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Mechanical Properties of Solids Class 11 Notes | CBSE Physics Chapter 8

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Mechanical Properties of Solids Class 11 Notes | CBSE Physics Chapter 8

Mechanical Properties of Solids is Chapter 8 of CBSE Class 11 Physics — the chapter that explains why a steel cable can hold a bridge but a rubber band cannot, and why a bone breaks under a certain load. It studies how solids deform under force and how they spring back, using the ideas of stress, strain, and elastic moduli. Master this chapter and you unlock a whole family of easy, formula-driven marks in boards, JEE, and NEET.

By the end of these notes you will be able to define stress and strain, state and apply Hooke's law, read a stress-strain curve, calculate Young's modulus, shear modulus, bulk modulus and Poisson's ratio, and find the elastic potential energy stored in a stretched wire. This is a scoring chapter carrying roughly 3–4 marks in boards, and a reliable source of single-concept numericals in entrance exams.

Table of Contents

Key Concepts

1. Elastic Behaviour of Solids

A solid is made of atoms held in a regular lattice by inter-atomic bonds that act like tiny springs. When you apply a force, these "springs" stretch or compress, and the body deforms. Remove the force, and the bonds pull the atoms back — the body regains its shape.

Elasticity is the property of a body by which it regains its original shape and size after the deforming force is removed. A steel ball is highly elastic; putty or wet clay is not.

Plasticity is the opposite property — the body retains the new shape after the force is removed. A body with no tendency to return is called a **perfectly plastic** body.

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2. Stress

Stress is the internal restoring force set up per unit area of cross-section when a body is deformed. In magnitude it equals the applied force per unit area at equilibrium.

Stress = F/A

- **SI unit:** N/m^2 or pascal (Pa)
- **Dimensional formula:** $[ML^{-1}T^{-2}]$
- Stress is a scalar (more precisely a tensor), not a vector.

Types of Stress

- **Tensile / Compressive (longitudinal) stress:** force perpendicular to area, causing change in length.
- **Shearing (tangential) stress:** force parallel to the surface, causing change in shape.
- **Hydraulic (volume) stress:** force applied uniformly from all sides by a fluid, causing change in volume.

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3. Strain

Strain is the fractional change in configuration (length, shape, or volume) of a body under stress. It is a ratio of two like quantities, so it has **no units and no dimensions**.

Types of Strain

- **Longitudinal strain** = change in length / original length = $\Delta L/L$
- **Shearing strain** = relative displacement / distance between layers = $\Delta x/L = \tan\theta \approx \theta$ (for small angles)
- **Volume strain** = change in volume / original volume = $\Delta V/V$

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4. Hooke's Law

Within the elastic limit, the stress developed in a body is directly proportional to the strain produced in it.

Stress ∝ Strain, so **Stress = E × Strain**

- The constant of proportionality **E** is called the **modulus of elasticity**.
- Its value depends only on the material, not on the dimensions of the body.
- **SI unit of modulus:** N/m^2 or pascal (same as stress, since strain is unitless).

Key idea: Hooke's law holds only up to the elastic limit. Beyond it, stress and strain are no longer proportional.

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5. Stress-Strain Curve

If a metal wire is loaded gradually and the stress is plotted against strain, we get a characteristic curve with distinct regions.

[DIAGRAM: Stress (y-axis) vs strain (x-axis) curve — straight line O→A (proportional limit), A→B elastic limit (yield point), B→D plastic region, D the ultimate tensile strength, E the fracture point.]

- **O to A — Proportional limit:** stress $\propto$ strain; Hooke's law obeyed; the graph is a straight line.
- **A to B — Elastic limit (yield point):** the wire still returns to its original length on removing the load, but the line curves.
- **B to D — Plastic region:** beyond the yield point, strain increases with little extra stress and a permanent (plastic) set remains.
- **D — Ultimate tensile strength:** the maximum stress the material can bear.
- **E — Fracture point:** the wire finally breaks.

Note: A large gap between the yield point and fracture point means the material is **ductile** (can be drawn into wires); a small gap means it is **brittle** (breaks soon after the elastic limit, like glass).

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6. Young's Modulus (Y)

Within the elastic limit, the ratio of longitudinal stress to longitudinal strain is a constant called **Young's modulus**.

