# Chapter Name: Properties of Matter

## Elasticity

Elasticity is the property of a material by virtue of which it regains its original shape and size after the removal of the deforming force.

If the body does not return to its original shape, it is said to be plastic.

## Stress and Strain

| Term | Definition | Unit |
|---|---|---|
| **Stress (σ)** | It is the internal restoring force per unit area developed inside a body when it is deformed. | Pascal (Pa) or $N/m^2$ |
| **Strain (ε)** | It is the ratio of change in dimension to the original dimension. It has no unit (dimensionless). | Unitless |

- **Formula of Stress**

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

Where;
- F = Applied Force
- A = Acted area where force has been applied

- **Formula of Strain**

$$\varepsilon = \frac{\text{Change in Dimension}}{\text{Original Dimension}}$$

## Types of Stress

1. **Tensile stress** – when the body is stretched.
2. **Compressive stress** – when the body is compressed.
3. **Shear stress** – when the body is subjected to tangential force.

## Types of Strain

1. **Longitudinal strain** – change in length/original length.
2. **Lateral strain** – change in diameter/original diameter.
3. **Shear strain** – angular deformation.
4. **Volumetric strain** – change in volume/original volume.

# Moduli of Elasticity

The ratio of stress to the corresponding strain within the elastic limit is called the modulus of elasticity. It measures the stiffness or resistance of a material to deformation.

There are mainly three types of elastic moduli:

### A. Young's Modulus (E):

It is the ratio of tensile (or compressive) stress to the corresponding strain within the elastic limit. It determines how difficult it is to stretch or compress a material.

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

### B. Bulk Modulus (K):

It is the ratio of bulk stress (uniform pressure) to the volumetric strain. It measures how incompressible a material is when subjected to uniform pressure.

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

### C. Modulus of Rigidity or Shear Modulus (G):

It is the ratio of shear stress to shear strain. It measures the material's resistance to shape change without change in volume.

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

### D. Poisson's Ratio (ν)

It is defined as the ratio of lateral strain to longitudinal strain. For most materials, the value of Poisson's ratio lies between 0 and 0.5

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

## Relations Between Elastic Constants

### Standard Relation

$$E = 2G(1+\nu) = 3K(1-2\nu)$$

### Relation between E,G and ν:

$$E = 2G(1+\nu)$$

$$G = \frac{E}{2(1+\nu)}$$

$$\nu = \frac{E}{2G} - 1$$

### Relation between E, K, and ν

$$E = 3K(1-2\nu)$$

$$K = \frac{E}{3(1-2\nu)}$$

$$\nu = \frac{3K-E}{6K}$$

## Relation between E, K, and G

$$\frac{E}{2G(1+\nu)} = \frac{E}{3K(1-2\nu)}$$

$$E = \frac{9KG}{3K+G}$$

$$G = \frac{3KE}{9K+E}$$

$$K = \frac{EG}{3(3G-E)}$$

## Poisson's Ratio (ν) in Different Forms

$$\nu = \frac{E}{2G} - 1$$

$$\nu = \frac{3K-E}{6K}$$

$$\nu = \frac{3K-2G}{2(3K+G)}$$

## Quick Reference for Memory

$$E = 2G(1+\nu)$$

$$E = 3K(1-2\nu)$$

$$E = \frac{9KG}{3K+G}$$

$$\nu = \frac{3K-2G}{2(3K+G)}$$

## Typical Range of Poisson's Ratio

- For most metals: $\nu$= 0.25 to 0.35
- For cork (almost no lateral strain): $\nu \approx 0$
- For perfectly incompressible materials: $\nu = 0.5$

