ARCHIMEDES' PRINCIPLE

Purpose

- **a.** To study buoyant force as a function of submersed volume.
- **b.** To verify Archimedes' Principle.
- **c.** To use Archimedes' Principle to determine the densities of a solid sample and a liquid sample.

Theory

a. Buoyancy and Archimedes' Principle

When an object is submerged in a fluid, it experiences a buoyant force, **B**. This buoyant force is the resultant of the pressure-based forces on the surfaces of the submerged object. The pressure is higher at greater depths in the fluid, and thus the buoyant force is directed upward.

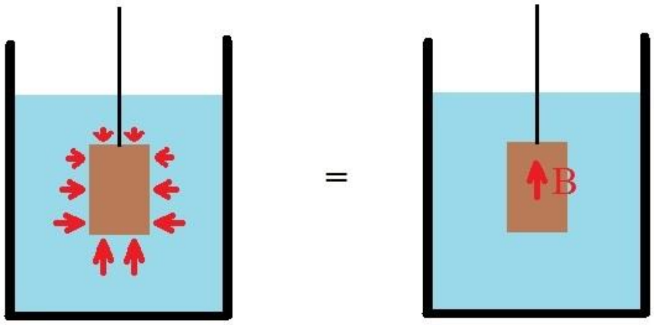

Figure 1. The buoyant force **B** is the resultant of the pressure-based forces.

Archimedes' Principle, which is derived in your textbooks, states that the magnitude of the buoyant force is equal to the weight of the fluid displaced by the submerged object.

$$B = W_{displaced\text{-}fluid} = m_{displaced\text{-}fluid}\, g = \rho_{fluid}\, V_{displaced\text{-}fluid}\, g \,. \qquad (1)$$

If the object is completely submerged in the fluid, the volume of displaced fluid is equal to the volume of the submerged object: $V_{\text{displaced-fluid}} = V_{\text{object}}$. Then

$$B = \rho_{fluid}\, V_{object}\, g \,. \qquad (2)$$

If the object is partially submerged, $V_{\text{displaced-fluid}}$ = partial volume of the object that is submersed. For a cylindrical solid object of uniform cross section area (A), if the cylinder is immersed in a fluid along the axis of the cylinder and h is the height of the object in the fluid,

$$B = \rho_{fluid}\, V_{immersed}\, g = \rho_{fluid}\, A h\, g. \qquad (3)$$

b. Effect of buoyancy on measurements of mass

When an object is hung from a scale, the reading of the scale, $m_{apparent}$, is based on the tension in the wire connecting the object to the scale: $W_{apparent} = m_{apparent}\, g = T_{wire}$. Normally, $T_{wire} = W_{object} = m_{object}\, g$, and the reading of scale, $m_{apparent}$, is an accurate measurement of m_{object}.

However, if the object is hung from the scale while submerged in a fluid, then $T_{wire} < W_{object}$ because of the contribution of the buoyant force **B**. Specifically, writing down the balance of the forces on the object (see Figure 2):

$$0 = \Sigma F_y = T_{wire} + B - W_{object} .$$

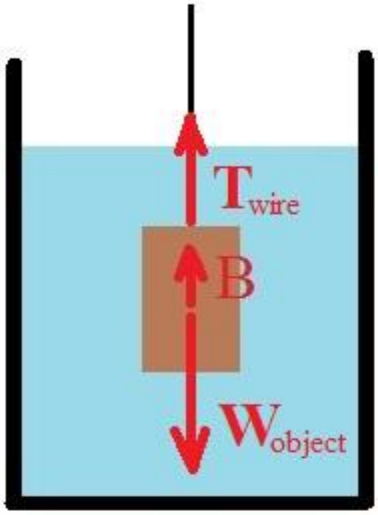

Figure 2. The equilibrium of forces on an object hanging from a scale while submerged.

Since the scale reading is always based on T_{wire},

$$W_{apparent} = T_{wire} = W_{object} - B .$$

$$B = W_{object} - W_{apparent} \tag{4}$$

The apparent weight of a submerged object is less than its actual weight, and the difference between these weights is the buoyant force.

What will happen to the apparent weight if the object is partially submerged?

