# Buoyant Force

**Apparatus:** Aluminum cylinders, pulley cord, scissors, small rods, right angle clamps, small bases, force sensors, lab jacks, 600 mL beakers, water, mystery fluid (about 5 liters of fluid, preferably with a density more than 20% different from water), digital calipers, hanging mass sets, PASCO Science Workshop 750 Interface & Power Supplies.

**Purpose:**

The purpose of this lab is to demonstrate Archimedes' Principle by submerging a small mass of known volume and comparing experimentally measured forces with theoretically calculated forces.

**Theory:**

According to Archimedes' Principle, the buoyancy force $F_b$ of a body is equal to the weight of displaced fluid $w_f$. This is written in equation form as

$$F_b = w_f = \rho_f V g$$

where $\rho_f$ is the density of the fluid, $V$ is the volume of the submerged object and $g$ is the magnitude of the acceleration due to gravity.

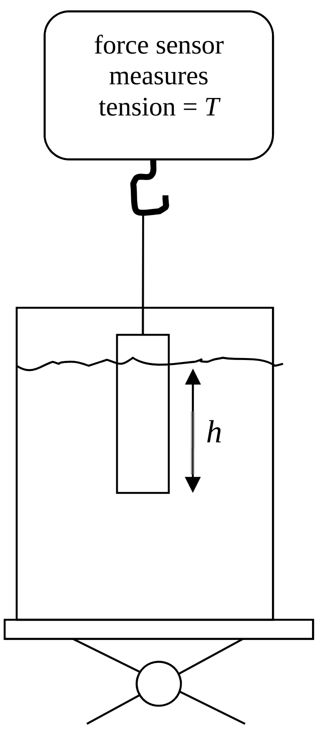
The volume $V$ can be rewritten in terms of cross-sectional area $A$ and height $h$ as

$$V = Ah$$

for objects with a constant cross-sectional area. By substitution we then have

$$F_b = \rho_f (Ah) g \ .$$

Thus, if $F_b$ is compared to $h$ for a known $A$ the density of a fluid may be determined.




In today's experiment it will be difficult to measure the buoyant force directly. Typically this is experiment is done by plotting $T$ versus $h$ and determining $\rho_f$ from the slope of a linear fit.

**Procedure:**

- Setup the PASCO interface and computer as demonstrated by your lab instructor. Connect a force sensor. Double click on the appropriate input (the one to which you connected the force sensor). In the pop-up window find the "FORCE SENSOR" and click on it.
- An icon will appear in the upper left corner that says Force. Drag this icon down to DIGITS. Hit the start button on the very top row of buttons.
- Set up a base and stand. Use a right angle clamp to set up a horizontal rod. The rod should be high enough above the ground to mount a beaker on a lab jack AND still have room for a hanging force sensor.
- Mount the force sensor on the horizontal rod with the hook end down. It should be hanging vertically.
- Hang several known masses on the force sensor. Verify that the force sensor is taking accurate measurements. If the numbers are way off your force sensor may not be perfectly vertical. Try adjusting the angle that it dangles. <u>If this doesn't improve things, read the calibration guide at the end of the lab.</u>
- Select an experimental mass and determine its volume. For example, if your selected mass is in the shape of a cylinder, then measure the diameter and height, then calculate the volume as equal to the area of the base ($\pi r^2$) times the height. Use the calipers to get accurate measurements.
- Hang the metal cylinder from the force sensor hook with a string.
- **Fill the beaker with enough water so that the mass will completely submerge without touching the bottom of the beaker.**
- Mark the actual cylinder with 1.0 cm increments as precisely as possible before submerging the cylinder. WATCH OUT! If you look closely, rasing the lab jack by 1.0 cm actually raises the water level by a slightly

different amount (because the cylinder displaces fluid as it is submerged). If the cylinder diameter is non-negligible compared to the beaker diameter you'll run into 5-10% errors!

- Now you are ready for data. Partially submerge the mass 1.0 cm beneath the surface of the fluid by raising the beaker from underneath. Wait 5-10 seconds with the mass submerged until the force reading stabilizes.
- Record the values of the force and *h* in your spreadsheet. Raise the beaker by another cm or so and record a second data point. Remember too that you want to record the depth of the water *h* and not the distance the lab jack moves. Continue until you have 8 data points.
- Use a linear trendline (show eqt'n and $R^2$ value on graph).
- Draw a free body diagram. Derive a result that relates *T* to *h*. In particular, try to solve for *T*=???.
- Notice that on your graph *h* is like the *x* coordinate while *T* is like the *y* coordinate. Identify all the garbage in front of the *x* coordinate as the slope. Write down an eqt'n **on your graph** that says "slope=???".
- Rearrange that equation algebraically to solve it for the density of the fluid ($\rho_{fl}$). **I expect to see this rearrangement on your graph** in the form of "$\rho_{fl}$ =???". This will be your **experimental value** of $\rho_{fl}$.
- Determine a percent difference for the experiment using water. **<u>NOTE: use this %difference as your estimate of precision for today's lab.</u>** This is a little different than our usual method.
- Repeat the data gathering process using another liquid with an unknown density different than that of water. Use your measurement data to calculate the density of the unknown liquid. This will be your **theoretical value** of the density.
- Determine the **experimental density** by measuring the mass of the liquid on the laboratory scale, then dividing by the volume. Don't forget to subtract out the mass of the beaker itself.
- Obtain a percent difference between the experimental and theoretical values of density for the mystery fluid.

**Conclusions:**

1. Suppose the aluminum cylinder was not solid but was actually hollow. Would you expect a positive or negative percent difference on your value of $\rho_{fl}$? Think: would your tension be increased or decreased? How would that affect the slope? How would that affect the value of $\rho_{fl}$?
2. Suppose this experiment was performed using a cylinder with identical dimensions but made from solid steel instead of solid aluminum. You are told that steel is roughly three times denser than aluminum. How would the graph differ? Consider both the intercept and the slope. Sketch what the graph of *T* vs *h* should look like.

**Calibration Procedures:**

Once you have your force sensor running, click on the Calibrate Sensors button above the picture of the interface box in the Experiment Setup window.
Hang a 50 g mass on the sensor. This will be calibration point 1, standard value of 0.49 N.
Hang a 100 g mass on the sensor. This will be calibration point 2, standard value of 0.98 N.
Click Done.