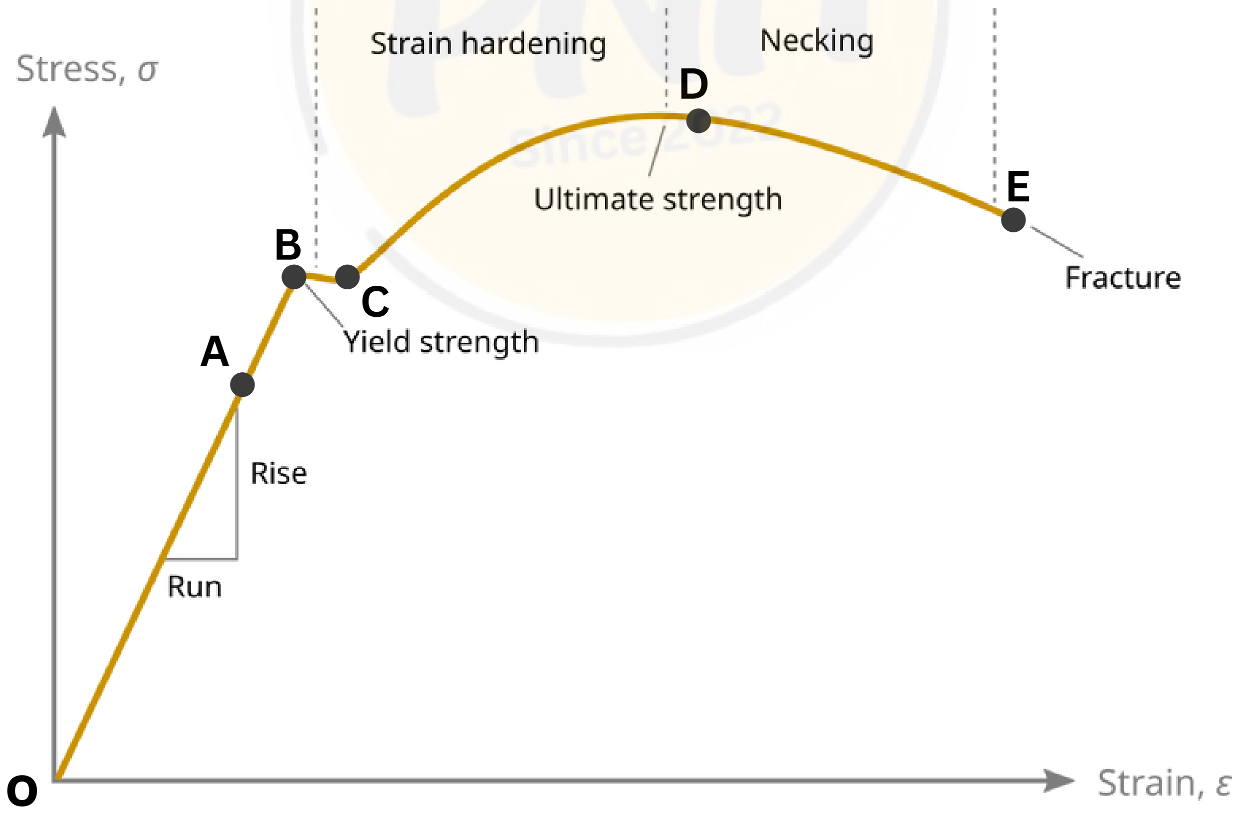
## Hooke's Law

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

$$\sigma \propto \varepsilon \quad \text{or} \quad \sigma = E\varepsilon$$

This law is valid only as long as the material remains elastic. Beyond this limit, the material undergoes permanent deformation and Hooke's law no longer holds true.

## Stress-Strain Curve



The stress-strain curve is a graphical representation that shows how a material behaves under an increasing load.

When a metal wire (like mild steel) is subjected to a gradually increasing load, the variation of stress with strain can be represented as follows:

**Proportional Limit (OA) :**
- In this region, stress is directly proportional to strain and Hooke's law is valid. The graph is a straight line through the origin.

**Elastic Limit (B) :**
- Beyond this point, the body will not return to its original shape completely after removing the load.

**Yield Point (C) :**
- At this stage, a small increase in stress causes a large strain. The material starts to deform permanently.

**Ultimate Stress Point (D) :**
- This point represents the maximum stress that the material can withstand. Beyond this, necking starts.