In this lab we will measure apparent weight of objects in different conditions to verify Archimedes' Principle as well as use this principle to determine the density of solid and liquid samples.

Apparatus

Spring scale, aluminum cylinder block, Tall graduated cylinder, laboratory jack, stand, clamp, Triple beam balance, Vernier calipers, metal cylinder with copper wire attached, hollow wooden block, beaker, tap water, liquid X, paper towels for drying.

Description of Apparatus

You will use a Spring Scale and a laboratory jack as shown in Figure 3(a) to perform part I of the experiment. The spring scale is attched to a clamp on a stand. At the lower end of the spring scale, a metal cylinder is hung. The spring scale reads the apparent weight of the object. The cylinder is slowly submerged in a fluid in a tall graduated cylinder placed on a laboratory jack. The height of the jack can be adjusted by rotating the knob on the side of the jack to change the level of submerge.

For other parts of the experiments, you will use a Triple Beam Balance to perform this experiment as shown in Figure 3 (b). It is a mechanical balance. It has a beam which is supported by a fulcrum. On one side of the fulcrum is a pan on which the object is placed. On the other side, the beam is split into three parallel beams. The beam remains balanced when net torque on both sides are equal. In measuring the mass of an object weight blocks on triple beams are adjusted to balance the beam. Remember the torque due to a same force (weight) can be increased by increasing the distance from the fulcrum.

The far beam reads only in 100 g increments. The middle beam reads only in 10 g increments. The weight blocks in these two beams must always sit in a "notch". They cannot be placed at arbitrary points on the beam. The weight on the front beam can be placed to read continuously from 0 to 10 grams. The balance should be placed on a leveled surface to use it. Before measuring you should check if the balance is properly zeroed. When all the weight blocks on triple beam are at zero gram position, the mark at the end of the triple beam must stay at Zero. You can adjust a knob at the other end of the beam to bring the mark to zero position.

You can measure the mass by putting an object on the hanging pan or hanging the object. There is also a adjustable plateform (see figure) that allows us to measure mass in a liquid.

