A Capstone Lab for AP Physics 1, Fluids

Acknowledgements: R. Vanco for volunteering to do the lab and write it for his classmates. Montclair Fund for Educational Excellence for equipping our fluids lab.

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The Fluids Unit in AP1

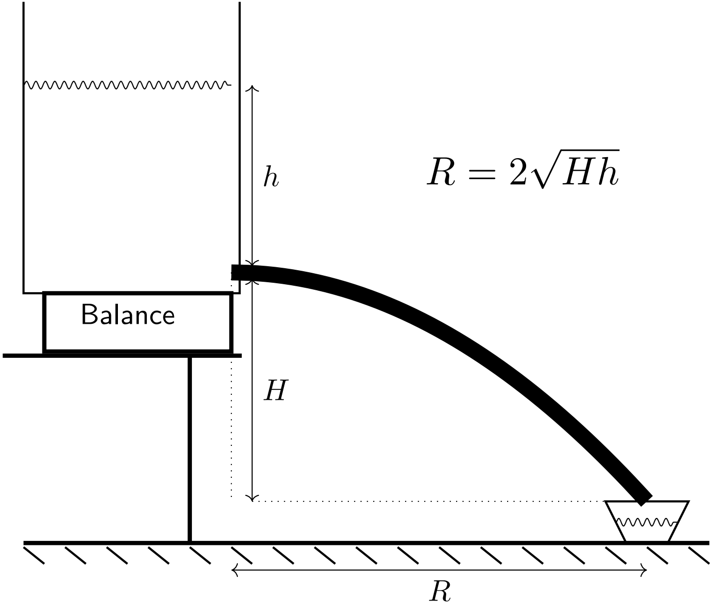
- new in 2025
- Content includes Bernoulli's Statement about Energy Density (pressure is an energy density)

$$P_1 + \rho g h_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g h_2 + \frac{1}{2}\rho v_2^2$$

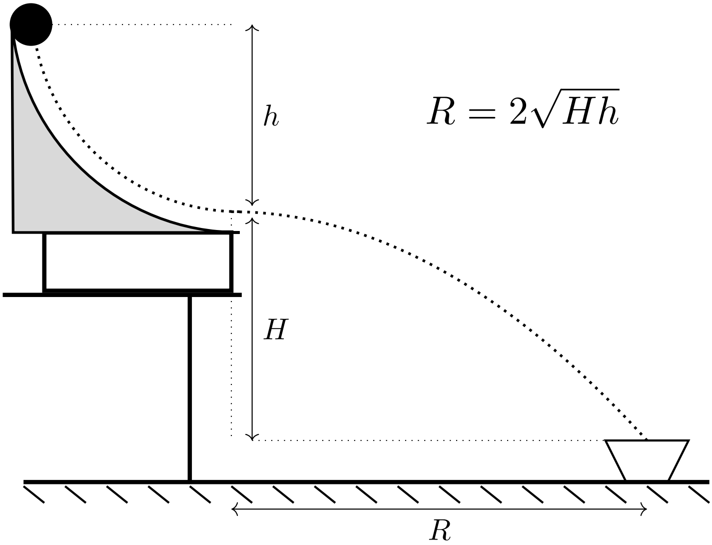
Torricelli's Law

- 1644: Torricelli argued speed of fluid from a hole depth h below surface is $v = \sqrt{2gh}$ (Torricelli 1644)
- Final equation in the course and exam description (CED)
- Points to a popular lab/demo

