Chapter 8: Mechanical Properties of Solids - NCERT Exercise Solutions

Physics Class 11

8.1 Young's Modulus Ratio: Steel vs Copper

Given: Steel wire (L_1 = 4.7 m, A_1 = 3.0×10^{-5} m^2) and copper wire (L_2 = 3.5 m, A_2 = 4.0×10^{-5} m^2) stretch by same amount under same load.

Solution: For same load F and same elongation ΔL:

$$\Delta L = FL_1/(Y_1A_1) = FL_2/(Y_2A_2)$$
$$Y_1/Y_2 = (L_1/A_1)/(L_2/A_2) = (L_1A_2)/(L_2A_1)$$
$$Y_1/Y_2 = (4.7 \times 4.0\times10^{-5})/(3.5 \times 3.0\times10^{-5}) = 1.79$$

Answer: Y_steel/Y_copper = 1.8

8.2 Material Properties from Graph

From the stress-strain graph:

(a) Young's modulus:

$$Y = \text{stress/strain} = 150\times10^6 \text{ Pa} / 0.002 = 7.5\times10^{10} \text{ Pa}$$

(b) Approximate yield strength: Answer: ~300×10^6 Pa (where linear relationship ends)

8.3 Comparing Materials A and B

From stress-strain graphs:

(a) Greater Young's modulus: Material A has **steeper slope** in linear region **(b) Stronger material:** Material B has **higher ultimate strength** (can withstand more stress before breaking)

8.4 True/False Statements

(a) Young's modulus of rubber > steel: FALSE - Steel has much higher Young's modulus (~200 GPa vs ~0.01 GPa for rubber)

(b) Coil stretching determined by shear modulus: TRUE - Coil springs undergo torsional deformation, which depends on shear modulus

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8.5 Wire Elongations Under Load

Given: Steel wire (d = 0.25 cm, L = 1.5 m) and brass wire (L = 1.0 m) with 4.0 kg load

Solution:

Area $A = \pi(0.125 \times 10^{-2})^2 = 4.91 \times 10^{-6}\ m^2$
Stress $= F/A = (4.0 \times 9.8)/4.91 \times 10^{-6} = 8.0 \times 10^6$ Pa

Steel elongation: $\Delta L_1 = (\text{stress} \times L)/Y = (8.0 \times 10^6 \times 1.5)/(2.0 \times 10^{11}) = 6 \times 10^{-5}$ m
Brass elongation: $\Delta L_2 = (8.0 \times 10^6 \times 1.0)/(0.91 \times 10^{11}) = 8.8 \times 10^{-5}$ m

Answer: Steel = 0.06 mm, Brass = 0.088 mm

8.6 Aluminum Cube Shear Deflection

Given: Cube edge = 10 cm, mass = 100 kg attached to opposite face, G = 25 GPa

Solution:

Shear stress = F/A = $(100\times9.8)/(0.1)^2$ = 9,800 Pa
Shear strain = stress/G = $9{,}800/(25\times10^9) = 3.92\times10^{-7}$
Deflection = strain × height = $3.92\times10^{-7} \times 0.1 = 3.92\times10^{-8}$ m

Answer: Vertical deflection = 39.2 nm

8.7 Steel Column Compression

Given: Four columns support 50,000 kg, inner radius = 30 cm, outer radius = 60 cm

Solution:

Load per column = 50,000/4 = 12,500 kg
Area per column = $\pi(0.6^2 - 0.3^2) = \pi(0.27) = 0.848$ m^2
Stress = $(12{,}500\times9.8)/0.848 = 1.44\times10^5$ Pa
Strain = stress/Y = $1.44\times10^5/(2.0\times10^{11}) = 7.2\times10^{-7}$

Answer: Compressional strain = 7.2×10^{-7}

8.8 Copper Tensile Strain

Given: Cross-section $15.2 \times 19.1\ mm^2$, force = 44,500 N, elastic deformation only

Solution:

Area = $15.2 \times 19.1 \times 10^{-6} = 2.90 \times 10^{-4}\ m^2$
Stress = $F/A = 44{,}500/(2.90 \times 10^{-4}) = 1.53 \times 10^8$ Pa
Strain = $stress/Y = 1.53 \times 10^8/(1.1 \times 10^{11}) = 1.39 \times 10^{-3}$

Answer: Strain = 1.4×10^{-3} or 0.14%

8.9 Steel Cable Maximum Load

Given: Radius = 1.5 cm, maximum stress = $10^8\ N/m^2$

Solution:

Area = $\pi r^2 = \pi(0.015)^2 = 7.07 \times 10^{-4}\ m^2$
Maximum load = stress × area = $10^8 \times 7.07 \times 10^{-4}$ = 70,700 N

Answer: Maximum load = 70.7 kN

8.10 Three-Wire Support System

Given: Steel bar (15 kg) supported by 3 wires (2 copper, 1 iron), each 2.0 m long, same tension

