# Lab 8. Buoyancy

## Goals

- To experimentally determine the relationship between the buoyant force on an object and the weight of water that it displaces.
- To compare the buoyant behavior of an object more dense than water with that of an object less dense than water.
- To calculate the densities of aluminum and wood cylinders from your data and to compare these densities to known values.

## Introduction

Buoyancy is the name given to the force that arises when an object displaces a fluid (either a gas or a liquid) in a force field (usually gravity). The buoyant force is responsible for keeping ships from sinking and for keeping hot air balloons in flight. If an object is at rest in or on a fluid, it experiences a net force of zero. The forces acting on a partially or completely submerged object at rest generally include the gravitational force, $F_g$, the buoyant force, $F_{Buoyant}$, and whatever additional force (if any) is required to hold the object in position. In the work below, this holding force is supplied by and measured with a force sensor. When the object is at rest,

$$F_{Sensor} + F_g + F_{Buoyant} = 0 \tag{8.1}$$

In this lab, you will measure the buoyant forces acting on two cylinders as they are submerged in water, and relate these forces to the weight of the water they displace. You will also calculate the average densities of each cylinder. The cylinders are marked at centimeter intervals along their lengths. The cylinders are lowered into a beaker with their long axes perpendicular to the water surface, so the volume submerged, $V_s$, is

$$V_s = \pi R^2 L_s = A L_s \tag{8.2}$$

where $L_s$ is the length of the submerged portion of cylinder, $R$ is the cylinder radius, and $A$ is the cylinder's cross-sectional area. The weight of the water displaced by the object is given by

$$W_{displaced} = \rho_w V_s g \tag{8.3}$$

where $\rho_w$ is the density of water ($1.000 \times 10^3$ kg/m$^3$).

## Buoyant force on an object more dense than water

Before beginning, draw a free-body diagram showing the forces on an object (more dense than water) partially submerged in water.

If you have questions on how to set up the force sensor, refer to the Force Sensor section of the Computer Tools Supplement at the back of the lab manual. The force sensor uses one of the analog input channels (A, B, or C) on the interface unit.

Carefully hang the aluminum cylinder on the force sensor. With the lab jack near its maximum height, adjust the position of the force sensor so that the cylinder sits completely inside the tall beaker without bumping the sides. Then add water to the beaker until the aluminum cylinder is completely submersed. This ensures that the beaker has enough water to cover the cylinder, but is not so full that water will spill when the cylinder is immersed. Use water from the sink at the back of your lab. If your beaker is already filled from a previous lab section, submerge the cylinder to verify that sufficient water remains for full immersion.

To begin the experiment, lower the lab jack so that the aluminum cylinder is completely out of the water. With the aluminum cylinder hanging in the air, tare the force sensor. This sets the force sensor reading to zero with the entire weight of the cylinder applied. The force sensor reading as the cylinder is immersed will then equal the change in force, that is, the upward buoyant force. Since the force sensor in this orientation reads positive for upward forces, the upward buoyant force will be sensed directly as a positive force.

One problem with the force sensors is a phenomenon called "zero drift." This phenomenon is a tendency over time for the sensor to depart the zero point which you defined when you tared the device. To see this in action, you may zero the sensor and record data without allowing anything to change in your setup. Over the course of 10 minutes, the computer will not read a constant zero force.

To minimize the impact of this drift on your data, you must gather the data quickly. Raising your lab jack carefully 1cm, pausing to record the measurements from the software, and then raising carefully another 1cm can take quite a while to do.

One option around this dilemma would be to tare your sensor before each time you raise the lab jack, and to add up the individual force measurements as you submerge more of your cylinder. This relies on an assumption that there is a linear relationship between the force applied and the length submerged. While this seems like a perfectly reasonable assumption, the entire point of this lab is to determine that very relationship. No experiment which makes assumptions about the results to select methods can ever be considered reliable!

So, to avoid constantly zeroing your sensor, but also minimize the impact of zero drift, you are challenged to take your readings quickly. One fast method is to avoid taking the time to transcribe data to your notebook at all during measurement. Starting with the cylinder out of the water, begin measurement, and start to raise the lab jack. Pause in raising the lab jack as you hit each 1cm mark on the cylinder. If you pause for a count of 3, it should be obvious in reviewing the graph of your data where the pause happened (you may need to zoom in on the graph to see this). Any sloped/curved section of the graph is time when you are moving the lab jack, and any flat section of the graph is time when you are pausing for measurement. Take an average of the readings in the flat section of the graph, and record that as your measurement for the relevant 1cm mark.

