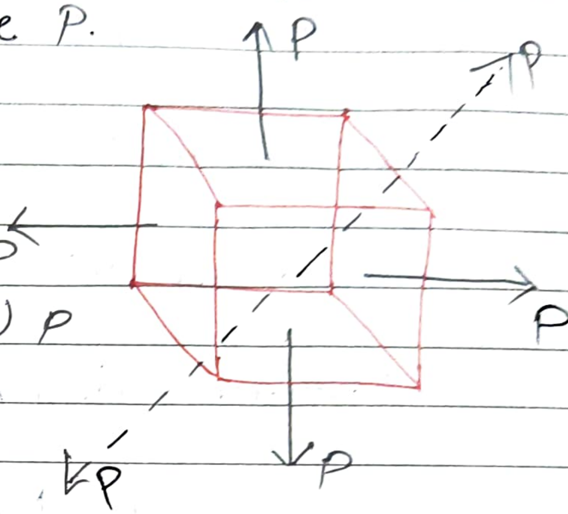
- Relation between Different Elastic Constant :→

$$Y = 3K(1-2\sigma) = 2\eta(1+\sigma) = \frac{9K\eta}{3K+\eta}$$

$$\sigma = \frac{3K-2\eta}{6K+2\eta}$$

where Y = Young's Modulus of elasticity.
K = Bulk Modulus of elasticity.
η = Shear Modulus of elasticity or Modulus of Rigidity.
σ = Poisson's Ratio.

Proof (1) Let us consider a cube whose sides of length 'l' are parallel to the three coordinates x, y, z. Let a uniform normal stress 'P' is applied are its surface. each side of the cube is under an ~~exten~~ extensional pressure P.



~~Extension produced in x-axis = Stress~~

The pressure (stress) P which is along the x-direction will elongate the x-axis and compress y and z-axes.

Extension produced in x-axis

$$= \frac{\text{Stress} \times \text{O.L.}}{Y} = \frac{Pl}{Y}$$

Compression produced in y-axis

$$= \frac{\sigma \times \text{Stress} \times \text{O.L.}}{Y} = \frac{\sigma Pl}{Y}$$

Compression produced in z-axis

$$= \frac{\sigma Pl}{Y}$$

The pressure (stress) P along y-axis will elongate the y-axis and compress x and z axes.

Extension produced in y axis $= \frac{Pl}{Y}$

Compression produced in x-axis $= \frac{\sigma Pl}{Y}$

Compression produced in z-axis $= \frac{\sigma P l}{Y}$

The pressure P (stress) along z-axis will elongate z-axis and compress x and y axes.

Extension produced in z-axis $= \frac{Pl}{Y}$

Compression produced in y-axis $= \frac{\sigma P l}{Y}$

Compression produced in x-axis $= \frac{\sigma P l}{Y}$

Net extension in x-axis $= \frac{Pl}{Y} - \frac{\sigma P l}{Y} - \frac{\sigma P l}{Y}$

$$= \frac{Pl}{Y}[1 - \sigma - \sigma]$$

$$= \frac{Pl}{Y}(1 - 2\sigma)$$

Net extension in y-axis $= \frac{Pl}{Y} - \frac{\sigma P l}{Y} - \frac{\sigma P l}{Y}$

$$= \frac{Pl}{Y}(1 - 2\sigma)$$

Net extension in z-axis $= \frac{Pl}{Y} - \frac{\sigma P l}{Y} - \frac{\sigma P l}{Y}$

$$= \frac{Pl}{Y}(1 - 2\sigma)$$

Now side of the cube $= l + \frac{Pl}{Y}(1 - 2\sigma)$

$$= l\left[1 + \frac{P}{Y}(1 - 2\sigma)\right]$$

Volume of the Cube $=$ (side)^3

$$= l^3\left[1+\frac{P}{Y}(1-2\sigma)\right]^3$$

Using Binomial Theorem $(1+x)^n = (1+nx)+\ldots$

$$V' = l^3\left[1+\frac{3P}{Y}(1-2\sigma)\right]$$ (Ignoring the other terms)

Change in volume $= V'-V$

$$= l^3\left[1+\frac{3P}{Y}(1-2\sigma)\right] - l^3$$

$$= \frac{3P}{Y} l^3 (1-2\sigma)$$

Volumetric strain $= \frac{\text{Change in volume}}{\text{Original volume}}$

$$= \frac{3P l^3 (1-2\sigma)}{Y\ (l^3)}$$

$$= \frac{3P}{Y}(1-2\sigma)$$

Bulk Modulus of Elasticity, K

$$= \frac{\text{Stress}}{\text{Volumetric Strain}}$$

$$K = \frac{P}{\frac{3P}{Y}(1-2\sigma)}$$

$$K = \frac{Y}{3(1-2\sigma)}$$

$$\boxed{Y = 3K(1-2\sigma)} \quad \text{— (A)}$$

2. Let us consider a cube of side 'l' upon which a stress 'P' along x-direction, extensional stress and compressional stress P along y-axis. there is no stress along z-axis.

