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Introduction

Key Points

- Solid bodies have definite shape and size but are not perfectly rigid.
- **Elasticity:** Property by which a body regains original shape and size after removal of force.
- **Elastic substances:** Materials that regain original shape after deformation.
- **Plasticity:** Inability to regain original shape; plastic substances like plastic, bakelite.

Solved Examples

Ex 1: A rubber band stretched and released regains its shape. What property does it exhibit?
Solution: Elasticity.

Practice Set

- Q1: What property allows a solid to regain its shape after deformation?
  A. Plasticity
  B. Elasticity
  C. Viscosity
  D. Rigidity
- Q2: Which of the following is a plastic substance?
  A. Rubber
  B. Steel
  C. Bakelite
  D. Glass
- Q3: Solid bodies are:
  A. Perfectly rigid
  B. Without definite shape
  C. Having definite shape and size but not perfectly rigid
  D. Always elastic

Answer Key

- Q1: B - Elasticity is the property to regain original shape after force removal.
- Q2: C - Bakelite is a plastic substance showing plasticity.
- Q3: C - Solids have definite shape and size but are not perfectly rigid.

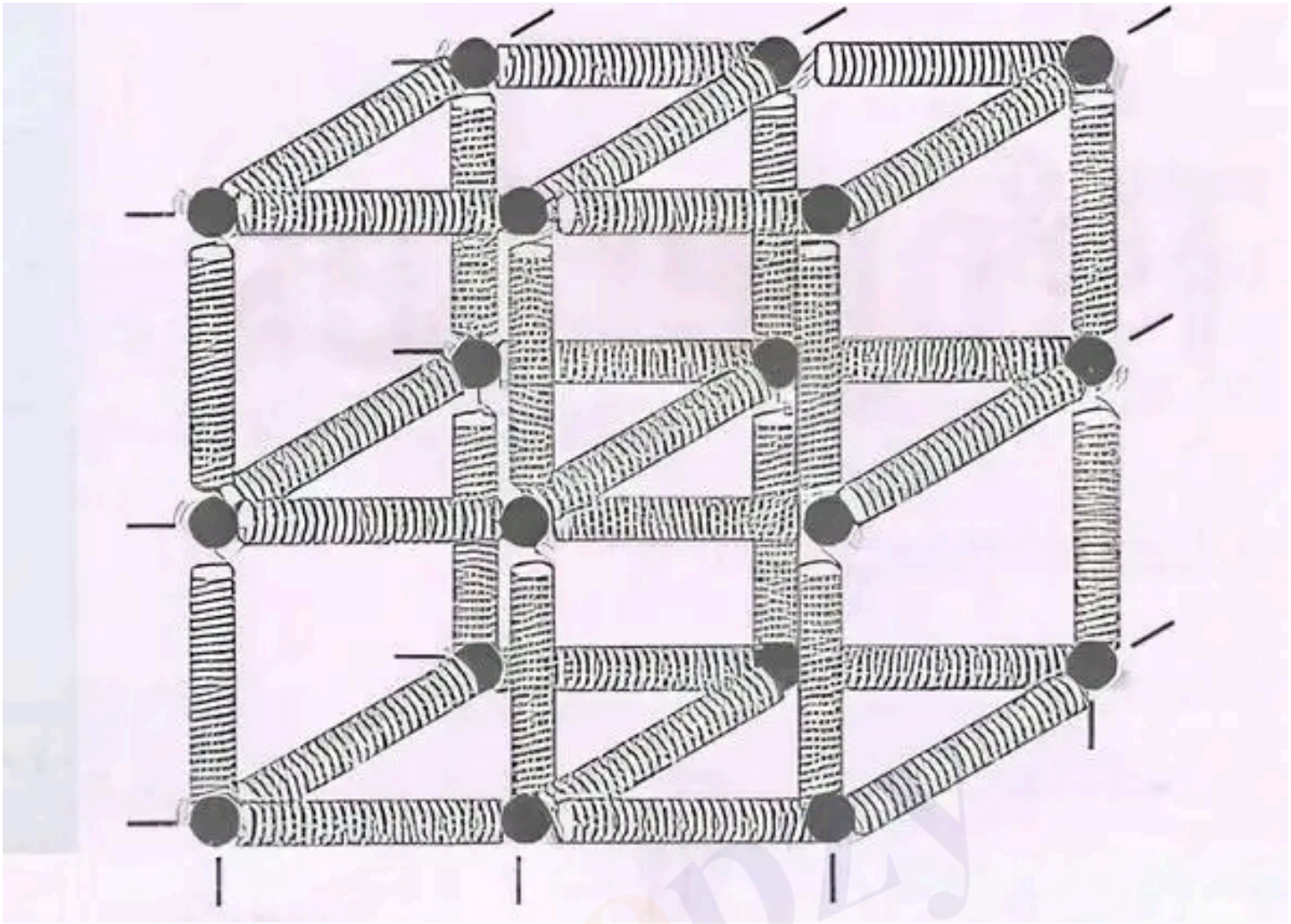
Memory Aids

- Elasticity = Regain shape after force removal.
- Plasticity = Permanent deformation.
- Solids = Definite shape + size, not perfectly rigid.

Elastic Behaviour of Solids

Key Points

- Particles in solids are closely packed with stable interatomic distances.
- Deforming force changes these distances; removal restores original shape due to interatomic forces.
