DENSITY AND ARCHIMEDES PRINCIPLE

PHYSICS 211 — LABORATORY 9

Rev. 08/2004

OBJECTIVES

This laboratory will permit you to find the density of several solid materials and of a liquid sample using a “brute-force” method and by using Archimedes principle.

EQUIPMENT AND MATERIALS

- Masses (equal; cubes with hangers; copper, aluminum, lead, tin, and zinc)
- Masses (equal; cylinders with hangers)
- Triple-beam balance
- Spring scale (0–2 N range)
- S-hooks
- Irregularly shaped mass
- Container of room-temperature water
- Container of unknown liquid at room temperature
- Granite pebbles secured with string hanger
- 250-ml graduated cylinder
- 500-ml graduated cylinder
- Mason (canning) jar or large beaker
- Table of densities for metals or access to internet
- Meter stick
- String

INTRODUCTION

Why can metal ships and icebergs float in water? Why do you appear to lose weight when immersed in water? Why can balloons rise in the atmosphere, level off, and descend? Why can submarines float on top of the water, descend to great depths, level off, and rise to the surface? Answers to all of these questions are dependent on a scientific principle first articulated by the ancient Greek scientist and inventor Archimedes (384–322 BCE).

Archimedes Principle

The principle that Archimedes “discovered” is called the ***principle of buoyancy*** or, simply, ***Archimedes principle***. Basically, *this principle states that a body 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***—i.e., to *liquids* and *gases* and to “solid” materials that behave *plastically* over long spans of geologic time.

Whether a given body will float, sink, or remain static in a given fluid is dependent on both the weight and volume of that material. The ***relative density***—the weight per unit volume of the body contrasted to that of the fluid—determines the ***buoyant force***. If the body is less dense than the fluid, it will float, or, in the case of a balloon, it will rise. If the body is denser than the fluid, it will sink. If the object has the same relative density, it will remain static—i.e., it will neither rise nor fall.

Relative density also determines the proportion of a floating body that will be submerged in a fluid. If the body is two thirds as dense as the fluid, then two thirds of its volume will be submerged, displacing in the process a volume of fluid the weight of which is equal to the entire weight of the body.

Density

The ***density*** (ρ) of a material of ***mass*** (m) and ***volume*** (V) is given by the equation:

$$\rho = m/V. \qquad (1)$$

Knowing any two of the three variables, of course, allows you to find the third.

Buoyant Force

Figure 1 shows a fluid at rest in a container. Each layer of fluid is supported against the force of gravity by the pressure of the layer just beneath it. Because more total weight must be supported as the fluid becomes deeper, the *pressure* (force per unit area) exerted by the fluid must increase with depth.

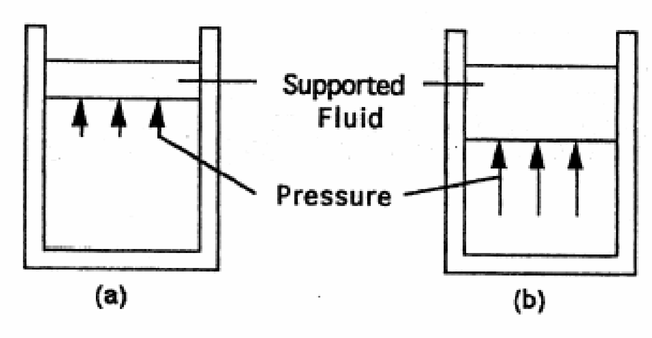

Figure 1—The pressure at any depth in a fluid supports the weight of the fluid above. *(a)* A fluid layer at shallow depth; *(b)* at greater depth.

When an object is immersed in a fluid as in Figure 2, the fluid pressure acts perpendicular to the surface of the object at every point of its surface. Pressures acting on one side of the object cancel pressures acting on the opposite side. However, the pressure acting on the bottom of the object is always greater than the pressure acting on the top of the object. This causes a net upward force on the object, which is called the ***buoyant force*** or, simply, the ***buoyancy***.