**Breaking Point (E) :**
- The material finally breaks and the stress suddenly drops to zero

## Significance of Stress-Strain Curve

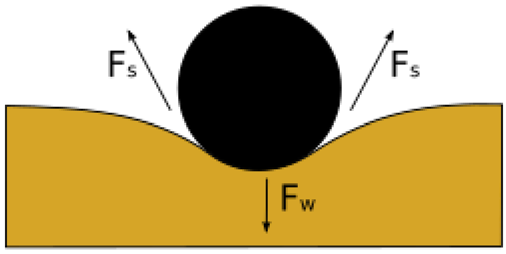
**A.** Helps determine mechanical properties:
- Elastic limit
- Yield strength
- Ultimate tensile strength
- Breaking stress

**B.** Distinguishes ductile, brittle, and plastic materials.
**C.** Used to design safe structures and machines by knowing the safe stress limits.

## Surface Tension

Surface tension is the property of a liquid by which its surface behaves like a stretched elastic sheet. It arises because molecules at the surface experience a net inward force due to cohesive forces between liquid molecules, unlike molecules inside the liquid which experience balanced forces in all directions. Essentially, surface tension tends to minimize the surface area of a liquid.

## Unit & Formula of Surface Tension




- Surface tension (γ) is defined as **force per unit length** or **energy per unit area**.
- Force per unit length: **N/m**
- Energy per unit area: **J/m²**

Mathematically:

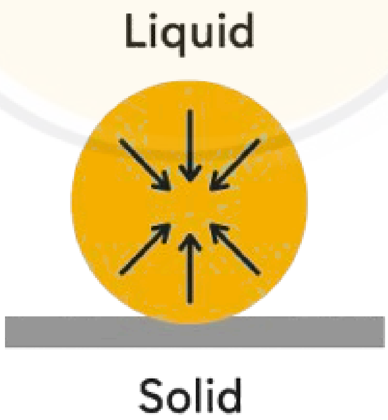
$$\gamma = \frac{F}{L} \quad \text{or} \quad \gamma = \frac{E}{A}$$

## Cohesive Forces

**Definition:** Cohesive forces are the attractive forces between molecules of the same substance.

***Example:***

- Water molecules attract each other due to hydrogen bonding. This is why water forms droplets on a surface instead of spreading completely.
- Mercury in a glass tube sticks to itself rather than the glass, forming a convex meniscus.

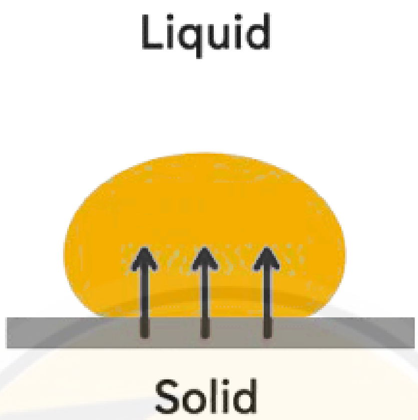



## Adhesive Forces

**Definition**: Adhesive forces are the attractive forces between molecules of a liquid and molecules of a different substance (solid or another liquid).

**Example:**

- Water molecules stick to the walls of a glass tube, causing a concave meniscus.
- Glue sticking to paper is due to adhesive forces between glue molecules and paper fibers.

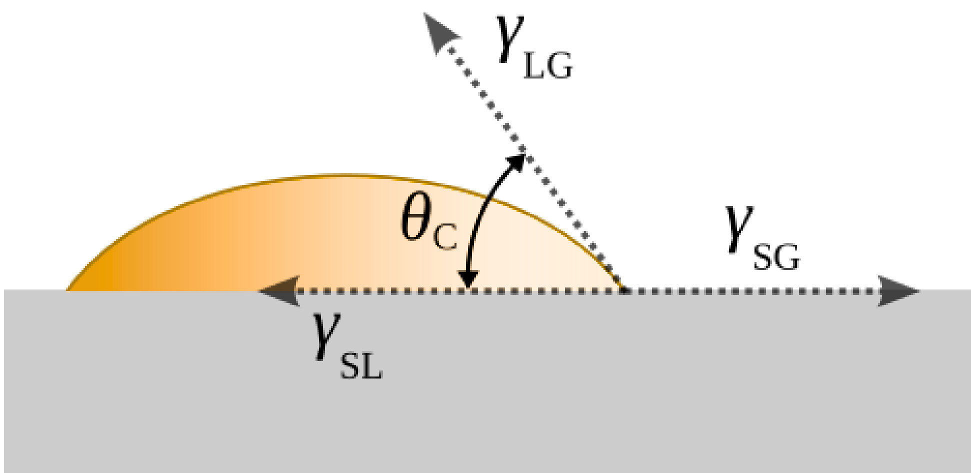



## Angle of Contact (θ)

Angle formed between the tangent to the liquid surface at the point of contact and the solid surface.

