

Density, pressure, buoyancy and moving fluids

AP Physics 1 (algebra-based) · Lesson

Quick answer: Fluids obey a few linked rules: density is mass per volume, pressure rises with depth as $P = P_0 + \rho gh$, buoyant force equals the weight of fluid displaced, continuity says $A v$ is constant in a pipe, and Bernoulli shows that faster flow means lower pressure.

Level: AP Physics 1 (algebra-based) · **Curriculum:** AP P1 Unit 8

What are density and pressure?

Density tells you how much mass is packed into a given volume. A litre of cooking oil has less mass than a litre of water, which is why oil spreads over the top of a pan of water. Pressure tells you how a force is spread over a surface. Liquids and gases are both fluids, and in a fluid at rest the pressure pushes on every surface it touches, always at right angles to that surface.

Definition
Density is mass per unit volume, $\rho = m/V$, measured in kg/m^3 . **Pressure** is the force acting perpendicular to a surface divided by the area of that surface, $P = F/A$, measured in pascals ($1 \text{ Pa} = 1 \text{ N/m}^2$).

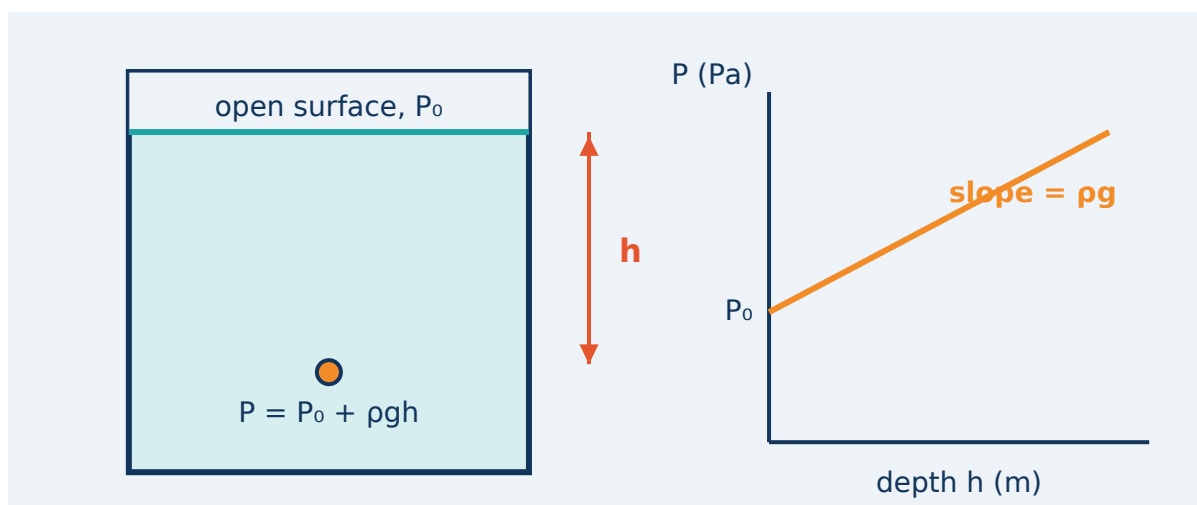
Material	Density (kg/m^3)
Air (room temperature)	1.2
Cooking oil	920
Ice	917
Fresh water	1000
Seawater	1025
Aluminium	2700
Mercury	13600

How does pressure change with depth?

Picture the water above Chiamaka as she dives in a lake near Lagos. Every layer above her adds weight, so the deeper she goes, the more the fluid above pushes down. The pressure also includes the push of the atmosphere on the surface. The result is a simple straight-line law that depends only on depth, not on the width or shape of the container.

Key law
In a fluid of constant density at rest, the **absolute pressure** at depth h is $P = P_0 + \rho gh$. The term ρgh is the **gauge pressure**, and P_0 is the pressure at the surface ($1.01 \times 10^5 \text{ Pa}$)

for open air at sea level).



Pressure grows in a straight line with depth. The slope of the graph is ρg .

Worked example

Chiamaka dives to 12 m in fresh water. Find the absolute pressure.

Data: $\rho = 1000 \text{ kg/m}^3$, $g = 9.81 \text{ m/s}^2$, $P_0 = 1.01 \times 10^5 \text{ Pa}$. $\rho gh = 1000 \times 9.81 \times 12 = 1.18 \times 10^5 \text{ Pa}$. $P = 1.01 \times 10^5 + 1.18 \times 10^5 = \mathbf{2.19 \times 10^5 \text{ Pa}}$, about twice atmospheric pressure.

