# FLUIDS DAY 2: BUOYANCY

**Physics in the Wild — Steel Ships & Hot Air:** A solid steel ball sinks instantly, yet a steel ship carrying thousands of tons floats. The trick is shape: a ship displaces a huge volume of water, more than the steel alone would. The displaced water's weight exceeds the ship's, and it floats. Hot-air balloons do the same with air.

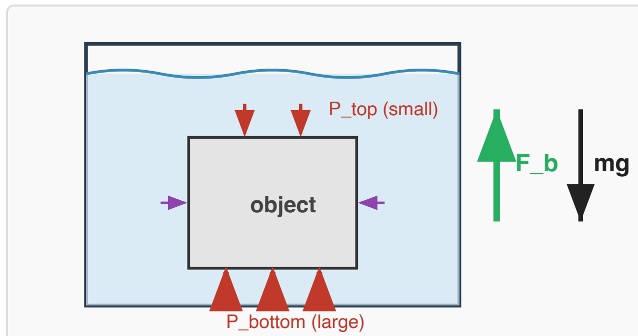
**Emergence:** buoyancy is NOT a fundamental force. It emerges from the pressure difference between the top and bottom of a submerged object — deeper fluid means higher pressure, so the bottom face is pushed up harder than the top is pushed down. The leftover difference *is* the buoyant force.

## ARCHIMEDES' PRINCIPLE

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

"The buoyant force equals the weight of the fluid displaced by the object."

*The diagram shows why:* small downward push on top + bigger upward push on bottom = net upward $F_b$.




**WE DO** **Exercise 1: Submerged Block**

A block of volume 0.002 m³ is fully submerged in water ($\rho$ = 1000 kg/m³). Find $F_b$.

## FLOATING CONDITION

If $\rho_{obj} < \rho_{fluid}$ → **floats** partially submerged. If $\rho_{obj} > \rho_{fluid}$ → sinks. If equal → neutral.

**For a floating object:** fraction submerged = $\rho_{obj} / \rho_{fluid}$

**YOU DO** **Exercise 2: Iceberg**

Ice has $\rho$ = 917 kg/m³. Seawater has $\rho$ = 1025 kg/m³. **(a)** Fraction below the surface? **(b)** Fraction above? **(c)** If $V_{total}$ = 500 m³, what volume is visible?

## APPARENT WEIGHT IN A FLUID

### WEIGHING SUBMERGED

$$W_{apparent} = mg - F_b = mg - \rho_{fluid} \cdot V \cdot g$$

Weigh the object in air, then on the same scale submerged. The reading drops — the difference *is* $F_b$. This lets you find density without measuring V directly. Archimedes used exactly this trick to test the king's crown.

### WE DO Exercise 3: Crown Test

An object weighs **15.0 N in air** and **11.0 N submerged in water**. **(a)** $F_b$? **(b)** $V_{object}$? **(c)** mass from air weight? **(d)** ρ? **(e)** Is it gold (ρ = 19,300 kg/m³)?

### SKILL Exercise 4: Submerging a Cylinder — FBD & Graph

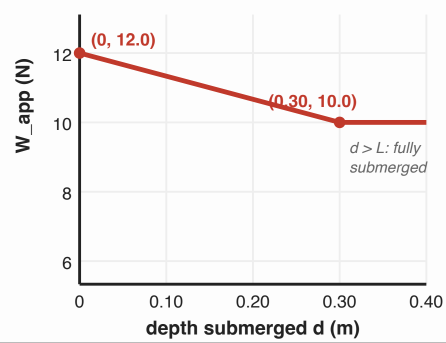
A student lowers a solid cylinder of length **L = 0.30 m** into water on a force probe. The graph shows the probe reading $W_{app}$ as a function of how deep the bottom of the cylinder is below the water surface, *d*.

**(a)** Draw a force diagram for the cylinder when it is *fully* submerged on the probe (d > L). Label every force.

**(b)** Use the *slope* of the linear region to find the cylinder's cross-sectional area A. (What does the slope physically represent?)

**(c)** Find the cylinder's volume V and density $\rho_{cyl}$.

**(d)** Predict and sketch the graph if the same cylinder were lowered into mercury ($\rho_{Hg}$ = 13,600 kg/m³). Would the cylinder ever fully submerge? Explain.