Determines whether a liquid wets a solid or not:

- $\theta < 90^\circ$ → liquid wets solid (adhesive > cohesive)
- $\theta > 90^\circ$ → liquid does not wet solid (cohesive > adhesive)

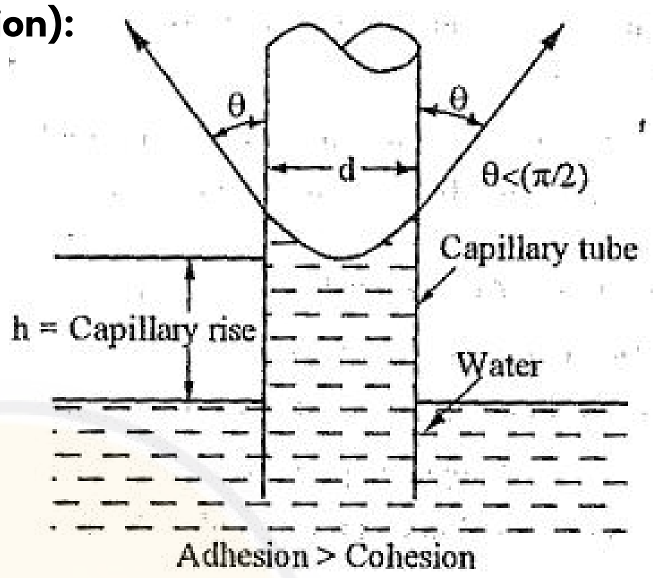


## Capillary Rise / Depression

Occurs when a liquid rises or falls in a narrow tube due to surface tension.

**Formula for capillary rise (or depression):**

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




Where:

- h = height of liquid column
- γ = surface tension of liquid
- θ = angle of contact
- ρ = density of liquid
- g = acceleration due to gravity
- r = radius of capillary

## Applications of Surface Tension

- **Formation of droplets and bubbles** – Surface tension keeps liquid droplets spherical.
- **Capillary action** – Essential for the movement of water in plants.
- **Floating of light objects** – Small objects like needles can float on water due to surface tension.
- **Detergents and soaps** – Reduce surface tension for cleaning and wetting.
- **Formation of meniscus in tubes** – Used in laboratory measurements.
- **In insects walking on water** – Surface tension supports small insects like water striders.

## Effect of Temperature and Impurities on Surface Tension

**Temperature:**

- As temperature increases, kinetic energy of molecules increases.
- Cohesive forces decrease → Surface tension decreases.

**Impurities:**

- Surfactants (soap, detergent) reduce surface tension.
- Some impurities may increase or decrease it depending on their nature.

## Viscosity

Viscosity is the property of a fluid that resists the relative motion between its layers. It is often described as the "thickness" or "internal friction" of a fluid.

**Example:** Honey has higher viscosity than water.

**Units:**
SI unit: Pa·s (Pascal-second)
CGS unit: Poise (1 Poise = 0.1 Pa·s)

**For liquids:** Resistance to flow is due to cohesive forces.
**For gases:** Resistance to flow is due to collisions between molecules (momentum transfer).


## Coefficient of Viscosity (η)

It is a measure of a fluid's resistance to flow under an applied force.

