PHY 1125: Physics - I

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Syllabus

Fluid Mechanics and Viscosity: Fluid, Rate of flow, Different fluid motions, Equation of continuity, Bernoulli's equation, Speed of efflux: Torricelli's theorem, Venturimeter, Viscosity, Newton's law of viscous flow, coefficient of viscosity, Reynold Number, Poiseuille's equation and corrections, Capillary flow method.

Surface tension: Molecular forces of cohesion & adhesion, Molecular range: sphere of influence, Surface tension, Free energy, Excess pressure across a curved film or membrane, Capillarity, Contact angle, Capillary rise method.

Elasticity: Hooke's law, Breaking stress, Stress-strain diagram, Different types of elasticity, Heat effect on elasticity, Poisson's ratio, Shearing stress and shearing strain, Relations among the elastic constants, Work done in a strain, Work of rupture, Deformation by bending, Bending moment.

Dynamics of circular motion: Moment of Inertia, Radius of Gyration, Theorem of perpendicular axes and parallel axes, Moment of inertia for different geometrical shapes and Flywheel.

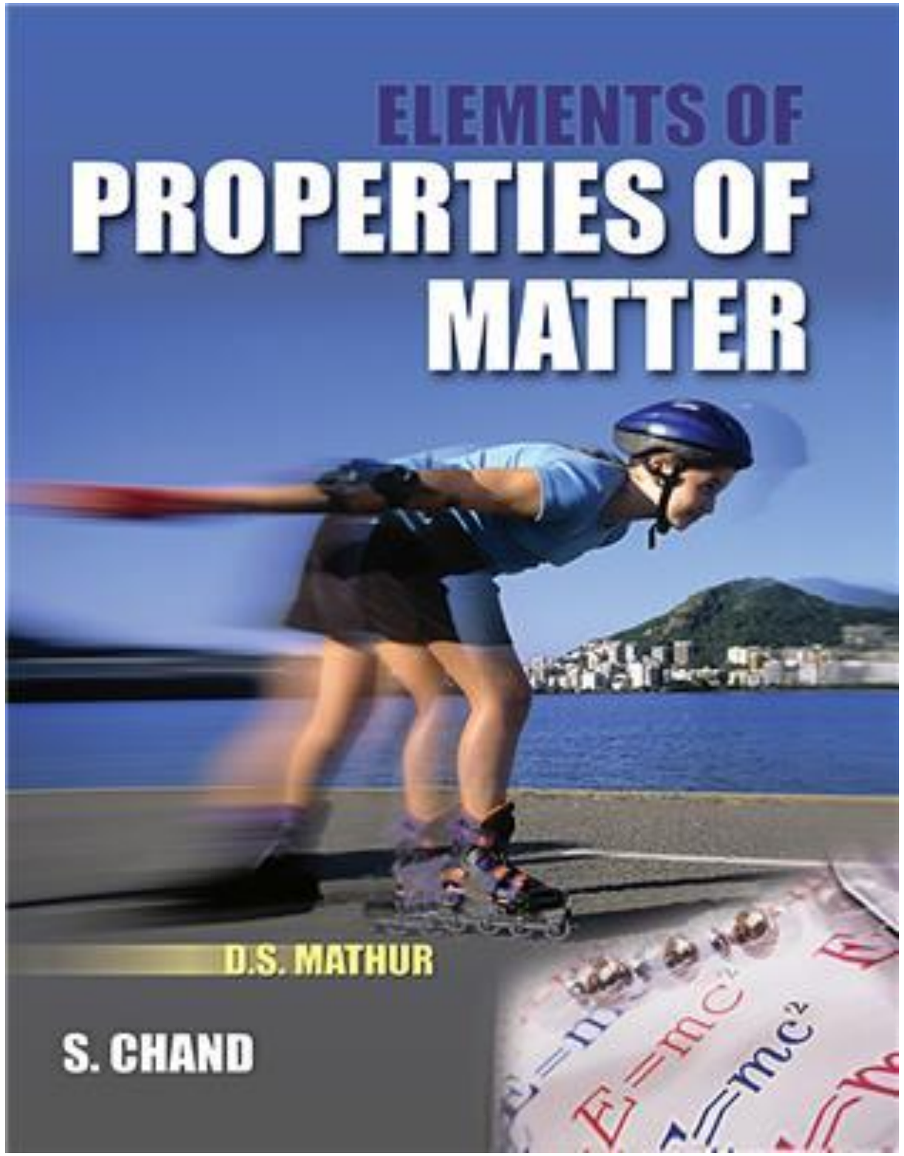
Interference: Huygen's principle, Interference, Young's double slit experiment, Fresnel's Biprism, Newton's ring, Thin film interference.

