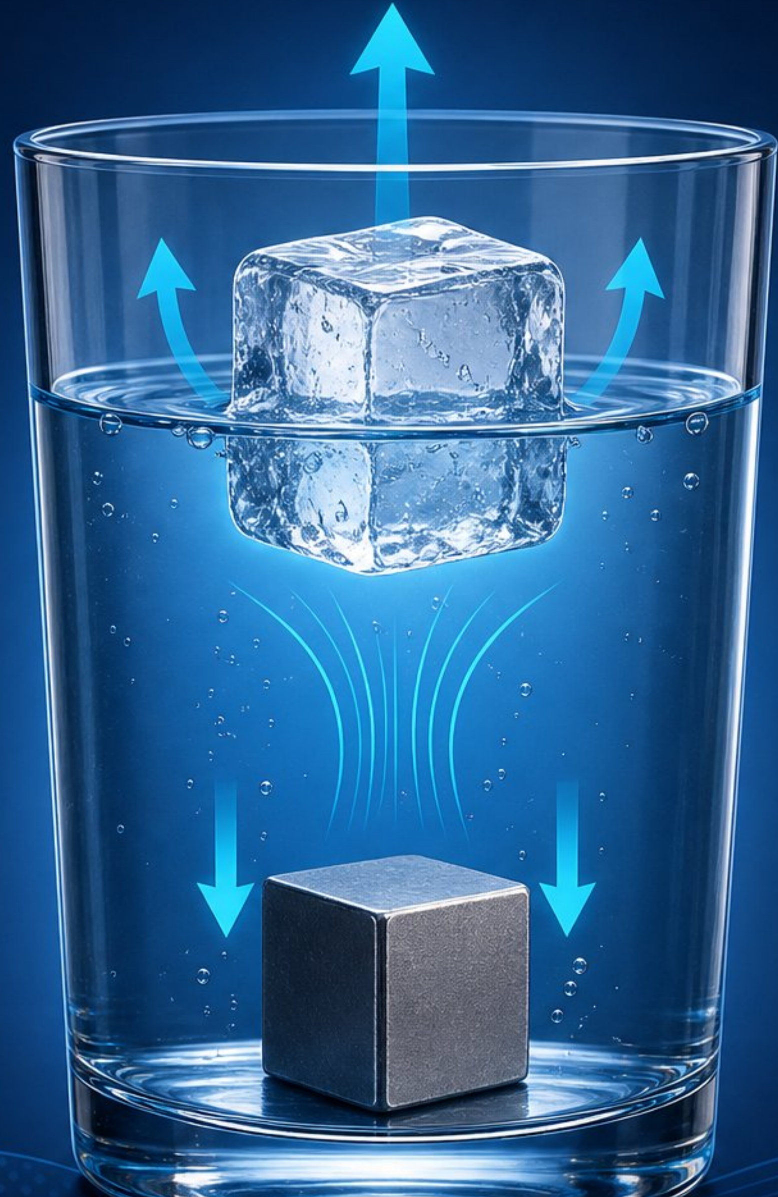
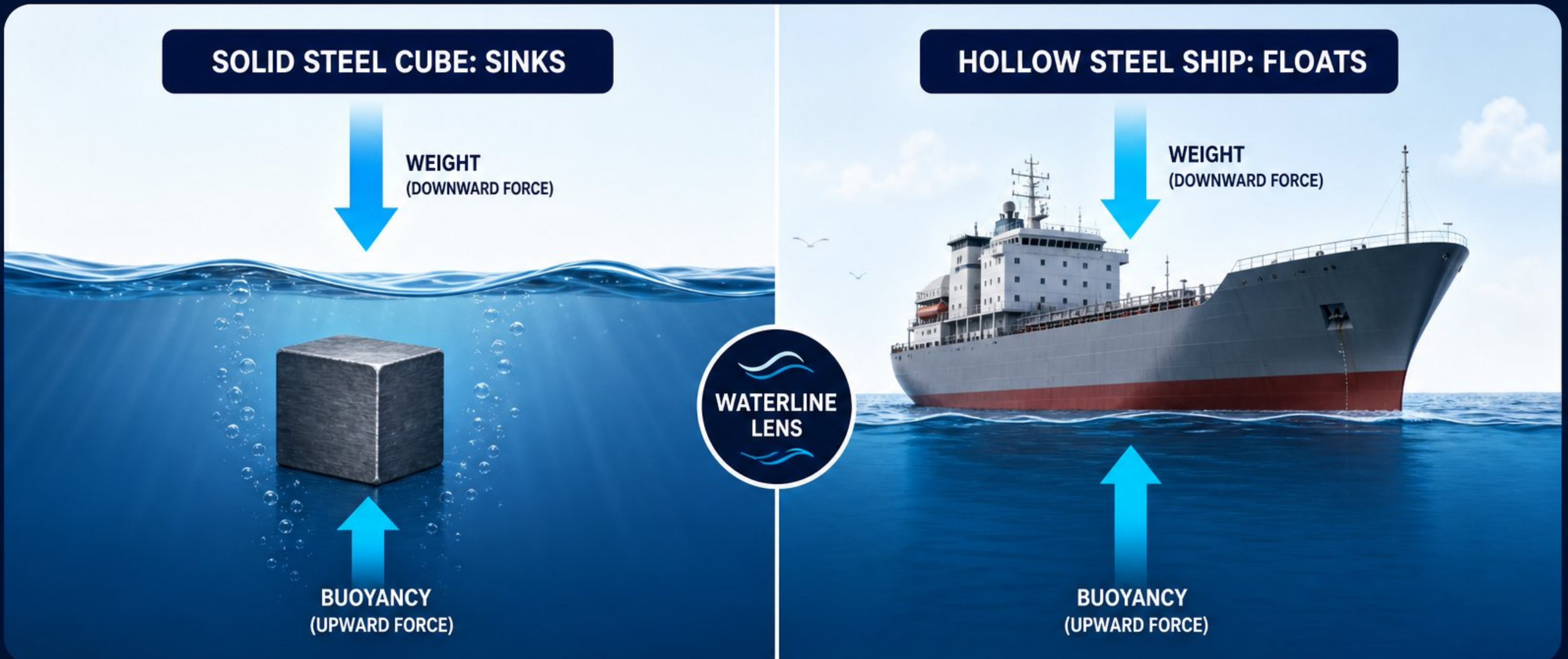
Why Objects Float: Density, Displacement, and Buoyancy