Y = Longitudinal stress / Longitudinal strain = $(F/A) / (\Delta L/L) = FL / (A \cdot \Delta L)$

- **SI unit:** N/m^2 or pascal; **dimensions:** $[ML^{-1}T^{-2}]$
- Steel has a higher Young's modulus than rubber, so steel is more elastic and harder to stretch.
- A high Y means a small strain for a given stress — the material is stiff.

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7. Shear Modulus / Modulus of Rigidity (G)

The ratio of shearing (tangential) stress to shearing strain within the elastic limit is the **shear modulus** or **modulus of rigidity**.

G = Shearing stress / Shearing strain = $(F/A) / \theta = F / (A \cdot \theta)$

- **SI unit:** N/m^2 or pascal
- G is generally about one-third of Young's modulus ($G \approx Y/3$) for most metals.
- Only solids have rigidity; liquids and gases cannot sustain a shear stress.

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8. Bulk Modulus (K)

The ratio of hydraulic (volume) stress to the volume strain within the elastic limit is the **bulk modulus**.

$K = -p / (\Delta V/V) = -pV / \Delta V$

- The negative sign shows that an increase in pressure decreases the volume.
- **SI unit:** N/m^2 or pascal
- The reciprocal of bulk modulus is the **compressibility**, $k = 1/K$.
- Solids have the highest K, then liquids, then gases — solids are least compressible.

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9. Poisson's Ratio (σ)

When a wire is stretched, it becomes longer but thinner — its length increases while its diameter decreases. The ratio of lateral strain to longitudinal strain is called **Poisson's ratio (σ)**.

σ = Lateral strain / Longitudinal strain = $-(\Delta d/d) / (\Delta L/L)$

- It is a pure ratio, so it has **no units and no dimensions**.
- Its theoretical range is **−1 to 0.5**; for most materials it lies between 0.2 and 0.4.

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10. Elastic Potential Energy in a Stretched Wire

Work done in stretching a wire is stored in it as **elastic potential energy**. Since the force builds up gradually from 0 to F, the average force is F/2.

$U = \frac{1}{2} \times \text{Stress} \times \text{Strain} \times \text{Volume} = \frac{1}{2} \times F \times \Delta L$

The energy stored **per unit volume** (elastic energy density) is:

$u = \frac{1}{2} \times \text{Stress} \times \text{Strain} = \frac{1}{2} \times Y \times (\text{Strain})^2$

Key idea: A catapult, a bow, and a spring all store elastic potential energy this way before releasing it as kinetic energy.

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11. Applications of Elastic Behaviour

The choice of materials and shapes in engineering comes straight from this chapter.

- **Beams and bridges:** a girder is given an **I-shape (I-section)** so it resists bending with less material, because the depression of a loaded beam $\delta \propto Wl^3 / (Ybd^3)$.
- **Cranes and ropes:** the rope of a crane is made thick (large area) so the stress stays safely below the elastic limit for the maximum load.
- **Pillars:** pillars with distributed (cross-section) ends carry more load than those with rounded ends, so building columns are designed accordingly.
- **Mountains:** the maximum height of a mountain on Earth (~10 km) is limited by the elastic strength of rock at its base.

Weightage in Board & Entrance Exams

Exam	Typical Weightage	Most-Tested Areas
CBSE Board (Class 11)	3–4 marks	Stress-strain definitions, Young's modulus numericals, stress-strain curve
JEE Main / Advanced	1–2 questions	Young's modulus, elastic energy, composite wires, bulk modulus
NEET	1–2 questions	Elastic moduli definitions, Poisson's ratio, stress-strain graph reading

[TABLE: Question-type split — VSA (1 mark): definitions of stress, strain, elastic limit, units; SA (2–3 marks): Young's modulus derivation, stress-strain curve, Poisson's ratio; LA (5 marks): elastic energy derivation, comparison of three moduli, applications of elasticity.]

Important Definitions

Term	Definition
Elasticity	Property by which a body regains its original shape and size after the deforming force is removed
Stress	Internal restoring force per unit area: Stress = F/A; unit Pa
Strain	Fractional change in configuration (length, shape, or volume); dimensionless
Hooke's law	Within the elastic limit, stress ∝ strain
Elastic limit	Maximum stress up to which a body returns to its original size on removing the load
Young's modulus (Y)	Ratio of longitudinal stress to longitudinal strain: Y = FL/(A·ΔL)
Shear modulus (G)	Ratio of shearing stress to shearing strain: G = F/(A·θ)
Bulk modulus (K)	Ratio of volume stress to volume strain: K = −pV/ΔV
Poisson's ratio (σ)	Ratio of lateral strain to longitudinal strain; dimensionless
Elastic potential energy	Energy stored in a stretched body: U = ½ × F × ΔL

Solved Examples

Example 1

A steel wire of length 2 m and cross-sectional area 1 mm^2 is stretched by a force of 100 N. Find the stress in the wire.