**Formula:**

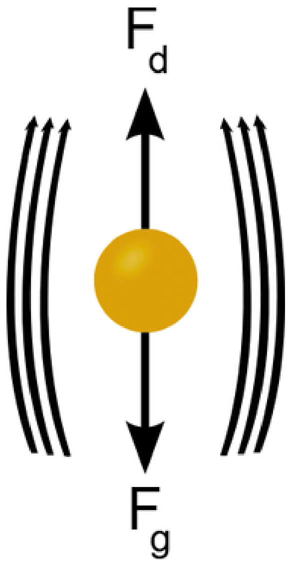
$$\eta = \frac{\text{Shear stress}}{\text{Rate of shear strain}}$$

Where:
- Shear stress = Force per unit area applied parallel to the surface
- Rate of shear strain = Velocity gradient perpendicular to the flow

**Units:** Same as viscosity – Pa·s

## Terminal Velocity

Terminal velocity is the constant speed attained by a small sphere falling through a viscous fluid when the net force on it becomes zero (gravitational force = buoyant force + viscous drag).




**Formula:**

$$v_t = \frac{2r^2(\rho_s - \rho_f)g}{9\eta}$$

Where:
r = radius of the sphere
ρ = density of the sphere
ρf = density of the fluid
g = acceleration due to gravity
η = coefficient of viscosity

## Stoke's Law

**Statement:** The viscous drag force F experienced by a small sphere moving slowly through a viscous fluid is directly proportional to its radius r, its velocity v, and the coefficient of viscosity η.

**Formula:**

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

- Where:
- F = viscous drag force (N)
- η = coefficient of viscosity (Pa·s)
- r = radius of the sphere (m)
- v = velocity of the sphere relative to fluid (m/s)

**Applications:**
- Measuring viscosity of liquids
- Determining particle size in fluids
- Sedimentation of fine particles

## Effect of Temperature on Viscosity

**Liquids:** Viscosity decreases with an increase in temperature (liquid flows more easily).

- Reason: Increased kinetic energy overcomes cohesive forces.

**Gases:** Viscosity increases with an increase in temperature.

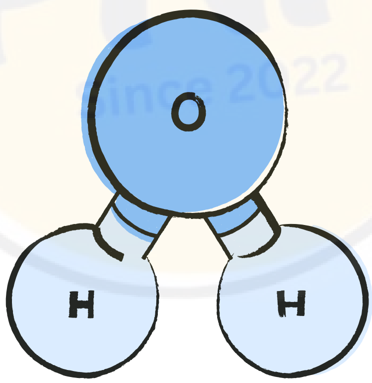
- Reason: Higher molecular speed increases momentum transfer between layers.

**Example:**

- Water flows faster at 50°C than at 10°C.
- Air has higher viscosity at 50°C than at 10°C.

## Hydrodynamics

Hydrodynamics is the branch of fluid mechanics that deals with the motion of fluids (both liquids and gases) and the forces acting on them. It focuses on understanding how fluids move under different conditions, how pressure, velocity, and height change, and how fluids interact with their surroundings.




$H_2O$

**Importance:**

- Used in designing ships, airplanes, and pipelines.
- Helps in predicting natural phenomena like river currents and ocean waves.
- Essential in engineering applications like hydraulics and fluid machinery.

## Fluid Motion

Fluid motion refers to the movement of fluids under the action of forces like gravity, pressure, and viscosity.

### 1. Types of Flow:

- **Steady Flow:**

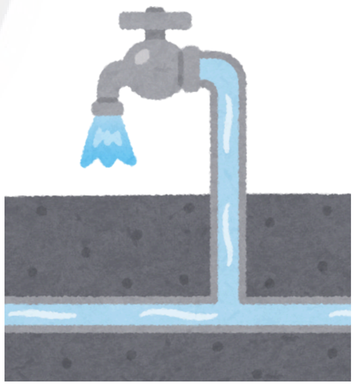
In steady flow, the velocity of the fluid at any point does not change with time.
Example: Water flowing slowly through a uniform pipe.
Characteristic: Streamlines remain constant over time.

- **Unsteady Flow:**

In unsteady flow, the velocity at a point changes with time.
Example: Water flowing in a river during rainfall or tides.
Characteristic: Streamlines can shift and vary over time.

### 2. Streamline Flow (Laminar Flow):

Definition: A streamline is an imaginary line in the fluid such that the velocity vector of fluid particles is tangent to it at every point.