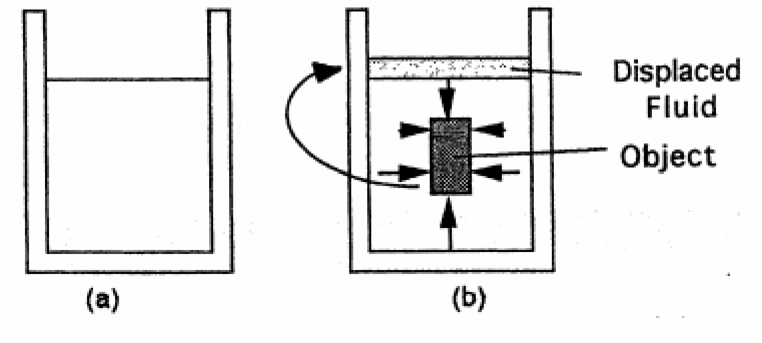

Figure 2—Pressure acting on an immersed object and graphic explanation of "displaced fluid." *(a)* Fluid level shown by horizontal line; *(b)* Fluid level rises when an object is immersed.

When an object is immersed in the fluid, some fluid must be pushed aside to make room for the object. This is called the ***displaced fluid*** (see Fig. 2b). It should be obvious that the volume of the displaced fluid is equal to the volume of the immersed object. Archimedes principle states that buoyant force is equal to the weight of the displaced fluid.

Thus, you can see that there are two forces acting on the immersed object—the *downward force of gravity* (weight of the object) and *the upward buoyant force*. As stated before, if the weight of the object exceeds the buoyant force, the object will accelerate downward—in other words, it will sink. There are three possibilities: (1) If the buoyant force exceeds the weight of the object, the object will accelerate upward—in other words, it will float, and is said to have ***positive buoyancy***. (2) If the buoyant force is less than the weight of the object, it will sink, and is said to have ***negative buoyancy***. (3) If the buoyant force equals the weight of the object, it remains static, and has ***neutral buoyancy***. Yet another way of stating those three possibilities follows: (1) If the weight of the object exceeds the weight of the displaced fluid, the object will sink; (2) if the weight of the displaced fluid exceeds the weight of the object, the object will float: (3) if the weight of the displaced fluid equals the weight of the object, it will remain stationary.

Measuring Buoyant Force

Figure 3 shows how buoyant force is measured.

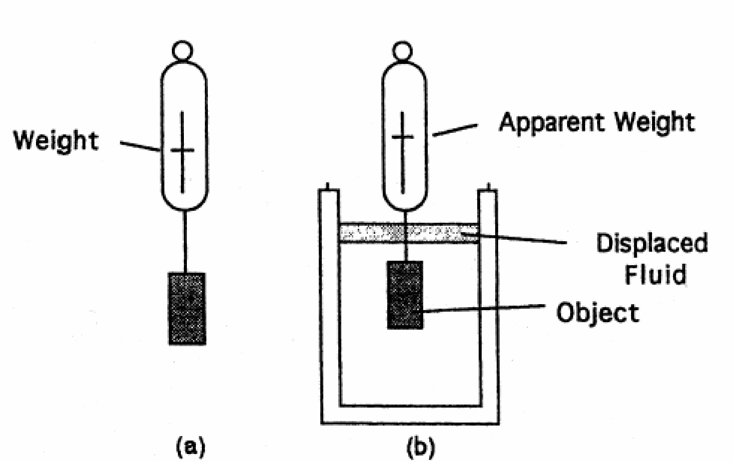

Figure 3—Measuring buoyant force with spring scales.

In Figure 3a, the spring scale just balances the force of gravity on the object, and thus the scale reads the weight of the object. In Figure 3b, the buoyant force acts upward on the object, and the scale reads less than in Figure 3a by an amount equal to the buoyant force. We call this second reading the ***apparent weight*** of the object. The ***buoyant force*** is calculated as

$$\text{Buoyant Force} = \text{Weight} - \text{Apparent Weight.} \qquad (2)$$

You can draw a number of conclusions from the data from this simple experiment.

