Fluids

AP Physics 1

Internal Structure and Density

The differences between solids, liquids, and gases come from how strongly their particles interact. A **fluid** 流体 (liquid or gas) has no fixed shape – it flows because its particles move past one another. **Density** 密度 is mass per unit volume:

$$\rho = \frac{m}{V}.$$

It depends on the substance and its state. An object sinks or floats depending on how its density compares with the surrounding fluid's – less dense floats, more dense sinks. An **ideal fluid** 理想流体 is **incompressible** 不可压缩 (constant density, whatever the pressure) and has no **viscosity** 黏度 (internal friction) – the model AP uses throughout.

Pressure

Pressure 压强 is the perpendicular force per unit area, a **scalar** 标量 measured in pascals (Pa):

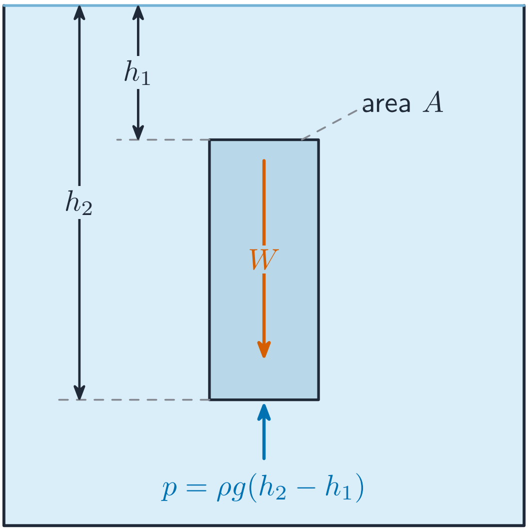
$$P = \frac{F_\perp}{A}.$$

In a fluid at rest, pressure increases with **depth** 深度 because of the weight of fluid above:

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

where P_0 is the pressure at the surface and h is the depth. Pressure acts **equally in all directions** at a point and pushes **perpendicular** to any surface.

Distinguish the two pressures AP asks about: the **gauge pressure** 表压 is the extra pressure the fluid column adds, $P_{\text{gauge}} = \rho g h$, while the **absolute pressure** 绝对压强 is the total, $P = P_0 + P_{\text{gauge}}$ (with P_0 usually atmospheric). A tyre gauge reading "200 kPa" is gauge pressure; the air inside is really at about 300 kPa absolute.



The weight of a liquid column sets the extra pressure at a depth

Worked example. Find the total pressure on a diver 10 m below the surface of water ($\rho = 1000\ \mathrm{kg/m^3}$, surface pressure $P_0 = 1.0 \times 10^5$ Pa):

$$P = P_0 + \rho g h = 1.0 \times 10^5 + 1000 \times 9.8 \times 10 = 1.98 \times 10^5\ \text{Pa}.$$

Every 10 m of water adds roughly one extra atmosphere of pressure. Notice the pressure does not depend on the shape or width of the container, only on the depth.

An aneroid barometer measures air pressure with a sealed metal box that flexes as the pressure outside changes

Fluids and Newton's Laws

An object in a fluid feels an upward **buoyant force 浮力** equal to the weight of the fluid it displaces – **Archimedes' principle 阿基米德原理**:

$$F_b = \rho_{\text{fluid}}\, g\, V_{\text{displaced}}.$$

Combine this with Newton's laws: the object floats when buoyancy balances weight, sinks when weight wins, and rises when buoyancy wins. A floating object displaces exactly its own weight of fluid.

