JEE MAIN · PAPER 1 · PHYSICS

07 Properties of Solids & Liquids

Formula & concept sheet

Elasticity, fluids at rest and in motion, surface tension and heat. Each idea is explained in plain words, then the formulas, then how it is used and asked.

INSIDE THIS SHEET

1	Elasticity	2
2	Fluids at rest	2
3	Fluids in motion	3
4	Surface tension	3
5	Thermal expansion and calorimetry	4
6	Heat transfer	4
7	Worked examples	5
8	Last-minute checklist	5

READ ALONGSIDE

NCERT XI · Mechanical Properties of Solids; Mechanical Properties of Fluids; Thermal Properties of Matter

HOW TO USE THIS SHEET

1. **Skim** — Read the Key ideas, then the formula cards.
2. **Memorise** — Learn the formulas and check every Trap box.
3. **Test** — Do the worked examples, then this chapter's PYQs.
4. **Revise** — Use the last-minute checklist before the exam.

Formula memorise · **Key idea** why it works · **Trap** marks lost here · **PYQ** how it is asked

Practise this chapter with real past-paper questions on Prep Vault. Written for revision, not as a first read.

CHAPTER 07

Properties of Solids & Liquids

NCERT XI · Mechanical Properties of Solids; Mechanical Properties of Fluids; Thermal Properties of Matter

Covers: elasticity · fluid pressure, buoyancy · flow, Bernoulli, viscosity · surface tension, capillarity · thermal expansion, calorimetry · conduction, convection, radiation.

1 Elasticity

A deformed solid pushes back. **Stress** is the restoring force per unit area, **strain** the fractional deformation. For small strains stress is proportional to strain (Hooke's law), and the ratio is a **modulus** of the material.

STRESS AND STRAIN

$$\sigma = \frac{F}{A},\ \varepsilon = \frac{\Delta L}{L}$$

stress in Pa; strain has no unit

YOUNG'S MODULUS

$$Y = \frac{FL}{A\,\Delta L}$$

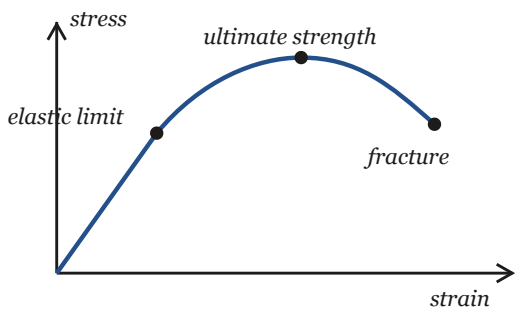
for a wire the spring constant is $k = \dfrac{YA}{L}$

BULK AND SHEAR MODULUS

$$B = -\frac{\Delta P}{\Delta V / V}$$

$$\eta = \frac{F/A}{\theta}$$

compressibility $= 1/B$; θ is the shear angle



Straight line: Hooke's law, slope $= Y$. Beyond the elastic limit the deformation is permanent.

ENERGY STORED

$$u = \tfrac{1}{2}\sigma\varepsilon = \frac{\sigma^2}{2Y}$$

$$U = \tfrac{1}{2}F\,\Delta L$$

per unit volume; the area under the stress–strain line

WIRE UNDER ITS OWN WEIGHT

$$\Delta L = \frac{MgL}{2AY}$$

half of the value for a load Mg at the end

POISSON'S RATIO

$$\sigma_p = -\frac{\Delta d/d}{\Delta L/L}$$

ranges between -1 and 0.5

THERMAL STRESS

$$\sigma = Y\alpha\,\Delta T$$

a rod clamped at both ends and heated or cooled

MODULI TOGETHER

$$Y = 3B(1-2\sigma_p) = 2\eta(1+\sigma_p)$$

links the three moduli

HOW IT IS USED AND ASKED

Extension of wires of different length, radius or material under the same load (use $\Delta L \propto L/(Ar^2)$ ratios), energy stored in a stretched wire, and the force on a clamped rod when it is heated.

2 Fluids at rest

A fluid at rest pushes equally in all directions at a point, and the pressure grows with depth because of the weight above. A body in a fluid feels an upward **buoyant force** equal to the weight of the fluid it displaces (Archimedes).

PRESSURE AT A DEPTH

$$P = P_0 + \rho g h$$

gauge pressure is $\rho g h$; $1\ \text{atm} = 1.013 \times 10^5\ \text{Pa}$

PASCAL'S LAW

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

pressure applied to a confined fluid is transmitted undiminished; hydraulic lift

BUOYANCY

$$F_B = \rho_{liq} V_{sub}\, g$$

floating: weight $= F_B$

FLOATING FRACTION

$$\frac{V_{sub}}{V} = \frac{\rho_{body}}{\rho_{liq}}$$

a body floats if $\rho_{body} < \rho_{liq}$

APPARENT WEIGHT IN A LIQUID

$$W' = W\left(1 - \frac{\rho_{liq}}{\rho_{body}}\right)$$

fully submerged

TWO LIQUIDS IN A U-TUBE

$$h_1\rho_1 = h_2\rho_2$$

heights measured from the common level of the interface

ACCELERATED CONTAINER

free surface tilts: $\tan\theta = \dfrac{a}{g}$

in a lift: $P = P_0 + \rho(g \pm a)h$

effective gravity $g \pm a$ inside the lift

FORCE ON A DAM WALL

$$F = \tfrac{1}{2}\rho g\, h^2\, w$$

water depth h, width w; pressure averages $\rho g h/2$

TRAP

Floating ice melts without changing the water level. Pressure depends on depth only, not on the vessel's shape.