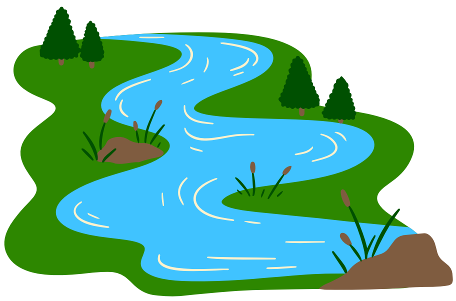
Characteristics:

- Fluid particles move along smooth paths.
- Layers do not cross each other.
- Flow is predictable and orderly.

Example: Flow of oil through a thin tube, flow of honey.

### 3. Turbulent Flow:

Definition: Turbulent flow is irregular and chaotic fluid motion where fluid particles move in all directions and layers mix.



Characteristics:

- Velocity at a point fluctuates rapidly.
- Streamlines are not well-defined.
- Causes mixing, eddies, and vortices.

Example: Rapid flow of water in a river, air flowing.

## Reynolds Number

Reynolds number is a dimensionless quantity that predicts the type of flow in a fluid. It determines whether the flow is laminar or turbulent.

$$Re = \frac{\rho v d}{\eta} \quad \text{or} \quad Re = \frac{vd}{\nu}$$

**Where;**

- ρ = fluid density
- v = fluid velocity
- d = characteristic length (e.g., pipe diameter)
- η = dynamic viscosity
- $\nu = \eta/\rho$ = kinematic viscosity

**Interpretation:**

- $Re<2000 \rightarrow$ Laminar flow
- $2000<Re<4000 \rightarrow$ Transition flow
- $Re>4000 \rightarrow$ Turbulent flow

**Significance:**

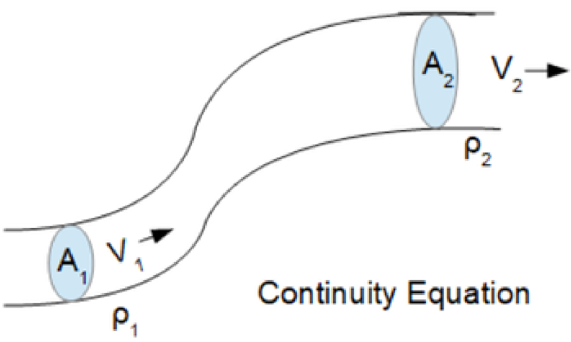
Helps engineers design pipes, pumps, and aircraft efficiently.

## Equation of Continuity

**Statement:**

For an incompressible fluid, the mass flow rate remains constant along a streamline.

$$A_1 v_1 = A_2 v_2$$



**Where;**

- A = cross-sectional area of the pipe
- v = fluid velocity

**Meaning:**

- If a pipe narrows, the fluid speeds up.
- If a pipe widens, the fluid slows down.
- **Example:** Garden hose – water speeds up when the nozzle is narrowed.

## Bernoulli's Theorem

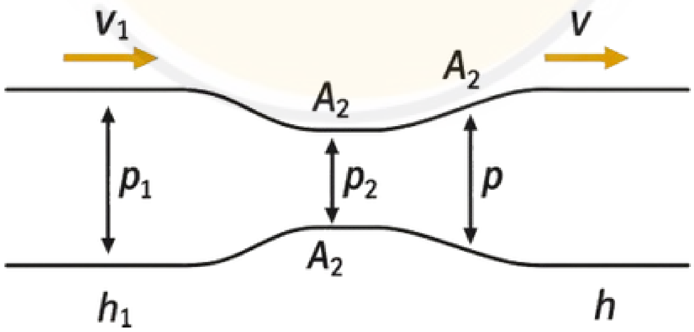
**Formula:**

For an ideal, incompressible, and non-viscous fluid along a streamline:

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

**Where;**

- P = pressure of the fluid
- ρ = fluid density
- v = fluid velocity
- h = height above a reference point
- g = acceleration due to gravity




**Applications (names only):**

- Venturimeter – measuring fluid flow rate
- Pitot tube – measuring airspeed of airplanes
- Flow measurement in pipes
- Airplane lift – Bernoulli's principle explains wing lift
- Blood flow in arteries – estimating pressure differences