Extensional stress (P) along x-axis will elongate the x-axis and compress y and z-axes.

Extension along x-axis $= \frac{Pl}{Y}$

compression along y-axis $= \frac{\sigma Pl}{Y}$

compression along z-axis $= \frac{\sigma Pl}{Y}$

Stress (P) along y-axis will compress the y-axis and it will elongate the x-axis and z-axis

compression along y-axis $= \frac{Pl}{Y}$

extension along x-axis $= \frac{\sigma Pl}{Y}$

extension along z-axis $= \frac{\sigma Pl}{Y}$

Net compression along y-axis $= \frac{\sigma Pl}{Y} + \frac{Pl}{Y}$

$= \frac{Pl}{Y}(1+\sigma)$

Net Elongation along x-axis $= \frac{\sigma Pl}{Y} + \frac{Pl}{Y}$

$= \frac{Pl}{Y}(1+\sigma)$

There is no extension nor compression also in z-axis. Net extensional strain along x-axis $= \frac{P\cancel{x}(1+\sigma)}{Y(\cancel{x})}$

$= \frac{P(1+\sigma)}{Y}$

Net compressional strain along y-axis

$= \frac{P(1+\sigma)}{Y}$

The extensional strain and compressional strain are perpendicular to each other and the sum of these strains is equal to shearing strain (θ).

Ext. strain + Comp. strain $= \theta$

$$\frac{P}{Y}(1+\sigma) + \frac{P}{Y}(1+\sigma) = \theta$$

$$\frac{2P}{Y}(1+\sigma) = \theta$$

$$\frac{P}{\theta} = \frac{Y}{2(1+\sigma)}$$

$$\frac{\text{Stress}}{\text{Shearing strain}} = \frac{Y}{2(1+\sigma)}$$

η (Modulus of Rigidity) $= \frac{Y}{2(1+\sigma)}$

$$\boxed{Y = 2\eta(1+\sigma)} \quad \text{— (B)}$$

$$1+\sigma = \frac{Y}{2\eta}$$

$$\sigma = \frac{Y}{2\eta} - 1 \quad \text{— (1)}$$

We know that $Y = 3K(1-2\sigma)$ — (ii)

putting eqn (i) in (ii)

$$Y = 3K\left[1 - 2\left(\frac{Y}{2\eta} - 1\right)\right]$$

$$Y = 3K - \frac{6KY}{2\eta} + 6K$$

$$Y + \frac{3KY}{\eta} = 9K$$

$$Y\left(1 + \frac{3K}{\eta}\right) = 9K$$

$$\Rightarrow Y\left(\frac{\eta + 3K}{\eta}\right) = 9K$$

$$\boxed{Y = \frac{9K\eta}{3K+\eta}} \quad \text{— (C)}$$

We know that $Y = 3K(1-2\sigma)$ — (iii)

and $Y = 2\eta(1+\sigma)$ — (iv)

equating eqn (iii) & (iv)

$$3K(1-2\sigma) = 2\eta(1+\sigma)$$

$$3K - 6K\sigma = 2\eta + 2\eta\sigma$$

$$6K\sigma + 2\eta\sigma = 3K - 2\eta$$

$$\sigma(6K + 2\eta) = 3K - 2\eta$$

$$\boxed{\sigma = \frac{3K - 2\eta}{6K + 2\eta}} \quad \text{— (D)}$$

• Theoretical Value of Poisson's Ratio :→

We know that $Y = 3K(1-2\sigma)$

$$Y = 2\eta(1+\sigma)$$

equating both equations

$$3K(1-2\sigma) = 2\eta(1+\sigma)$$

If σ is positive then R.H.S +ve

$$3K(1-2\sigma) = 2\eta(1+\sigma) \quad \text{--- (1)}$$

L.H.S will be positive,

when $1-2\sigma > 0$

$$1 > 2\sigma$$

$$\sigma < 1/2$$

$$\sigma < 0.5$$

If σ is negative, then L.H.S of eqn (1) will be positive R.H.S will be positive, when

$$1+\sigma > 0$$

$$\sigma > -1$$

Hence, σ lies between -1 to $1/2$

The practical value of σ lies between 0 to 0.5 because σ can never be negative.

