FREE NOTES · NCERT + JEE/NEET LEVEL

Mechanical Properties of Fluids

Pressure, Pascal's law, buoyancy, continuity, Bernoulli, viscosity, Stokes' law, terminal velocity, surface tension and capillarity, with everyday examples for every topic.

01 Pressure
02 Pressure with depth
03 Pascal's law & hydraulic lift
04 Buoyancy (Archimedes' principle)
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01 Pressure

Fluid = anything that can flow (liquids and gases). They have no fixed shape.

$$P = F / A$$

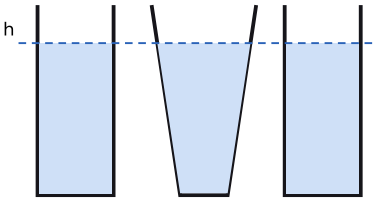
Normal force per unit area. Unit pascal (Pa) = N/m². A scalar. 1 atm = 1.013 × 10^5 Pa = 76 cm Hg. 1 bar = 10^5 Pa, 1 torr = 1 mm Hg.

Smaller area, larger pressure: a sharp nail goes in easily, a camel's wide feet don't sink into sand, a high heel leaves a mark on the floor.

02 Pressure with depth

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

P_0 = atmospheric pressure, h = depth. **Gauge pressure** = P − P_0 = ρgh (what a tyre gauge reads).



Equal pressure at the bottom of all three

HYDROSTATIC PARADOX

Pressure is the same at the same depth, regardless of the shape of the vessel or how much water it holds. Narrow and wide vessels filled to the same height have the same pressure at the bottom.

BAROMETER

The height of a mercury column equals atmospheric pressure: $P_0 = \rho_{Hg} g h$, h ≈ 76 cm. With water you'd need ≈ 10.3 m.

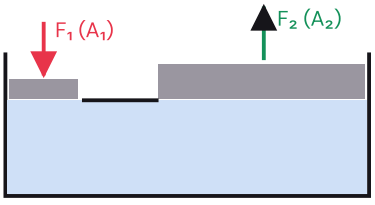
OPEN-TUBE MANOMETER

A level difference h in a U-tube ⇒ gauge pressure = ρgh. Filled with mercury or water.

03 Pascal's law & hydraulic lift

PASCAL'S LAW

Pressure applied to an enclosed fluid is transmitted **equally in all directions and to every point**.



Small force on a small piston ⇒ large force on a large piston

HYDRAULIC LIFT / BRAKE

$$F_1/A_1 = F_2/A_2 \Rightarrow F_2 = F_1\,(A_2/A_1)$$

Force is multiplied but not energy: the small piston moves farther, $A_1d_1 = A_2d_2$. Car hydraulic brakes, dentist's chair, hydraulic press.

04 Buoyancy (Archimedes' principle)

$$\text{Upthrust (buoyant force)} = \rho_{\text{fluid}} \times V_{\text{submerged}} \times g$$

The weight of fluid displaced by the submerged part. Apparent weight = true weight − upthrust.

Condition	Result
$\rho_{body} > \rho_{fluid}$	Sinks
$\rho_{body} = \rho_{fluid}$	Stays suspended anywhere
$\rho_{body} < \rho_{fluid}$	Floats; fraction submerged = ρ_{body}/ρ_{fluid}

Example: ice (0.9) floats in water (1.0) 90% submerged, which is why only 10% of an iceberg is visible.

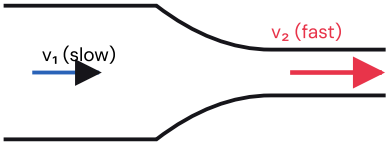
05 Streamline flow & continuity

Streamline (steady) flow: velocity at each point doesn't change with time; particles follow the same path (streamline). Two streamlines never cross. At high speed the flow becomes **turbulent** (eddies).

EQUATION OF CONTINUITY

$$A_1 v_1 = A_2 v_2$$

For an incompressible fluid. Volume flow rate (Av) is the same everywhere. Faster where narrow, slower where wide. This is **conservation of mass**.



Narrower pipe ⇒ faster water

Pinch a garden hose with your thumb and the water shoots farther: smaller area ⇒ higher speed.

REYNOLDS NUMBER

$R_e = \rho v d/\eta$ (unitless). R_e < 1000: streamline. R_e > 2000: turbulent. In between: unsteady.

06 Bernoulli's principle

STATEMENT

In streamline flow, at every point along a streamline:

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

Pressure energy + kinetic energy + potential energy (per unit volume) = constant. This is **energy conservation**.
Conditions: non-viscous, incompressible, steady flow.

IN ONE LINE

At the same height: **where speed is higher, pressure is lower**.