**Common Misconception:** "Heavy objects sink." A massive steel aircraft carrier floats while a tiny steel marble sinks. It's not about mass — it's about whether the object can displace enough fluid weight to support itself.

# FLUIDS DAY 3: FLOW & BERNOULLI

**Physics in the Wild — Why Planes Fly & Balls Curve:** Airplane wings, curveballs, and the shower curtain blowing inward all involve pressure differences in moving air. Bernoulli is one useful tool, but the first expert move is deciding whether its assumptions actually apply.

**Emergence:** tracking the $10^{26}$ molecules in a glass of water is hopeless. But zoom out, treat the fluid as a continuous medium, and a beautiful equation emerges: $P + \frac{1}{2}\rho v^2 + \rho g y =$ constant. We don't need to know what every molecule is doing — the emergent description is the only one that's practical.

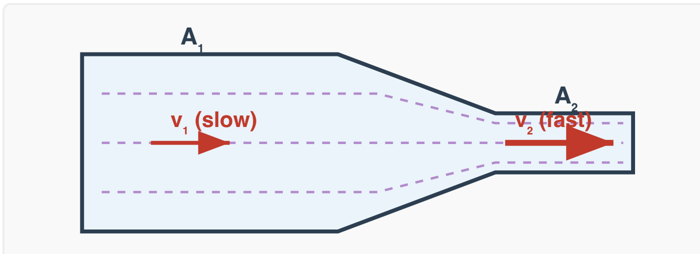
## CONTINUITY: WHAT FLOWS IN MUST FLOW OUT

### EQUATION OF CONTINUITY

$$A_1 v_1 = A_2 v_2$$

**Incompressible fluid:** volume flow rate $Q = Av$ is constant.

Narrow pipe → **faster** flow. Wide pipe → slower flow.




### WE DO Exercise 5: Narrowing Pipe

A water pipe narrows from $A = 4.0 \times 10^{-3}$ m² to $A = 1.0 \times 10^{-3}$ m². Water enters at 2.0 m/s. Find the speed in the narrow section.

### YOU DO Exercise 6: Blood in Capillaries

Blood flows through the aorta (r = 1.0 cm) at 0.30 m/s. Into a capillary (r = $4.0 \times 10^{-6}$ m). If *all* the blood went through one capillary, how fast would it flow? (You have billions — that's why!)

## BERNOULLI'S EQUATION

**ENERGY CONSERVATION FOR FLUIDS**

$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2$$

**Key insight:** along one steady, ideal streamline at the same height, greater speed means lower pressure.

**BERNOULLI'S ASSUMPTIONS — CHECK BEFORE YOU USE IT**

The equation only holds when *all* of the following are true between the two points you're comparing:

1. **Steady flow** — conditions at any point don't change in time.
2. **Incompressible fluid** — density ρ is constant. (Liquids ✓. Gases below ~Mach 0.3 ✓. Shock waves and explosions ✗.)
3. **Inviscid** — no significant friction. (Long pipes, boundary layers, and sharp bends all violate this.)
4. **No external work** — no pump, fan, or shaft adding or removing energy between the two points.
5. **Same streamline** — the two points must lie on a single connected path of flow. Comparing across *different* streamlines is *not* Bernoulli — it's an unjustified shortcut.

*If any assumption fails, switch tools (work-energy theorem, F = ma on a fluid parcel, etc.). Knowing when a tool applies is half of physics.*

WE DO **Exercise 7: Horizontal Pipe**

Horizontal pipe. Point 1: $v_1$ = 2.0 m/s, $P_1$ = 250,000 Pa. Point 2 (narrower): $v_2$ = 6.0 m/s. Find $P_2$. ($y_1 = y_2 \rightarrow$ gravity term cancels.)

BONUS **Exercise 8 — Bonus Credit: Wing Lift — Two Stories**

A wing has area A = 12 m². Air over the curved upper surface moves at $\mathbf{v_{top}}$ **= 90 m/s**; along the (nearly flat) lower surface at $\mathbf{v_{bot}}$ **= 70 m/s**. $\rho_{air}$ = 1.2 kg/m³. Upper-surface radius of curvature **r ≈ 1.5 m**; curved-flow region above the wing has effective thickness **Δn ≈ 0.30 m**.