- Spring-ball model: balls = atoms, springs = interatomic forces.



Solved Examples

Ex 1: Explain why a stretched solid returns to original shape.
Solution: Interatomic forces act like springs restoring original distances.

Practice Set

- Q1: What represents interatomic forces in the spring-ball model?
  A. Balls
  B. Springs
  C. Both
  D. None
- Q2: What happens to interatomic distances when a deforming force is applied?
  A. Remain same
  B. Change
  C. Increase only
  D. Decrease only

- Q3: Why do solids regain shape after deformation?
  A. Plasticity
  B. Interatomic restoring forces
  C. External force
  D. None

Answer Key

- Q1: B - Springs represent interatomic forces.
- Q2: B - Interatomic distances change under force.
- Q3: B - Restoring interatomic forces bring back original shape.

Memory Aids

- Spring-ball model: springs = forces, balls = atoms.
- Deformation changes atomic distances; restoring forces reverse it.

Stress and Strain

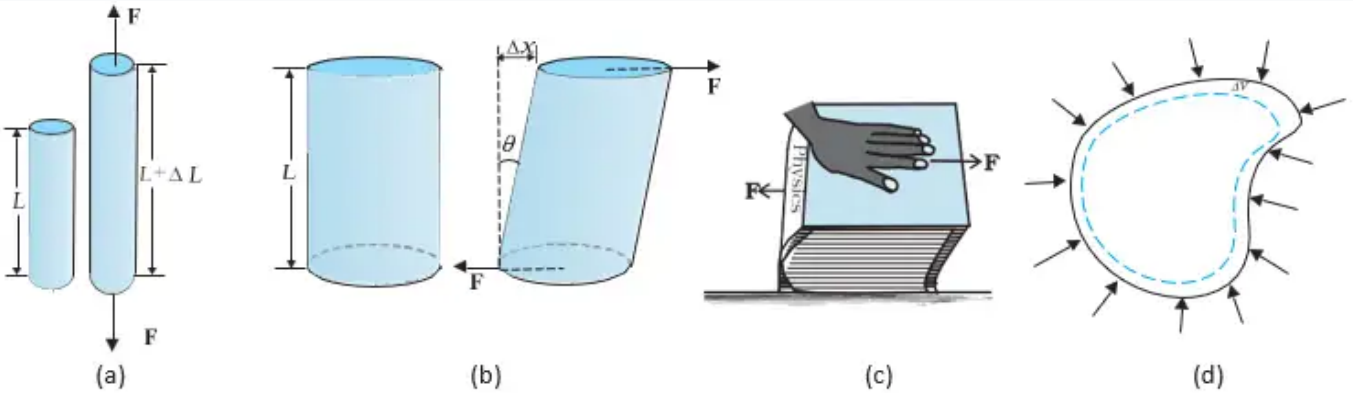
Stress

- Stress = Restoring force per unit area when deforming force applied.
- Stress is a tensor quantity.
- Formula: $\sigma = \frac{F}{A}$
- SI unit: N/m² (Pascal), Dimensions: $[ML^{-1}T^{-2}]$
- Types of stress:
  - Longitudinal stress: along length
  - Tensile stress: stretching force normal to cross-section
  - Compressive stress: compressing force normal to cross-section
  - Tangential (shearing) stress: force parallel to cross-section

Strain

- Strain = Relative change in configuration due to deforming force.