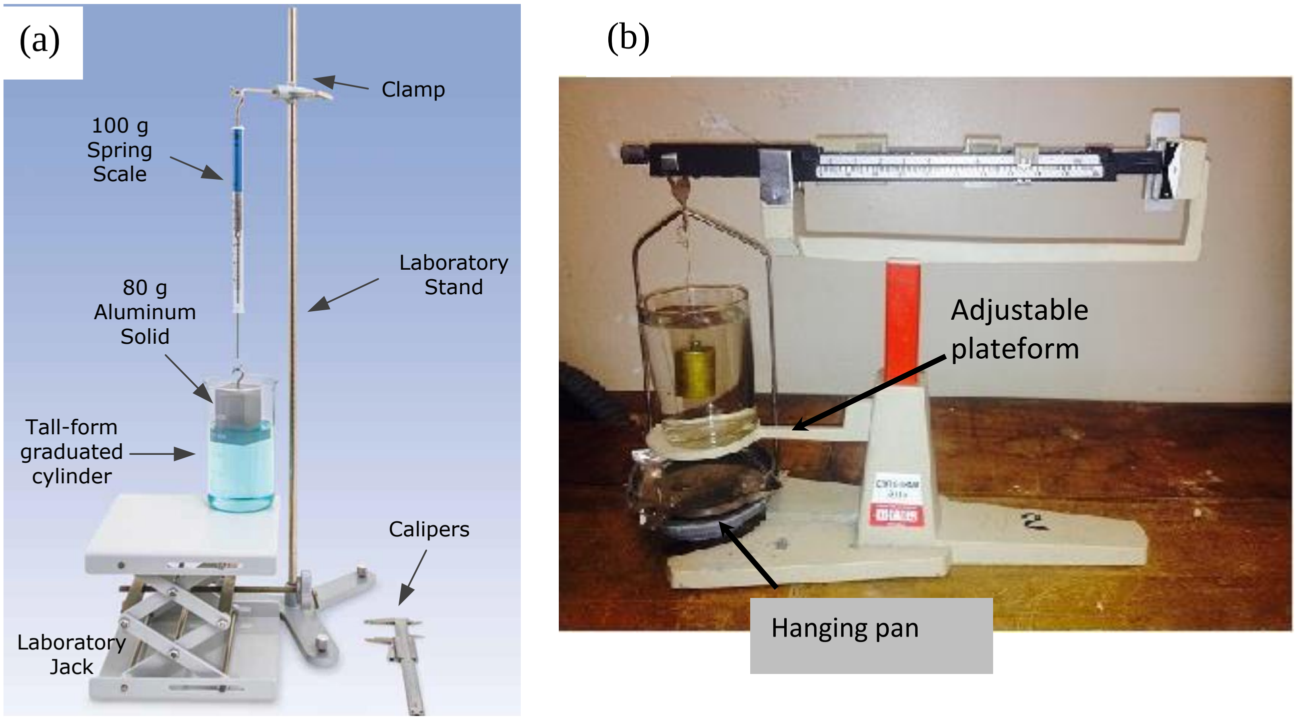

Figure 3. (a) Using the spring scale to measure buoyant force by varying submerge of a cylinder.
(b) Using the triple beam balance to measure the apparent mass of a submerged cylinder.

Procedure

Part I. Studying buoyant force with partially immersed volume

In this part of the experiment, you will study how the buoyant force varies when a solid object is slowly submerged into a liquid.

1. Hang the solid aluminum block on the spring scale.
2. Fill the graduated cylinder to exactly 60 mL with water and put it on the laboratory jack. Adjust the height of the jack so that the **top of the graduated cylinder is well below the hanging object on the spring scale.**
3. Now, align the graduated cylinder so that **the aluminum block does not touch the cylinder wall when moving down**. Adjust the laboratory jack so that the mass hangs just above the water level (not touching the water).
4. Record the reading on the spring scale in the Table 1 for the initial value (0 mL).
5. Adjust the laboratory jack to submerge the aluminum mass in the water until there is a 4 mL change in volume on the graduated cylinder. Record the corresponding reading from the spring scale in the Table 1.
6. Repeat the previous step with 4 mL increments until the entire block is submerged.

Now, slowly lower the jack and remove the cylinder with liquid and put away carefully.

Part II. Verifying Archimedes' Principle

7. Measure the diameter and height of the metal cylinder with the calipers. You will use these values to determine the volume of the cylinder.
8. Use the triple beam balance to measure the mass of the metal cylinder. (Do not remove the hanging pan when making this measurement; instead, make sure that the scale is properly zeroed when the empty pan is hanging.) Attach the metal cylinder to the scale, using the cylinder's wire. Determine the mass of the cylinder from the scale and record in Table 2.
9. Place a beaker with tap water on the adjustable platform above the scale pan (see figure), and hang the metal cylinder so that it is **completely submerged** in the water. Record the reading of the triple beam balance for the hanging submerged cylinder. Remove the cylinder and dry it.

Part III. Determining the volume and density of the wooden block using Archimedes' Principle

10. If you just put a wooden block in water, it will float. *Why do you think it floats on water?*

    In order to submerge the wooden block into water, place the hollow wooden block in the hanging pan of the triple beam balance, and determine its mass. Record your measurement in Table 3. Note that the block has a complicated shape, so that its volume would be difficult to determine using the calipers.

11. Place the lower end of the cylinder into the hole in the block. Suspend the cylinder-block combination from the triple beam balance while it is fully submerged in water. Record the reading of the triple beam balance for the hanging submerged cylinder-block combination. From your previously measured mass of the metal cylinder, you can determine mass of the wooden block.

Part III. For determining the density of liquid X using Archimedes' Principle.

12. Now, place a beaker of liquid X on the adjustable platform above the scale pan, and hang the metal cylinder so that it is completely submerged in liquid X. Record the reading of the triple beam balance for the hanging submerged cylinder in Table 4. Remove the cylinder and dry it.

Extra activities

1. Measure the volume of the wooden block my submerging it in a graduated beaker of water. Since the block naturally floats, you will need to hold it under the water using something of negligible volume, like a wire. Compare this measured wooden block volume to the volume determined using Archimedes' Principle.
2. Measure the density of liquid X by pouring some in a graduated beaker and measuring its mass with the scale. You will also need to measure the mass of the empty beaker. Compare your measured liquid X density to the value determined using Archimedes' Principle.

