## I. Objectives

1. Demonstrate Archimedes’ Principle.
2. Calculate the mass, volume, and density of various objects to determine which will float.
3. Practice using the CGS system.

## II. Introduction

**This lab utilizes glassware. You must wear appropriate safety attire.**

Archimedes’ Principle states that an object immersed in a fluid is buoyed up by a force equal to the weight of the displaced fluid. The principle applies to both floating and submerged bodies and to all fluids, including liquids and gases. It explains not only the buoyancy of ships and other vessels in water, but the rise of balloons in the air and the apparent loss of weight of objects underwater. In fact, each of us is buoyed up by the air around us by a force of about 0.8 N.

In determining whether an object will float in a fluid, mass and volume must be considered. The density of the object compared to the fluid determines the net buoyant force. If the object is less dense than the fluid, it will float or, in the case of a balloon, it will rise. If the object is more dense than the fluid, it will sink. Another way of stating this is that if an object is unable to displace a weight of fluid equal to its own weight it will sink.

Relative density also determines the proportion of a floating object that will be submerged in a fluid. If the object is, for example, two thirds as dense as the fluid, then two thirds of its volume will be submerged, displacing a volume of fluid with a weight equal to the weight of the entire object. In the case of a submerged object, the apparent weight of the object is equal to its weight in air minus the weight of an equal volume of fluid.

The fluid most often encountered in applications of Archimedes' Principle is water, and the specific gravity of a substance is a convenient measure of its relative density compared to water. A substance with a specific gravity of 0.5, for example, is half as dense as water.

## III. Calculations

Archimedes' Principle can be stated mathematically as:

$$F_B = W_{fluid} = \rho_{fluid} V_{fluid} g$$

where $F_B$ is the buoyant force, and $W_{fluid}$ is the weight of the displaced fluid. The maximum buoyant force occurs when the entire object is submerged:

$$F_B^{MAX} = \rho_{fluid} V_{object} g$$

The weight of the object is:

$$W_{object} = \rho_{object} V_{object} g$$

and the weight of the fluid is:

$$W_{fluid} = \rho_{fluid} V_{fluid} g$$

Since the fluid we will be using is water

$$1.0\ mL = 1.0\ cm^3$$

$$\rho_{fluid} = \rho_{water} = 1.0\ grams/mL = 1.0\ grams/cm^3$$

Because we are using *cm* and *grams* we need to use

$$g = 981\ cm/s^2$$

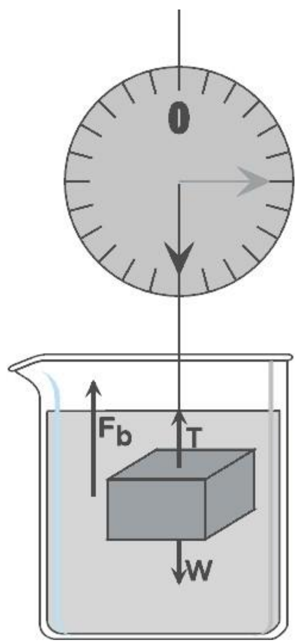
**not** $g = 9.81\ m/s^2$ and the resulting weights and forces are in *dynes* **not** *newtons*!!!

<u>Part 1 Sinking Objects</u>

The net force on a sinking object in a fluid can be expressed as the difference between the buoyant force, $F_B$, and the weight of the object when it is not in the fluid:

$$F_{net} = W_{object} - F_B$$

$$F_{net} = \rho_{object} V_{object} g - \rho_{fluid} V_{fluid} g$$



We can use a spring scale to determine $F_{net}$ and calculate $F_B$:

$$F_B = W_{object} - F_{net}$$

We also know that:

$$F_B = W_{fluid}$$

$$W_{fluid} = W_{object} - F_{net}$$

<u>Part 2 Floating Objects</u>

If $F_B < F_B^{MAX}$ then the object will float, meaning that:

$$\rho_{fluid} V_{fluid} g < \rho_{fluid} V_{object} g$$

which simplifies to:

$$V_{fluid} < V_{object}$$

This implies that the volume of the displaced fluid is smaller than the volume of the object, and that part of the object is not submerged. This means that the density of the object is lower than the density of the fluid.

If the object is floating on the surface of the fluid it is not accelerating and $F_{net} = 0\ N$:

$$0 = \rho_{object} V_{object} g - \rho_{fluid} V_{fluid} g$$

$$0 = \rho_{object} V_{object} - \rho_{fluid} V_{fluid}$$

$$\rho_{fluid} V_{fluid} = \rho_{object} V_{object}$$

$$V_{fluid} = \frac{\rho_{object} V_{object}}{\rho_{fluid}}$$

$$\frac{\rho_{object}}{\rho_{fluid}} = \frac{V_{fluid}}{V_{object}}$$

Remember that:

$$\rho = \frac{m}{V}$$

Part 3 Float Your Boat

See Part 1 and Part 2, above.

Part 4 Water and Ice

You will complete the calculations as part of the Discussion Questions.

