# Archimedes' Principle

## Equipment

| Qty | Item | Parts Number |
|---|---|---|
| 1 | Force Sensor | PS-2104 |
| 1 | Lab Jack | SE-9373 |
| 1 | Beaker | SE-7288 |
| 1 | 250 mL Graduated Cylinder | |
| 1 | Large Rod | ME-8738 |
| 1 | Small Rod | ME-8988 |
| 1 | Double Rod Clamp | ME-9873 |
| 1 | Wooden Cylinder | |
| 2 | Metal Cylinders | |

## Purpose

The Purpose of this activity is to show some basic properties of the buoyant force. Namely that the buoyant force is a function of the density of the fluid, that the buoyant force is equal to the weight of the fluid displace by a submerged or floating object, and that the apparent weight of a submerged object is the difference between its weight and the buoyant force acting on it.

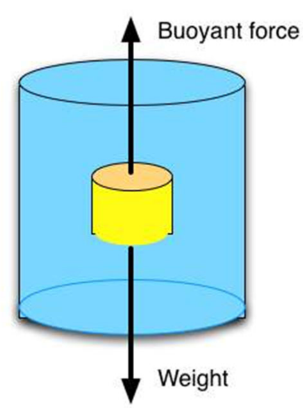
## Theory

Archimedes' Principle states that the upward buoyant force exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces; it is also applicable to gases:

$$F_B = m_f g$$

There are 2 ways to measure buoyancy: direct and displacement. Direct measurement is the difference between the actual weight of the object ($W_o$) and its apparent weight ($W_a$) when fully submerged. Displacement measurement utilizes the fact that the volume of fluid displaced ($V_f$) is equal to the volume of the object ($V_o$) that is submerged. Recall that density ($\rho$) = m/V, such that:

$$F_B = (\rho_f V_f)g = (\rho_f V_o)g$$




From the free body diagram:

$$F_B - F_g = g(\rho_f V_o - m_o) = -m_o a$$

where, solving for acceleration we find

$$a = g\left(\frac{\rho_f}{\rho_o} - 1\right)$$

where it can be observed that

$$\rho_f > \rho_o \Rightarrow +a\ Object\ will\ float$$
$$\rho_f = \rho_o \Rightarrow a = 0\ Object\ is\ in\ dynamic\ equilibrium$$
$$\rho_f < \rho_o \Rightarrow -a\ Object\ will\ sink$$

If the object is only partially submerged, then the volume of fluid displaced is the volume of the part of the object actually submerged. For example, a cylinder has a volume $V_c = \pi r^2 l = A_c l$, where $A_c = \pi r^2$ is the cross sectional area and l is the length. Assume the cylinder is submerged by a depth d, then $V_{sub} = A_c d$ such that:

$$F_B = \rho_f g V_{sub} = \rho_f g A_c d$$

It is important to note that the buoyant force and depth of the object are directly related such that buoyant force will *increase* with depth until the object is fully submerged.

## Setup Part 1

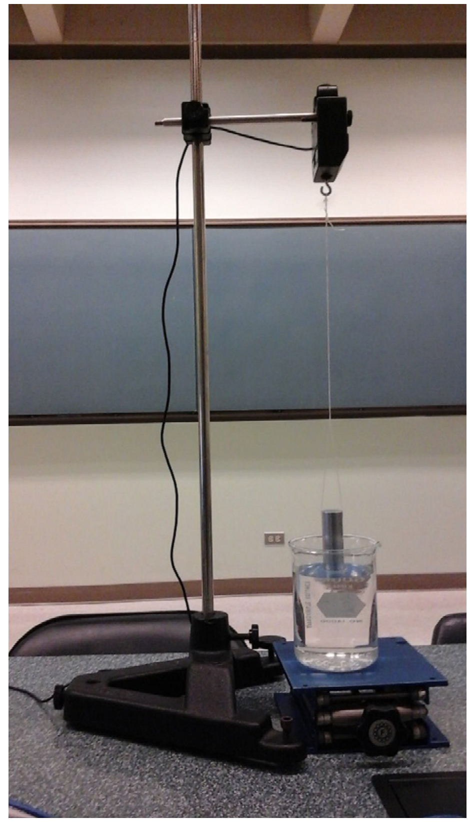
1. Fill up your graduated cylinder with enough water such that your wooden cylinder sample will float in it without touching the bottom of the graduated cylinder. (Around the 170 ml mark should do.)