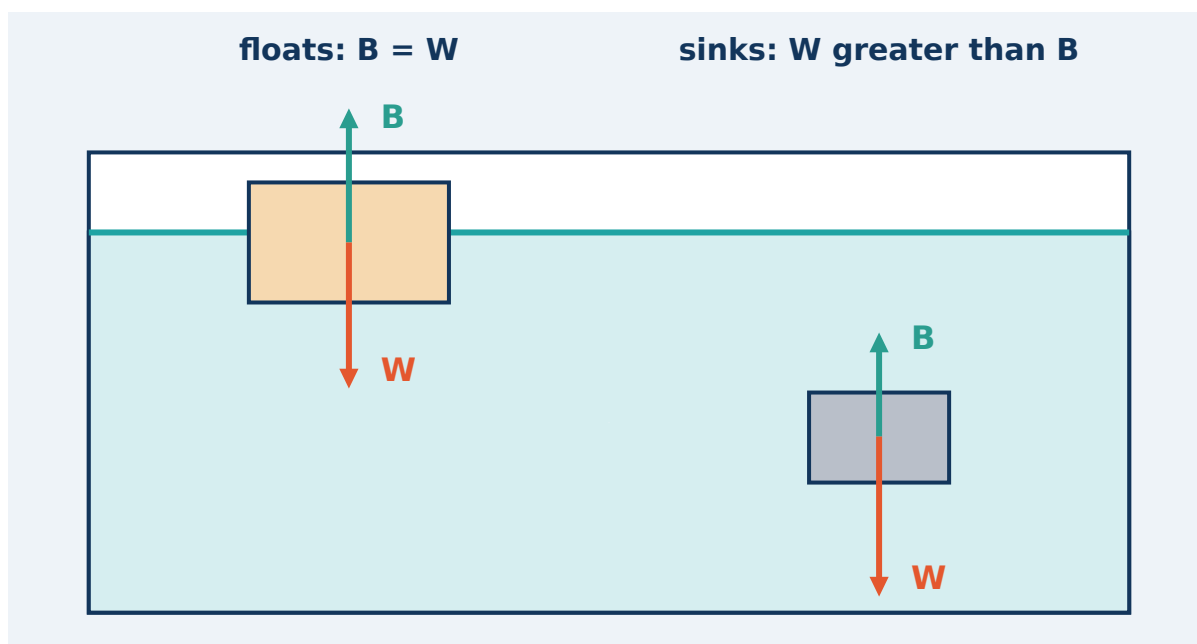
What is the buoyant force?

Pressure grows with depth, so the water pushes up on the bottom of a submerged object harder than it pushes down on the top. The difference is an upward force. Archimedes found that this force equals the weight of the fluid the object pushes aside.

Formula

$$F_B = \rho_{\text{fluid}} V_{\text{sub}} g$$

F_B is the buoyant force (N), ρ_{fluid} the fluid density (kg/m^3), V_{sub} the submerged volume (m^3) and $g = 9.81 \text{ m/s}^2$. An object floats when ρ_{object} is less than ρ_{fluid} .



Both blocks feel an upward buoyant force B and a downward weight W . Only the floating block has them equal.

Worked example

Wanjiru places a block of mass 0.60 kg and volume $1.0 \times 10^{-3} \text{ m}^3$ in water. Does it float, and how much is submerged?

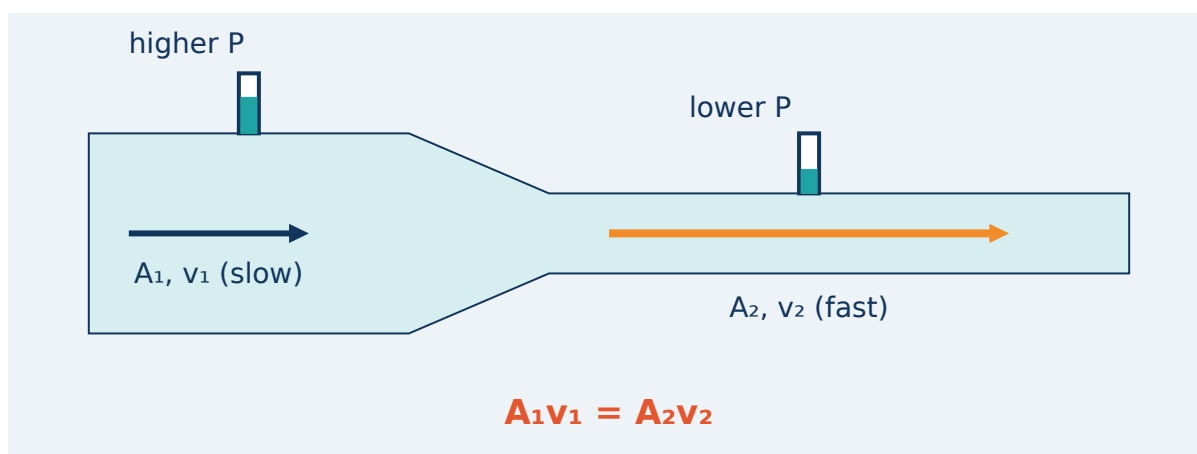
$\rho = 0.60 / 1.0 \times 10^{-3} = 600 \text{ kg/m}^3$, below 1000 , so it floats. At rest $F_B = W = 0.60 \times 9.81 = \mathbf{5.9 \text{ N}}$. Then $V_{\text{sub}} = 5.886 / (1000 \times 9.81) = 6.0 \times 10^{-4} \text{ m}^3$, so **60 %** of the block is under water.