- Why do some objects float, sink, or remain suspended?
- Three key concepts: density, displacement, and buoyancy
- Learning objective: Explain floating, sinking, and suspension using density and displaced fluid

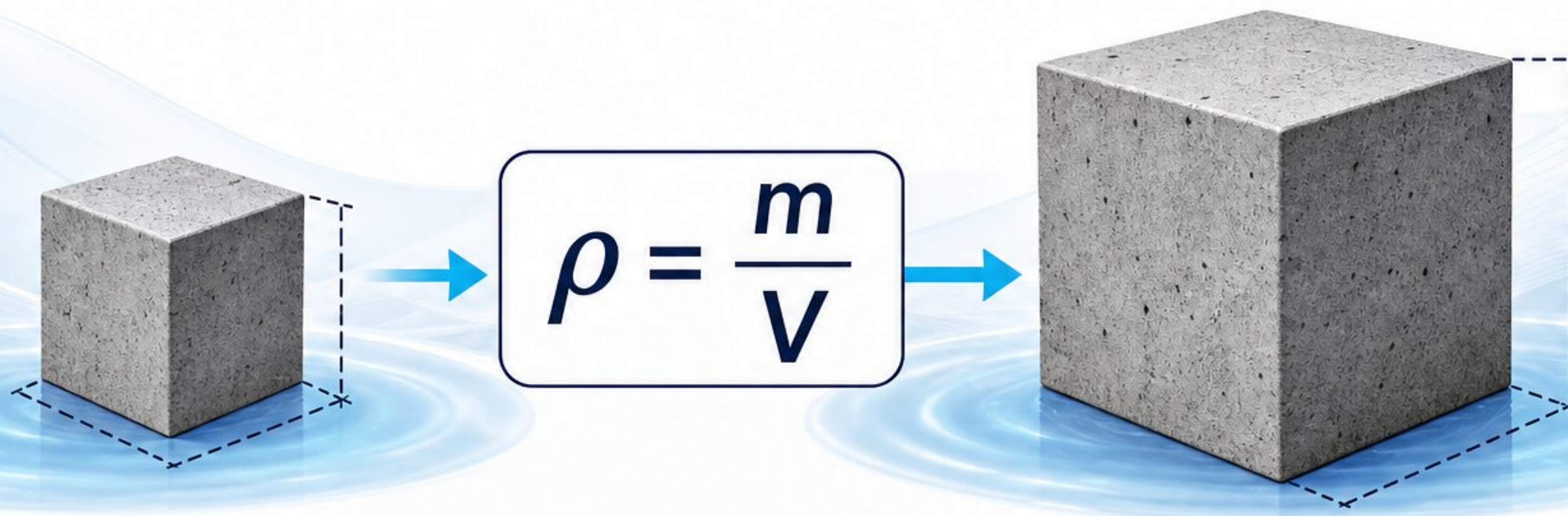


The Big Misconception: Weight vs. Density



- Heavy sinks, light floats is a common but incorrect belief
- Solid steel cube sinks; hollow steel ship floats
- Same material, different outcomes: weight alone doesn't decide
- Density, not weight or mass, is the critical property

