

CLASS 11 PHYSICS • CHAPTER 9

9.4 Bernoulli's Principle

Fluid Dynamics & The Conservation of Energy

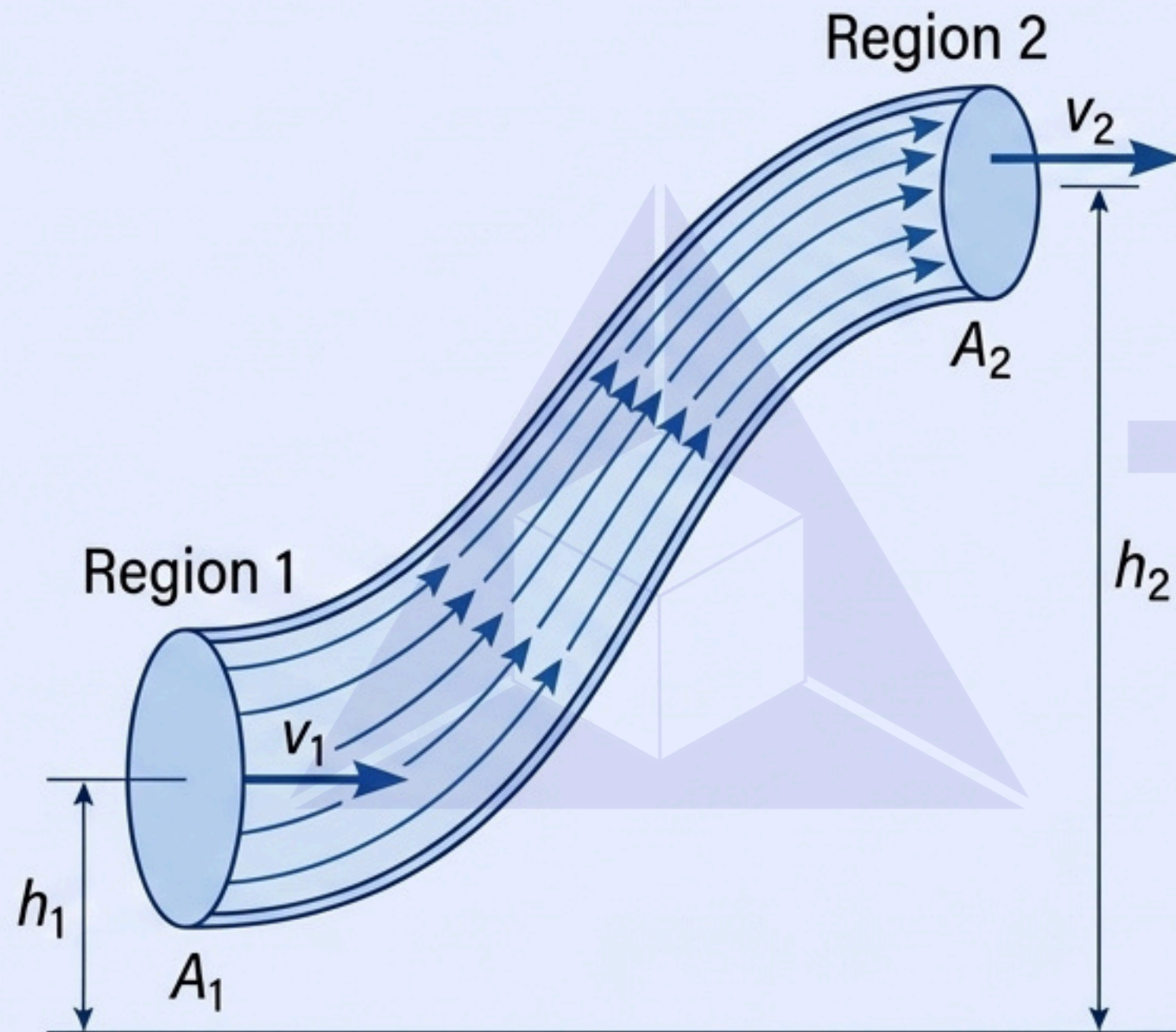
Master the core mechanics of steady fluid flow for NEET & JEE.

The Energy of a Flowing Fluid

As an incompressible fluid flows steadily through a pipe, work is done on it by pressure, and its height and speed change.

- **Pressure Work:** Fluid experiences different pressures in different regions.
- **Kinetic Energy:** Speed changes due to varying cross-sectional areas.
- **Potential Energy:** Elevation changes alter gravitational potential.

KEY ASSUMPTION: Fluid is incompressible, non-viscous, and flow is steady (streamline).