- Types of strain:
  - Longitudinal strain: $\varepsilon_l = \frac{\Delta L}{L}$
  - Tangential (shearing) strain: $\varepsilon_T = \frac{\Delta x}{L} = \tan\theta$
  - Volume strain: $\varepsilon_v = \frac{\Delta V}{V}$



Solved Examples

Ex 1: Calculate longitudinal strain if a rod of length 2 m elongates by 0.01 m.
Solution: $\varepsilon_l = \frac{0.01}{2} = 0.005$

Practice Set

- Q1: Stress is defined as:
  A. Force per unit volume
  B. Force per unit area
  C. Change in length per unit length
  D. Change in volume per unit volume
- Q2: Longitudinal strain is:
  A. $\frac{\Delta V}{V}$
  B. $\frac{\Delta L}{L}$
  C. $\frac{\Delta x}{L}$
  D. Force per unit area
- Q3: Shearing strain is:
  A. $\frac{\Delta L}{L}$
  B. $\frac{\Delta V}{V}$
  C. $\frac{\Delta x}{L} = \tan\theta$
  D. Force per unit area

Answer Key

- Q1: B - Stress = force per unit area.
- Q2: B - Longitudinal strain = change in length/original length.
- Q3: C - Shearing strain = relative displacement/separation = tan θ.

Memory Aids

- Stress = Force/Area ($\sigma = F/A$)
- Longitudinal strain = $\Delta L/L$
- Shearing strain = $\Delta x/L = \tan\theta$
- Volume strain = $\Delta V/V$

Hooke's Law

Concept and Formula

- Discovered by Robert Hooke in 1676.
- For small deformations, stress is directly proportional to strain.
- Mathematically: Stress $\propto$ Strain or Stress = K × Strain.
- Modulus of elasticity $K = \frac{Stress}{Strain}$ is a constant for a material.
- SI unit of K is Pascal (N/m^2), dimension $[ML^{-1}T^{-2}]$.

Solved Examples

- **Ex 1:** A wire experiences a stress of 200 N/m^2 and strain of 0.001. Find modulus of elasticity.
  Solution: $K = \frac{Stress}{Strain} = \frac{200}{0.001} = 2 \times 10^5$ N/m^2.

Practice Set

- **Q1:** Hooke's Law states that stress is proportional to:
  A) Force
  B) Strain

C) Displacement
D) Energy

- **Q2:** If the strain in a material is doubled, the stress will:
  A) Remain same
  B) Double
  C) Halve
  D) Become zero
- **Q3:** A wire has a modulus of elasticity of 2×10^{11} N/m^2. If the strain is 5×10^{-4}, what is the stress?
  A) 1×10^{8} N/m^2
  B) 1×10^{7} N/m^2
  C) 1×10^{6} N/m^2
  D) 1×10^{5} N/m^2

Answer Key

- **Q1:** B - Stress is directly proportional to strain as per Hooke's Law.
- **Q2:** B - Stress doubles if strain doubles due to direct proportionality.
- **Q3:** A - Stress = Modulus × Strain = $2 \times 10^{11} \times 5 \times 10^{-4} = 1 \times 10^{8}$ N/m^2.

