



Name: \_\_\_\_\_

Date: \_\_\_\_\_

## Student Exploration: Archimedes' Principle

**Vocabulary:** Archimedes' principle, buoyant force, density, displace, mass, volume, weight

**Prior Knowledge Questions** (Do these BEFORE using the Gizmo.)

1. Why does a small pebble sink in water? \_\_\_\_\_  
\_\_\_\_\_
2. A motorboat is a lot heavier than a pebble. Why does the boat float? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

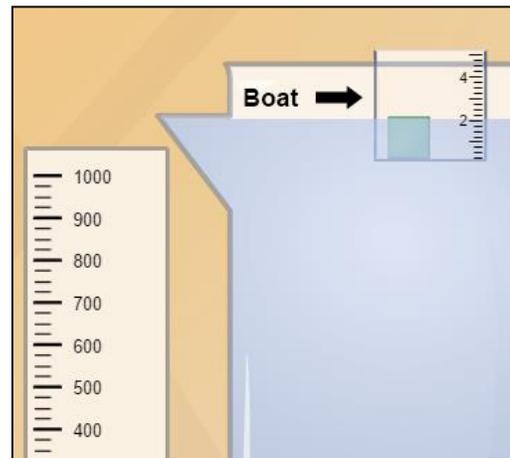
### Gizmo Warm-up

When you place an object in liquid, the downward pull of gravity causes it to start to sink. As the object sinks, the liquid pushes back up on the object with a force that opposes gravity.

In the *Archimedes' Principle* Gizmo, you will see how these forces cause objects to either sink or float.

1. Check that the **Width**, **Length**, and **Height** of the boat are set to 5.0 cm. Drag one of the green **50-g cubes** into the rectangular "boat."

What happens? \_\_\_\_\_



2. Add cubes until the boat sinks. What **mass** of cubes causes the boat to sink? \_\_\_\_\_

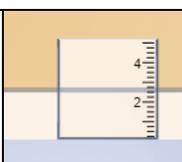
(Note: In this Gizmo, the mass of the boat itself is insignificant.)

3. Click **Reset**. Experiment with different boat dimensions until you create a boat that holds the most cubes without sinking.

A. What are the boat's dimensions? Width: \_\_\_\_\_ Length: \_\_\_\_\_ Height: \_\_\_\_\_

B. How much mass can the boat hold without sinking? \_\_\_\_\_



<b>Activity A:</b> <b>Displaced liquid</b>	<u>Get the Gizmo ready:</u> <ul style="list-style-type: none"> <li>• Click <b>Reset</b>.</li> <li>• Set the <b>Width</b>, <b>Length</b>, and <b>Height</b> to 5.0 cm.</li> <li>• Be sure the <b>Liquid density</b> is set to 1.0 g/mL.</li> </ul>	
---	---	---

**Question: How does the mass of the boat relate to the amount of displaced liquid?**

1. Observe: Place several of the **50-g cubes** into the boat. What happens to some of the liquid in the tank? \_\_\_\_\_

The liquid that is pushed into the graduated cylinder is called **displaced** liquid.

2. Predict: How do you think the mass of the boat will relate to the amount of displaced liquid?  
 \_\_\_\_\_

3. Observe: Click **Reset**. Drag two cubes into the boat, yielding a total mass of 100 grams. How much water is displaced into the graduated cylinder? (Units are mL.) \_\_\_\_\_

4. Experiment: Click **Reset**. Choose a new set of boat dimensions. Add cubes to the boat and record the **volume** of displaced liquid. (If the boat sinks, try a larger set of dimensions.) Record your findings for three boats in the table (include units). Leave the last column blank.

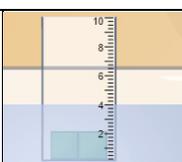
Width (cm)	Length (cm)	Height (cm)	Boat mass (g)	Volume of displaced liquid (mL)	Mass of displaced liquid (g)

5. Calculate: **Density** is equal to mass per unit volume. To calculate density, divide an object's mass by its volume.

If the liquid's density is 1 gram per milliliter (the density of water), the mass in grams is equal to the volume in milliliters. Use this information to fill in the last column of your data table.

6. Draw conclusions: What is the relationship between the mass of the boat and the mass of the displaced liquid? \_\_\_\_\_  
 \_\_\_\_\_



<b>Activity B:</b> <b>How low does it go?</b>	<u>Get the Gizmo ready:</u> <ul style="list-style-type: none"> <li>• Click <b>Reset</b>.</li> <li>• Be sure the <b>Liquid density</b> is set to 1.0 g/mL.</li> <li>• Set the <b>Height</b> of the boat to 10.0 cm.</li> </ul>	
--	---	---

**Introduction:** In activity A, you learned that, for floating boats, the mass of the boat is equal to the mass of displaced liquid. You can use this knowledge to predict how deep a boat will sink.