Experimental Setup

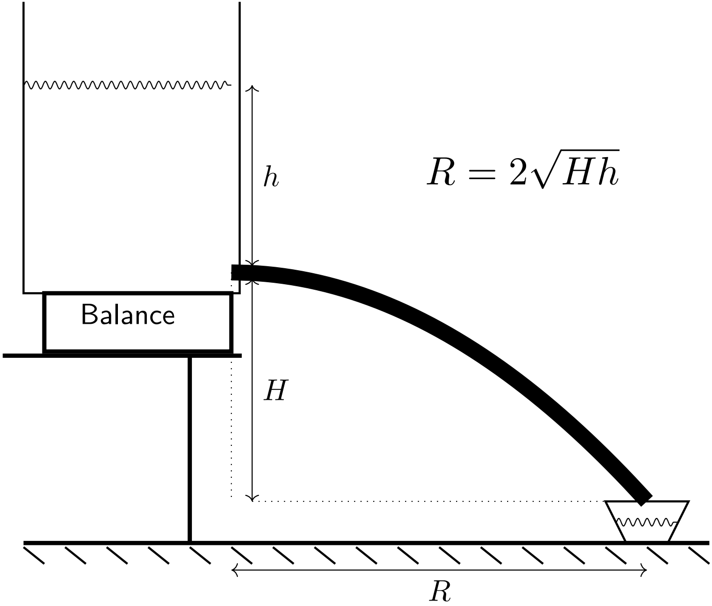


This recalls the horizontal launch problem



$$R = 2\sqrt{Hh}$$

Experimental Setup

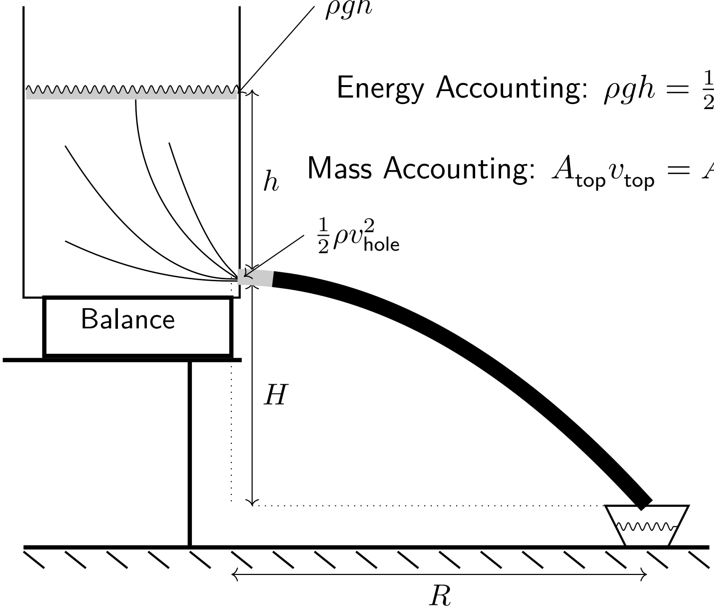


$$R = 2\sqrt{Hh}$$

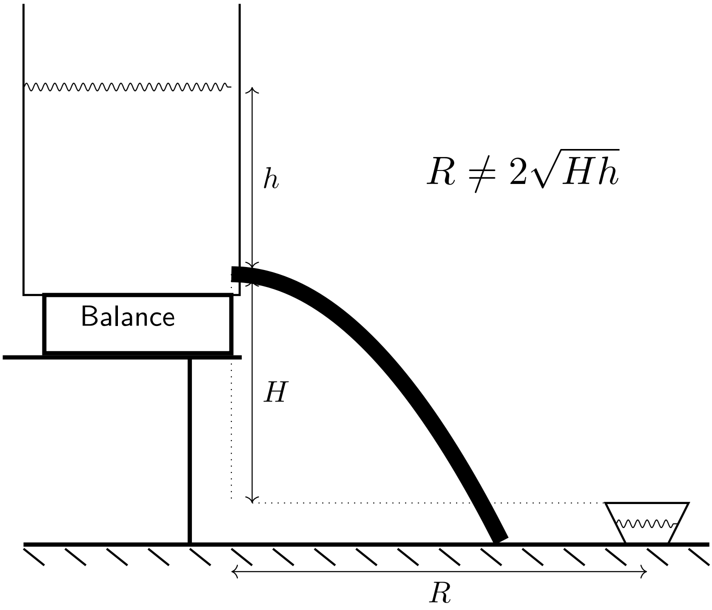
What happens in the tank?