Answer: Stress = F/A = 100 / (1×10^{-6}) = **1×10^8 N/m^2 (10^8 Pa)**.

Example 2

A wire of original length 4 m stretches by 2 mm under a load. Find the longitudinal strain.

Answer: Strain = ΔL/L = (2×10^{-3}) / 4 = **5×10^{-4}** (no units).

Example 3

A force of 200 N stretches a wire of length 3 m and area 2×10^{-6} m^2 by 1.5 mm. Find Young's modulus.

Answer: Y = FL / (A·ΔL) = (200 × 3) / ($2 \times 10^{-6} \times 1.5 \times 10^{-3}$) = 600 / ($3 \times 10^{-9}$) = **$2 \times 10^{11}$ N/m^2**.

Example 4

The bulk modulus of water is 2.2×10^9 N/m^2. Find the pressure required to reduce a given volume of water by 0.1%.

Answer: ΔV/V = 0.1% = 10^{-3}. p = K × (ΔV/V) = $2.2 \times 10^9 \times 10^{-3}$ = **2.2×10^6 N/m^2**.

Example 5

A wire is stretched by 1 mm under a force of 50 N. Find the elastic potential energy stored in it.

Answer: U = ½ × F × ΔL = ½ × 50 × (1×10^{-3}) = **0.025 J (2.5×10^{-2} J)**.

Example 6

When a wire is stretched, its length increases by 0.2% and its diameter decreases by 0.05%. Find Poisson's ratio.

Answer: σ = lateral strain / longitudinal strain = 0.05% / 0.2% = 0.0005 / 0.002 = **0.25**.

Important Questions for Board Exams

1-Mark Questions (VSA)

1. Define stress and give its SI unit.
2. Why has strain no units or dimensions?

3. Which is more elastic — steel or rubber? Justify.
4. What does the negative sign in the formula for bulk modulus indicate?
5. Define Poisson's ratio and state its dimensions.

2–3-Mark Questions (SA)

1. State Hooke's law and define modulus of elasticity. Give its SI unit.
2. Draw and explain the stress-strain curve for a metal wire, marking the elastic limit, yield point, and fracture point.
3. Distinguish between Young's modulus, shear modulus, and bulk modulus.
4. Why are girders given an I-shape? Explain using the depression formula.

5-Mark Questions (LA)

1. Define Young's modulus and derive its expression $Y = FL/(A \cdot \Delta L)$. Explain why solids are more elastic than liquids and gases.
2. Derive an expression for the elastic potential energy stored per unit volume in a stretched wire, and show that $u = \frac{1}{2} \times$ stress $\times$ strain.
3. Explain three applications of the elastic behaviour of materials in everyday engineering (bridges, cranes, pillars).

Quick Revision Points

- Elasticity = tendency to regain shape; plasticity = tendency to keep the new shape
- Stress = F/A (unit Pa, dimensions $[ML^{-1}T^{-2}]$); strain = fractional change (dimensionless)
- Three stresses: tensile/compressive, shearing, hydraulic — giving length, shape, volume strain
- Hooke's law: stress $\propto$ strain within the elastic limit; stress = E × strain
- Stress-strain curve: proportional limit → elastic limit (yield) → plastic region → ultimate strength → fracture
- Young's modulus $Y = FL/(A \cdot \Delta L)$; higher Y means stiffer material
- Shear modulus $G = F/(A \cdot \theta) \approx Y/3$; only solids have rigidity
- Bulk modulus $K = -pV/\Delta V$; compressibility = 1/K; gases most compressible
- Poisson's ratio σ = lateral strain / longitudinal strain; range –1 to 0.5
- Elastic energy $U = \frac{1}{2} \times F \times \Delta L$; energy density $u = \frac{1}{2} \times$ stress $\times$ strain $= \frac{1}{2} Y(\text{strain})^2$
- Applications: I-shaped girders, thick crane ropes, designed pillars, mountain-height limit

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Next Chapter: Chapter 9 — Mechanical Properties of Fluids