3 Fluids in motion

In steady flow of an ideal fluid, what enters a pipe leaves it, so the fluid speeds up where the pipe narrows. **Bernoulli's principle** is energy conservation along a streamline: high speed, low pressure.

EQUATION OF CONTINUITY

$$A_1v_1 = A_2v_2$$

volume flow rate $Q = Av$ is constant

BERNOULLI'S EQUATION

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

steady, incompressible, non-viscous flow along a streamline

TORRICELLI'S LAW

$$v = \sqrt{2gh}$$

speed of efflux at depth h below the free surface

RANGE OF A JET

$$R = 2\sqrt{h(H-h)}$$

hole at depth h in a tank of water depth H; maximum $R = H$ at $h = H/2$

VENTURI METER

$$v_1 = A_2\sqrt{\frac{2\,\Delta P}{\rho(A_1^2 - A_2^2)}}$$

ΔP between the wide and the narrow section

POISEUILLE'S FORMULA

$$Q = \frac{\pi P r^4}{8\eta\ell}$$

flow through a narrow tube; strongly dependent on r^4

VISCOUS FORCE

$$F = \eta A\,\frac{dv}{dx}$$

η in Pa s; it falls as a liquid is heated

STOKES' LAW

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

drag on a small sphere moving slowly

TERMINAL VELOCITY

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

ρ sphere, σ fluid; $v_t \propto r^2$

HOW IT IS USED AND ASKED

Reynolds number $R_e = \rho v D/\eta$: below about 1000 the flow is laminar, above about 2000 turbulent. Asked as Bernoulli with a change of height or area (venturi, a jet from a tank) and terminal-speed ratios for spheres of different radii. Not valid for viscous or turbulent flow.

4 Surface tension

A liquid surface acts like a stretched skin. **Surface tension** is force per unit length, or energy per unit area; it makes drops round and lifts liquid in narrow tubes.

SURFACE TENSION AND ENERGY

$$T = \frac{F}{\ell} = \frac{W}{\Delta A}$$

surface energy $= T\,\Delta A$; a soap film has **two** surfaces

EXCESS PRESSURE

drop: $\Delta P = 2T/R$

soap bubble: $4T/R$

an air bubble in a liquid also gives $2T/R$; pressure is higher inside

CAPILLARY RISE

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

$\theta < 90^\circ$ rises (water), $> 90^\circ$ falls (mercury)

MERGING DROPS

new radius $R = n^{1/3} r$

energy released $= 4\pi r^2 T\,(n - n^{2/3})$

the surface area decreases, so energy is released

BLOWING A SOAP BUBBLE

$W = 8\pi R^2 T$

two surfaces of area $4\pi R^2$ each

PULL ON A WIRE FRAME

$F = 2T\ell$

soap film on a frame of length ℓ, two surfaces

TRAP

A soap bubble has two surfaces ($4T/R$), a drop or an air bubble inside a liquid has one ($2T/R$). If a capillary is too short the liquid does not overflow: the meniscus radius adjusts so $h\,r$ stays constant.

5 Thermal expansion and calorimetry

Heating makes most materials expand. **Temperature** tells which way heat flows; the heat needed to change a body's temperature depends on its mass and specific heat, and a change of state absorbs or releases **latent heat** at constant temperature.

THERMAL EXPANSION

$\Delta L = L\alpha\Delta T$

$\beta = 2\alpha,\ \gamma = 3\alpha$

area and volume coefficients for isotropic solids

LIQUIDS IN A CONTAINER

$\gamma_{apparent} = \gamma_{real} - \gamma_{vessel}$

water is densest at 4°C; $\rho' = \rho(1 - \gamma\Delta T)$

PENDULUM CLOCK

fractional change in period $= \frac{1}{2}\alpha\Delta T$

heating makes the clock lose time

HEAT AND LATENT HEAT

$Q = mc\,\Delta T, \quad Q = mL$

water $4186\ \mathrm{J\,kg^{-1}K^{-1}}$; ice melts at 3.34×10^5, steam $2.26 \times 10^6\ \mathrm{J\,kg^{-1}}$

MIXING

heat lost $=$ heat gained

$$T = \frac{\sum m_i c_i T_i}{\sum m_i c_i}$$

check whether the ice melts completely before applying

SPECIFIC HEAT OF ICE AND STEAM

$c_{ice} \approx 2100,\ c_{steam} \approx 2000$

in $\mathrm{J\,kg^{-1}K^{-1}}$

6 Heat transfer

Heat moves by **conduction** (through the material, with no bulk motion), **convection** (with the moving fluid) and **radiation** (electromagnetic waves, no medium needed).