Bernoulli's Equation: The Ultimate Energy Balance

As we move along a streamline, the sum of pressure, kinetic energy, and potential energy remains perfectly constant.

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

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2$$

EXAM TIP: This is simply the Work-Energy Theorem applied to a fluid volume.



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$$E=mc^2$$



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Deconstructing the Equation: Energy Per Unit Volume

Energy Per Unit Volume



PRESSURE ENERGY

$$P$$

The pressure energy per unit volume of the fluid. Represents the work done by pressure forces.

KINETIC ENERGY

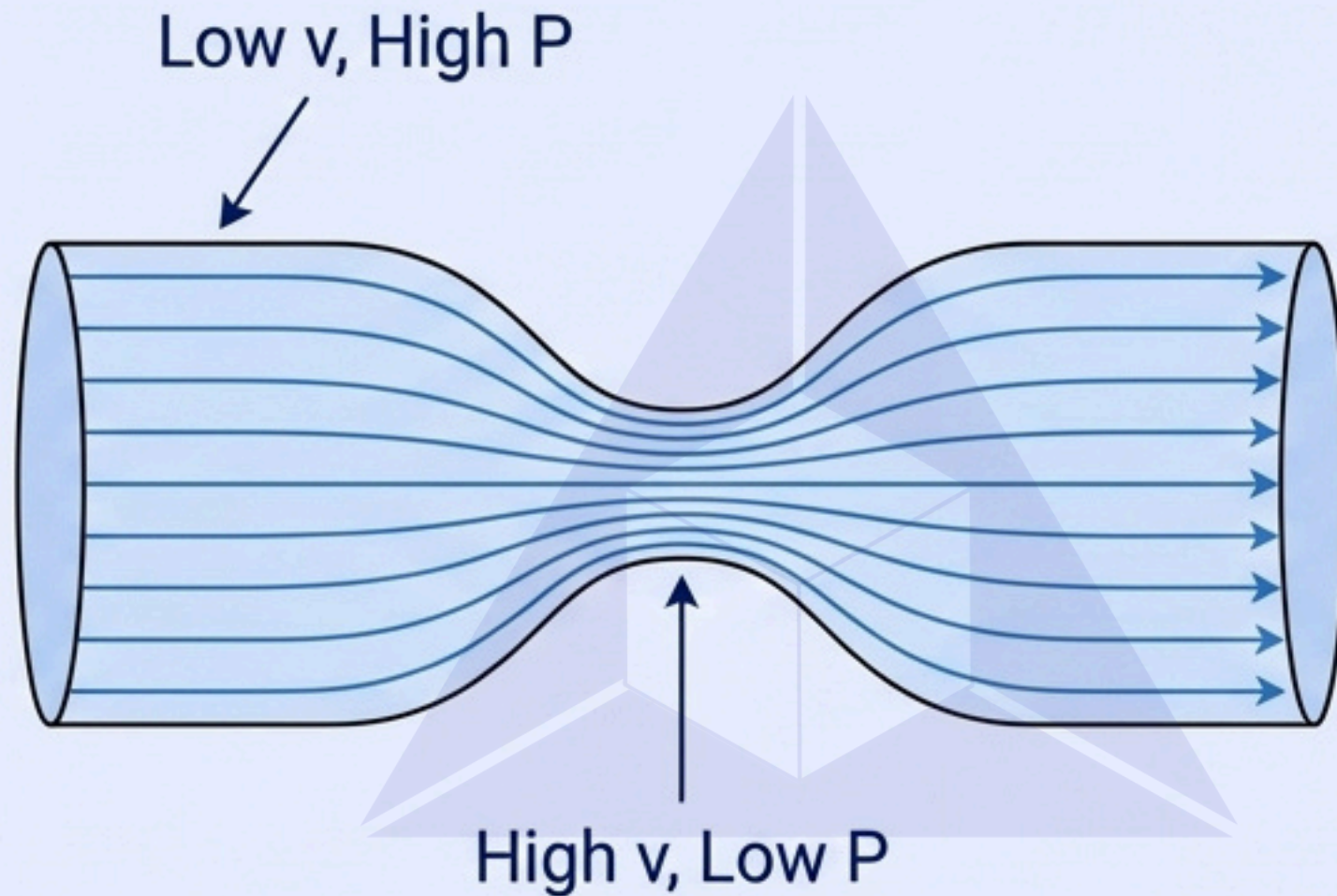
$$\frac{1}{2} \rho v^2$$

The kinetic energy per unit volume. Depends on the fluid's density (ρ) and velocity (v).