07 Applications of Bernoulli

Application	Explanation
Torricelli's law (water from a hole in a tank)	$v = \sqrt{(2gh)}$, h = depth of the hole below the surface
Venturimeter	Lower pressure in the narrow part; measure the pressure difference to find flow speed
Aeroplane lift	Air is faster above the wing ⇒ lower pressure ⇒ net upward push (dynamic lift)
Roofs blown off in a storm	Fast wind above ⇒ low pressure above ⇒ higher pressure inside pushes the roof up
Spinning ball (Magnus effect)	Air moves faster on one side ⇒ the ball curves (swing)
Sprayer / atomizer, Bunsen burner	Fast air creates low pressure ⇒ liquid or gas is sucked in
Two trains / boats passing close	Fast air/water between them ⇒ low pressure ⇒ they are pulled together

TORRICELLI: HOW FAR THE WATER LANDS

Tank height H, hole at depth h below the surface: $\text{range} = 2\sqrt{(h(H - h))}$, maximum when h = H/2.

08 Viscosity

A **friction-like** force between layers of a fluid that opposes their relative motion. Honey is very viscous, water much less.

$$F = -\eta\, A\, (dv/dx)$$

η = coefficient of viscosity. Unit Pa·s (= poiseuille); CGS unit poise (1 Pa·s = 10 poise). dv/dx = velocity gradient.

EFFECT OF TEMPERATURE

Heating **decreases** the viscosity of a **liquid** (hot oil flows easily) but **increases** that of a **gas**.

09 Stokes' law & terminal velocity

STOKES' LAW

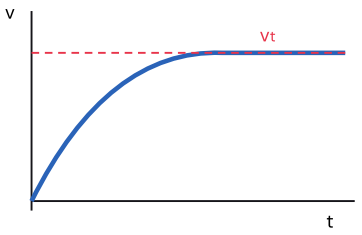
$$F = 6\pi \eta r v$$

Drag force on a small sphere (radius r, speed v) in a viscous fluid.

TERMINAL VELOCITY

$$v_t = 2 r^2 (\rho - \sigma) g / (9 \eta)$$

ρ = density of the body, σ = of the fluid. When weight = upthrust + drag, acceleration is 0 and speed stays constant. $v_t \propto r^2$.



Speed rises and then levels off at v_t

That's why raindrops fall slowly (otherwise a drop from kilometres up would hit like a bullet). Tiny cloud droplets have such a small v_t that they seem to float. Parachutes work on the same idea.

TRICK

8 equal drops merge into one: radius doubles (volume 8 times) ⇒ v_t becomes 4 times.

10 Surface tension

A liquid's surface behaves like a **stretched membrane**. Surface molecules feel a net inward pull, so the liquid tries to keep its surface area as small as possible (that's why drops are round).

$$S = F / L = \text{Surface energy} / \text{Area}$$

Unit N/m = J/m². Work to increase area by ΔA = S × ΔA. A soap bubble has **two surfaces**, so work = 2SΔA. Higher temperature ⇒ lower S. Adding soap/detergent ⇒ lower S.

Angle of contact θ	Liquid-solid	Example
θ < 90° (acute)	Liquid wets the surface, concave meniscus	Water-glass
θ > 90° (obtuse)	Doesn't wet, convex meniscus	Mercury-glass, water-wax/leaf

11 Drops, bubbles & capillarity

Object	Excess pressure inside
Liquid drop	$2S/r$
Air bubble (inside a liquid)	$2S/r$
Soap bubble (in air, 2 surfaces)	$4S/r$

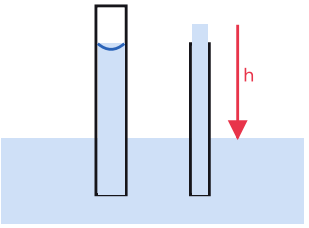
NOTE

A smaller bubble has higher pressure. Connect two bubbles and air flows **from the smaller to the larger**.

CAPILLARY RISE

$$h = 2\,S\cos\theta\,/\,(\rho\,g\,r)$$

A liquid rises ($\theta < 90°$) or falls (mercury, $\theta > 90°$) in a narrow tube. $h \propto 1/r$, so $hr = \text{constant}$.



Water rises higher in a narrower tube

Examples: oil rising in a lamp wick, blotting paper absorbing ink, water rising in plants (partly), a towel soaking up water.

Small drops merging: n drops (radius r) merge into one of radius $R = n^{(1/3)}\,r$; the surface area decreases ⇒ energy is **released** (heat). Splitting a big drop needs energy.

12 JEE Extra + Tricks

JEE LEVEL

- Torricelli: efflux speed $v = \sqrt{(2gh)}$; horizontal range from a hole is maximum when the hole is at half the height of the liquid column.
- Terminal velocity $v_t = 2r^2(\rho - \sigma)g/(9\eta) \propto r^2$.
- Capillary rise $h = 2T\cos\theta/(r\rho g)$; $h \cdot r$ = constant (Jurin's law); in a tube of insufficient length, liquid does not overflow (radius of meniscus adjusts).
- Excess pressure: liquid drop $2T/r$, soap bubble $4T/r$ (two surfaces), air bubble in liquid $2T/r$.
- Work to form a soap bubble = $T \times 8\pi r^2$ (two surfaces).
- Reynolds number $Re = \rho vD/\eta$: <1000 streamline, >2000 turbulent (approx.).