Make a graph that compares the buoyant force (on the $y$-axis) with the weight of the water displaced (on the $x$-axis) for each value of $L_s$ (so one data point for 1 cm submerged, another for 2 cm submerged...). From the graph, can you deduce a simple mathematical relationship between the two? Discuss/Explain. Look up Archimedes' Principle in a textbook. Do your results support the validity of Archimedes' Principle?

## Buoyant force on an object less dense than water

Before beginning, draw a free-body diagram showing the forces on an object (less dense than water) partially submerged in water. Do the directions of the forces shown depend on the density of the object, or do only the magnitudes depend on the density?

Replace the aluminum cylinder with the wood cylinder, which attaches directly to the force sensor by a screw. **Do not remove the threaded screw in the top of the wood cylinder!** Its mass is negligible relative to the mass of the cylinder itself. **Do not screw the cylinder more than 5 mm (about 1/4 inch) into the force sensor.** The force sensor can be damaged by screwing it in too far. It does not need to screw in until unable to screw in further, only far enough that it will not fall off when released.

Again, measure the buoyant force as the submerged portion of the cylinder is increased in 1-cm increments. Do the buoyant force and the weight of the displaced water obey the same relation in this case? Discuss/explain.

## Relative density of aluminum and wood

In your notebook, show that the density of any solid unknown material $\rho_{Unknown}$ obeys the following relationship:

$$\frac{\rho_{Unknown}}{\rho_w} = \frac{W_{Unknown}}{F_{MaxBuoyant}} \tag{8.4}$$

where $W_{Unknown}$ is the weight of the unknown object, $F_{MaxBuoyant}$ is the maximum buoyant force on the object (that is, the buoyant force when it is totally submerged in water), and $\rho_w$ is the density of water.

Use Equation 8.4 to calculate the density of the aluminum and the wood. Compare your calculated densities with accepted values from a textbook, handbook, or reputable online source. The density of natural wood can vary considerably, and often it is difficult to identify what wood you are working with. Additionally, wood will change in density with environmental conditions and age. A reasonable range of density for wood is that of oak, $0.60 \rightarrow 0.90\frac{g}{cm^3}$. Ultra-light woods like Balsa can go as low as $0.11\frac{g}{cm^3}$, while some hardwoods like ebony may even exceed water with densities as high as $1.33\frac{g}{cm^3}$ List some examples in your notebook. In contrast, the density of aluminum should not vary more than 0.05%. Does your measured density for aluminum agree with the handbook value of $2.7\frac{g}{cm^3}$ within the limits of the expected error for this experiment? If your measurement and the handbook value disagree by more than three standard deviations, carefully examine your calculations and procedures for sources of error.

# Some additional questions

Consider the following questions:

1. How can an aircraft carrier (or a concrete canoe) float when the density of the material used to build it is greater than the density of water?
2. Does air create a buoyant force? If so, how can you estimate the magnitudes of the buoyant forces due to the atmosphere on your wood and aluminum cylinders?
3. Is the direction of the buoyant force always opposite the direction of the gravitational force?
4. Does the buoyant force on a totally submerged object change as the object moves farther and farther below the surface of the fluid?

| | No Effort | Progressing | Expectation | Scientific |
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| **SL.B.b**<br>Is able to explain patterns in data with physics principles<br>Labs: 1, 2, 5, 8, 10, 11 | No attempt is made to explain the patterns in data | An explanation for a pattern is vague, OR the explanation cannot be verified through testing, OR the explanation contradicts the actual pattern in the data. | An explanation is made which aligns with the pattern observed in the data, but the link to physics principles is flawed through reasoning or failure to understand the physics principles. | A reasonable explanation is made for the pattern in the data. The explanation is testable, and accounts for any significant deviations or poor fit. |
| **SL.B.c**<br>Is able to explain steps taken to minimize uncertainties and demonstrate understanding through performance where able.<br>Labs: 3, 4, 7-9, 11 | No explicitly identified attempt to minimize uncertainties and no attempt to describe how to minimize uncertainties present | No explicitly identified attempt to minimize uncertainties is present, but there is a description of how to minimize experimental uncertainty. | An attempt is made and explicitly identified for minimizing uncertainty in the final lab results, but the method is not the most effective. | The uncertainties are minimized in an effective way. |
| **CT.A.d**<br>"Is able to identify sources of uncertainty "<br>Labs: 3, 4, 7-9, 11 No attempt is made to identify experimental uncertainties. | descworst | An attempt is made to identify experimental uncertainties, but many sources of uncertainty are not addressed, described vaguely, or incorrect. | Most experimental uncertainties are correctly identified. But there is no distinction between random and experimental uncertainty. | All experimental uncertainties are correctly identified. There is a distinction between experimental uncertainty and random uncertainty. |