Computation

1. For part I of the experiment, calculate the buoyant force for each volume in the Table 1 using Eq. 4.
2. From the data in the table, plot a graph of buoyant force, B, as a function of V. Make sure to label the axes appropriately. Does the graph look linear?
3. Draw a best fit line and find the slope of the line. What is the significance of the slope? From the slope the graph, determine the density of the water.
4. For other parts of the experiments, calculate and complete the tables based on the data from the measurements. Densities of the metal cylinder and water will be provided. Include your final results in your report.
5. One of the achievements of Archimedes was the ability to determine the volume of an object by measuring the volume of water displaced upon being submerged. In this lab, you applied Archimedes principle to measure the volume of the cylinder and in addition, the volume of the block. Use a set of calipers to measure both the volume of the cylinder and the volume of the block. Compare your experimentally determine volume for the cylinder and the block by Archimedes principle to that determined using the calipers. **Be sure to check this prior to leaving the laboratory**. Discuss the data in the lab report.
6. While the density of wood varies, how does your measured density for the wooden block compare to known values? You can look up some common wood densities on the internet. Discuss your data in the lab report.

Questions

1. If a string is attached instead of the spring scale in part I of the experiment, how does the tension in the string vary if the cylinder is slowly submerged into the liquid?
2. What do you expect the slope of the curve in part I if salt water is used instead of fresh water?
3. When using the scale to measure the mass of the cylinder in step 8, does it experience a buoyant force due to its immersion in air? If so, approximate the magnitude of this buoyant force.
4. When using the scale to measure the submerged cylinder in step a3, does it matter if the cylinder touches the bottom of the beaker in which it is submerged? How would such contact affect your measurement, if at all?

Data Sheets

Date experiment performed:

Name of the group members:

Table 1. Studying buoyant force with partially immersed volume

Volume Immersed, V (mL)	**Spring Scale Reading, W_{app}** (N)	**Buoyant Force, B** (N)
0		
4		
8		
12		

From the graph of buoyant force (B) versus volume (V),

Slope of the curve =

Density of the liquid =

Tables for measurements and calculations (measurements in shaded boxes)

Table 2 for verifying Archimedes' Principle for cylinder submerged in water

Mass of cylinder (measured in g, converted to kg)	
Weight of cylinder $W_{cylinder}$ (calculated in N)	
Apparent mass of cylinder submerged in water (measured in g, converted to kg)	
Apparent weight for cylinder submerged in water (calculated in N)	
Buoyant force, B, based on difference between $W_{cylinder\text{-}apparent}$ and $W_{cylinder}$ (calculated in N)	
Diameter of cylinder (measured in mm, converted to m)	
Height of cylinder (measured in mm, converted to m)	
Volume of cylinder (calculated in m^3)	
Buoyant force, B, based on Archimedes's Principle	
Percent error between B measured with scale and B based on Archimedes' Principle	

Table 3 for using Archimedes' Principle to determine the volume and density of a solid object

Mass of wooden block (measured in g, converted to kg)	
Weight of block W_{block} (calculated in N)	
Weight of cylinder $W_{cylinder}$ (in N), taken from table above	
Apparent mass of block and cylinder submerged together in water (measured in g, converted to kg)	
Apparent weight for block and cylinder submerged together in water (calculated in N)	
Buoyant force, B, on cylinder and block, based on difference between actual weight and apparent weight (calculated in N)	
Volume of cylinder and block together, based on B and Archimedes' Principle (calculated in m^3)	
Volume of cylinder (in m^3), taken from table above	
Volume of block by itself (calculated in m^3)	
Density of block (calculated in kg/m^3)	

Table 4 for using Archimedes' Principle to determine the density of a fluid

Weight of cylinder $W_{cylinder}$ (in N), taken from first table	
Apparent mass of cylinder submerged in liquid X (measured in g, converted to kg)	
Apparent weight for cylinder submerged in liquid X (calculated in N)	
Buoyant force, B, based on difference between $W_{cylinder-apparent}$ and $W_{cylinder}$ (calculated in N)	
Volume of cylinder (in m^3), taken from first table	
Density of liquid X based on Archimedes's Principle (calculated in m^3)	