Water clock and Torricelli's law

FizziQ activity · High school · 30 min

Scan to open in FizziQ

A pierced bottle drains onto a connected balance; students plot the collected mass m(t) in FizziQ Connect and model the slowing flow with Torricelli's theorem.

Learning objectives

- Measure the mass of water collected over time using a connected sensor
- Plot and interpret the m(t) curve to identify the non-linearity of the flow
- Understand the relationship between hydrostatic pressure and flow velocity
- Apply Torricelli's theorem to model the outflow
- Discuss the limitations of a water clock for uniform time measurement

Instruments and sensors

FizziQ Connect balance (mass measurement) · Force sensor (FizziQ Connect module)

Materials

- Smartphone or tablet with the FizziQ app
- FizziQ Connect module with force sensor (balance)
- Plastic bottle with a small hole near the bottom
- Collection container
- Water
- Stopwatch
- Note: the protocol remains adaptable to any comparable connected balance or data acquisition tool.

Protocol

1. Open FizziQ Connect and select 'External sensors'. Connect to the M5 Stack module via Bluetooth and select the mass (force) measurement.
2. Fill the plastic bottle with water and place the collection container on the balance. Tare (zero) the balance.
3. Position the pierced bottle above the collection container so water flows through the hole into the container on the balance.
4. Start recording in FizziQ Connect. The mass of collected water is recorded continuously.
5. Let the water flow until the bottle is nearly empty. This typically takes 3 to 10 minutes depending on the hole size.
6. Stop the recording and examine the mass versus time graph.
7. Observe that the curve rises steeply at first (high flow rate when the bottle is full) then flattens (flow rate decreases as the water level drops).
8. The curve is not a straight line, confirming that the flow rate is not constant. Try fitting a parabolic function to the data.
9. Calculate the flow rate (slope of the mass curve) at several different times. Verify that the flow rate decreases over time.
10. Compare your data with the theoretical model from Torricelli's theorem: the flow velocity depends on $\sqrt{h}$, so the mass curve follows a parabolic law.

Expected results

The m(t) curve shows a characteristic shape: it rises rapidly at the beginning (high flow rate when the bottle is full), then its slope decreases progressively until the bottle empties. The curve is well fitted by a parabolic function, consistent with Torricelli's theorem. The flow rate at the start is typically 2-5 times higher than at the end.

Questions

- Why does the flow rate decrease over time? What is the connection to pressure?
- What mathematical function best models the m(t) curve?
- What shape should a container have to produce a constant flow rate?
- How did ancient civilizations compensate for the non-uniform flow of water clocks?
- What are the main sources of error between theory and experiment?
- How does the hole diameter affect the emptying time?

Going further

- Compare the flow for different hole diameters and verify the dependence on s^2 for the emptying time
- Use bottles of different shapes (cylindrical, conical) and compare the m(t) curves
- Design a water clock that measures time uniformly by choosing the right container shape
- Compare the experimental emptying time with the theoretical prediction $T = (S/s)\sqrt{2h_0/g}$
- Add a graduated scale to the collection container and calibrate it as a clock