**Question: How far will a boat sink in water?**

1. **Experiment:** Turn on **Magnify waterline**. Experiment with several different sets of boat dimensions and loads. In the table, record each boat's width, length, and mass; the depth to which it sinks, and the volume of displaced liquid. Leave the last column blank.

Width (cm)	Length (cm)	Boat mass (g)	Sinking depth (cm)	Volume of displaced water (mL)	

2. **Calculate:** Label the last column in your table **Volume underwater**. To calculate the volume of the boat that is underwater, multiply the width, length, and depth of the boat. Record the underwater volume of each boat. The units of volume are  $\text{cm}^3$  and mL ( $1 \text{ cm}^3 = 1 \text{ mL}$ ).
3. **Analyze:** What is the relationship between a boat's mass, the volume of displaced water, and the volume of the boat that is under water? \_\_\_\_\_  
\_\_\_\_\_
4. **Make a rule:** If you know the width, length, and mass of a boat, how can you calculate how deep it will sink in water? \_\_\_\_\_
5. **Practice:** Based on what you have learned, calculate how deep each of the following boats will sink. Use the Gizmo to check your answers.

Boat	Width	Length	Boat mass	Sinking depth (calculated)	Sinking depth (actual)
A	8.0 cm	5.0 cm	100 g		
B	6.0 cm	5.0 cm	150 g		

**(Activity B continued on next page)**



**Activity B (continued from previous page)**

7. Predict: Not all liquids have the same density as water. How do you think increasing the density of the liquid will change each of the following?

A. How far the boat sinks into the liquid: \_\_\_\_\_

B. The volume of displaced liquid: \_\_\_\_\_

C. The mass of displaced liquid: \_\_\_\_\_

8. Observe: Set the **Width**, **Length**, and **Height** of the boat to 5 cm. Add one cube to the boat. Move the **Liquid density** slider back and forth.

What do you notice? \_\_\_\_\_

\_\_\_\_\_

9. Gather data: Measure how far the boat sinks into liquids with each density listed below. Click **Reset** between each trial. Calculate the volume and mass of displaced liquid. (Note: The mass of the displaced liquid is equal to the volume of the liquid multiplied by its density.)

Boat mass	Liquid density	Sinking depth (cm)	Volume of displaced liquid (mL)	Mass of displaced liquid (g)
50 g	0.5 g/mL			
50 g	1.0 g/mL			
50 g	2.0 g/mL			

10. Analyze: In the first part of this activity, you discovered that when a boat is placed in water, the volume of displaced water is equal to the mass of the boat. What is true now?

\_\_\_\_\_

11. Summarize: If you know the length, width, and mass of the boat as well as the density of the liquid, how would you calculate how far the boat sinks into the liquid?

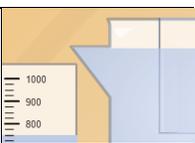
\_\_\_\_\_

\_\_\_\_\_

12. Practice: A rectangular boat has a width of 5 cm, a length of 8 cm, and a mass of 150 g. How far will the boat sink into liquid with a density of 1.2 g/mL? Check your answer.

\_\_\_\_\_



<b>Activity C:</b>  <b>Weight and buoyancy</b>	<u>Get the Gizmo ready:</u> <ul style="list-style-type: none"> <li>• Click <b>Reset</b>, and turn off <b>Magnify waterline</b>.</li> <li>• Set the <b>Width</b>, <b>Length</b>, and <b>Height</b> to 10.0 cm.</li> </ul>	
--	--	---

**Introduction:** When a boat is placed in liquid, two forces act on the boat. Gravity pulls the boat down with a force equal to the **weight** of the boat. Weight is measured in newtons (N). To calculate the weight of a boat, multiply its mass in grams by 0.00982.

As the boat sinks into the liquid, the liquid pushes back. The force of the liquid pushing up on the boat is called the **buoyant force**.