Solution: For same tension and same elongation:

$\Delta L = FL/(YA) = \text{constant}$
Therefore: $A \propto 1/Y$
$A_{copper}/A_{iron} = Y_{iron}/Y_{copper} = (2.0\times10^{11})/(1.1\times10^{11}) = 1.82$
$d_{copper}/d_{iron} = \sqrt{1.82} = 1.35$

Answer: Diameter ratio = 1.35:1

8.11 Whirling Mass Wire Extension

Given: $m = 14.5$ kg, $L = 1.0$ m, $\omega = 2$ rev/s $= 4\pi$ rad/s, $A = 0.065$ cm^2

Solution: At bottom of circle, total tension:

$T = mg + m\omega^2L = 14.5\times9.8 + 14.5\times(4\pi)^2 \times1.0 = 142 + 2{,}280 = 2{,}422$ N
Stress $= T/A = 2{,}422/(0.065\times10^{-4}) = 3.73\times10^8$ Pa
Extension $= (\text{stress} \times L)/Y = (3.73\times10^8 \times 1.0)/(2.0\times10^{11}) = 1.86\times10^{-3}$ m

Answer: Extension = 1.86 mm

8.12 Water Bulk Modulus

Given: Initial volume = 100.0 L, pressure increase = 100.0 atm, final volume = 100.5 L

Solution:

$\Delta V = 100.5 - 100.0 = 0.5$ L
Volume strain $= \Delta V/V = 0.5/100.0 = 0.005$
Pressure $= 100 \times 1.013\times10^5 = 1.013\times10^7$ Pa
Bulk modulus $B = \text{pressure}/\text{volume strain} = 1.013\times10^7/0.005 = 2.03\times10^9$ Pa

Air bulk modulus ≈ 10^5 Pa Ratio: B_water/B_air ≈ 20,000 (water much less compressible)

8.13 Water Density at Depth

Given: Pressure = 80.0 atm, surface density = 1.03×10^3 kg/m^3

Solution:

Pressure = 80 × 1.013×10^5 = 8.1×10^6 Pa
Volume strain = pressure/B = $8.1\times10^6/(2.2\times10^9)$ = 3.68×10^{-3}
Density increase = ρ_0 × volume strain = 1.03×10^3 × 3.68×10^{-3} = 3.79 kg/m^3
Final density = 1.03×10^3 + 3.79 = 1.034×10^3 kg/m^3

Answer: Density = 1.034×10^3 kg/m^3

8.14 Glass Volume Change

Given: Hydraulic pressure = 10 atm, B_glass = 37×10^9 Pa

Solution:

Pressure = 10 × 1.013×10^5 = 1.013×10^6 Pa
Fractional volume change = pressure/B = $1.013\times10^6/(37\times10^9)$ = 2.74×10^{-5}

Answer: $\Delta V/V$ = 2.7×10^{-5} or 0.003%

8.15 Copper Cube Volume Contraction

Given: Edge = 10 cm, pressure = 7.0×10^6 Pa, B_copper = 140×10^9 Pa

Solution:

Original volume = $(0.1)^3 = 10^{-3}$ m^3
Volume strain = pressure/B = $7.0\times10^6/(140\times10^9) = 5\times10^{-5}$
Volume contraction = volume strain × original volume = $5\times10^{-5} \times 10^{-3} = 5\times10^{-8}$ m^3

Answer: Volume contraction = 5×10^{-8} m^3 = 0.05 cm^3

8.16 Water Pressure for 0.10% Compression

Given: Volume reduction = 0.10% = 10^{-3}, B_water = 2.2×10^9 Pa

Solution:

Required pressure = B × volume strain = $2.2\times10^9 \times 10^{-3} = 2.2\times10^6$ Pa
Pressure increase = 2.2×10^6 Pa = 21.7 atm

Answer: Pressure increase = 2.2 MPa or 22 atm

Key Formulas Reference

Stress and Strain

- **Stress:** $\sigma = F/A$
- **Longitudinal strain:** $\varepsilon = \Delta L/L$

- **Volume strain:** $\Delta V/V$
- **Shear strain:** $\gamma = \Delta x/L = \tan\theta$

Elastic Moduli

- **Young's modulus:** $Y = \sigma/\varepsilon = (F/A)/(\Delta L/L)$
- **Shear modulus:** $G = \tau/\gamma = (F/A)/\theta$
- **Bulk modulus:** $B = -p/(\Delta V/V)$

Key Relationships

- **Hooke's law:** Stress $\propto$ Strain (within elastic limit)
- **Energy density:** $u = \frac{1}{2}\sigma\varepsilon = \frac{1}{2}$(stress × strain)
- **Poisson's ratio:** ν = (lateral strain)/(longitudinal strain)