Defining Density: Mass, Volume, and Material Identity

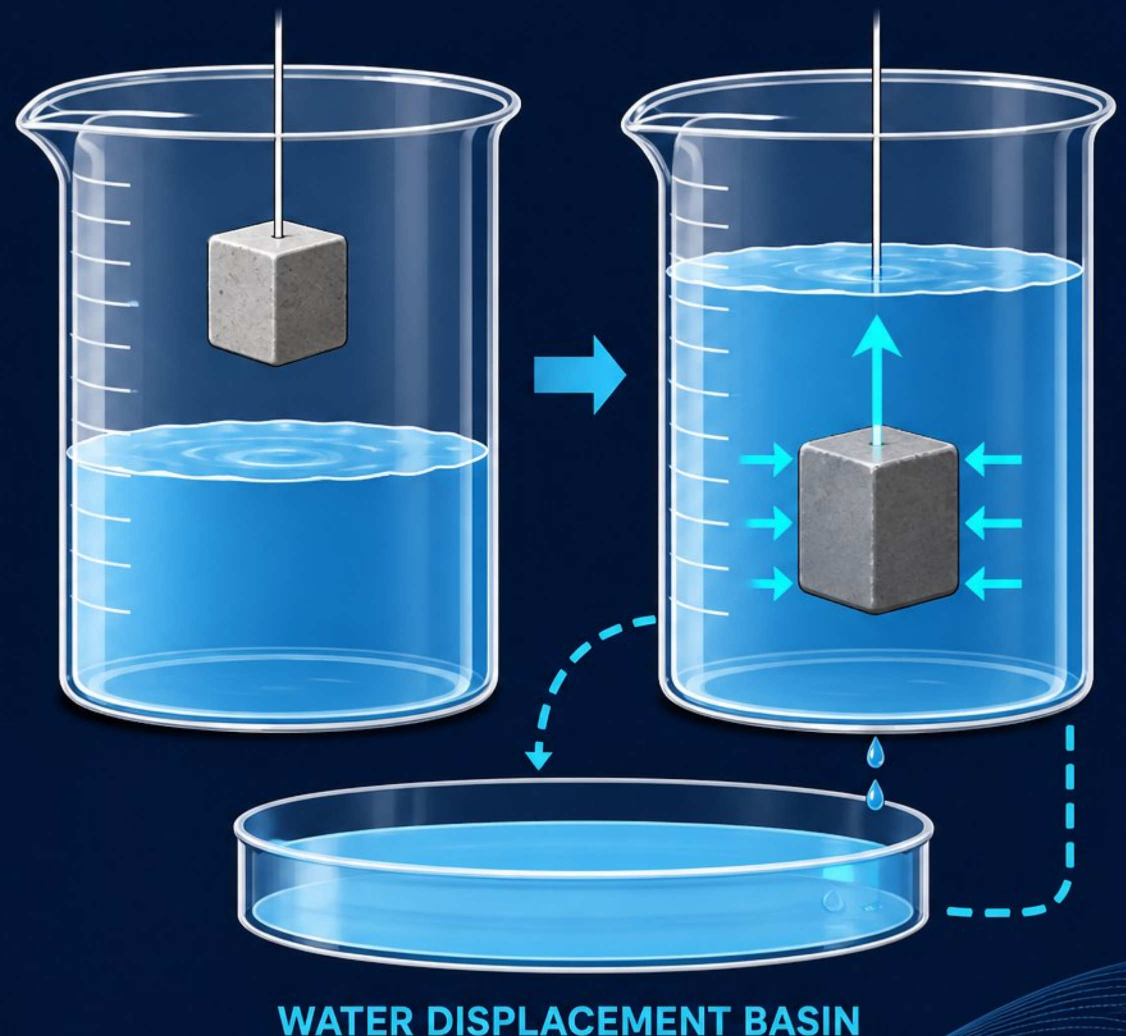


$$\rho = \frac{m}{V}$$

- Density is mass per unit volume: $\rho = m / V$
- Density is an intrinsic property, not affected by object size
- SI units: kg/m^3; common lab units: g/cm^3
- Reference densities: water 1000, ice 917, steel 7850 (kg/m^3)
- Wood density varies widely: ~600–750 kg/m^3

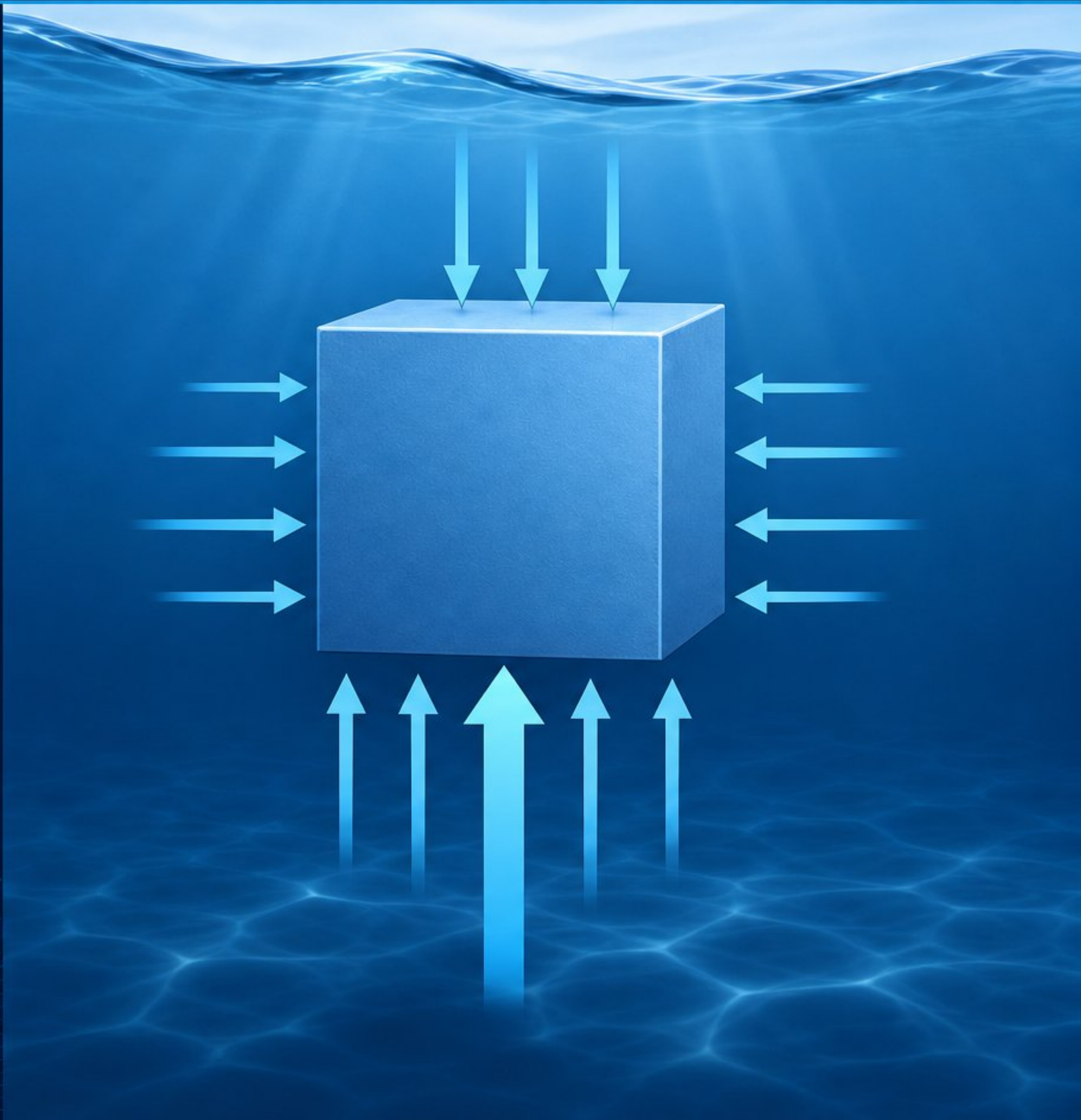
Archimedes' Principle: The Principle of Displacement

- A submerged object displaces its own volume of fluid
- The weight of displaced fluid creates the upward buoyant force
- More submerged volume = more fluid displaced = greater force
- Water level rises by exactly the object's submerged volume