Diffraction: Diffraction, Fresnel & Fraunhofer diffraction, Diffraction grating and its use, Zone Plate, Resolving power of a grating, Dispersive power of a grating, Bragg's law, X-ray diffraction, Debye-scherrer equation.

Polarization: Polarization, Polarization by reflection, Brewster's law; Double refraction, Nicol prism, Malus law, Specific rotation, Laurent's half shade polarimeter.

Laser Physics: Spontaneous and stimulated emission, properties of laser beam, laser types, pumping schemes, Application of laser in textiles.

Reference



Elasticity: Hooke's law, Breaking stress, Stress-strain diagram, Different types of elasticity, Heat effect on elasticity, Poisson's ratio, Shearing stress and shearing strain, Relations among the elastic constants, Work done in a strain, Work of rupture, Deformation by bending, Bending moment.

Chapter VIII

Elements of Properties of Matter - D. S. Mathur

Elasticity and deformation of objects

Elasticity: The property of a material to return to its original shape and size after the deforming force is removed.

Deformation: Change in shape or size of a body under an applied force.

Types of Deformation:

- **Elastic deformation:** Temporary, reversible (within elastic limit).
- **Plastic deformation:** Permanent, irreversible (beyond elastic limit).

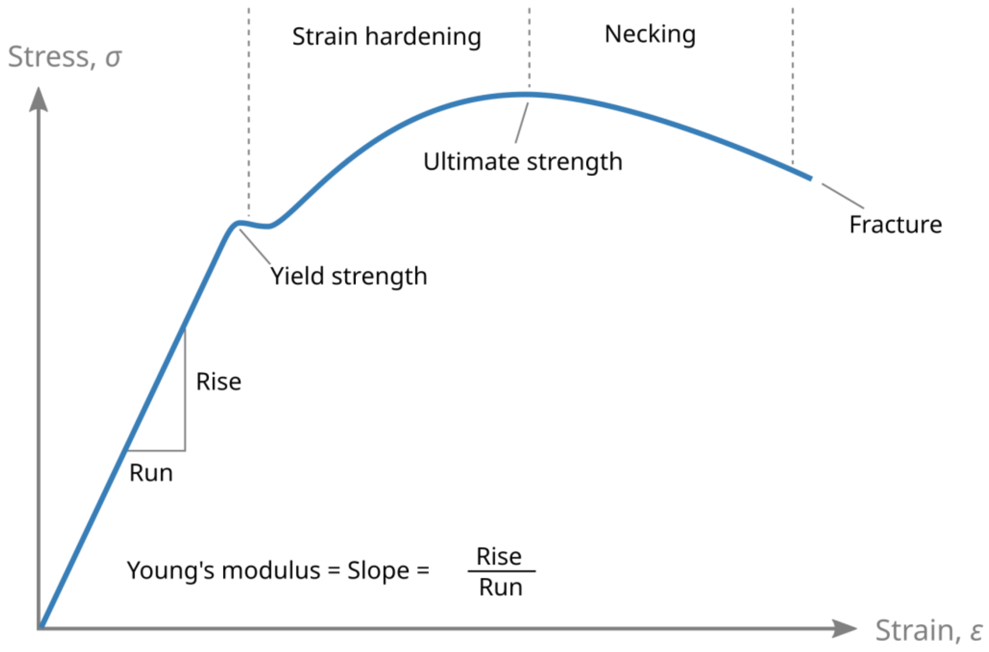
Examples:

