FLUIDS DAY 4: TORRICELLI LAB & SYNTHESIS

Physics in the Wild: Designing Fountains

Evangelista Torricelli, Galileo's last student, figured out that water exits a hole in a tank at the same speed as if it had fallen freely from the water surface to the hole. He used this to design fountains for the Medici family in Florence. Dam engineers use this same physics every day.

Emergence: *Bernoulli's equation makes a precise, testable prediction: water exits at $v = \sqrt{2gd}$, then follows projectile motion. Today you test whether treating 10^{26} chaotic water molecules as a smooth, continuous fluid actually predicts reality. Spoiler: it does. That's emergence at work.*

PURPOSE

Test Torricelli's theorem by predicting how far water squirts from holes at different depths in a container, then connect the full fluids unit before the quiz.

THEORY

THE PREDICTION

Step 1 — Exit speed: $v = \sqrt{2gd}$, where d = depth below surface.

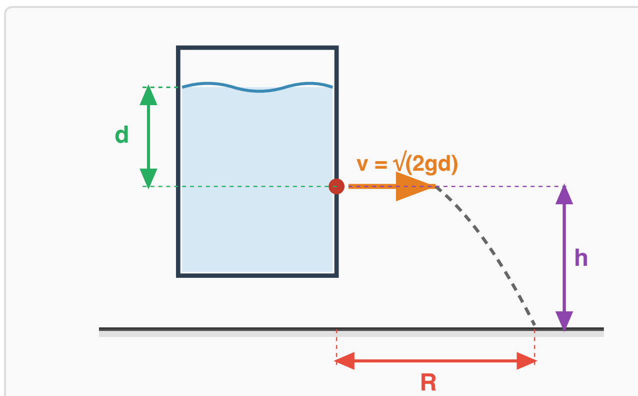
Step 2 — Projectile motion: water exits horizontally, falls height h.

Time to fall: $t = \sqrt{2h/g}$

Horizontal range: $R = v \times t = \sqrt{2gd} \times \sqrt{2h/g}$

$$R = 2\sqrt{d \cdot h}$$

d = depth of hole below surface; h = height of hole above landing surface.



EQUIPMENT

Large container (2L bottle or tall bucket), ruler/meter stick, tape, collection tray, water source, paper towels

PROCEDURE

1. Make 3–4 small holes at different heights along the side of the container. Cover each with tape.
2. Set the container on the edge of a table or elevated surface. Measure the height of each hole above the floor/tray.
3. Fill the container to a marked level. Measure the water surface height.
4. Remove the tape from ONE hole at a time. Quickly mark where the stream lands.
5. Measure the horizontal range R from directly below the hole to the landing mark.
6. For each hole, calculate d (water surface height minus hole height) and h (hole height above landing surface).
7. Predict $R_{pred} = 2\sqrt{(d \times h)}$.
8. Repeat for all holes. Refill water to the same level between trials.

⚠ **Note:** The water level drops as water flows out. Work quickly, or have a partner continuously refill. Alternatively, use a large container where the level doesn't drop significantly during measurement.

DATA

Hole #	h_{hole} (m)	h_{water} (m)	$d = h_{water} - h_{hole}$ (m)	$h_{fall} = h_{hole} - h_{landing}$ (m)	$R_{pred} = 2\sqrt{(d \cdot h)}$ (m)	$R_{measured}$ (m)	% error
1							
2							
3							
4							
Water surface height: __________ m **Landing surface height:** __________ m							

ANALYSIS

GRAPH Plot $R_{measured}$ (y-axis) vs $R_{predicted}$ (x-axis) on graph paper. If the theory is perfect, all points should fall on the line $y = x$. Draw this reference line.

ANALYSIS 1 How close are your data points to the $y = x$ line? Are they consistently above or below? What systematic error could explain this?

ANALYSIS 2 List the assumptions Bernoulli's equation makes that might not hold perfectly in your experiment.

ANALYSIS 3 Which hole produced the maximum range? According to the formula $R = 2\sqrt{(d \times h)}$, at what depth d should you place a hole to maximize the range? (Hint: if the container has water height H, then $h = H - d$. So $R = 2\sqrt{(d(H - d))}$. What value of d maximizes this?)

CONNECT The exit speed $v = \sqrt{(2gd)}$ is identical to the speed of a ball dropped from height d. Why is this NOT a coincidence? Explain using energy conservation.

SYNTHESIS & QUIZ PREP

SKILL Narrowing Pipe with Continuity & Bernoulli

A horizontal pipe narrows from A_1 = 0.040 m² to A_2 = 0.010 m². Water enters at v_1 = 2.0 m/s and P_1 = 200,000 Pa. **(a)** Find v_2. **(b)** Find P_2. **(c)** Where is pressure lowest?

SKILL Submarine at Depth

A submarine at 200 m depth in seawater (ρ = 1025 kg/m³) has a viewport area of 0.050 m². **(a)** Find gauge pressure. **(b)** Find absolute pressure. **(c)** Estimate the inward force on the viewport from gauge pressure.

SKILL Wing or Pitot Tube

Choose one. A pitot tube measures dynamic pressure $\frac{1}{2}\rho v^2$ = 3600 Pa with ρ_{air} = 1.2 kg/m³. Find v. *Or:* air moves at 60 m/s over a wing and 50 m/s underneath. Find $\Delta P = P_{bottom} - P_{top}$.

Quiz next class covers Days 1–4: density, pressure, gauge vs absolute pressure, buoyancy, floating, continuity, Bernoulli, and Torricelli/projectile motion.