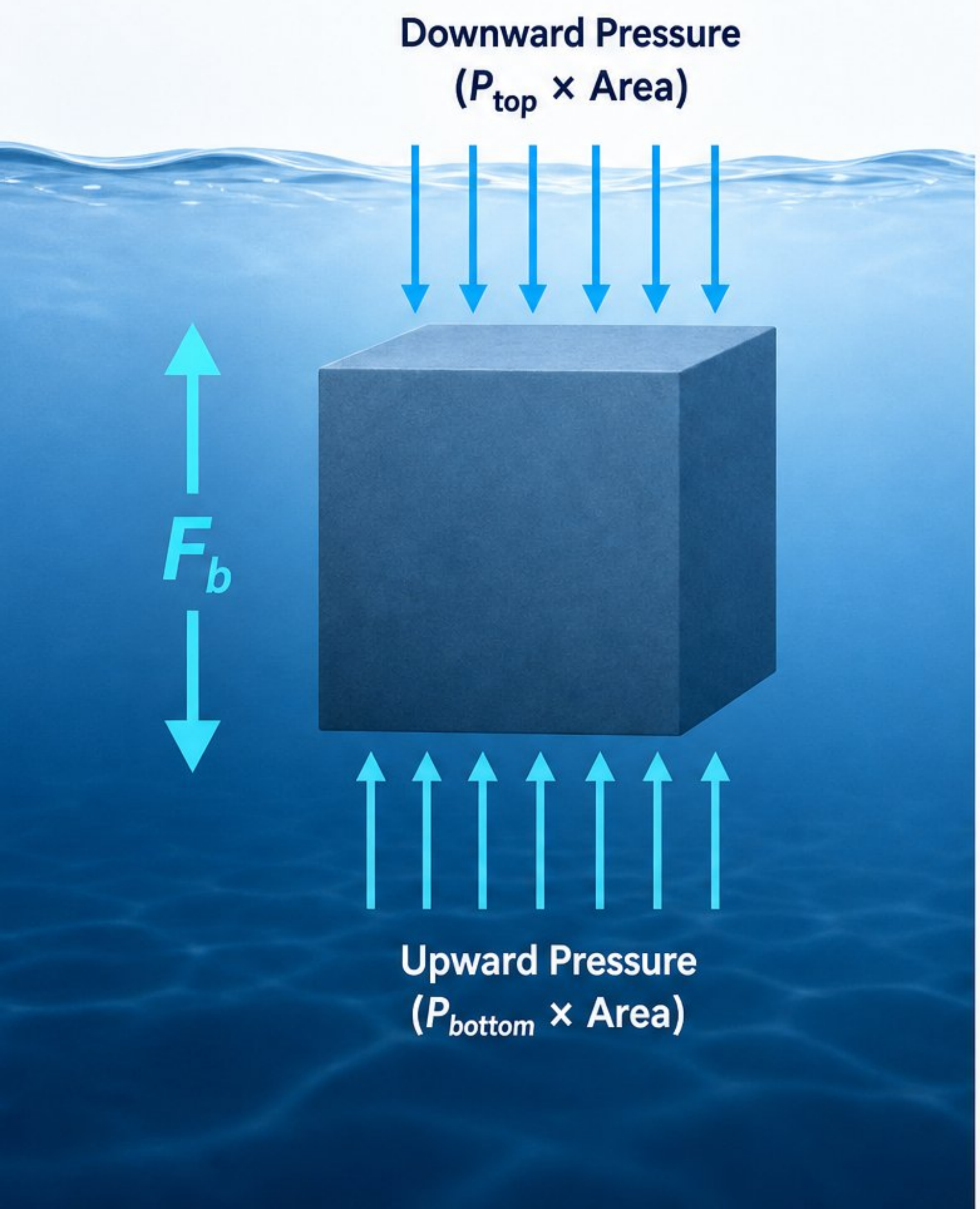


The Origin of Buoyant Force: Fluid Pressure Differences

- Fluid pressure increases with depth
- Higher pressure at bottom creates net upward push
- This net pressure force is the buoyant force
- Acts on every object in fluid, floating or sinking