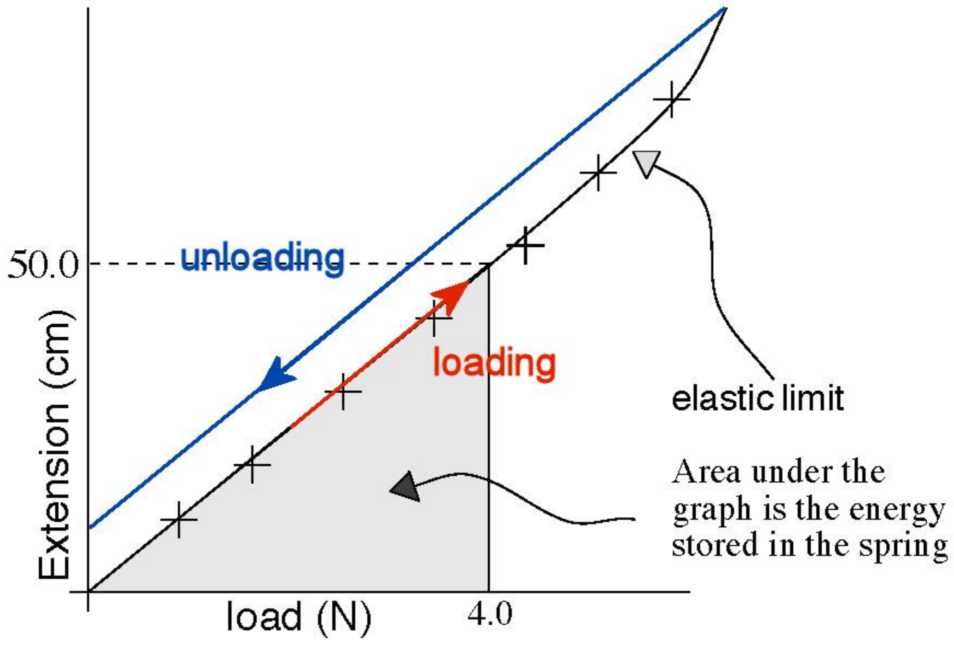
- Bridges & flyovers → expand and contract elastically with temperature.
- Bending a paper clip permanently (plastic).
- Compressed spring (elastic).

Key Idea:
Elasticity tells us **how materials respond to forces** — this leads us to stress, strain, and Hooke's law.

Hooke’s law

Hooke's law is the fundamental law of elasticity and states that, provided the strain is small, the stress is proportional to the strain; so that, in such a case, the ratio stress/strain is a constant, called the modulus of elasticity, (a term first introduced by Thomas Young), or the coefficient of elasticity.





Factors affecting elasticity

- Nature of material – metals (high), rubber (low)
- Temperature – elasticity decreases with heat (rubber is an exception)
- Impurities/composition – steel is more elastic than pure iron
- Heat/mechanical treatment – annealing, quenching, cold working modify elasticity
- Age/fatigue – repeated use reduces elasticity (e.g., old springs)
- Type of stress applied – tensile, compressive, shear stresses affect elasticity differently

Three types of elasticity

Young's Modulus (Y)

- Ratio of longitudinal stress to longitudinal strain
- Stretching/compressing along length

Bulk Modulus (K)

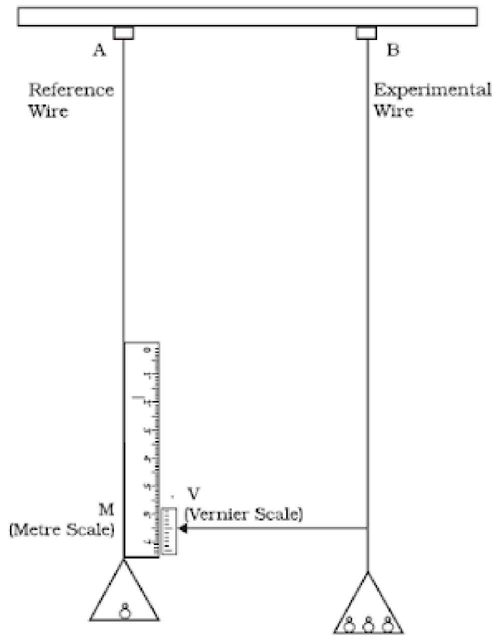
- Ratio of volumetric stress to volumetric strain
- Uniform compression/expansion of volume

Shear Modulus (Modulus of Rigidity)

- Ratio of shearing stress to shearing strain
- Shape deformation without volume change

Young’s Modulus (Y)

- Measures elasticity in length (tensile or compressive)
- Defined as: Longitudinal stress / Longitudinal strain
- Stress = Force / Area
- Strain = Change in length / Original length
- Unit: Pascal (N/m^2)
- Higher value means stiffer material (steel > rubber)



Young's Modulus (Y)

$$\text{Longitudinal Strain} = \frac{\text{Change in length}}{\text{Original length}} = \frac{l}{L}$$

$$\text{and Longitudinal stress} = \frac{\text{Deforming force}}{\text{Area of cross section}} = \frac{F}{A}$$