**Question: How do gravity and the buoyant force affect a boat?**

- Observe: Turn on **Show data**. Place four cubes in the boat.
  - What is the **Boat weight**? \_\_\_\_\_
  - What is the **Buoyant force**? \_\_\_\_\_
  - What is the **Net force** on the boat? \_\_\_\_\_
  
- Analyze: Try dragging the boat up or down. Pay attention to the **Buoyant force**.
  - What happens to the buoyant force when the boat is pulled down? \_\_\_\_\_
  - Why do you think this happens? \_\_\_\_\_  
\_\_\_\_\_
  - What happens to the buoyant force when the boat is lifted up? \_\_\_\_\_
  - Why do you think this happens? \_\_\_\_\_  
\_\_\_\_\_
  
- Explore: Answer the following questions by dragging the boat up or down in the liquid.
  - What happens to the boat when its weight is greater than the buoyant force? \_\_\_\_\_  
\_\_\_\_\_
  - What happens to the boat when its weight is less than the buoyant force? \_\_\_\_\_  
\_\_\_\_\_
  - What happens to the boat when its weight is equal to the buoyant force? \_\_\_\_\_  
\_\_\_\_\_

**(Activity C continued on next page)**

**Activity C (continued from previous page)**

4. Observe: Click **Reset**. Set the **Liquid density** to 1.0 g/mL. Add a **50-g cube** to the boat.

- A. What is the weight of the boat? \_\_\_\_\_
- B. What is the mass of the displaced liquid in the graduated cylinder? \_\_\_\_\_
- C. What is the weight of the displaced liquid? \_\_\_\_\_  
(Hint: If the mass is measured in grams,  $w = m \cdot 0.00982$ .)
- D. What is the **Buoyant force** on the boat? \_\_\_\_\_

5. Predict: What do you think is the relationship between the buoyant force and the weight of displaced liquid? \_\_\_\_\_

6. Collect data: As you add cubes to the boat, record the boat's weight, the mass of displaced liquid in the graduated cylinder, the weight of displaced liquid, and the buoyant force.

Number of cubes	Boat weight (N)	Mass of displaced liquid (g)	Weight of displaced liquid (N)	Buoyant force (N)
2				
3				
4				

7. Analyze: What do you notice? \_\_\_\_\_  
\_\_\_\_\_

8. Make a rule: **Archimedes' principle** states that an object is pushed up by a buoyant force that is equal to the \_\_\_\_\_ of the displaced liquid.

9. Apply: A hollow ball weighs 40 newtons. In a water tank, it displaces 15 newtons of water.

- A. What is the buoyant force on the ball? \_\_\_\_\_
- B. Will the ball float or sink? Explain your reasoning. \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



<b>Extension:</b> <b>Sinking boats</b>	<u>Get the Gizmo ready:</u> <ul style="list-style-type: none"> <li>• Click <b>Reset</b>. Check that <b>Show data</b> is turned off.</li> <li>• Set the <b>Width</b>, <b>Length</b>, and <b>Height</b> to 5.0 cm.</li> <li>• Be sure the <b>Liquid density</b> is set to 1.0 g/mL.</li> </ul>	
---	--	---

**Question: What are the forces on a sinking boat?**

1. Observe: Place three **50-g cubes** into the boat. What happens? \_\_\_\_\_  
 \_\_\_\_\_

2. Calculate: Notice that the boat has filled up with water and sunk to the bottom. In this model, the walls of the boat are very thin. Therefore, the volume of water displaced by the boat is equal to the volume of water displaced by the cubes.

A. Each cube is 2 cm × 2 cm × 2 cm. What is the volume of each cube? \_\_\_\_\_

B. What is the total volume of cubes in the boat? \_\_\_\_\_

C. If the water density is 1.0 g/mL, what is the mass of displaced water? \_\_\_\_\_

D. What is the weight of displaced water? (Recall  $w = m \cdot 0.00982$ ) \_\_\_\_\_

E. What is the buoyant force on the boat? \_\_\_\_\_

F. What is the mass and weight of the boat? Mass: \_\_\_\_\_ Weight: \_\_\_\_\_

G. What is the net force on the boat? (Hint: Downward force is negative.) \_\_\_\_\_

Turn on **Show data** to check your answers to parts E, F, and G. Recheck your calculations if necessary.

3. Apply: A valuable statuette from a Greek shipwreck lies at the bottom of the Mediterranean Sea. The statuette has a mass of 10,566 g and a volume of 4,064 cm<sup>3</sup>. The density of seawater is 1.03 g/mL.

A. What is the weight of the statuette? \_\_\_\_\_

B. What is the mass of displaced water? \_\_\_\_\_

C. What is the weight of displaced water? \_\_\_\_\_

D. What is the buoyant force on the statuette? \_\_\_\_\_

E. What is the net force on the statuette? \_\_\_\_\_

F. How much force would be required to lift the statuette? \_\_\_\_\_