The Buoyant Force Equation

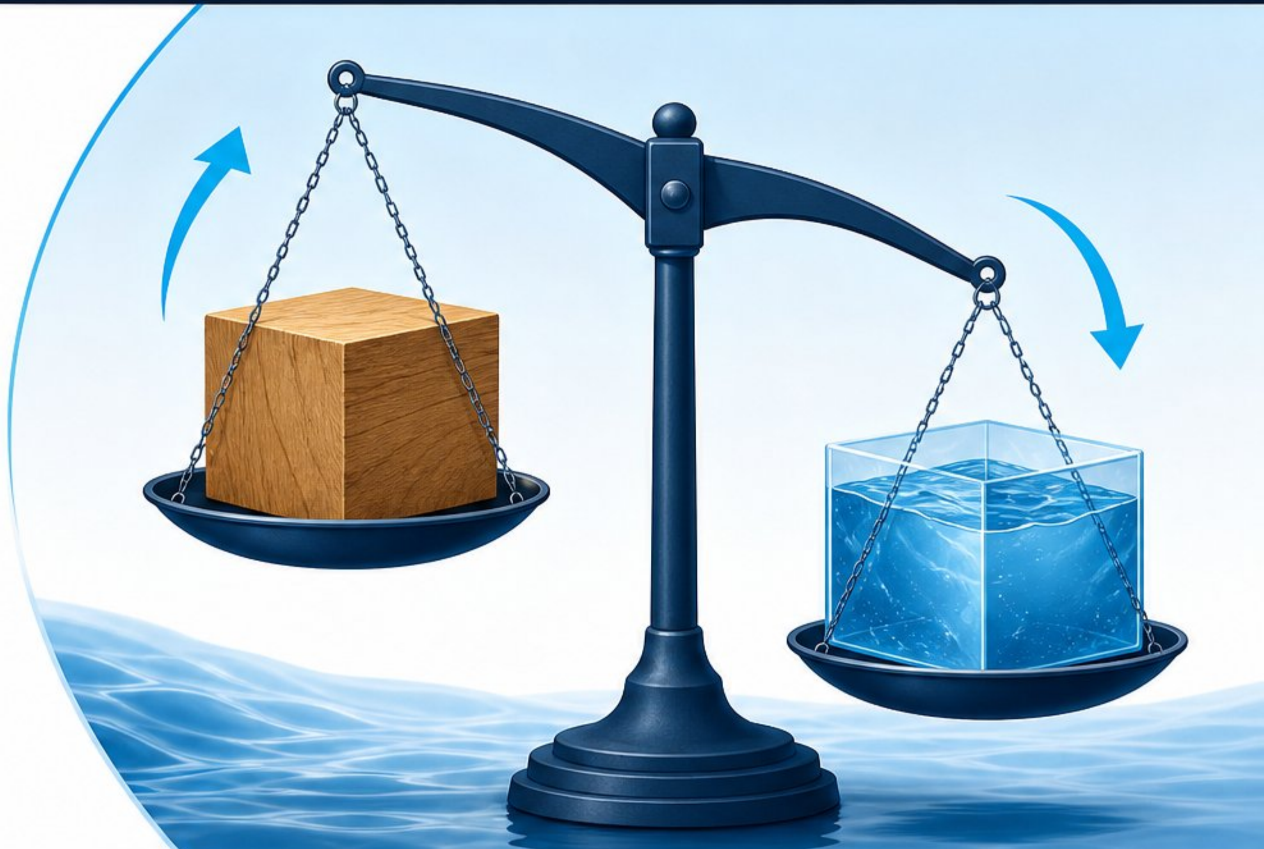


$$F_b = \rho_{fluid} \times V_{displaced} \times g$$

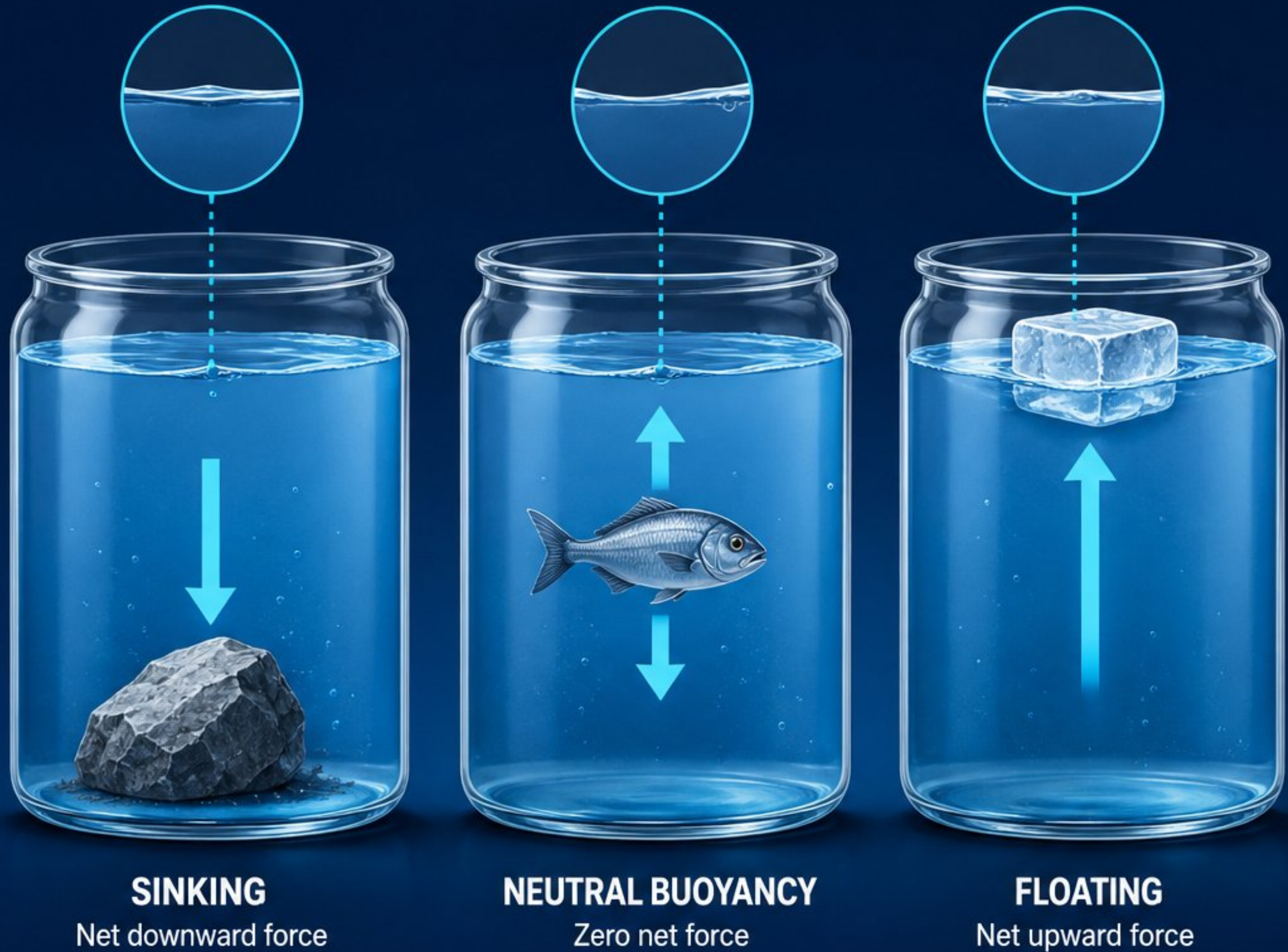
- $F_b = \rho_{fluid} \times V_{displaced} \times g$
- Derives from pressure difference: $(P_{bottom} - P_{top}) \times \text{Area}$
- Buoyant force = weight of displaced fluid
- Depends only on fluid density and displaced volume

The Floating Rule: Comparing Densities

- Objects float when average density is less than fluid density
- Sinking stops when displaced fluid weight equals object weight
- Average density accounts for hollow spaces and composite materials
- Steel ships float because hull encloses air, lowering average density