Therefore, Young's modulus of elasticity;

$$\boxed{Y = \frac{F/A}{l/L} = \frac{FL}{Al}}$$

If $l = L$ and $A = 1\,\text{m}^2$

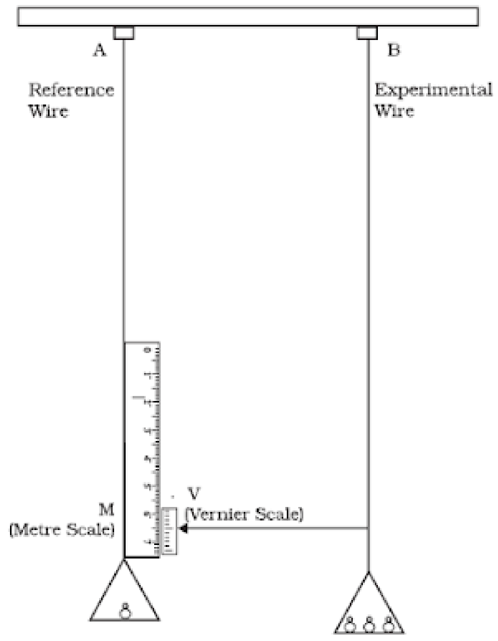
Then, $Y = F$

If r is the radius of the wire and the mass M is hanging on it then;

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

Therefore; $$Y = \frac{MgL}{\pi r^2 l}$$

In MKS system the unit of Y is Nm^{-2}.



Young's Modulus (Y)

Values of Y, η and K for Some Materials

Table

Material	Y ($N.m^{-2}$) $\times 10^{10}$	η ($N.m^{-2}$) $\times 10^{10}$	K ($N.m^{-2}$) $\times 10^{10}$
Aluminium	7	3	7
Copper	11	4·2	14
Iron	19	7	10
Steel	21	8·4	16
Brass	9	3·6	6