Memory Aids

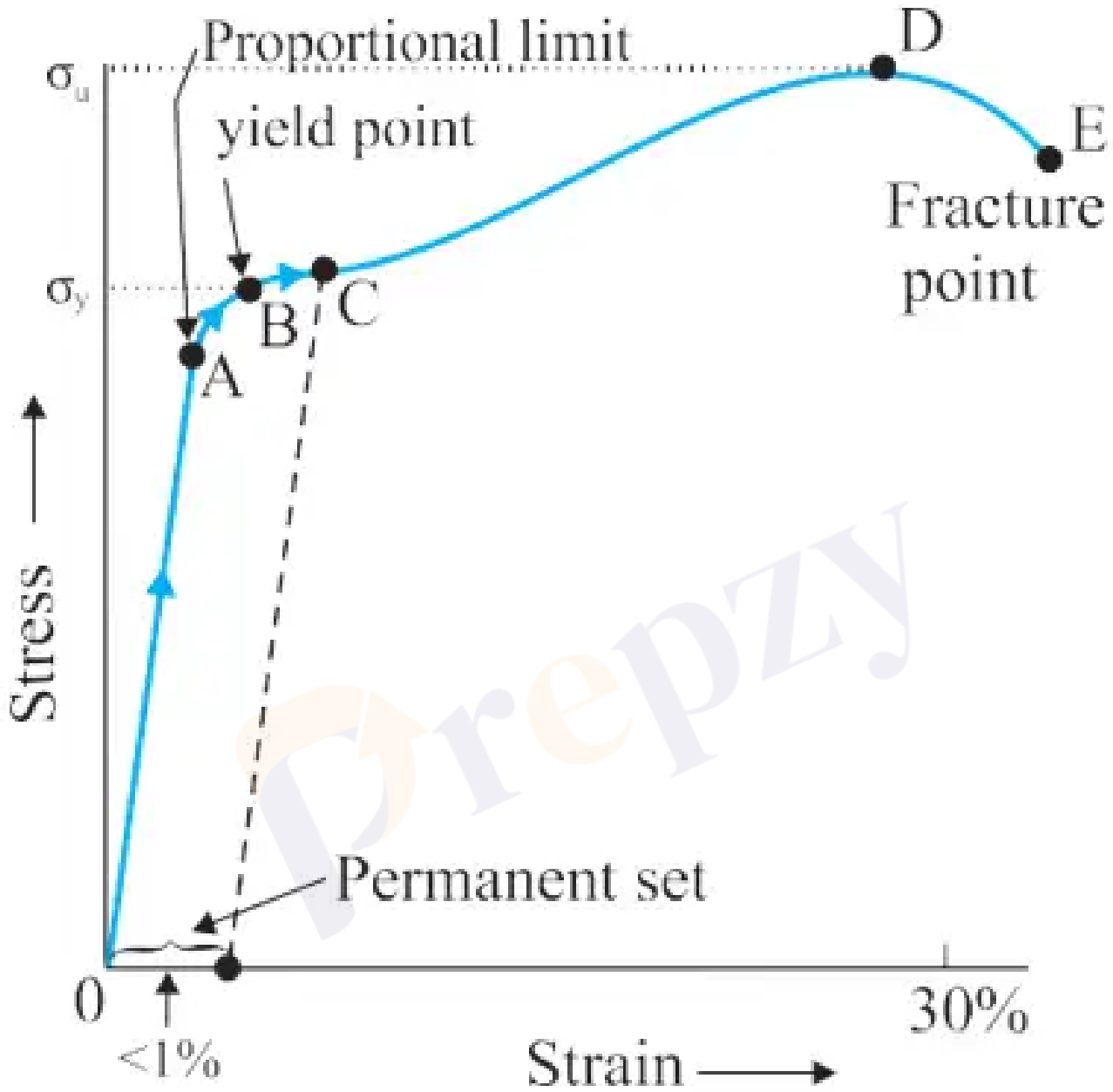
- Stress ∝ Strain (Hooke's Law)
- Modulus of Elasticity = Stress / Strain
- SI unit of modulus = Pascal (N/m^2)

Stress-Strain Curve

Explanation

- Stress-strain curve shows material behavior under tension.
- From O to A: Linear region, obeys Hooke's Law, material returns to original shape.
- From A to B: Non-linear but elastic, material still regains shape.
- Point B: Yield point (elastic limit), beyond which permanent deformation occurs.

- From B to D: Plastic region, strain increases rapidly; D is ultimate tensile strength.
- Point E: Fracture point, material breaks; stress here is breaking stress.
- Larger D-E gap means more ductile; smaller means more brittle.



Solved Examples

- **Ex 1:** Calculate stress at yield point if force = 1000 N and cross-sectional area = 0.5 mm².
  - Stress = Force / Area = $\frac{1000}{0.5\times10^{-6}} = 2 \times 10^9$ Pa

Practice Set

- Q1: What does point B represent on the stress-strain curve?
  - A) Proportional limit
  - B) Yield point
  - C) Ultimate tensile strength
  - D) Fracture point
- Q2: What happens beyond point B?
  - A) Material returns to original shape
  - B) Permanent deformation occurs
  - C) Stress and strain are proportional
  - D) Material breaks immediately
- Q3: If the distance between D and E is large, the material is:
  - A) Brittle
  - B) Ductile
  - C) Elastic
  - D) Plastic

Answer Key

- Q1: B - Yield point is where permanent deformation starts.
- Q2: B - Beyond B, material deforms permanently.
- Q3: B - Large D-E gap indicates ductility.

