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Mechanical Properties of Fluids Class 11 Notes | CBSE Physics Chapter 9

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Mechanical Properties of Fluids Class 11 Notes | CBSE Physics Chapter 9

Mechanical Properties of Fluids is Chapter 9 of CBSE Class 11 Physics — the chapter that explains why a needle floats, why aeroplanes fly, why a dam is built thicker at the bottom, and how a hydraulic jack lifts a car with one hand. A *fluid* is anything that flows — liquids and gases — and this chapter gives you the rules that govern all of them.

By the end of these notes you will be able to apply Pascal's law to hydraulic machines, use Bernoulli's principle to explain lift and the venturimeter, work out terminal velocity from Stokes' law, and solve capillary-rise and excess-pressure problems with confidence. This chapter carries roughly 6–8 marks in boards and is a steady source of single-correct questions in JEE and NEET.

Table of Contents

Key Concepts

1. Thrust and Pressure

Thrust is the total force a fluid exerts perpendicular to a surface. **Pressure** is the thrust acting per unit area of that surface.

P = F/A

- **SI unit:** pascal (Pa) = N/m². Pressure is a **scalar** quantity.
- This is why a sharp knife (small area) cuts more easily than a blunt one — the same force gives much larger pressure.
- 1 atmosphere (atm) = 1.013×10^5 Pa = 760 mm of Hg.

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2. Density and Relative Density

Density (ρ) is the mass of a fluid per unit volume.

$\rho = m/V$ — SI unit kg/m^3.

Relative density (specific gravity) is the ratio of the density of a substance to the density of water at 4 °C. It has no units, since it is a ratio.

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3. Variation of Pressure with Depth

Inside a fluid at rest, pressure increases with depth because the deeper layers support the weight of everything above them.

$P = P_0 + \rho g h$

- P_0 = atmospheric pressure at the surface, h = depth below the surface.
- Pressure at a point depends only on depth, not on the shape of the container (hydrostatic paradox).
- This is why a dam wall is built thicker at the bottom — pressure is highest there.

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4. Atmospheric and Gauge Pressure

Atmospheric pressure is the pressure exerted by the weight of the air column above us, measured by a mercury barometer.

Gauge pressure is the pressure relative to atmospheric pressure — it is the $\rho g h$ part only. **Absolute pressure** is the total, including atmosphere.

- **Absolute pressure:** $P = P_0 + \rho g h$
- **Gauge pressure:** $P - P_0 = \rho g h$ (what a tyre gauge or manometer reads)

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5. Pascal's Law

Pascal's law states that a pressure applied to an enclosed fluid is transmitted **undiminished and equally** to every point of the fluid and to the walls of the container.

It follows that in a connected fluid at rest, pressure is the same at all points at the same horizontal level.

Hydraulic Machines

Hydraulic lifts and brakes are direct applications of Pascal's law. A small force on a small piston produces a large force on a large piston.

$F_1/A_1 = F_2/A_2$, so **$F_2 = F_1 \times (A_2/A_1)$**

Because $A_2 > A_1$, the output force F_2 is multiplied — this is how a hydraulic jack lifts a car with a gentle push.

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6. Streamline and Turbulent Flow

In **streamline (laminar) flow**, every fluid particle passing a point follows the same smooth path with the same velocity — the streamlines never cross.

In **turbulent flow**, the velocity exceeds a critical value and the motion becomes irregular, with eddies and whirls. Smoke rising steadily then breaking up is the everyday picture of this change.

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7. Equation of Continuity

For an incompressible, non-viscous fluid in streamline flow, the mass entering a tube per second equals the mass leaving it. So the volume flow rate is constant.

$A_1v_1 = A_2v_2 = \text{constant}$

- It is simply the conservation of mass for a flowing fluid.
- Where the pipe is narrow, the fluid speeds up — that is why a river flows faster where it is shallow and narrow.

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8. Bernoulli's Principle

For an ideal (incompressible, non-viscous) fluid in streamline flow, the sum of pressure energy, kinetic energy, and potential energy per unit volume stays constant along a streamline.

$P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$

It is a statement of conservation of energy for a flowing fluid. The key takeaway: **where speed is high, pressure is low**.

Applications of Bernoulli's Principle

- **Aeroplane lift (aerofoil):** air moves faster over the curved top of the wing, so pressure there is lower, giving an upward lift.
- **Venturimeter:** measures the flow speed of a liquid by relating the pressure drop in a narrowed section to velocity.
- **Atomiser / spray pump:** fast-moving air lowers pressure and draws liquid up the tube.
- **Magnus effect:** a spinning ball swerves because air moves faster on one side, lowering pressure there.

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9. Viscosity

Viscosity is the internal friction between adjacent layers of a fluid moving at different speeds. It opposes relative motion between the layers — honey is more viscous than water.