Difference Between Pressure and Stress

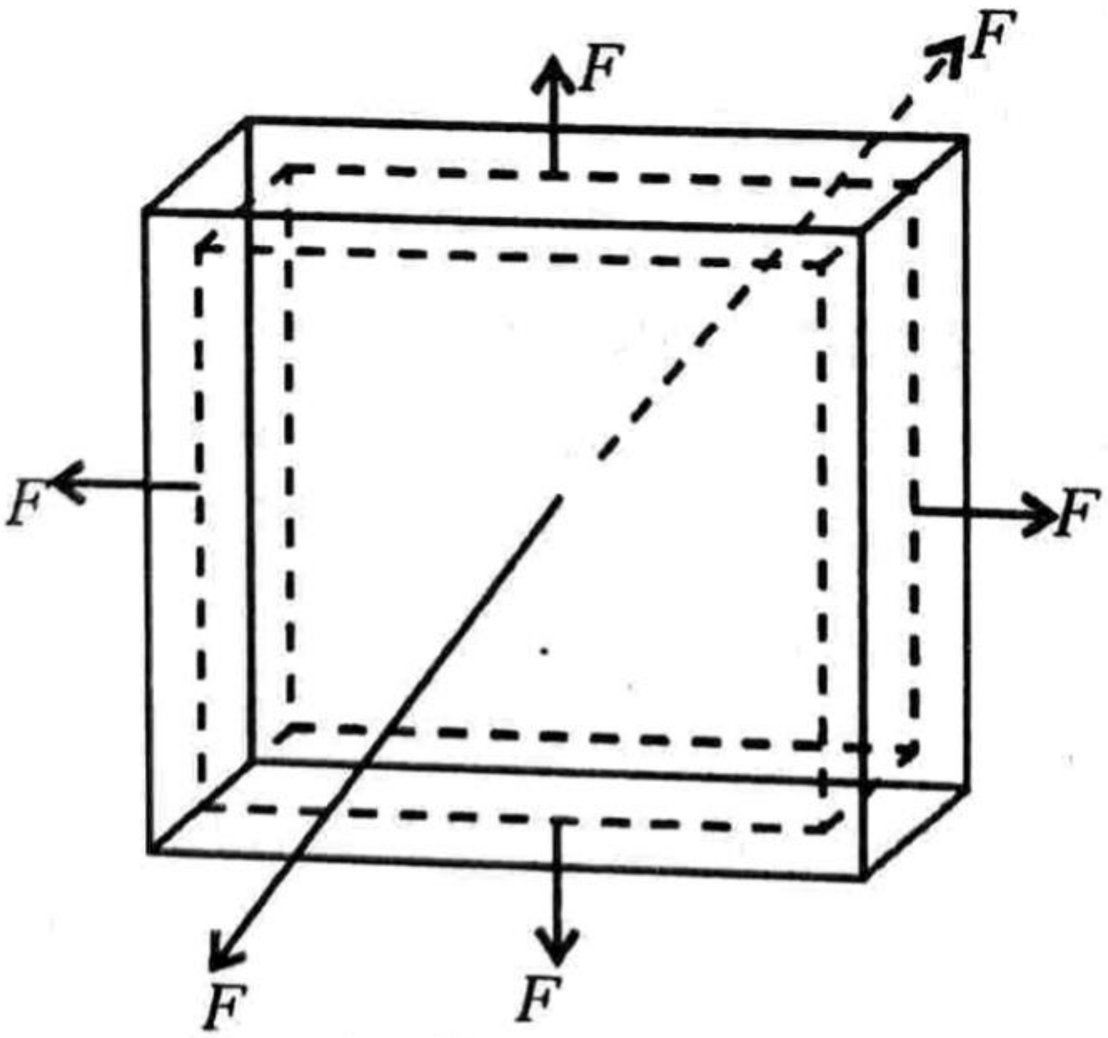
Pressure

- Force per unit area, **applied externally** on a surface
- Always **acts normal (perpendicular)** to the surface
- Scalar quantity (same in all directions for a given point in a fluid)
- Example: Air pressure on the walls of a balloon

Stress

- Internal restoring force per unit area developed **inside a material** when deformed
- Can act **normal (tensile or compressive)** or **tangential (shear)**
- Tensor quantity (direction matters)
- Example: Stress inside a stretched rubber band or bent beam

Bulk Modulus



$$\text{bulk strain} = \frac{\text{change of volume}}{\text{original volume}}$$

Bulk Modulus

(2) **Bulk Modulus**. Here, the force is applied *normally* and *uniformly* to the whole surface of the body ; so that, *while there is a change of volume, there is no change of shape*. Geometrically speaking, therefore, we have here *a change in the scale of the coordinates* of the system or the body. *The force applied per unit area*, (*or pressure*), *gives the* **Stress**, *and the change per unit volume, the* **Strain,** *their ratio giving the Bulk Modulus for the body. It is usually denoted by the letter K.*

Thus, if F be the force applied *uniformly and normally* on a surface area a, the stress, or pressure, is F/a or P ; and, if v be the change in volume produced in an original volume V, the strain is v/V. and, therefore,

$$\text{Bulk Modulus, } K = \frac{F/a}{v/V} = \frac{F.V}{a.v} = \frac{P.V}{v} \qquad [\because F/a = P.$$