## Procedure Part 1

1. Measure the length and diameter of your wooden cylinder sample, then record those values in the provided table.
2. Using a mass scale, measure the mass of your wooden cylinder sample, then record it in the provided table.
3. Before you place your wooden cylinder sample in the water, measure the volume of what is in your graduated cylinder and record it in the table provided as the initial volume, $V_i$.
4. Place your wooden cylinder sample in the water, then measure the new volume, and record that volume $V$ in the table provided.

## Setup Part 2

1. Using the Vernier caliper, measure the diameter and length of each of the cylinder masses, and then record the values in the provided table.
2. Using the listed equipment, construct the setup shown in the provided picture.
    - It doesn't matter which cylinder mass is being used.
    - Make sure the hook of the force sensor is pointing straight down or the sensor won't measure all the force being applied to it.



- Fill up the beaker with enough water that the mass cylinder can be completely submerged without touching the bottom of the beaker.
- Initially the table jack should be at its lowest possible position.
- Adjust the height of the force sensor such that the very bottom of the cylinder mass that is hanging from the sensor is almost, but not quite, touching the surface of the water in the beaker.

3. Make sure the PASCO Universal Interface is turned on and connected to the computer.
4. Double click the PASCO Capstone Icon to open up the PASCO Capstone software.
5. Plug in the force sensor to the port labelled PASPort 1. The force sensor will automatically be detected by the PASCO 850 Universal Interface.
    - At the bottom of the screen set the Force Sensor sample rate to 5 Hz.
6. In the Tool Bar, on the left side of the screen, click on the Hardware Setup icon to open up the Hardware Setup window.
    - In the Hardware Setup window, you should see an image of the PASCO 850 Universal Interface. Beneath the image of the PASCO 850 Universal Interface, click on the properties icon in the bottom right corner of the window, which will open the properties window.
    - In the properties window you will see Change Sign, select it so that a check sign appears.
    - Click OK to close the properties window.
    - *If the image of the PASCO 850 Universal Interface does not appear, click on the Choose Interface tab in the Hardware Setup window to open the Choose Interface window.*
    - *In the Choose Interface window select PASPORT, then select Automatically Detect, and finally click OK.*
7. On the image of the PASCO 850 Universal Interface, click on PASPort 1 to open up the sensor list.
    - At the bottom of the screen set the Force Sensor sample rate to 5 Hz.
8. In the Tool Bar, click on the Data Summary icon to open up the Data Summary window.
    - In the Data Summary window, click on Force (N) to make the Force Sensor's properties icon appear directly to the right. Once the property icon appears, click on it to make the properties window open.
    - In the Properties window, select Numerical Format, then change Number of Decimal Places to 3, and finally click OK.
9. At the top right of the Data Summary window click the push pin icon to rescale the main window, allowing the Tool Bar and the associated windows to remain open during the experiment.

10. In the Display Bar, on the right side of the screen, double click the Graph icon to cause a black graph to appear on Page #1.
    - In the graph for the y-axis, click on Select Measurements, then select Force (N).
    - The computer will automatically select time (s) for the x-axis.
11. REMOVE THE MASS FROM THE FORCE SENSOR SO NOTHING IS TOUCHING THE FORCE SENSOR HOOK.
12. In the Tool Bar, click on the Calibration icon to open the Calibration window.
    - In the Calibration window, Force should already be selected so click Next.
    - For the type of calibration, select One Standard (1 point offset), and click Next.
    - Set Standard Value to 0.00 N, then click Set Current Value to Standard Value, and then finally click Finish.