CONDUCTION

$$\frac{dQ}{dt} = \frac{kA\,\Delta T}{\ell}$$

thermal resistance $R = \dfrac{\ell}{kA}$; slabs in series add resistances

SLABS IN SERIES

$$k_{eq} = \frac{\ell_1 + \ell_2}{\ell_1/k_1 + \ell_2/k_2}$$

same area; in parallel $k_{eq} = \dfrac{k_1 A_1 + k_2 A_2}{A_1 + A_2}$

STEFAN–BOLTZMANN LAW

$P = e\sigma A T^4$

net $= e\sigma A(T^4 - T_0^4)$

$\sigma = 5.67 \times 10^{-8}\ \mathrm{W\,m^{-2}K^{-4}}$; T in kelvin

WIEN'S DISPLACEMENT LAW

$\lambda_m T = b \approx 2.9 \times 10^{-3}\ \mathrm{m\,K}$

a hotter body radiates most strongly at a shorter wavelength

NEWTON'S LAW OF COOLING

$$\frac{T_1 - T_2}{t} = K\left(\frac{T_1 + T_2}{2} - T_0\right)$$

$T - T_0 = (T_i - T_0)e^{-Kt}$

for small temperature differences from the surroundings T_0

HOW IT IS ASKED

Final temperature of a mixture (with ice or steam), time to melt or heat, heat flow through composite slabs or rods, the change in radiated power when the temperature doubles ($\times 16$), and the cooling time between two temperatures.

7 Worked examples

STRETCHED WIRE

A steel wire, $L = 2\ \text{m}$, $A = 1\ \text{mm}^2$, $Y = 2 \times 10^{11}\ \text{Pa}$, carries $100\ \text{N}$. Extension?

$$\Delta L = \frac{FL}{AY} = \frac{100 \times 2}{10^{-6} \times 2 \times 10^{11}} = 1\ \text{mm}$$

JET FROM A TANK

Water leaves a hole $5\ \text{m}$ below the free surface of a wide tank ($g = 10$). Speed?

$$v = \sqrt{2gh} = \sqrt{2 \times 10 \times 5} = 10\ \text{m s}^{-1}$$

CAPILLARY RISE

Water ($T = 0.07\ \text{N m}^{-1}$, $\theta = 0$) in a tube of radius $0.5\ \text{mm}$ ($\rho = 1000$, $g = 10$). Rise?

$$h = \frac{2 \times 0.07}{1000 \times 10 \times 0.5 \times 10^{-3}} = 2.8\ \text{cm}$$

MERGING DROPS

Eight drops of radius $1\ \text{mm}$ merge ($T = 0.07\ \text{N m}^{-1}$). New radius and energy released?

$R = 2\ \text{mm}$; $4\pi r^2 T(8 - 4) \approx 3.5 \times 10^{-6}\ \text{J}$

TERMINAL VELOCITY

Steel ball, $r = 1\ \text{mm}$, $\rho = 7800$, in glycerin ($\sigma = 1260$, $\eta = 0.8\ \text{Pa s}$). Terminal speed?

$$v_t = \frac{2 \times 10^{-6} \times 6540 \times 10}{9 \times 0.8} \approx 1.8\ \text{cm s}^{-1}$$

ICE AND WATER

$100\ \text{g}$ of ice at 0°C is added to $400\ \text{g}$ of water at 50°C. Final temperature?

cooling to 0° gives $20\,000\ \text{cal}$; melting uses $8\,000$;
$\frac{12\,000}{500} = 24^\circ\text{C}$

CONDUCTION

A copper rod, $A = 1\ \text{cm}^2$, length $0.5\ \text{m}$, $k = 400$, ends 100°C apart. Heat flow?

$$\frac{kA\Delta T}{\ell} = \frac{400 \times 10^{-4} \times 100}{0.5} = 8\ \text{W}$$

RADIATION

The absolute temperature of a hot body is doubled. By what factor does its radiated power change?

$P \propto T^4$, so $2^4 = 16$ times

WHICH FORMULA?

Wire and load: Y. Pressure at a depth or a floating body: ρgh and F_B. A narrowing pipe or a jet: continuity and Bernoulli. A curved liquid surface or a tube: T. Heating a body: $mc\Delta T$, mL. A temperature difference across a material: $kA\Delta T/\ell$.

8 Last-minute checklist

- Elasticity: $\Delta L \propto \frac{FL}{AY}$; compare wires through the ratios of L, A (or r^2) and Y.
- Pressure depends on depth, not on the shape of the vessel; a floating body has weight equal to buoyancy.
- Bernoulli only for steady, ideal flow along a streamline; terminal velocity uses $(\rho - \sigma)$.
- Soap bubble: two surfaces, $4T/R$; drop: one surface, $2T/R$.
- Radiation needs kelvin; conduction through layers adds thermal resistances in series.

Now test it. Practise this chapter with past-paper and bank questions on Prep Vault. **Practice this chapter →**