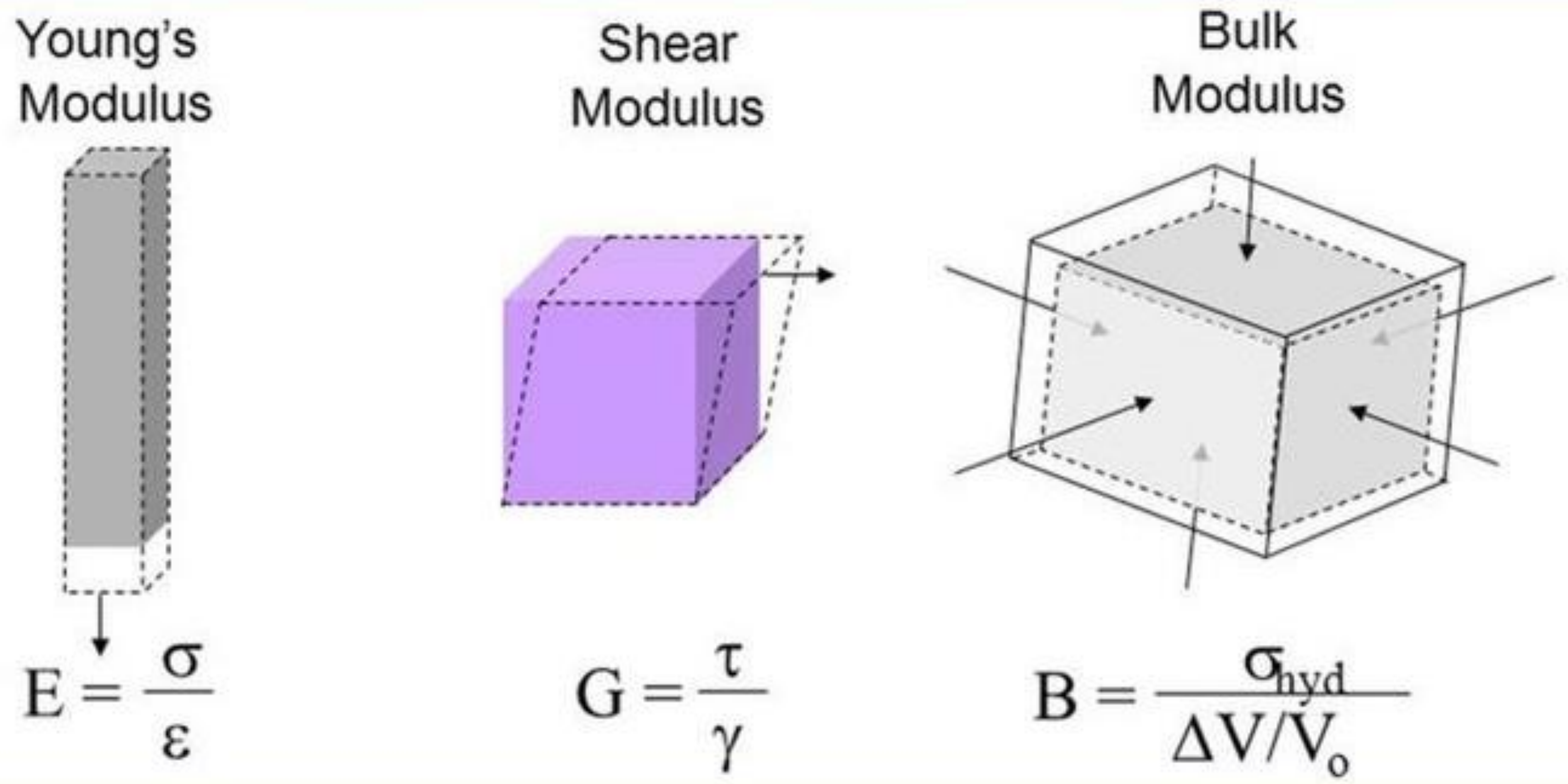
Bulk Modulus

If, however, the change in volume be not proportional to the stress or the pressure applied, we consider the infinitesimal change in volume dV, for the corresponding change in pressure dP; so that, we have

$$K = dP.V/dV.$$

The Bulk Modulus is sometimes referred to as **incompressibility** and hence its reciprocal is called **compressibility** ; so that, *compressibility* of a body is equal to $1/K$, where K is its *Bulk Modulus*. It must thus be quite clear that whereas bulk modulus is stress per unit strain, *compressibility represents strain per unit stress.*

Modulus of Rigidity



Modulus of Rigidity

(3) **Modulus of Rigidity**. In this case, while there is a change in the shape of the body, there is no change in its volume. As indicated already, it takes place by the movement of contiguous layers of the body, one over the other, very much in the manner that the cards would do when a pack of them, placed on the table, is pressed with the hand and pushed horizontally. Again, speaking geometrically, we have, in this case, *a change in the inclinations of the coordinate axes* of the system or the body.

Modulus of Rigidity

Consider a rectangular solid cube, whose lower face *aDCc*, (Fig. 171), is fixed, and to whose upper face a tangential force *F* is applied in the direction shown. The couple so produced by this force and an equal and opposite force coming into play on the lower fixed face, makes the layers, parallel to the two faces, move over one another, such that the point *A* shifts to *A′*, *B* to *B′*, *d* to *d′* and *b* to *b′*, *i.e.*, *the lines joining the two faces turn through an angle θ*†.

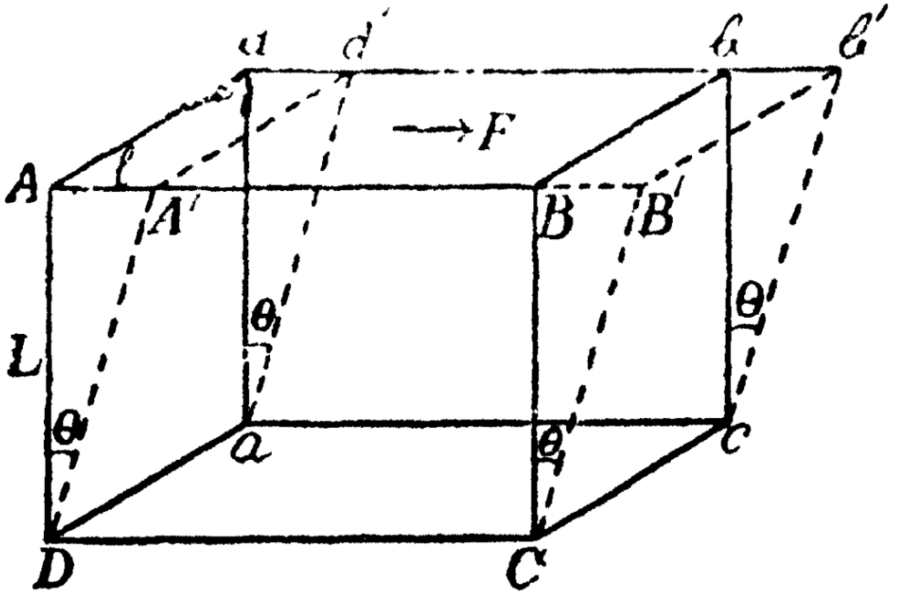


Fig. 171.