The viscous force between two layers is given by Newton's law of viscous flow:

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

- **η (eta)** = coefficient of viscosity; SI unit **Pa·s** (or $N\cdot s/m^2$); CGS unit poise.

- dv/dx is the velocity gradient between the layers.
- Viscosity of a liquid *decreases* with temperature; viscosity of a gas *increases* with temperature.

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10. Stokes' Law and Terminal Velocity

When a small sphere falls through a viscous fluid, it experiences a retarding force given by **Stokes' law**:

$F = 6\pi\eta rv$

As the sphere speeds up, the viscous drag and the upthrust grow until they balance the weight. The body then moves with a constant maximum speed called the **terminal velocity**.

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

Here ρ is the density of the sphere, σ the density of the fluid, and r the radius. A raindrop reaching steady speed and a parachutist's slow descent are everyday examples.

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11. Reynolds Number

The **Reynolds number (Re)** is a pure number that decides whether flow will be streamline or turbulent.

$Re = \rho vD/\eta$

- $Re < 1000$ → streamline (laminar) flow.
- $Re > 2000$ → turbulent flow.
- Between 1000 and 2000 → unstable, may switch between the two.
- It is dimensionless, as it is a ratio of inertial force to viscous force.

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12. Surface Tension and Surface Energy

Surface tension (S or T) is the force per unit length acting along the surface of a liquid, perpendicular to a line drawn on it. It makes a liquid surface behave like a stretched elastic membrane.

$S = F/L$ — SI unit N/m.

Molecules at the surface have fewer neighbours, so they possess extra potential energy. The **surface energy** is the work done in increasing the surface area by unity:

Surface energy = $S \times \Delta A$

- A small drop becomes spherical because a sphere has the least surface area for a given volume.
- Surface tension *decreases* with rise in temperature and becomes zero at the critical temperature.

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13. Angle of Contact

The **angle of contact (θ)** is the angle between the tangent to the liquid surface at the point of contact and the solid surface, measured inside the liquid.

- **$\theta < 90°$** (acute): liquid wets the solid and the meniscus is concave — e.g. water in glass.
- **$\theta > 90°$** (obtuse): liquid does not wet the solid and the meniscus is convex — e.g. mercury in glass.

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14. Capillary Rise

When a fine tube is dipped in a liquid, the liquid rises (or falls) inside it due to surface tension. This is **capillarity**.

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

- The narrower the tube (small r), the higher the rise — h is inversely proportional to r.
- Water rises in a glass capillary ($\cos\theta$ positive); mercury is depressed ($\cos\theta$ negative).
- Capillarity explains how water climbs up a paper towel and rises in the stems of plants.

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15. Excess Pressure in Drops and Bubbles

Because of surface tension, the pressure inside a curved liquid surface is greater than outside. The excess pressure depends on the number of free surfaces.

Surface	Free surfaces	Excess pressure
Liquid drop	1	$P = 2S/r$
Air bubble inside liquid	1	$P = 2S/r$
Soap bubble	2	$P = 4S/r$

Note: A smaller bubble has a larger excess pressure, so when two bubbles join, air flows from the small one into the big one.

Weightage in Board & Entrance Exams

Exam	Typical Weightage	Most-Tested Areas
CBSE Board (Class 11)	6–8 marks	Pascal’s law, Bernoulli, surface tension, capillarity
JEE Main / Advanced	1–2 questions	Bernoulli & continuity, terminal velocity, excess pressure
NEET	1–2 questions	Pressure with depth, viscosity, surface tension, capillary rise

[TABLE: Question-type split — VSA (1 mark): definitions & SI units; SA (2–3 marks): Pascal's law, terminal velocity, excess pressure; LA (5 marks): Bernoulli's theorem derivation, capillary-rise expression.]

Important Definitions

Term	Definition
Pressure	Thrust per unit area: $P = F/A$; SI unit pascal (a scalar)
Pascal's law	Pressure applied to an enclosed fluid is transmitted equally in all directions
Gauge pressure	Pressure above atmospheric: $P - P_0 = \rho g h$
Equation of continuity	For incompressible flow, $A_1 v_1 = A_2 v_2$ (conservation of mass)
Bernoulli's theorem	$P + \frac{1}{2}\rho v^2 + \rho g h$ = constant along a streamline
Viscosity (η)	Internal friction opposing relative motion of fluid layers: $F = -\eta A(dv/dx)$
Stokes' law	Viscous drag on a small sphere: $F = 6\pi\eta r v$
Terminal velocity	Constant maximum speed of a body falling through a viscous fluid: $v_t = 2r^2(\rho - \sigma)g/9\eta$
Reynolds number	$Re = \rho v D/\eta$ — decides laminar vs turbulent flow (dimensionless)
Surface tension (S)	Force per unit length on a liquid surface: $S = F/L$; SI unit N/m
Angle of contact	Angle inside the liquid between the liquid surface and the solid at contact
Capillary rise	Rise of liquid in a fine tube: $h = 2S \cos\theta/(\rho r g)$

Solved Examples

Example 1

Find the pressure at the bottom of a tank of water 5 m deep. (ρ = 1000 kg/m³, g = 10 m/s², $P_0 = 1.0 \times 10^5$ Pa)

Answer: $P = P_0 + \rho g h = 1.0 \times 10^5 + (1000 \times 10 \times 5) = 1.0 \times 10^5 + 0.5 \times 10^5 =$ **1.5×10^5 Pa**. Gauge pressure = $\rho g h$ = **0.5×10^5 Pa**.