• Poisson's Ratio (σ) for Incompressible Materials :→

For incompressible solid, the bulk modulus of elasticity is →

$$\because \quad K = \frac{\text{Stress}}{\Delta V/V}$$

$$K = \frac{\text{Stress} \times V}{\Delta V}$$

For incompressible matter, $\Delta V = 0$

$\therefore K = \infty$

We know that $Y = 3K(1-2\sigma)$

$1-2\sigma = Y/3K$

For incompressible solid, $K = \infty$

$1-2\sigma = 0$

$2\sigma = 1$

$\sigma = 1/2$

$\boxed{\sigma = 0.5}$

Surface Tension

- **Molecular Forces :-** The phenomenon of surface tension is due to force of attraction between the molecule.

There are two types of molecular forces.

(i) Cohesive Force (ii) Adhesive Force.

(i) **Cohesive Force :-** ~~The~~ Cohesive force is the force of attraction between molecules of the same substance.

e.g. → A water molecule in water being attached by neighbouring water molecules. These are the strong molecular forces.

(ii) **Adhesive Force :-** Adhesive force is a force of attraction between molecules of

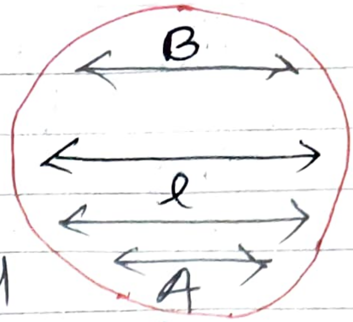
different substances.
e.g.:→ If a drop of water placed on glass surface. molecule of water and glass attract each other with adhesive force.
These are not so strong a a compared to cohesive forces.

• Molecular Range:→
Maximum distance up to which the molecules attract each other known as molecular range.
i) Usually molecular range is of the order of 10^{-7} cm.
ii) It is of the order 10^{-9} m (nm) in liquid.

• Sphere of Influence:→
The effective range of attraction of the molecule is called sphere of influence.
The molecules near the surface of a liquid are strongly pulled inward and hence they have a certain amount of energy due to their positions this energy is known as "Surface Energy".

• Surface Tension:→
It is a property of a liquid behaves like a streched elastic membrane is called Surface Tension.

- **Explaination :→**



Consider an imaginary line AB drawn on the free surface of the liquid whose length is 'l' to this line equal and opposite forces act a perpendicular. They are called surface tension forces, for this reason stretched elastic membrane is formed on the free surface of liquid.

- **Defination :→**

"Surface tension of a liquid is defined as the force per unit length 'l' acting at a right angle to an imaginary line drawn on the free surface of liquid".

Mathematically $\boxed{T = \frac{F}{l}}$

Where 'T' is surface Tension of a given liquid

- S.I unit N/m or Nm^{-1}
- In C.G.S system the unit of surface tension is dyne/cm.
- Dimension - $[M^1 T^{-2}]$

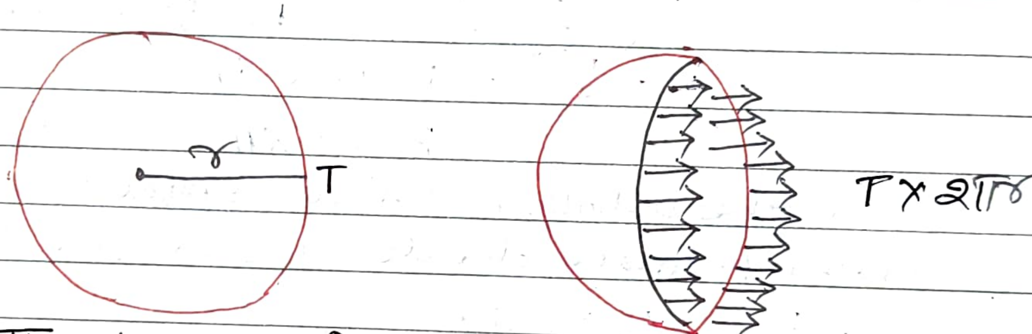
$$T = \frac{F}{L} = \frac{M^1 \cancel{L} T^{-2}}{\cancel{L}} = [M^1 T^{-2}]$$

When increase in tempreature surface tension decrease.

- **Excess Pressure Inside A Liquid Drop:** →

Consider a spherical liquid drop of radius r. Let T be its surface tension. Since, the drop has convex surface molecule on it experiences the resultant force due to surface tension directed inwards. Since, the drop is in equilibrium position the pressure acting inside must be greater than the pressure outside.

Imagine that the drop is divided into two semisphere and let us consider the equilibrium of any one of them.



The force acting on the semisphere.

(1) The force due to excess pressure acting the plan face it is directed towards.

$$P = F/A$$
$$P \times A = F$$
$$F = PA$$
$$F = P \times \pi r^2 \quad \text{—— (1)}$$

(ii) its weight which is negligible

(iii) The resultant force due to surface tension acting on the circumference of the circle

$$F = T \times 2\pi r \quad \text{—— (2)}$$

its is directed inward.