Energy Accounting: $\rho g h = \frac{1}{2}\rho v_{\text{hole}}^2$

Mass Accounting: $A_{\text{top}} v_{\text{top}} = A_{\text{hole}} v_{\text{hole}}$



Lab Goes Poorly



What students see

Typical Range is 60% of predicted

The AP1 model gives us no insight into errors

AP1 CED Asserts that viscosity of ideal fluid is zero (super fluid?)

Last Physics Lab of their lives is terribly unimpressive.

Proposed Lab

- Soft drink bottle, thumb tack for hole
- Before the experiment **Measure**: $M(0)$ (mass of bottle filled at t=0), A_{top}, A_{hole}, $h(0)$, and H.
- **Record**: Time, Range $R(t)$, and mass of bottle $M(t)$.
- **Calculate columns**: $h(t)$, $v_{\text{continuity}}$, $v_{\text{Torricelli}}$, and $v_{\text{observed}} = R/\sqrt{2gH}$.
- **Plot**:
  - Plot velocity vs depth
  - Plot v^2 vs depth

Student Results

Credit: Ronan Vanco, Montclair HS '27

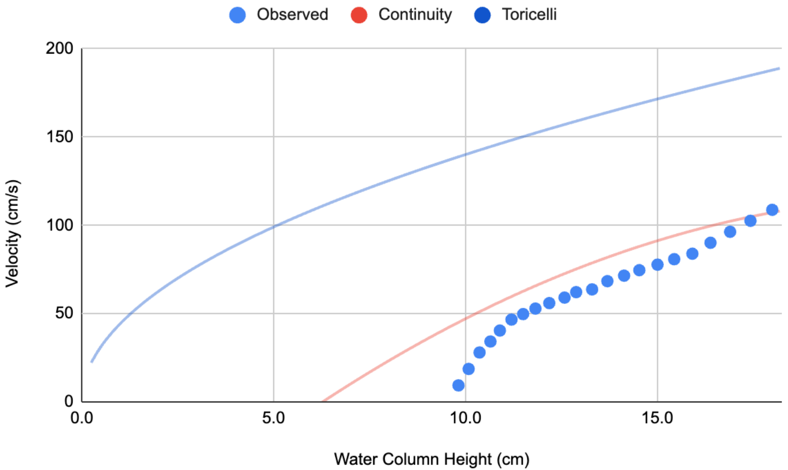


Figure 1: velocity plot

Student Results

Credit: Ronan Vanco, Montclair HS '27

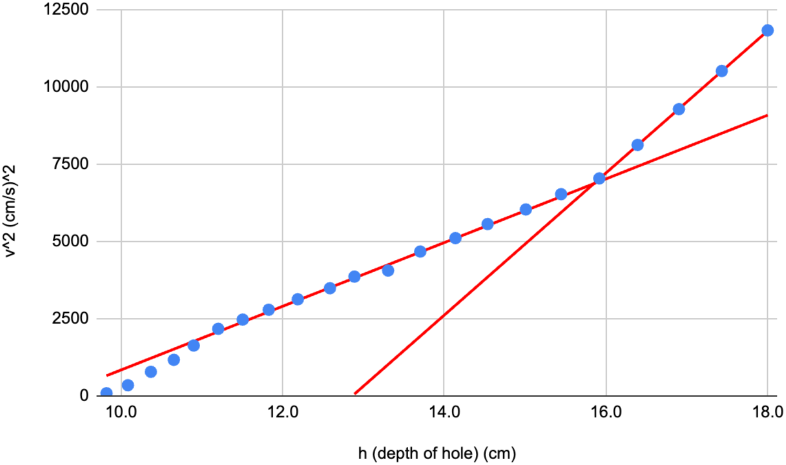


Figure 2: v^2 vs depth plot

The Results: Viscosity Matters!

