**Water Bottle Gas Law Demo**

**Purpose:** To teach students about Boyle's law using a water bottle and water displacement.

**How it works:**

I came up with the idea for this lab when I drank a bottle of water on an airplane. When it came time to throw the water bottle away at the end of the flight, I found that the sides were squished inwards. Investigation found that this occurs because the air pressure inside of an airplane at cruising altitude is about 80 kPa, as opposed to the ~100 kPa that's found at sea level.[[1]](#footnote-2) As a result, there is about 20% less gas in the bottle that was sealed at high altitude than there is at the bottle sealed at low altitude. Assuming a volume of about 550 mL, this corresponds to a change in volume of about 110 mL, easily enough to be noticeable when flying.

Using the relative volumes of the two bottles through water displacement and Boyle's Law (P1V1 = P2V2), it's possible to determine that the cabin pressure of an airplane is about 80 kPa. More about this calculation in a moment.

**What you need to do:**

To perform this demo yourself, all you need is two water bottles: One that was sealed in an airplane at cruising altitude and another that was sealed at whatever location you live. Show your students the bottle you sealed at your current pressure (it'll be full) and the bottle that you closed off at airplane cruising altitude (the sides will be squished inward). Explain that the reason that the squished bottle appears to be squished is that the air pressure outside of the bottle crushed the sides of the bottle inward until the pressure of each is equalized.

Using water displacement (a gallon milk bottle with the top cut off and a large graduated cylinder should be fine), determine the volume of the filled bottle and the partially-crushed one. When I performed this demo myself, I found that the volume of the filled bottle was 545 mL and the partially-crushed bottle was 465 mL.

To find the air pressure at which the crushed bottle was filled, use Boyle's law, P1V1 = P2V2, where P1 is the cabin air pressure you're solving for, V1 is the volume of the inflated bottle, P2 is your local air pressure, and V2 is the volume of the partially-crushed bottle. Using the data that I collected, I found that the pressure at high altitude is:

P1V1 = P2V2

P1(545 mL) = (101 kPa)(465 mL)

P1 = 86.2 kPa

You may be wondering why the P and V values in the equation are placed where they are. Basically, what we're doing is that we're doing an experiment where the water bottle at full volume was closed at a high altitude pressure, and the higher atmospheric pressure at ground level caused it to be compressed. Essentially, the P1 and V1 values correspond to the pressure and volume when the bottle was initially sealed, and P2 and V2 correspond to the pressure and volume of the bottle after it was squished by the higher air pressure at sea level. The only reason we have the second bottle that we sealed after landing is to figure out what the precise volume of the bottle would have been before closing it at high altitude.

**Errors, problems, and other stuff:**

The main error that people run into when doing this lab is that they find the cabin pressure of an airplane to be higher than one might expect (roughly 90 kPa rather than the 80 kPa that's actually present). The reason this occurs is that the sides of the bottle somewhat resist squishing, so the bottle doesn't compress as much as one might expect from Boyle's law. This difference in air pressure may be more or less important depending on where you live, so just be aware it happens.

If you live at high altitudes, the shrinking of this bottle will be less significant than you might expect. Because airplanes generally have an internal air pressure equal to about 2,000 meters of altitude, you'll find much less of an effect if you're performing this lab in Denver, CO (altitude ~1,500 meters) than if you do it in Washington, DC (altitude ~100 meters). Please do this experiment on your own before showing it to your students, because it wouldn't be too great if you teach in Bogot[á](https://en.wikipedia.org/wiki/Bogotá), Quito, or

Calgary and your kids get the idea that Boyle's law isn't real.

**Enhancements and improvements:**

This lab can be made better by trying the following things:

* If you've got enough space in your carry-on luggage, carry a bunch of water bottles so you can do this experiment with the entire class. My recommendation, however, is that you seal the lids on each bottle with very strong glue before giving them to the students, because all it takes is one squeeze to let more air in and render the bottles useless.
* If you're very ambitious, you can try to include temperature in here to use the combined gas law rather than Boyle's law. This may be done by heating the bottle in a water bath so the temperature of the sealed bottle is increased, thus increasing the pressure. However, keep in mind that this will increase the error in this lab.
* Use this lab as an opportunity to talk about experimental error. There's an inherent limitation in finding the cabin pressure of an airplane in this way. Discuss how it might be better to perform this lab using a sealed Ziploc bag or a syringe. (Note: I've tried the Ziploc bag thing, and these bags aren't airtight enough to reliably work. Additionally, I'm not sure I'd recommend anybody take a syringe on a plane unless they have a valid medical excuse).
* If this lab is performed shortly before spring break, give extra credit to students who take their own data using data they collect on their own if they travel. You may want to have students work in groups for this, however, because it's unlikely that more than a couple of students in each class will be traveling via air.

**Additional:**

For some cool information about airplane cabin pressurization and how it works, check out the AeroSavvy website (<http://aerosavvy.com/aircraft-pressurization/>).

1. World Health Organization: <http://www.who.int/ith/mode_of_travel/cab/en/>, Engineeringtoolbox.com (<http://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html>). [↑](#footnote-ref-2)