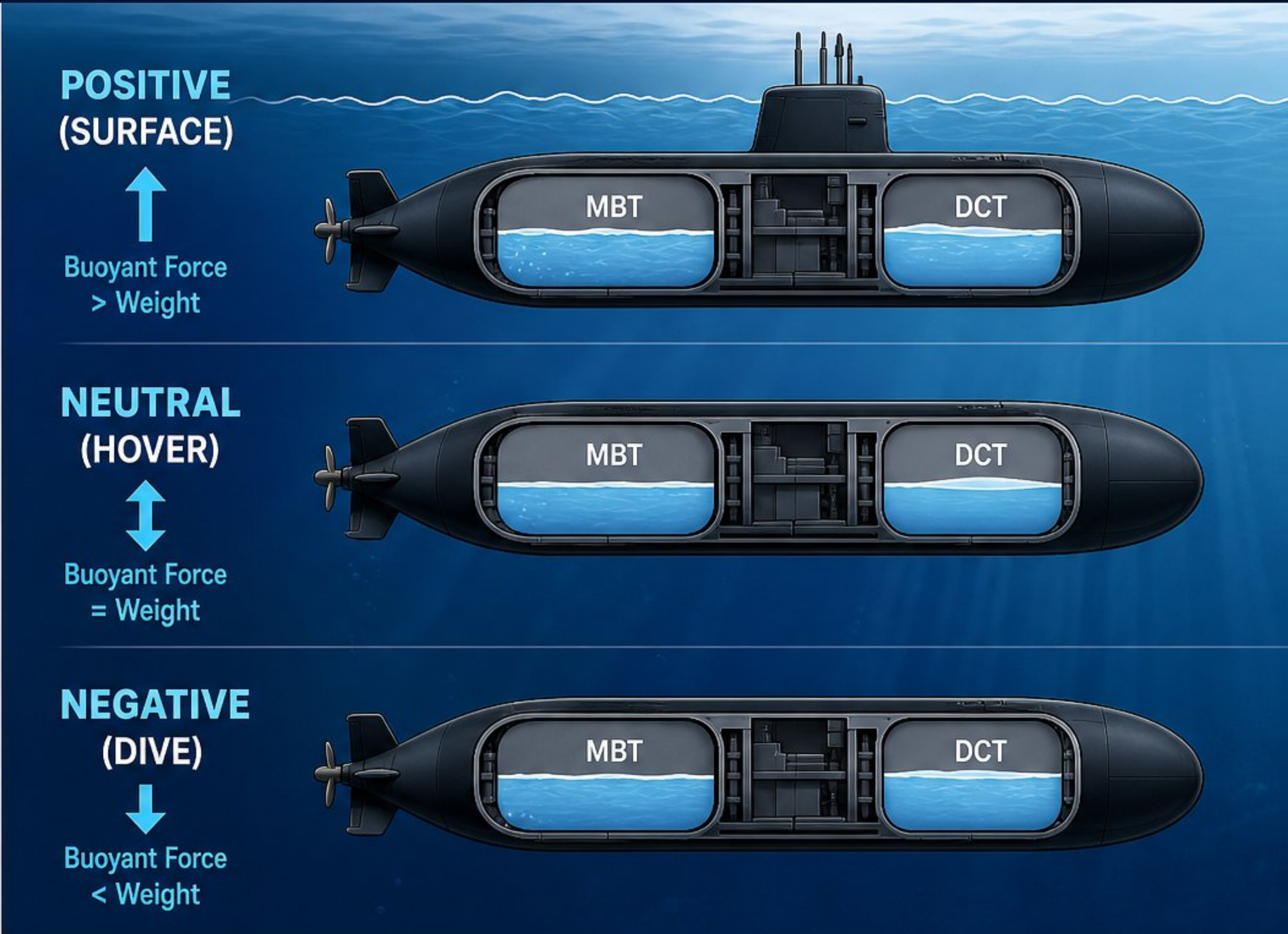
Sinking, Suspension, and Neutral Buoyancy



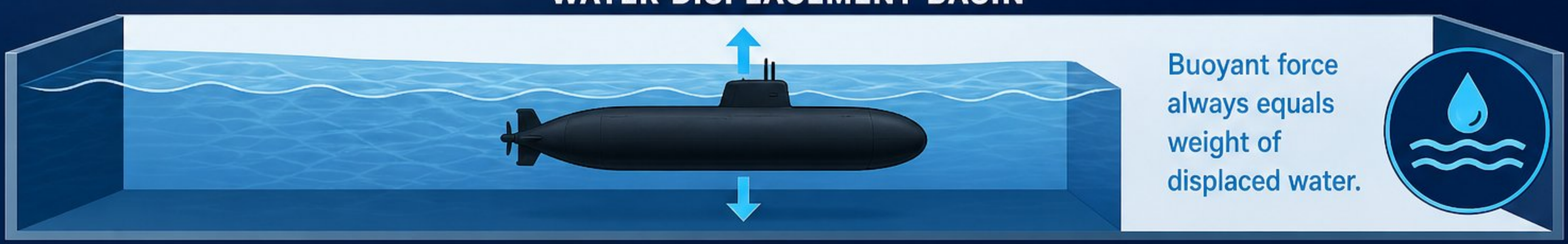
- Sinking: object density > fluid density → net downward force
- Neutral buoyancy: object density = fluid density → zero net force
- Floating: object density < fluid density → net upward force
- Examples: rock sinks, submarine hovers, ice floats
- Average density determines outcome, not shape alone

Case Study: How Submarines Control Buoyancy

- Ballast tanks change average density without changing hull volume
- Three states: positive (surface), neutral (hover), negative (dive)
- Main Ballast Tanks (MBT) handle large buoyancy shifts
- Depth Control Tanks (DCT) fine-tune neutral buoyancy
- Buoyant force always equals weight of displaced water