## IV. Equipment and Materials

Electronic balance, graduated cylinder, various floating and sinking objects, 1.0 N spring scale, thread, plastic "boat," metal bowl "boat lake," masses, calculator

## V. Procedure

Part 1 Sinking Objects

1. Identify 5 objects that will sink.
2. Determine the mass $m_{object}$ of each in grams.
3. Be sure that you have recorded the initial volume of water in the graduated cylinder. Submerge each object and calculate its volume by determining the change of volume in the cylinder. Calculate the change in volume in $V_{object}$ in mL after the object is submerged in the graduated cylinder.
4. Use this volume to determine the density of the object $\rho_{object}$ in grams/cm$^3$. The volume is the same as the number of cubic centimeters of water displaced. Use this to determine the mass of the displaced water $m_{fluid}$ in grams.
5. Attach a spring balance to the object and raise it slightly from the bottom of the graduated cylinder, but don't raise it above the water. If necessary, tie a thread around the object and make a loop at the other end to hang from the spring balance. The reading on the spring balance is $F_{net}$ in newtons. Be sure to convert this to dynes!
6. Complete Table 1 by entering your **experimental** (***not* calculated**) data in columns **B, C, and H**. Based on that data **calculate** the numbers for columns **D, E, F, G, I, and J**.

Part 2 Floating Objects

7. Identify 5 objects that will float.

8. Determine the mass $m_{object}$ of each in grams.

9. Be sure that you have recorded the initial volume of water in the graduated cylinder. The volume can be calculated by submerging the object with a thin, pointed object and determining the change in volume of the water in the graduated cylinder. Calculate the change in volume $V_{object}$ in mL after the object is submerged in the graduated cylinder.

10. Use this volume to determine the density of the object $\rho_{object}$. The volume is the same as the number of cubic centimeters of water displaced. *Do not* use this to determine the mass of the displaced water, $m_{fluid}$ in grams.
11. Release the object and allow it to float. Determine the volume of the part of the object that *remains* submerged. This is numerically the same as the number of cubic centimeters of water displaced. Use *this* to determine $m_{fluid}$ in *grams*.

12. Complete Table 2 by entering your **experimental** (***not* calculated**) data in columns **B, C, and F**. Based on that data **calculate** the numbers for columns **D, E, G, I, and J**.

Part 3 Float Your Boat

13. Determine the mass of an empty "boat" and record it in Table 3.

14. Carefully fill the boat to the rim with water and record its mass in Table 3.

15. Pour the water into the plastic container "lake," and add enough water to the "lake" so that its depth is greater than that of the "boat."

16. Float the "boat" in the "lake."

17. Begin adding masses to the "boat" until it just begins to sink.

18. Complete Table 3.

**VI. Data**

Table 1 Sinking Objects

| A | B | C | D = B/C | E = 981 x B | F = C | G = 981 x F | H | I = E – H | J = \| G – I \| |
|---|---|---|---|---|---|---|---|---|---|
| Object | Mass of the object $m_{object}$ in grams | Volume of the object, $V_{object}$ = volume of displaced water, in cm$^3$ | Density of the object $\rho_{object}$ in grams/cm$^3$ | Weight of the object $W_{object}$ in dynes | Mass of displaced water $m_{fluid}$ in grams | Weight of displaced water $W_{fluid}$ in dynes | Net force on the object $F_{net}$ in dynes | Buoyant force $F_B$ = $W_{object} - F_{net}$ in dynes | $F_B - W_{fluid}$ in dynes (should be 0 dynes) |
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| | | | | | | | | | |

Table 2 Floating Objects

| A | B | C | D = B/C | E = 981 x B | F | G = 981 x F | H | I = E – H | J = \| G – I \| |
|---|---|---|---|---|---|---|---|---|---|
| Object | Mass of the object $m_{object}$ in grams | Volume of the *sub-merged* object, $V_{object}$ = volume of displaced water, in cm$^3$ | Density of the object $\rho_{object}$ in grams/cm$^3$ | Weight of the object $W_{object}$ in dynes | Mass of displaced water *after* the object is allowed to float, $m_{fluid}$ in grams | Weight of displaced water after the object is allowed to float, $W_{fluid} = F_B$ in dynes | Net force on the object, $F_{net}$ in dynes | Buoyant force $F_B = W_{object}$ in dynes | $F_B - W_{fluid}$ in *dynes* (should be 0 dynes) |
| | | | | | | | 0.0 | | |
| | | | | | | | 0.0 | | |
| | | | | | | | 0.0 | | |
| | | | | | | | 0.0 | | |
| | | | | | | | 0.0 | | |

Table 3 Floating Boat

| A | B | C = B – A | D | E = A + D | F = \| B – E \| |
|---|---|---|---|---|---|
| Mass of empty boat in grams | Mass of boat filled with water in grams | Mass of water in grams | Added mass in grams when boat just begins to sink | Mass of empty boat + added mass in grams when boat just begins to sink | Difference between mass of boat + water and mass of boat + masses in grams |
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## VII. Discussion Questions

Part 1 Sinking Objects

1. What criteria did you use to select the sinking objects?

2. The weight of the displaced fluid *should* be the same as the buoyant force. Explain why.

3. Is there a buoyant force on objects that sink? Explain your answer.

Part 2 Floating Objects

4. What criteria did you use to select the floating objects?

5. Why should there be no difference between $W_{object}$ and $F_B$ in this part of the experiment?

6. Why can't we measure $F_{net}$ easily for floating objects?

Part 3 Float Your Boat

7. Other than mathematical errors, what would account for the difference between mass of boat + water and mass of boat + masses in grams?

Part 4 Water and Ice

8. What is the numerical value for the density of ice?

9. Why do ice cubes float? What does this tell you about what happens when water freezes?

10. What real life evidence is there for this?

11. Using the formula $V_{fluid} = \frac{\rho_{object} V_{object}}{\rho_{fluid}}$, where $\rho_{fluid}$ is the density of water, $\rho_{object}$ is the density of the iceberg, and $V_{object}$ = 100,000 $m^3$ is the volume of the iceberg, explain why approximately 90% of the iceberg is below the water.