The face ABCD is then said to be **sheared** through *an angle θ. This angle θ* (*in radians*), *through which a line originally perpendicular to the fixed face is turned, gives the strain or* **the shear strain**, *or the* **angle of shear**, *as it is often called.* As will

Modulus of Rigidity

be readily seen, $\theta = AA'/DA = l/L$, where l is the *displacement* AA' and L, the length of the side AD or the *height* of the cube ; or θ = *relative displacement of plane ABba/distance from the fixed plane aDCc.* So that, if the distance from the fixed plane, *i.e.*, $L = 1$, we have $\theta = l$ = *relative displacement* of plane $ABba$.

Thus, *shear strain* (*or shear*) *may also be defined as the relative displacement between two planes unit distance apart.*

And, *stress or* **tangential stress** *is clearly equal to the force F divided by the area of the face ABbd, i.e., equal to F/a. The ratio of the tangential stress to the shear strain gives the* **co-efficient of rigidity** *of the material of the body, denoted by n.*

Thus, *tangential stress* $= F/a$, and *shear strain* $= \theta = l/L$.

And, therefore, *Co-efficient of Rigidity*, or *Modulus of Rigidity* of the material of the cube is given by

$$n = \frac{F/a}{\theta} = \frac{F/a}{l/L} = \frac{F.L}{a \cdot l} \quad \ldots \quad \ldots \quad \ldots \quad (i)$$

This is a relation exactly similar to the one for Young's Modulus, with the only difference that, here, F is the tangential stress, not a linear one, and l, a displacement at right angles to L, instead of along it.

Modulus of Rigidity

Again, if the shearing strain, or shear, be not proportional to the shearing stress applied, we have

$$n = \frac{dF/a}{d\theta},$$

where $d\theta$ is the increase in the angle of shear for an infinitesimal increase dF/a in the shearing stress.

Further, it is clear from relation (*i*) above, that if $a = 1$, and $\theta = 1$ *radian* (or $57° \ 18'$), we have $n = F$.

*We may thus define modulus of rigidity of a material as the shearing stress per unit shear, i.e., a shear of 1 radian, taking Hooke's law to be valid even for such a large strain**.

Work done per unit volume in a strain

112. Work done per unit volume in a strain. In order to *deform* a body, work must be done by the applied force. The energy so spent is stored up in the body and is called the *energy strain*. When the applied forces are removed, the stress disappears and ***the energy of strain appears as heat***.

Let us consider the work done during the three cases of strain.

(*i*) **Elongation Strain**—(*stretch of a wire*). Let F be the force applied to a wire, fixed at the upper end. Then, clearly, for a small increase in length dl of the wire, the work done will be equal to $F.dl$. And, therefore, during the whole stretch of the wire from 0 to l.

$$\textit{work done} = \int_0^l F.dl.$$

Work done per unit volume in a strain

Now, Young's modulus for the material of the wire, *i.e.*,

$$Y = F.L/a.l.,$$

where L is the original length, l, the increase in length, a, the cross-sectional area of the wire, and F, the force applied.

And $\therefore$ $$F = Y.a.l/L.$$

Therefore, work done during the stretch of the wire from 0 to l is given by

$$W = \int_0^l \frac{Y.a}{L}.l.dl = \frac{Y.a}{L}\int_0^l l.dl.$$

$$= \frac{Y.a}{L}.\frac{l^2}{2} = \frac{1}{2}.\frac{Y.a.l}{L}.l.$$

Work done per unit volume in a strain

But $\qquad Y.\gamma.l/L = F$, the *force* applied.

Hence $\qquad W = \frac{1}{2} F.l = \frac{1}{2} \times$ *stretching force* $\times$ *stretch*.

$\therefore$ work done per *unit* volume $= \frac{1}{2} Fl \times \frac{1}{L.a}$. $\qquad$ [$\because$ *volume* of the wire $= L \times a$.