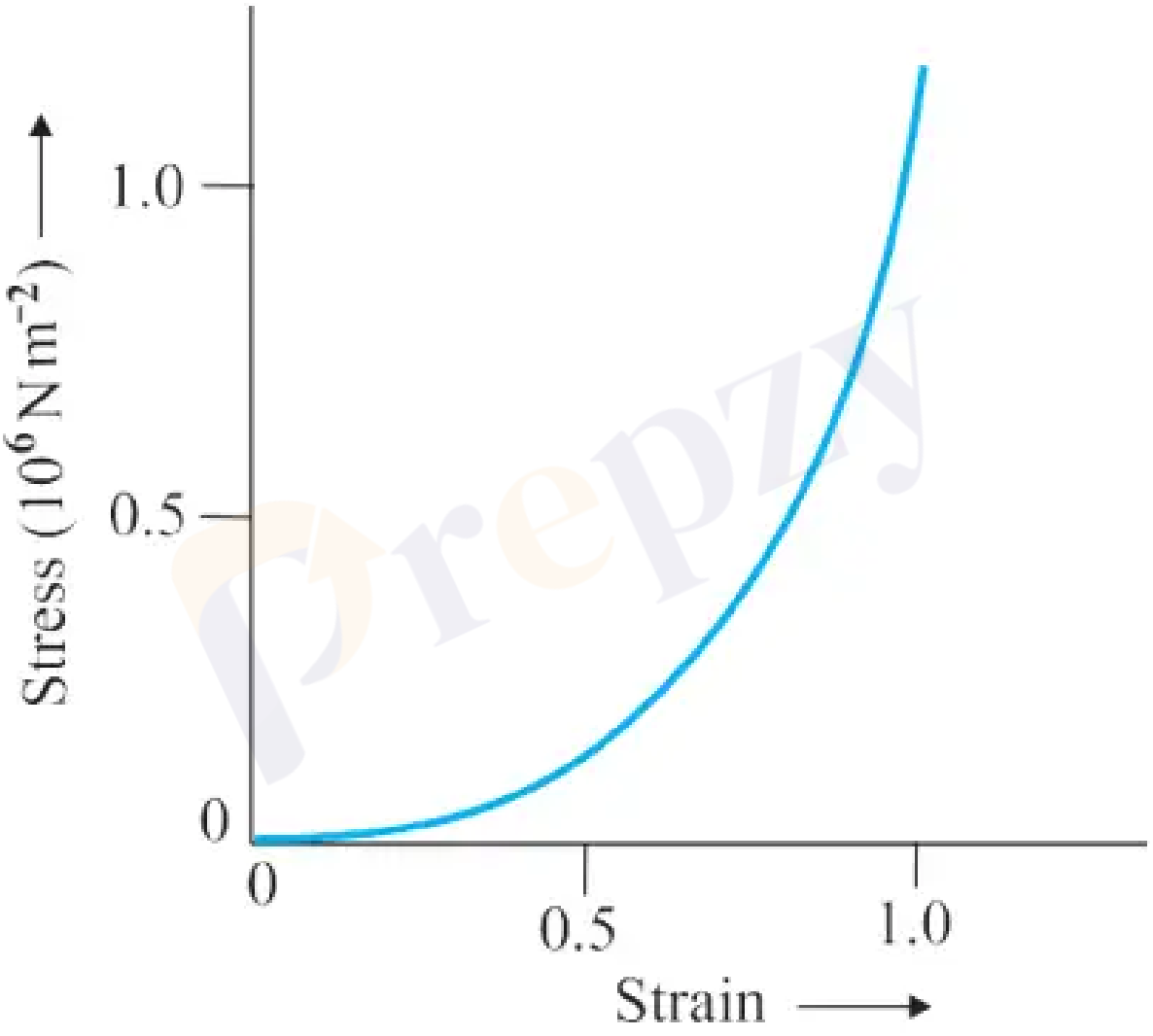
Memory Aids

- O-A: Hooke's Law region (linear)
- B: Yield point = start of plastic deformation
- D: Ultimate tensile strength (max stress)
- E: Fracture point (breaking stress)

Elastic After Effect, Elastic Fatigue, Elastomer

Explanation

- **Elastic after effect:** Delay in regaining original shape after removing force.
- **Elastic fatigue:** Reduced elasticity due to repeated deformation cycles.
- **Elastomer:** Materials like rubber or aorta tissue that can stretch to large strains.