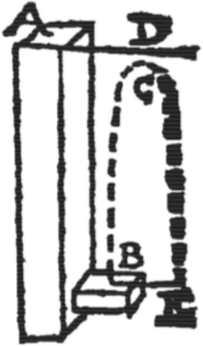
- When? When $v_{\text{fluid}} \neq 0$
- Mass is conserved
- Torricelli's law has the right scaling, but is not quantitatively correct.
- **Opportunity**: This is where advanced physics jumps in. So go to college!

Discussion

- Lots of demos and textbooks ignore viscosity
- You lose the essence of our experience with fluids
- Read more:
  - Feynman's discussion of this lab (Vol II, Chapter 40) (Feynman, Leighton, and Sands 1965)
  - Life at Low Reynolds Number (Purcell 2014)

Did Torricelli Actually Do This?

Torricelli, 1644



Feynman 1964

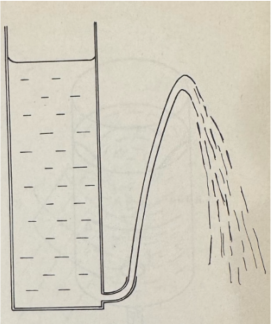


Fig. 40–10. Proof that v is not equal to $\sqrt{2gh}$.

Figure 3: Fountains

Conclusions

1. Zero Viscosity only works for static fluids ($v = 0$)
2. Fluids can be a good wrap up and review if:

a. Don't dismiss viscosity
b. Wrap results in science practice to grow understanding

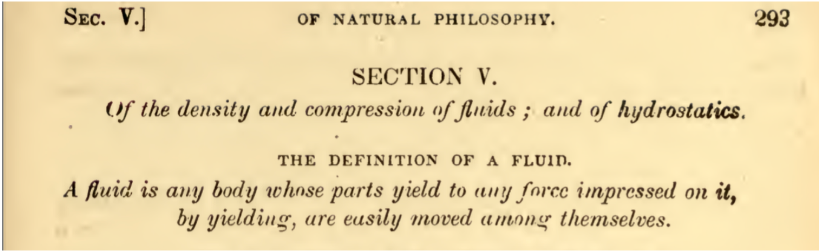
3. Or limit fluids labs to **statics** and **continuity**

Feedback please before we write this up for *The Physics Teacher*.

Additional Physics 1

Ideal fluids have zero elastic modulus **not zero viscosity**.

Newton may have cared about fluids because air is intermediate between water and space.



SEC. V.] OF NATURAL PHILOSOPHY. 293

SECTION V.

Of the density and compression of fluids ; and of hydrostatics.

THE DEFINITION OF A FLUID.

A fluid is any body whose parts yield to any force impressed on it, by yielding, are easily moved among themselves.

Figure 4: Newton's definition of a fluid

20th century notation: Shear modulus $G = G' + iG''$ Ideal fluid has $G' = 0$, and $G'' \propto \eta\omega$.

Additional Physics 2

Big Tanks

Fluid dynamics in the bottle will scale with the Reynolds number $Re = \frac{\rho v L}{\eta}$.

- Re with a small (1mm) hole and soft drink bottle: $\approx 10^3$, marginally laminar
- Re with a large (1cm) hole and large tub ($h \approx 25$cm): $\approx 10^5$, turbulent

Bigger demos work better, but are still fragile.

More importantly, they hide the physics behind the obscure fact that turbulent flow has less viscous loss than laminar flow

References

Feynman, Richard P., Robert B. Leighton, and Matthew Sands. 1965. *The Feynman Lectures on Physics, Vol. II: Mainly the Theory of Electricity and Magnetism*. Reading, MA: Addison-Wesley.

Purcell, Edward M. 2014. "Life at Low Reynolds Number." In *Physics and Our World: Reissue of the Proceedings of a Symposium in Honor of Victor f. Weisskopf*, 47–67. World Scientific.

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