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| **CT.B.a**<br>Is able to describe physics concepts underlying experiment<br>Labs: 1, 2, 5, 8, 10, 11 | No explicitly identified attempt to describe the physics concepts involved in the experiment using student's own words. | The description of the physics concepts underlying the experiment is confusing, or the physics concepts described are not pertinent to the experiment for this week. | The description of the physics concepts in play for the week is vague or incomplete, but can be understood in the broader context of the lab. | The physics concepts underlying the experiment are clearly stated. |
| **QR.A**<br>Is able to perform algebraic steps in mathematical work.<br>Labs: 2-4, 6-12 | No equations are presented in algebraic form with known values isolated on the right and unknown values on the left. | Some equations are recorded in algebraic form, but not all equations needed for the experiment. | All the required equations for the experiment are written in algebraic form with unknown values on the left and known values on the right. Some algebraic manipulation is not recorded, but most is. | All equations required for the experiment are presented in standard form and full steps are shown to derive final form with unknown values on the left and known values on the right. Substitutions are made to place all unknown values in terms of measured values and constants. |
| **QR.B**<br>Is able to identify a pattern in the data graphically and mathematically<br>Labs: 1, 2, 5, 8, 10, 11 | No attempt is made to search for a pattern, graphs may be present but lack fit lines | The pattern described is irrelevant or inconsistent with the data. Graphs are present, but fit lines are inappropriate for the data presented. | The pattern has minor errors or omissions. OR Terms labelled as proportional lack clarity - is the proportionality linear, quadratic, etc. Graphs shown have appropriate fit lines, but no equations or analysis of fit quality | The patterns represent the relevant trend in the data. When possible, the trend is described in words. Graphs have appropriate fit lines with equations and discussion of any data significantly off fit. |
| **QR.C**<br>Is able to analyze data appropriately<br>Labs: 1-12 | No attempt is made to analyze the data. | An attempt is made to analyze the data, but it is either seriously flawed, or inappropriate. | The analysis is appropriate for the data gathered, but contains minor errors or omissions | The analysis is appropriate, complete, and correct. |
| **IL.A**<br>Is able to record data and observations from the experiment<br>Labs: 1-12 | "Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. " | "Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. " | Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference. | All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed. |

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| **IL.B**<br>Is able to construct a force diagram<br>Labs: 1-12 | No force diagrams are present. | Force diagrams are constructed, but not in all appropriate cases. OR force diagrams are missing labels, have incorrectly sized vectors, have vectors in the wrong direction, or have missing or extra vectors. | Force diagram contains no errors in vectors, but lacks a key feature such as labels of forces with two subscripts, vectors are not drawn from the center of mass, or axes are missing. | The force diagram contains no errors, and each force is labelled so that it is clearly understood what each force represents. Vectors are scaled precisely and drawn from the center of mass. |
| **WC.B**<br>Is able to draw a graph<br>Labs: 1, 2, 4-8, 10, 11 | No graph is present. | A graph is present, but the axes are not labeled. OR there is no scale on the axes. OR the data points are connected. | "A graph is present and the axes are labeled, but the axes do not correspond to the independent (X-axis) and dependent (Y-axis) variables or the scale is not accurate. The data points are not connected, but there is no trend-line. " | The graph has correctly labeled axes, independent variable is along the horizontal axis and the scale is accurate. The trend-line is correct, with formula clearly indicated. |

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

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Lab 8 Buoyancy:

Name: ________________________ Lab Partner: ________________________

**EXIT TICKET:**

- ☐ Quit Capstone and any other software you have been using.
- ☐ Replace the small hook in the force sensor.
- ☐ empty your water pitcher into the sink at the back of the room
- ☐ Verify that the redundant 90°clamps are tightened in place on the rod stand.
- ☐ Straighten up your lab station. Put all equipment where it was at start of lab.
- ☐ Required Level of Effort.
  - ☐ Complete the pre-lab assignment ☐ Arrive on time
  - ☐ Work well with your partner ☐ Complete the lab or run out of time

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