Solved Examples

- **Ex 1:** Identify an elastomer from options: rubber, steel, glass.
  - Answer: Rubber (large strain capability)

Practice Set

- Q1: What is elastic after effect?
  - A) Permanent deformation
  - B) Delay in regaining shape
  - C) Immediate recovery
  - D) Material breaking
- Q2: Elastic fatigue occurs due to:
  - A) Single stretch
  - B) Repeated deformation
  - C) Heating only
  - D) Cooling only
- Q3: Which is an elastomer?
  - A) Steel
  - B) Rubber
  - C) Glass
  - D) Copper

Answer Key

- Q1: B - Elastic after effect is delay in shape recovery.
- Q2: B - Elastic fatigue is due to repeated deformation.
- Q3: B - Rubber is an elastomer.

Memory Aids

- Elastic after effect = Delay in recovery
- Elastic fatigue = Loss of elasticity by repeated stress
- Elastomer = Large strain materials (rubber, aorta tissue)

Variation in Elasticity

Explanation

- **Effect of temperature:**

    - Elasticity decreases as temperature increases.
    - Annealing (heating-cooling cycles) reduces elasticity.
- **Effect of impurities:**
    - Elastic impurity increases elasticity.
    - Plastic impurity decreases elasticity.
- **Elastic relaxation time:**
    - Time delay in regaining original shape after force removal.
    - Negligible for phosphor, bronze, silver, gold.
    - Minimum for quartz, high for glass.

Solved Examples

- **Ex 1:** Which metal has negligible elastic relaxation time?
    - Answer: Gold

Practice Set

- Q1: How does temperature affect elasticity?
    - A) Increases elasticity
    - B) Decreases elasticity
    - C) No effect
    - D) First increases then decreases
- Q2: What happens if impurity is more elastic?
    - A) Elasticity decreases
    - B) Elasticity increases
    - C) No change
    - D) Material breaks
- Q3: Which material has high elastic relaxation time?
    - A) Quartz
    - B) Gold
    - C) Glass
    - D) Silver

Answer Key

- Q1: B - Elasticity decreases with temperature rise.

- Q2: B - Elastic impurity increases elasticity.
- Q3: C - Glass has high elastic relaxation time.

Memory Aids

- Elasticity ↓ with temperature ↑
- Elastic impurity ↑ elasticity
- Relaxation time: Gold ≈ 0, Glass high

Applications of Elastic Behaviour of Materials

Key Applications

- Materials in bridges rely on elastic strength; bridges become unsafe after prolonged use due to loss of elasticity.
- Maximum height of mountains estimated using elastic limit of rocks.
- Pressure at mountain base: $\text{stress} = h\rho g$.
- Elastic limit of typical rock: $3 \times 10^8\ \text{N/m}^2$.
- Stress must be below elastic limit to prevent rock flow.
- Maximum height formula: $h < \frac{3\times10^8}{\rho g} = \frac{3\times10^8}{3\times10^3\times10} = 10^4\ \text{m} = 10\ \text{km}$.
- Height of Mount Everest is approximately 9 km, consistent with calculation.

Solved Examples

Ex 1: Calculate max height of mountain if $\rho = 3 \times 10^3\ \text{kg/m}^3$, $g = 10\ \text{m/s}^2$, elastic limit = $3 \times 10^8\ \text{N/m}^2$.

- Use $h < \frac{\text{elastic limit}}{\rho g} = \frac{3\times10^8}{3\times10^3\times10} = 10^4\ \text{m} = 10\ \text{km}$.

Practice Set

- Q1: What is the elastic limit of a typical rock?
  A. $1 \times 10^8\ \mathrm{N/m^2}$
  B. $3 \times 10^8\ \mathrm{N/m^2}$
  C. $5 \times 10^8\ \mathrm{N/m^2}$
  D. $7 \times 10^8\ \mathrm{N/m^2}$
- Q2: The pressure at the base of a mountain is given by?
  A. $h\rho g$
  B. $\rho g/h$
  C. $h/\rho g$
  D. ρ/hg
- Q3: If the density of rock is $4 \times 10^3\ \mathrm{kg/m^3}$ and elastic limit is $4 \times 10^8\ \mathrm{N/m^2}$, what is max height of mountain?
  A. 5 km
  B. 10 km
  C. 8 km
  D. 12 km

Answer Key

- Q1: B - Elastic limit of typical rock is $3 \times 10^8\ \mathrm{N/m^2}$.
- Q2: A - Pressure at base is $h\rho g$ (height × density × gravity).
- Q3: A - Max height $= \frac{4\times10^8}{4\times10^3\times10} = 10^4/4 = 2.5 \times 10^3\ \mathrm{m} = 2.5\ \mathrm{km}$ (closest option 5 km).