- We can find the ***weight*** of the object.
- We can find the ***weight*** (W) ***of the displaced fluid***, because this is just equal to the buoyant force.
- We can find the ***mass*** (m) ***of the displaced fluid*** from the relation:

$$W = m \times g \qquad (3)$$

- From the ***mass*** (m) ***of the displaced fluid*** and the ***density*** (ρ) ***of the fluid***, we can find the ***volume*** (V) ***of the displaced fluid*** from the relation:

$$\rho = \frac{m}{V} \qquad (4)$$

- The volume of the displaced fluid is the same as the volume of the object, so you also have the volume of the object.
- If the fluid is in a graduated cylinder, the graduations provide an alternate method of determining the volume of the displaced liquid. Simply read the volume of the. liquid from the cylinder before and after the object is immersed and subtract. (One milliliter, ml, = 1 cm^3.)

EXPERIMENTAL PROCEDURE

You will do three experiments to find the density of a solid or liquid. In the first experiment, you use a straightforward method to find mass and volume, and this will be called the "brute-force" method. In the other two experiments, you will use Archimedes principle to help determine the mass or the volume of the sample.

Experiment 1. Density of Metals: Brute-Force Method

Simply measure the dimensions of a metal cylinder and calculate its volume V using:

$$V = base\ area \times length \qquad (5)$$

where *base area* is just the area of a circle, calculated from the radius r as:

$$Area\ = \pi\, r^2\,. \qquad (6)$$

Measure the weight of the metal cylinder using the spring scale and use your result to find the mass of the cylinder. Then, calculate the density ρ directly from:

$$\rho\ =\ \frac{m}{V}\,. \qquad (7)$$

Look up the standard densities of copper, aluminum, lead, tin, and zinc to calculate your experimental errors.

Experiment 2. Density of Rock: Buoyant-Force Method

You will still measure the weight of the rock with the spring scale and use this to find the mass, but you now have no convenient formula for volume. However, you can find the volume of the rock from the buoyant force exerted on the rock when we immerse it in a liquid of known density.

Fill a canning jar or large beaker with water, and measure the buoyant force exerted on the rock immersed in water. You will have to rig a sling made of thread so that the rock can be suspended from the spring scale. Water is a convenient liquid to use because its density equals 1 g/cm^3. See whether you can figure out the details.

Granite is a rock primarily made up of the minerals feldspar and quartz and represents the average composition of the Earth's crust. The average density of the crust is 2.70 g/cm^3. Use this figure to calculate your experimental error.

Experiment 3. Density of Unknown Liquid: Buoyant-Force Method

You will not find the mass and volume of the whole liquid sample but just the mass and volume of the liquid that is displaced when you immerse a metal cylinder of known volume into the liquid.

Fill a graduated cylinder about half full of the unknown liquid. Measure the buoyant force on the copper cylinder of Experiment 1 when it is immersed in the liquid. See whether you can apply Archimedes principle to find the unknown variables.

Take care not to add any water to the unknown liquid, and return the unknown liquid to its container when you complete your experiment.

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WORKSHEET: DENSITY AND ARCHIMEDES PRINCIPLE

Name: ____

Table 1—Density of Metals: "Brute-Force" Method

Metal	Diameter (cm)	Radius (cm)	Length (cm)	Area (cm^2)	Volume (cm^3)	Weight (N)	Mass (g)	Calculated Density (g/cm^3)	Standard Density (g/cm^3)	Exper. Error (%)
Copper										
Aluminum										
Lead										
Tin										
Zinc										

Table 2—Density of Rock: Buoyant-Force Method

Weight Rock (N)	Apparent Weight Rock (N)	Buoyant Force (N)	Mass Rock (g)	Weight Displaced Water (N)	Mass Displaced Water (g)	Volume Displaced Water (cm^3)	Volume Rock (cm^3)	Calculated Density Rock (g/cm^3)	Density Rock (g/cm^3)	Exper. Error (%)
									2.70	

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Table 3—Density of Unknown Liquid: Buoyant-Force Method

Metal ______________ (Name and density)

Liquid _____________

Weight Metal (N)	**Apparent Weight Metal (N)**	**Buoyant Force (N)**	**Weight Displaced Liquid (N)**	**Mass Displaced Liquid (g)**	**Volume Metal from Table 1* (cm^3)**	**Volume Displaced Liquid (cm^3)**	**Density Liquid (g/cm^3)**

* As a check, the figure for volume of the metal used should equal the number of milliliters the water rises in the graduated cylinder.