POTENTIAL ENERGY

$$\rho g h$$

The gravitational potential energy per unit volume. Depends on elevation (h).



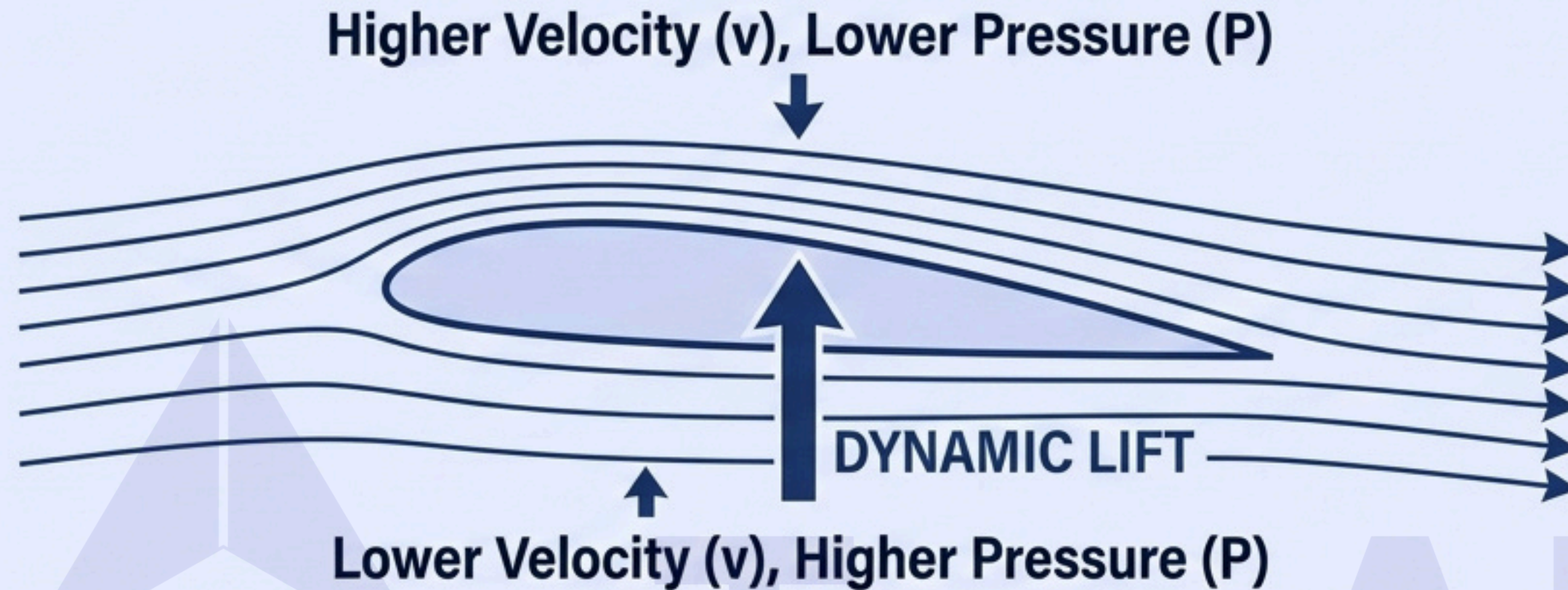
The Speed-Pressure Tradeoff

Horizontal Flow ($h_1 = h_2$)

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

- When a pipe is perfectly horizontal, potential energy (ρgh) cancels out.
- By the Equation of Continuity ($Av = \text{constant}$), fluid must speed up in narrower sections.
- To keep the total energy constant, as velocity (v) increases, pressure (P) must decrease.

Result: Faster flow = Lower pressure.



Application: Dynamic Lift

MAGNUS EFFECT: This same pressure differential causes spinning balls to curve!

- **The Shape:** An aerofoil forces air to travel a longer, faster path over the top of the wing.
- **The Flow:** Streamlines crowd together above the wing → Velocity (v) is higher.
- **The Pressure:** By Bernoulli's Principle, higher velocity above means lower pressure above.
- **The Lift:** The higher pressure below pushes the wing up, creating an upward force called Dynamic Lift.

Core Concepts to Remember

- Bernoulli's Principle is the conservation of energy applied to ideal, steady fluid flow.
- Total energy per unit volume ($P + \frac{1}{2}\rho v^2 + \rho gh$) remains constant along a streamline.
- In horizontal flow, an increase in fluid speed results in a decrease in pressure.
- This principle explains real-world phenomena like the dynamic lift of aircraft wings.



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