What does the continuity equation say?

Water is almost incompressible, so the volume that enters one end of a pipe each second must leave the other end. Where the pipe is narrow, the water has to move faster. This is why your thumb over a hose makes the jet shoot out.

Key law

Continuity: $A_1 v_1 = A_2 v_2$. The volume flow rate $Q = Av$ (in m^3/s) is the same at every section of a pipe of steady, incompressible flow.



The same volume per second passes every section, so the narrow part is faster and has the lower pressure.

Worked example

Aarav's main pipe has a diameter of 4.0 cm and carries water at 0.80 m/s. It narrows to 2.0 cm. Find the new speed.

Area scales with diameter squared, so $A_1/A_2 = (4.0/2.0)^2 = 4$. Then $v_2 = 4 \times 0.80 = \mathbf{3.2 \text{ m/s}}$. The flow rate is $Q = \pi(0.020)^2 \times 0.80 = 1.0 \times 10^{-3} \text{ m}^3/\text{s}$, which is 1.0 litre per second.

How does Bernoulli's equation link speed and pressure?

Bernoulli's equation is energy conservation for a flowing fluid. Along a streamline, pressure energy, kinetic energy and gravitational energy per unit volume trade off, so faster fluid at the same height has lower pressure.

Key law

$P + \frac{1}{2}\rho v^2 + \rho gy = \text{constant}$ along a streamline, for steady, incompressible flow without friction.

Worked example

Water at 2.0 m/s and $1.80 \times 10^5 \text{ Pa}$ enters a horizontal pipe section where it speeds up to 6.0 m/s. Find the new pressure.

Same height, so $P_2 = P_1 + \frac{1}{2}\rho(v_1^2 - v_2^2) = 1.80 \times 10^5 + 500 \times (4.0 - 36) = 1.80 \times 10^5 - 1.6 \times 10^4 = \mathbf{1.64 \times 10^5 \text{ Pa}}$.

Common mistake

Do not use the buoyant force formula with the whole volume of a floating object. Only the submerged part pushes water aside. Also remember that pressure depends on depth, never on how wide the container is.

Lina's tip

Before any fluid problem, ask which law applies: depth ($P_0 + \rho gh$), buoyancy (displaced weight), same flow rate ($A v$), or speed change (Bernoulli). Name it first, then write the equation.

Key points to remember

- Density $\rho = m/V$ in kg/m^3 ; pressure $P = F/A$ in pascals
- Pressure at depth: $P = P_0 + \rho gh$, with $P_0 = 1.01 \times 10^5 \text{ Pa}$ at sea level
- Buoyant force $F_B = \rho_{\text{fluid}} V_{\text{sub}} g$; it floats when the object's density is lower
- Continuity for incompressible flow: $A_1 v_1 = A_2 v_2$
- Bernoulli: $P + \frac{1}{2}\rho v^2 + \rho gy$ is constant along a streamline

Density, pressure, buoyancy and moving fluids: frequently asked questions

What is the difference between gauge pressure and absolute pressure?

Gauge pressure is the pressure above atmospheric pressure, ρgh in a liquid. Absolute pressure adds the atmospheric pressure at the surface, so $P = P_0 + \rho gh$. A tyre gauge reads gauge pressure.

Why does a steel ship float when a steel nail sinks?

A hull encloses a large volume of air, so the ship's average density is below that of water. It pushes aside enough water to equal its weight, while a solid nail cannot.

Does water pressure depend on the shape of the container?

No. At a given depth the pressure depends only on the depth, the fluid density and the surface pressure. A narrow tube and a wide lake give the same pressure at the same depth.

Why does water speed up in a narrower pipe?

Water is nearly incompressible, so the volume per second must be the same everywhere. A smaller area therefore needs a larger speed, following $A_1 v_1 = A_2 v_2$.

When can Bernoulli's equation be used?

Use it for steady flow of an incompressible fluid with negligible friction, along one streamline. It fails when the flow is turbulent, when energy is added by a pump or when friction is large.