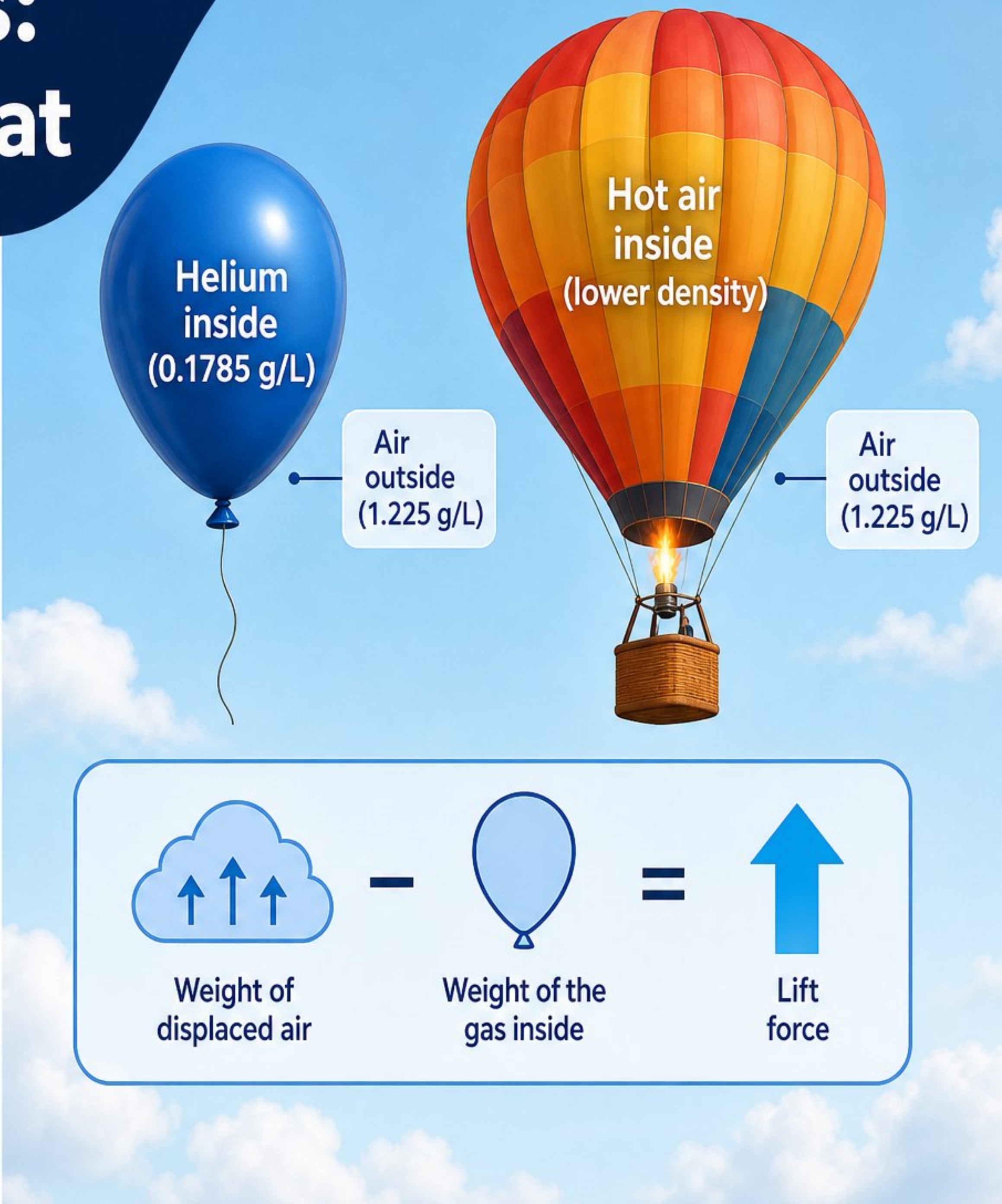


WATER DISPLACEMENT BASIN



Density in Gases: Why Balloons Float

- Archimedes' principle applies to all fluids: liquids and gases
- Helium balloons float: helium (0.1785 g/L) is less dense than air (1.225 g/L)
- Hot air balloons rise because heated air has lower density
- Lift force = weight of displaced air minus weight of the gas inside