$= \frac{1}{2} \cdot \frac{F}{a} \cdot \frac{l}{L} = \frac{1}{2}$ *stress* $\times$ *strain*. $\qquad$ [$\because F/a =$ *stress*. and $l/L =$ strain.

Work done per unit volume in a strain

(*ii*) **Volume Strain.** Let p be the stress applied. Then, over an area a the force applied is $p.a$, and, therefore, the work done for a small movement dx, in the direction of p, is equal to $p.a.dx$. Now, $a.dx$ is equal to dv, the small change produced in volume. Thus, work dono for a change dv is equal to $p.dv$.

And, therefore, total work done for the *whole change in volume*, from 0 to v, is given by

$$W = \int_0^v p.dv.$$

Now, $\quad K = p.V/v$; so that, $p = K.v/V$,

Work done per unit volume in a strain

where V is the original volume, and K, the *Bulk Modulus*.

$$\text{And } \therefore W = \int_0^v \frac{K.v}{V}\,.\,dv = \frac{K}{V}\int_0^v v.dv = \frac{K}{V}\cdot\frac{1}{2}v^2.$$

$$= \frac{1}{2}\cdot\frac{Kv}{V}.v = \frac{1}{2}p.v = \frac{\quad}{2}\ \textit{stress} \times \textit{change in volume}.$$

Or, work done per *unit* volume $= \frac{1}{2}\,p.v/V = \frac{1}{2}$ *stress* $\times$ *strain*.

Work done per unit volume in a strain

(*iii*) **Shearing Strain.** Consider a cube (Fig. 176), with its lower face DC fixed ; and let F be the *tangential force* applied to its upper face in the plane of AB, so that the face $ABCD$ is distorted into the position $A'B'CD$, or *sheared* through an angle θ. Let the distance AA' be equal to $BB' = x$. Then, work done during a small displacement dx is equal to $F.dx$. And, therefore, work done for the *whole of the displacement*, from 0 to x, is given by

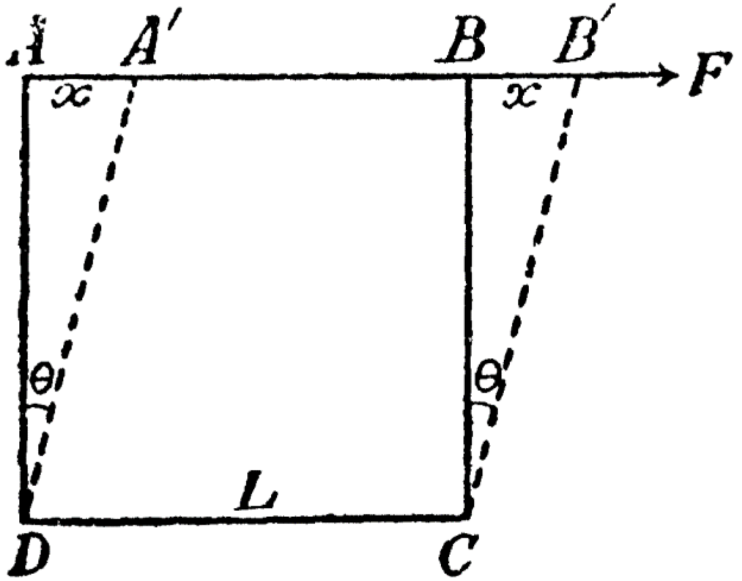


Fig. 176.

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

Now, $n = F/a\theta$, or $F = n.a.\theta$, and $a = L^2$; also $\theta = x/L$, where L is the length of each edge of the cube.

So that, $F = n.L^2.x/L = n.L.x.$

Work done per unit volume in a strain

$\therefore$ work done during the *wole stretch* from 0 to x, *i.e.*,

$$W = \int_0^x n.L.x.dx = \frac{1}{2}.n.Lx^2.$$

$\therefore$ work done per *unit* volume $= \frac{1}{2} \cdot \frac{n.L.x^2}{L^3}$. $\left[\because\right.$ *volume* of the cube $= L^3$

$$= \frac{1}{2} \cdot \frac{n.x.L}{L^2} \times \frac{x}{L} = \frac{1}{2} \cdot \frac{F}{a} \cdot \frac{x}{L} = \tfrac{1}{2}\, stress \times strain.$$

Thus, we see that, in any kind of strain, *work done per unit volume is equal to* $\frac{1}{2}$ *stress* $\times$ *strain.*

Next

- Work of rupture
- Deformation by bending, Bending moment