## Procedure Part 2

1. Click on the Tare button that is on the side of the force sensor right before you begin the experiment, and right after you have performed Step 12 from the Setup.
2. Hang the metal cylinder back on the hook of the force sensor.
3. Near the bottom left of the screen click on the Record bottom to start collecting data.
    - Let the computer collect data for about 5 seconds, then click the Stop button at the bottom left of the screen.
4. Near the top left of the graph click on the Highlight Range of Points icon to make a highlight box appear on the graph.
    - Move and rescale the highlight box as needed so that all the data points are highlighted.
5. Near the top left of the graph click on the down arrow next to the large sigma (Σ).
    - Make sure that Mean is selected.
    - Now click on the large Sigma itself to make the value of the mean appear on the graph.
    - Record the absolute value as the weight W of this metal cylinder.
6. Twist the knob on the side of the lab jack to raise the jack until the metal cylinder is just completely submerged into the water, without touching the bottom of the beaker.
    - The top of the metal cylinder should be right under the surface of the water.
7. Near the top left of the graph click on the Highlight Range of Points icon to make a highlight box appear on the graph.
    - Move and rescale the highlight box as needed so that all the data points are highlighted.
8. Near the top left of the graph click on the down arrow next to the large sigma (Σ).
    - Make sure that Mean is selected.
    - Now click on the large Sigma itself to make the value of the mean appear on the graph.
    - Record the absolute value as the apparent weight, $W_A$, of this metal cylinder.
9. Repeat Procedure Part 2 steps 1 – 8 for the other metal cylinder.

## Analysis of Archimedes' Principle Lab

**Name______________________________________________ Group#________**

**Course/Section________________________________________**

**Instructor_____________________________________________**

**Table Part 1**

| **Wooden Cylinder** | **Values** |
|---|---|
| Mass (kg) | |
| Weight (N) | |
| Length (m) | |
| Diameter (m) | |
| Radius (m) | |
| Volume ($m^3$) | |
| Density ($kg/m^3$) | |
| | |
| **Water** | **Values** |
| Density ($kg/m^3$) | 1000 $kg/m^3$ |
| $V_i$($m^3$) | |
| $V$ ($m^3$) | |
| $\Delta V$ ($m^3$) | |
| Weight of displaced water (N) | |

Complete Table, show any calculations in the space provided (10 points)

1. Draw a free body diagram of the wooden cylinder floating in the water, then write the force summation equation from that free body diagram. (Ignore if the wooden cylinder is touching the top of the graduated cylinder.) (10 points)

2. The weight of a floating object should be equal to the weight of the fluid it displaces. Calculate the % difference between the weight of your wooden cylinder, and the weight of the water it displaced when floating. Besides some small experimental error, does your result agree with the theory? If not, give some reasons why is doesn't. (5 points)

**Table Part 2 (Accepted Density of Water 1000 kg/m$^3$)**

| Brass Cylinder | Values |
|---|---|
| Weight (N) | |
| Length (m) | |
| Diameter (m) | |
| Radius (m) | |
| Volume (m$^3$) | |
| $W_A$ (N) | |
| | |
| **Aluminum Cylinder** | **Values** |
| Weight (N) | |
| Length (m) | |
| Diameter (m) | |
| Radius (m) | |
| Volume (m$^3$) | |
| $W_A$ (N) | |

Complete Table, show any calculations in the space provided (10 points)

3. Draw a free body diagram for either one of the metal cylinders for when it was submerged in the water, and then write the force summation equation for that free body diagram. In the equation, let the tension in the string be the apparent weight. Algebraically solve this equation for the buoyant force. (10 points)

4. From your force summation equation, calculate the buoyant force for each of the metal cylinders. (10 points)

5. Calculate the weight of the water displaced by the metal cylinders. Since their volumes are more or less identical you only have to do this once. (5 points)

6. Calculate the % difference between the buoyant force and the weight of the displaced water for each metal cylinder. (10 points)

7. Ignoring any small experimental differences, did the different densities of the two different metal cylinders affect the value of the buoyant force they each experienced? If it did, explain why it did. (6 points)

8. Why did the wooden cylinder float in water while the two metal cylinders sank? (6 points)

9. Briefly explain what apparent weight is. (6 points)

10. What are some reasons that account for our percent error? (6 points)

11. Do our experiments confirm Archimedes' Principle? Justify your answer. (6 points)