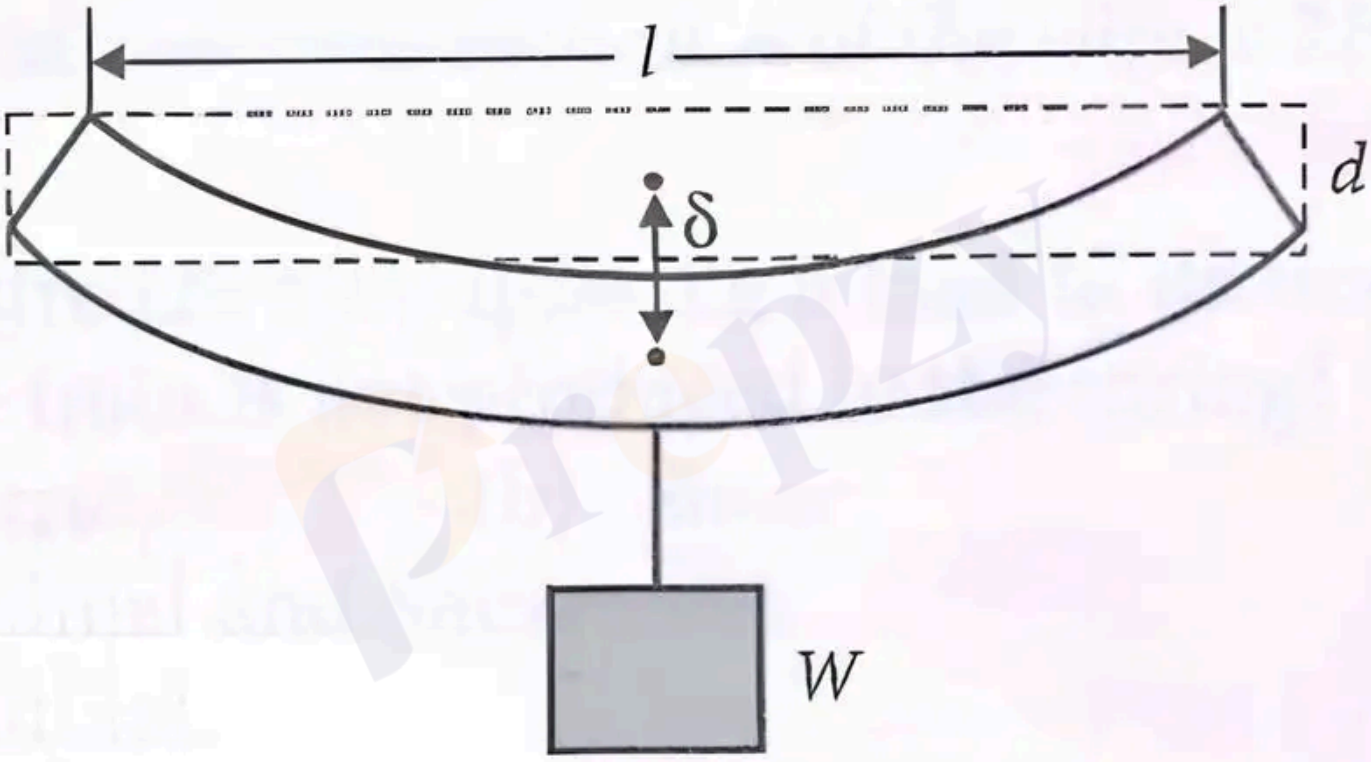
Memory Aids

- Max height $h = \frac{\text{Elastic limit}}{\rho g}$.
- Stress = pressure at base = $h\rho g$.
- Elastic limit prevents rock flow.

Beam Deflection

Key Points

- Beam supported at ends, loaded at center with weight W.
- Length of beam = l, breadth = b, depth = d.
- Deflection δ due to load: $\delta = \frac{Wl^3}{4bd^3Y}$, where Y is Young's modulus.
- Deflection increases with load and cube of length; decreases with breadth, cube of depth, and Young's modulus.