Example 2

In a hydraulic lift the small piston has area 0.01 m² and the large piston 0.5 m². A force of 100 N is applied to the small piston. Find the force on the large piston.

Answer: $F_2 = F_1 \times (A_2/A_1) = 100 \times (0.5/0.01) = 100 \times 50 =$ **5000 N**.

Example 3

Water flows through a pipe whose area narrows from 4 cm^2 to 1 cm^2. If the speed in the wide section is 2 m/s, find the speed in the narrow section.

Answer: By continuity $A_1v_1 = A_2v_2$, so $v_2 = (A_1v_1)/A_2 = (4 \times 2)/1 =$ **8 m/s**.

Example 4

An air bubble of radius 1 mm forms inside water of surface tension 0.072 N/m. Find the excess pressure inside it.

Answer: Excess pressure $= 2S/r = (2 \times 0.072)/(1 \times 10^{-3}) = 0.144/0.001 =$ **144 Pa**.

Example 5

A spherical drop of radius 0.2 mm falls through air ($\eta = 1.8 \times 10^{-5}$ Pa·s). Taking drop density 1000 kg/m^3 and neglecting air density, find the terminal velocity. ($g = 10$ m/s^2)

Answer: $v_t = 2r^2\rho g/9\eta = [2 \times (2 \times 10^{-4})^2 \times 1000 \times 10] / (9 \times 1.8 \times 10^{-5}) = (2 \times 4 \times 10^{-8} \times 10^4) / (1.62 \times 10^{-4}) \approx$ **4.94 m/s**.

Example 6

Water ($S = 0.072$ N/m, $\theta = 0°$, $\rho = 1000$ kg/m^3) rises in a capillary of radius 0.2 mm. Find the height of rise. ($g = 10$ m/s^2)

Answer: $h = 2S \cos\theta/(\rho rg) = (2 \times 0.072 \times 1)/(1000 \times 2 \times 10^{-4} \times 10) = 0.144/2 =$ **0.072 m = 7.2 cm**.

Important Questions for Board Exams

1-Mark Questions (VSA)

1. Why is pressure a scalar quantity even though force is a vector?
2. State the SI unit of the coefficient of viscosity.
3. Why does a soap bubble have greater excess pressure than a water drop of the same radius?
4. Why are dam walls made thicker at the bottom?
5. What is the angle of contact for mercury in glass — acute or obtuse?

2–3-Mark Questions (SA)

1. State Pascal's law and explain the working of a hydraulic lift.
2. Derive the expression for terminal velocity of a sphere falling through a viscous fluid.
3. Define surface tension and surface energy, and show how they are related.

4. Using the equation of continuity, explain why a stream of water narrows as it falls from a tap.

5-Mark Questions (LA)

1. State and prove Bernoulli's theorem for the streamline flow of an ideal fluid.
2. Derive the expression for the rise of liquid in a capillary tube ($h = 2S \cos \theta/\rho rg$) and discuss the factors it depends on.
3. Explain the lift on an aeroplane wing and the working of a venturimeter using Bernoulli's principle.

Quick Revision Points

- Pressure $P = F/A$ (scalar); SI unit pascal; 1 atm = 1.013×10^5 Pa
- Pressure with depth: $P = P_0 + \rho gh$; gauge pressure = ρgh
- Pascal's law: pressure transmitted equally → hydraulic lift $F_2 = F_1(A_2/A_1)$
- Equation of continuity: $A_1v_1 = A_2v_2$ (conservation of mass)
- Bernoulli: $P + \frac{1}{2}\rho v^2 + \rho gh$ = constant; high speed → low pressure
- Viscous force $F = -\eta A(dv/dx)$; η unit Pa·s; liquids less viscous when hot
- Stokes' law $F = 6\pi\eta rv$; terminal velocity $v_t = 2r^2(\rho - \sigma)g/9\eta$
- Reynolds number $Re = \rho vD/\eta$; <1000 laminar, >2000 turbulent
- Surface tension $S = F/L$ (N/m); surface energy = $S \times \Delta A$
- Angle of contact: acute → wetting (water), obtuse → non-wetting (mercury)
- Capillary rise $h = 2S \cos \theta/(\rho rg)$; excess pressure: drop $2S/r$, soap bubble $4S/r$

Next Chapter: Chapter 10 — Thermal Properties of Matter