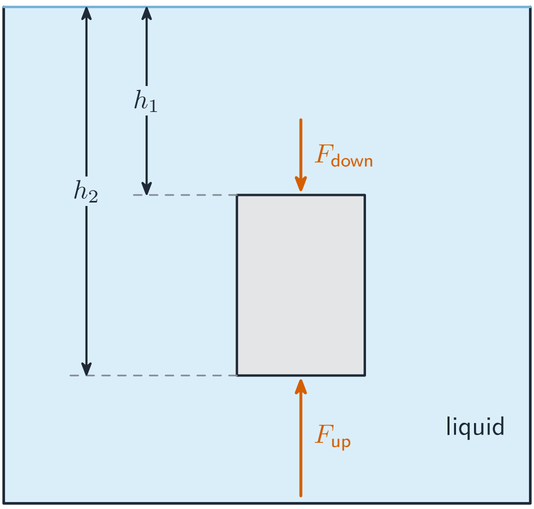
Worked example. A block of density 600 kg/m^3 floats in water (1000 kg/m^3). What fraction is under the surface? For floating, the buoyant force equals the weight, so $\rho_{\text{fluid}}\, g\, V_{\text{sub}} = \rho_{\text{object}}\, g\, V$:

$$\frac{V_{\text{sub}}}{V} = \frac{\rho_{\text{object}}}{\rho_{\text{fluid}}} = \frac{600}{1000} = 0.60.$$

So 60% sits below the water – the same reason most of an iceberg (density $\approx$ 900) hides underwater.

Fluids and Conservation Laws

For an ideal fluid flowing steadily, two conservation ideas apply:



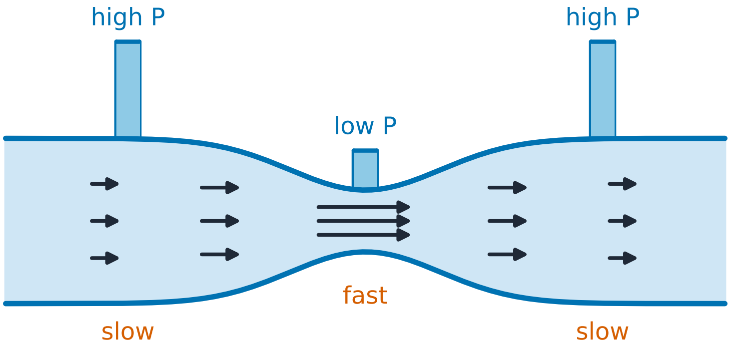
Upthrust arises because the pressure on the bottom of an object exceeds that on the top

- **Continuity 连续性** (conservation of mass): the volume flow rate is constant, so $A_1 v_1 = A_2 v_2$. A narrower pipe forces **faster** flow.

- **Bernoulli's equation** 伯努利方程 (conservation of energy per volume): along a streamline,

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

Together they explain why fluid speeds up and its pressure drops where a pipe narrows or where flow is fastest.



$$A_1 v_1 = A_2 v_2 \quad \cdot \quad P + \tfrac{1}{2}\rho v^2 = \text{const} \ \ \text{(horizontal)}$$

Where the pipe narrows the fluid speeds up (continuity) and its pressure drops (Bernoulli)

Worked example. Water flows at 2.0 m/s through a pipe of cross-section 0.010 m^2, then enters a narrower section of 0.0040 m^2. By continuity the speed there is

$$v_2 = \frac{A_1 v_1}{A_2} = \frac{0.010 \times 2.0}{0.0040} = 5.0 \text{ m/s}.$$

By Bernoulli's equation this faster stream is at **lower** pressure – the effect that lifts an aeroplane wing and pulls two passing ships together.

Exam skill. Choose the right law by what changes. If the pipe changes *width*, start with continuity ($A_1 v_1 = A_2 v_2$) to get the speeds; if you then need a *pressure*, feed those speeds into Bernoulli. Watch the height term $\rho g y$ only when the pipe also changes level.

Exam tips

- Pressure with depth is $P = P_0 + \rho g h$ — it depends on **depth only**, not the container's shape or width.

- **Buoyant force** = weight of fluid displaced ($\rho_{\text{fluid}}\, g V_{\text{disp}}$); a floating object displaces its own weight, so the fraction submerged is $\rho_{\text{object}}/\rho_{\text{fluid}}$.
- Compare densities to predict floating vs sinking; a floating object is in equilibrium (buoyancy = weight), not weightless.
- Use **continuity** $A_1 v_1 = A_2 v_2$: a narrower pipe means faster flow.
- **Bernoulli**: where a fluid flows faster its pressure is lower (wing lift, spray).