13 Solved numericals ($g = 10\ m/s^2$)

Q1. Hydraulic lift: small piston 10 cm², large piston 1000 cm². Force needed to lift a 1000 kg car?
$F_1 = F_2 \times A_1/A_2 = 10^4 \times 10/1000 = 100$ N. **Ans: 100 N**

Q2. Total pressure at 3 m depth in a swimming pool? ($P_o = 10^5$ Pa)
$P = 10^5 + 1000 \times 10 \times 3 = 1.3 \times 10^5$ Pa. **Ans: 1.3×10^5 Pa**

Q3. Water flows at 3 m/s in a 2 cm radius pipe, which narrows to 1 cm radius. Speed there?
$A \propto r^2 \Rightarrow v_2 = 3 \times 4 = 12$ m/s. **Ans: 12 m/s**

Q4. A hole is 5 m below the water surface in a tank. Speed of the water?
$v = \sqrt{(2gh)} = \sqrt{100} = 10$ m/s. **Ans: 10 m/s**

Q5. A steel ball of radius 2 mm (ρ = 8000) falls through glycerine (σ = 1300, η = 0.83 Pa·s). Terminal velocity?
$v = 2 \times (2 \times 10^{-3})^2 \times 6700 \times 10/(9 \times 0.83) = 0.536/7.47 \approx 0.072$ m/s. **Ans: ≈ 7 cm/s**

Q6. A capillary of radius 0.5 mm, water S = 0.07 N/m, θ = 0. How high does water rise?
$h = 2 \times 0.07/(1000 \times 10 \times 5 \times 10^{-4}) = 0.14/5 = 0.028$ m. **Ans: 2.8 cm**

Q7. Excess pressure inside a soap bubble of radius 1 cm (S = 0.03 N/m)? Work to blow it?
$\Delta P = 4S/r = 0.12/0.01 = 12$ Pa. $W = S \times 2 \times 4\pi r^2 = 0.03 \times 8\pi \times 10^{-4} \approx 7.5 \times 10^{-5}$ J. **Ans: 12 Pa, ≈ 7.5×10^{-5} J**

14 Common mistakes

- Writing 2S/r for a soap bubble. It has two surfaces: 4S/r, and a factor of 2 in work too.
- Thinking pressure depends on the vessel's shape.
- Thinking gas viscosity also falls on heating. It rises.
- Treating a hydraulic lift as an energy multiplier.
- Thinking terminal velocity $\propto$ r (it is $\propto r^2$).
- Forgetting to convert cm and mm to m.

15 Formula sheet

Pressure at depth	$P = P_0 + \rho gh$
Pascal / hydraulic	$F_1/A_1 = F_2/A_2$
Buoyant force	$\rho_f V g$
Continuity	$A_1v_1 = A_2v_2$
Bernoulli	$P + \frac{1}{2}\rho v^2 + \rho gh = \text{const}$
Torricelli	$v = \sqrt{(2gh)}$
Viscous force	$F = \eta A\, dv/dx$
Stokes / terminal	$6\pi\eta rv$ / $2r^2(\rho - \sigma)g/9\eta$
Reynolds number	$R_e = \rho vd/\eta$
Surface tension	$S = F/L$, $W = S\Delta A$
Excess pressure	drop $2S/r$, soap bubble $4S/r$
Capillary rise	$h = 2S\cos\theta/(\rho gr)$

16 Practice questions

1. Wood (ρ = 600) floats in water. What fraction is submerged?
2. The radius of a capillary is halved. How high does water rise now?
3. Two soap bubbles have radii 1 : 2. Ratio of their excess pressures?
4. A tank is 20 m tall with a hole in the middle (10 m). How far does the water land?
5. A raindrop's radius triples. Terminal velocity?

ANSWERS

1) 0.6 (60%) · 2) Twice as high · 3) 2 : 1 · 4) $2\sqrt{(10 \times 10)} = 20$ m · 5) 9 times

17 Quick revision: 5 minutes before the exam

STATICS

- $P = P_o + \rho gh$; independent of shape.
- Pascal: $F_1/A_1 = F_2/A_2$.
- Fraction submerged = ρ_{body}/ρ_{fluid}.
- 1 atm = 76 cm Hg = 1.013×10^5 Pa.

FLOW

- $A_1v_1 = A_2v_2$ (mass conservation).
- $P + \frac{1}{2}\rho v^2 + \rho gh = \text{const}$ (energy).
- Higher speed ⇒ lower pressure.
- Torricelli $v = \sqrt{(2gh)}$.

VISCOSITY

- $F = 6\pi\eta rv$; $v_t \propto r^2$.
- Heating: liquid η falls, gas η rises.
- $R_e < 1000$ streamline, > 2000 turbulent.

SURFACE TENSION

- Drop $2S/r$, soap bubble $4S/r$.
- $h = 2S\cos\theta/\rho gr$, $hr = \text{const}$.
- Drops merging ⇒ energy released.

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