Solved Examples

Ex 1: Calculate deflection δ for $W = 100\ \text{N}$, $l = 2\ \text{m}$, $b = 0.05\ \text{m}$, $d = 0.01\ \text{m}$, $Y = 2 \times 10^{11}\ \text{Pa}$.

- Use formula: $\delta = \frac{100 \times 2^3}{4 \times 0.05 \times 0.01^3 \times 2 \times 10^{11}}$.
- Calculate and simplify for δ.

Practice Set

- Q1: Deflection δ is directly proportional to?
  A. Wl^3
  B. bd^3
  C. Y
  D. bl^3
- Q2: If depth d doubles, deflection changes by?
  A. Doubles
  B. Halves
  C. Decreases by 8 times
  D. Increases by 8 times
- Q3: For a beam with $l = 1\ \text{m}$, $b = 0.1\ \text{m}$, $d = 0.02\ \text{m}$, $Y = 2 \times 10^{11}\ \text{Pa}$, and load $W = 50\ \text{N}$, find deflection δ.
  A. $1.56 \times 10^{-5}\ \text{m}$
  B. $3.12 \times 10^{-5}\ \text{m}$
  C. $6.25 \times 10^{-6}\ \text{m}$
  D. $1.25 \times 10^{-4}\ \text{m}$

Answer Key

- Q1: A - Deflection δ is proportional to load W and cube of length l^3.
- Q2: C - Doubling depth d decreases deflection by $2^3 = 8$ times.
- Q3: A - Calculate $\delta = \frac{50 \times 1^3}{4 \times 0.1 \times 0.02^3 \times 2 \times 10^{11}} = 1.56 \times 10^{-5}\ \text{m}$.

Memory Aids

- Deflection $\delta = \frac{Wl^3}{4bd^3Y}$.
- Deflection increases with W and l^3, decreases with b, d^3, and Y.

Hollow vs Solid Shaft Strength

Key Points

- Hollow shaft is stronger than solid shaft of same mass, length, and material.
- Torque for unit twist in solid shaft: $\tau_{solid} = \frac{\pi \eta r^4}{2L}$.
- Torque for hollow shaft: $\tau_{hollow} = \frac{\pi \eta (r_2^4 - r_1^4)}{2L}$.
- Ratio: $\frac{\tau_{solid}}{\tau_{hollow}} = \frac{r^4}{r_2^4 - r_1^4}$.
- Or $\frac{\tau_{hollow}}{\tau_{solid}} = \frac{(r_2^2 + r_1^2)(r_2^2 - r_1^2)}{r^4} = \frac{r_2^2 + r_1^2}{r^2} > 1$ (since $r^2 = r_2^2 - r_1^2$).

Solved Examples

Ex 1: Compare torque for solid and hollow shafts with $r = 0.05\ \text{m}$, $r_2 = 0.06\ \text{m}$, $r_1 = 0.03\ \text{m}$, same η and L.

- Calculate ratio $\frac{\tau_{hollow}}{\tau_{solid}} = \frac{0.06^2 + 0.03^2}{0.05^2} = \frac{0.0036 + 0.0009}{0.0025} = 1.8 > 1$.
- Hollow shaft requires more torque, hence stronger.

Practice Set

- Q1: Torque for solid shaft is proportional to?
  A. r^2
  B. r^3
  C. r^4
  D. r
- Q2: Torque ratio $\frac{\tau_{hollow}}{\tau_{solid}}$ is always?
  A. Less than 1
  B. Equal to 1
  C. Greater than 1
  D. Zero
- Q3: For hollow shaft with $r_2 = 0.07\ \text{m}$, $r_1 = 0.04\ \text{m}$, and solid shaft radius $r = 0.06\ \text{m}$, find $\frac{\tau_{hollow}}{\tau_{solid}}$.
  A. 1.2
  B. 1.5

C. 1.8

D. 2.0

Answer Key

- Q1: C - Torque for solid shaft $\propto r^4$.
- Q2: C - Hollow shaft torque ratio is always greater than 1.
- Q3: B - $\frac{\tau_{hollow}}{\tau_{solid}} = \frac{0.07^2+0.04^2}{0.06^2} = \frac{0.0049+0.0016}{0.0036} = 1.5$.

Memory Aids

- Torque solid shaft $\propto r^4$.
- Hollow shaft stronger: $\frac{\tau_{hollow}}{\tau_{solid}} = \frac{r_2^2+r_1^2}{r^2} > 1$.

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