Class 11 Physics · Chapter 8: Mechanical Properties of Solids

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. The dimensional formula of stress is [1]

(a) $[MLT^{-2}]$ (b) $[ML^{-1}T^{-2}]$

(c) $[ML^{2}T^{-2}]$ (d) $[M^{0}L^{0}T^{0}]$

Answer: (b) Stress = F/A, so $[MLT^{-2}]/[L^{2}] = [ML^{-1}T^{-2}]$. $[MLT^{-2}]$ is force itself; $[M^{0}L^{0}T^{0}]$ belongs to strain.

2. The compressibility of solids, liquids and gases, in increasing order, is [1]

(a) gas < liquid < solid (b) solid < liquid < gas

(c) liquid < solid < gas (d) solid < gas < liquid

Answer: (b) Bulk modulus is largest for solids and smallest for gases, and compressibility is 1/B, so solid < liquid < gas: atoms in solids are most tightly coupled, gas molecules least.

3. Which statement about the elastic tissue of the aorta is correct? [1]

(a) It obeys Hooke's law over the whole of its elastic region.

(b) It has a well defined plastic region, like a metal.

(c) It fractures at a strain below 1%, like glass.

(d) Its elastic region is very large, but it does not obey Hooke's law over most of it.

Answer: (d) NCERT notes that for aortic tissue the elastic region is very large, Hooke's law fails over most of it, and there is no well defined plastic region; such materials are elastomers.

4. On the stress–strain curve of a metal, the yield point is also known as the [1]

(a) elastic limit (b) proportional limit

(c) ultimate tensile strength (d) fracture point

Answer: (a) The yield point B is also called the elastic limit; the stress there is the yield strength σ_y. The proportional limit A comes earlier, and D and E come later.

5. In a tensile test on a rod of a new ceramic, the rod fractures almost as soon as the stress reaches the ultimate tensile strength. The material is [1]

(a) ductile (b) plastic

(c) brittle (d) an elastomer

Answer: (c) When the ultimate strength point D and the fracture point E are close, the material is brittle. A ductile material shows a long stretch between D and E.

6. A cube of gelatin of side 5.0 cm stands on a plate to which its base sticks. A horizontal force of 0.50 N on its top face moves that face 1.0 cm sideways. Find the shearing strain and the shear modulus of the gelatin. [2]

Shearing strain = $\Delta x/L = 1.0/5.0 = 0.20$. Shearing stress = $F/A = 0.50/(0.050 \times 0.050) = 2.0 \times 10^{2}$ N m^{-2}. G = stress/strain = $200/0.20 = 1.0 \times 10^{3}$ N m^{-2}.

- strain = $\Delta x/L = 0.20$ (1)
- $G = (F/A)/\text{strain} = 1.0 \times 10^{3}$ N m^{-2} (1)

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7. Hooke's law is described as an empirical law. What does this mean? Name one class of materials that does not obey it, with an example. [2]

Empirical means it is found from experiment and observation, not derived from a deeper principle; it holds for most materials for small deformations. Elastomers, such as rubber or the tissue of the aorta, can be stretched to large strains but do not show stress proportional to strain.

- empirical: found from experiment, valid for most materials at small deformation (1)
- elastomers, e.g. rubber or aortic tissue (1)

8. Stress and pressure are both measured in N m^{-2}. A student argues that since force is a vector, stress must be a vector too. Is the student right? Explain. [2]

No. Stress cannot be assigned one specific direction: it describes the restoring force per unit area across a section, and its direction depends on which section is considered. Only the force acting on the portion of the body on a specified side of a section has a definite direction, so stress is not a vector quantity.

- no, stress is not a vector (1)
- it cannot be assigned a single direction; only the force on one side of a chosen section has one (1)

9. Show that the work done in stretching a wire of length L and cross-section A by an amount l, within the elastic limit, is ½ × stress × strain × volume. Hence write the energy stored per unit volume. [3]

At extension x the force is F = YAx/L (from Y = FL/(AΔL)). For a further extension dx the work done is dW = F dx = (YA/L) x dx. So W = $\int_0^l$ (YA/L) x dx = ½ (YA/L) l^2 = ½ × Y × $(l/L)^2$ × AL. Since Y(l/L) = stress and l/L = strain, W = ½ × stress × strain × volume. This work is stored as elastic potential energy, so u = W/(AL) = ½ σε.

- F = YAx/L and dW = F dx (1)
- integrates to ½$(YA/L)l^2$ (1)
- rewrites as ½ × stress × strain × volume and u = ½σε (1)

10. A light rigid bar 1.0 m long hangs horizontally from two vertical wires of equal length 1.0 m and equal cross-section 1.0 mm^2, one of steel (Y = 2.0 × 10^{11} N m^{-2}) at one end and one of aluminium (Y = 7.0 × 10^{10} N m^{-2}) at the other. A 30 kg load is hung on the bar. Where must it be hung for the bar to stay horizontal? Find the tensions and the common extension (g = 10 m s^{-2}). [3]

Horizontal bar means equal extensions; with equal L and A, T = YAΔL/L ∝ Y, so T_s/T_a = 200/70. With T_s + T_a = 300 N: T_s = 300 × 200/270 = 222 N and T_a = 77.8 N. Moments about the steel end: T_a × 1.0 = 300 × x, so x = 77.8/300 = 0.26 m from the steel end. Extension = $T_sL/(AY_s)$ = 222 × 1.0/(1.0 × 10^{-6} × 2.0 × 10^{11}) = 1.11 × 10^{-3} m.

- equal extension gives T ∝ Y, T_s = 222 N, T_a = 77.8 N (1)
- moments give x = 0.26 m from the steel wire (1)
- extension = 1.11 × 10^{-3} m (1)

11. A wooden plank 30 cm broad and 5.0 cm thick is used as a footbridge over a drain, supported at its ends with a person standing at its centre. Using δ = $Wl^3/(4bd^3Y)$, find how many times more it sags when laid flat than when set on its edge. Why is the plank on edge still not a safe bridge? [3]

Flat: b = 0.30 m, d = 0.050 m. On edge: b = 0.050 m, d = 0.30 m. δ ∝ $1/(bd^3)$, so δ_flat/δ_edge = (0.050 × 0.30^3)/(0.30 × 0.050^3) = $(0.30/0.050)^2$ = 36. On edge the plank is deep and thin; unless the load is exactly in the right place it can buckle sideways, so a deep thin section is not safe for a moving load.

- δ ∝ $1/(bd^3)$ with b and d for each position (1)
- ratio = 36 (1)
- deep thin plank buckles unless the load is exactly placed (1)