**(a) Naive Bernoulli.** Pretend top and bottom share a streamline. Compute $\Delta P = \tfrac{1}{2}\rho(v_{top}^2 - v_{bot}^2)$ and predicted lift F = ΔP · A. State *two reasons* this is suspect.

**(b) Streamline curvature.** A fluid parcel on the curve at speed v needs centripetal acceleration v²/r. The only thing that can push a non-touching parcel is a pressure gradient, so (force/volume) = ρ · v²/r gives **dP/dn = ρv²/r**. **(b1)** Compute dP/dn (Pa/m). **(b2)** Multiply by Δn for ΔP. **(b3)** Multiply by A for a curvature-based lift estimate.

**(c) Compare.** Same magnitudes? What does each method capture vs. miss? Which is the honest causal mechanism (F=ma on a fluid parcel) and which is energy bookkeeping along a streamline that doesn't actually connect top to bottom?

**Tool check:** Bernoulli holds along one steady, ideal streamline. Paper/wing shortcuts compare different streamlines, so first ask: **am I staying on one streamline?**

## TORRICELLI'S THEOREM: DRAINING A TANK

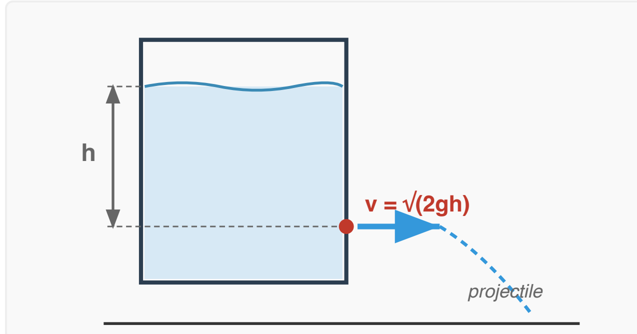
### SPECIAL CASE OF BERNOULLI'S

**Open tank, hole in side:** both surface and hole are at atmospheric pressure (P cancels). Surface barely moves ($v_1 \approx 0$). Bernoulli collapses to:

$$v = \sqrt{2gh}$$

where $h$ = depth of hole below the water surface.

*Same formula as an object dropped from height h — both are energy conservation.*




**WE DO** **Exercise 9: Tank Drainage**

Water exits a hole 2.0 m below the surface of a large open tank. Find the exit speed.

**SKILL** **Exercise 10: Torricelli + Projectile Motion**

A tank sits on a table. A hole is drilled **0.80 m below the water surface** and **1.2 m above the floor**. **(a)** Exit velocity? **(b)** Time for the stream to fall to the floor? **(c)** Horizontal range from the wall?

**Tomorrow:** Short Torricelli lab to test the √(2gh) prediction, plus synthesis problems before the quiz.

# EXIT TICKET & HOMEWORK

## EXIT Garden Hose

Water flows through a garden hose (diameter 2.0 cm) at 1.5 m/s. You place your thumb over the end, reducing the opening to 0.50 cm diameter. **(a)** Exit speed? **(b)** Pressure difference between hose interior and exit? **(c)** Why does the stream shoot farther?

## HOMEWORK PROBLEMS

### [1] Floating Density

An object floats with 80% of its volume submerged in water. Find its density.

### [2] Cylinder Held Under Water

A solid cylinder ($\rho = 800$ kg/m³, $V = 0.005$ m³) is held under water by a string attached to the bottom of the tank. Find the tension in the string.

### [3] Vertical Pipe (Bernoulli)

A pipe carries water from the basement ($y = 0$, $v = 1.0$ m/s, $P = 3.0 \times 10^5$ Pa) to the second floor ($y = 5.0$ m), where it narrows so $v = 3.0$ m/s. Find the pressure on the second floor.

### [4] Tank Drainage + Projectile

A large water tank has a hole 3.0 m below the waterline and 1.5 m above the ground. **(a)** Exit speed? **(b)** Horizontal range?

**Tomorrow:** Torricelli lab, synthesis problems, and quiz prep.