Practical Problem-Solving: Predict Float or Sink

Waterline Lens

1 Identify fluid density

ρ_{fluid}

2 Find object's average density

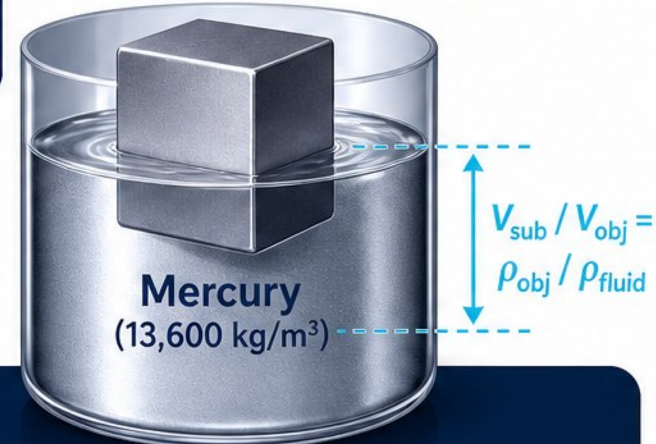
ρ_{obj}

3 Compare the two densities directly

ρ_{obj} vs. ρ_{fluid}

$\rho_{obj} < \rho_{fluid}$ **Float**

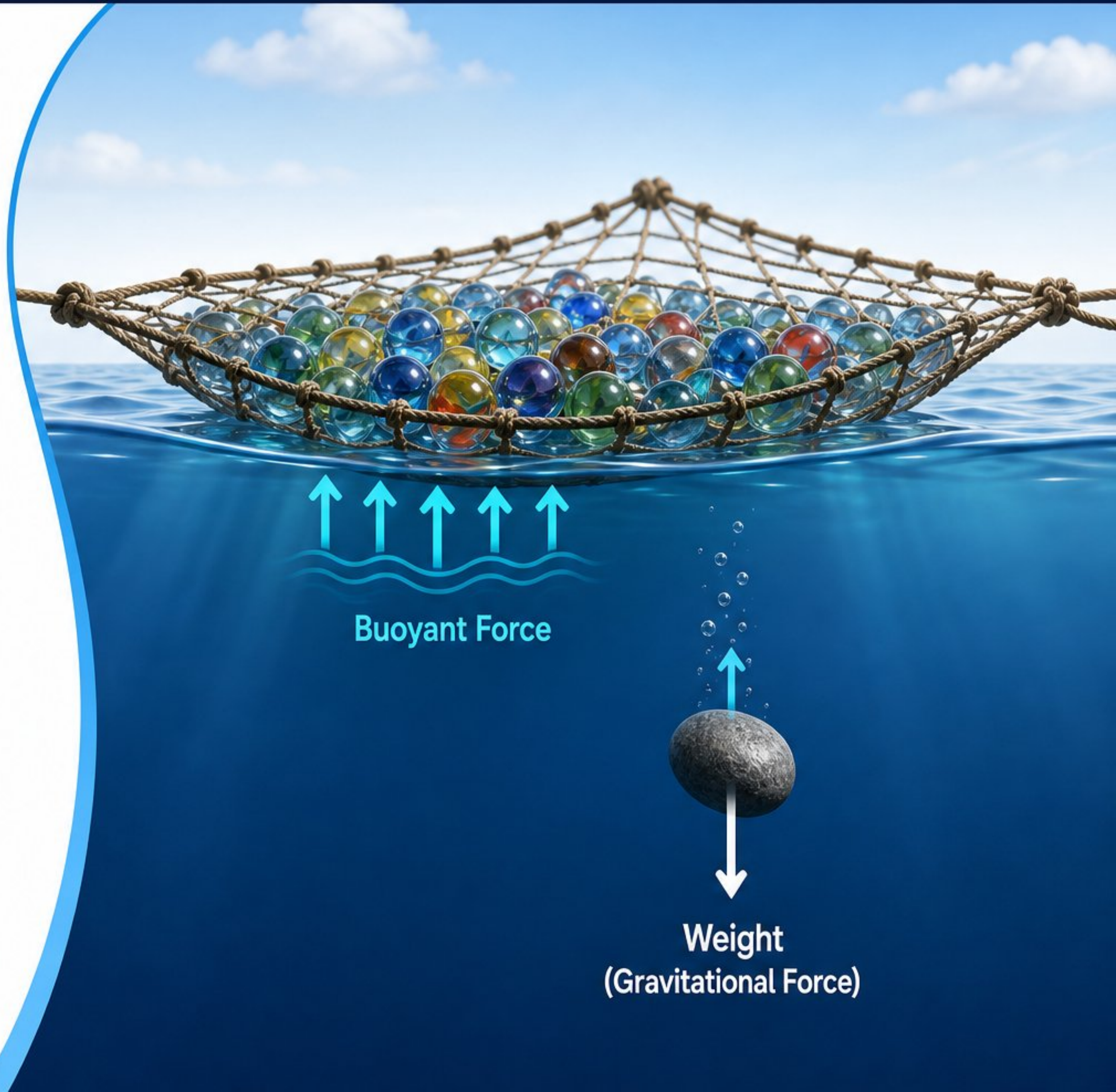
$\rho_{obj} > \rho_{fluid}$ **Sink**



- Step 1: Identify fluid density, Step 2: Find object's average density
- Step 3: Compare the two densities directly
- Example: Aluminum (2700 kg/m^3) floats in mercury (13,600 kg/m^3)
- Submerged fraction: $V_{sub} / V_{obj} = \rho_{obj} / \rho_{fluid}$
- Many metals float in mercury; gold (19,300 kg/m^3) sinks

Common Pitfalls and Misconceptions

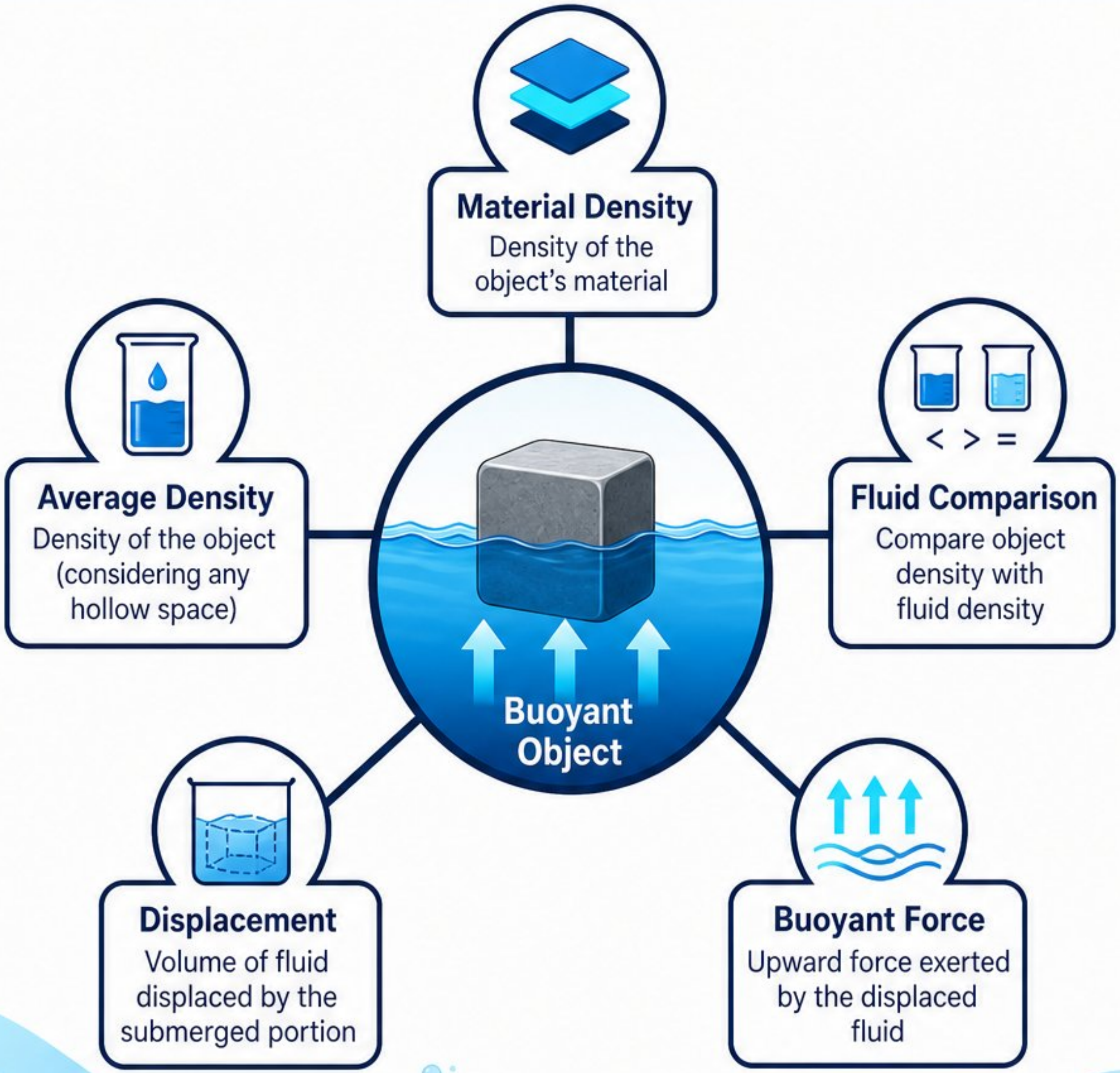
- Heavy objects can float if volume makes average density low
- Shape alone does not decide; only average density matters
- Buoyant force depends on fluid density, not object density
- Gases like helium add mass; total density must be lower than air



Applying Concepts to Everyday Examples

- Ice floats on water because it is less dense
- Cork floats in water but sinks in air
- Oil floats on water (less dense) and sinks in air
- Hot air balloons rise until density equals surrounding air

Summary: The Density-Displacement-Buoyancy Chain



Density → Compare with fluid → Displacement → Buoyant force

- **Float:** object density < fluid density
- **Sink:** object density > fluid density
- **Suspend:** object density = fluid density (neutral buoyancy)
- **Predict outcomes:** identify densities, compare, calculate submerged fraction
- **Test with household items:** ice, oil, cork, metal objects