Archimedes’ Principle

Buoyancy is the ability of a fluid to sustain a body floating in it or to diminish the apparent weight of a body submerged in it. Archimedes’ principle states that this apparent reduction in weight is equal to the weight of the fluid displaced. It is the purpose of this experiment to study Archimedes’ principle and its application to the determination of density and specific gravity. In particular, the specific gravities of a solid heavier than water, a solid lighter than water, and a liquid other than water will be measured.

THEORY

The density of a body is defined as its mass per unit volume. It is usually expressed in grams per cubic centimeter. The specific gravity of a body is the ratio of its density to the density of water at the same temperature. Since for a given location the weight of a body is taken as a measure of its mass, the specific gravity may be taken as the ratio of the weight of a given volume of a substance to the weight of an equal volume of water. Because the mass of 1 cm³ of water at 4°C is 1 g, the specific gravity of a body at this temperature is also numerically equal to its density in grams per cubic centimeter.

If a body is totally immersed in a fluid, the volume of fluid displaced must be equal to the volume of the body, because if the body weren’t there, its volume would be occupied by the fluid. Moreover, the hydrostatic pressure on the bottom of the body is greater than that on the top because hydrostatic pressure rises as depth increases. The situation is illustrated in Fig. 13.1, which shows a beaker of fluid with an object (which we have made rectangular in the interest of simplicity) submerged in it. Let us begin by imagining an area of 1 cm² on the bottom of the beaker as shown at the right in Fig. 13.1. The dotted lines indicate that we may think of this 1-cm² patch as supporting a column of fluid 1 cm² in cross section extending up to the surface a distance d above it, the depth of fluid being d cm. Thus, a volume of fluid 1 × d cm³ with a weight of ρgd dynes is sitting on that 1 cm² of the bottom. Here ρ is the fluid’s density and g is the acceleration of gravity in centimeters per second squared. Hence, the pressure sustained by the bottom of the beaker is ρgd dynes weighing on every square centimeter, or ρgd dynes/cm². Note that this is the gauge pressure. The absolute pressure must include the pressure due to the atmosphere on the fluid surface—we could imagine the dotted lines in Fig. 13.1 going on up to the top of the atmosphere and indicating a column of air 1 cm² in cross section sitting on top of the column of li-

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*The CGS (centimeter-gram-second) system will be used in this experiment as it is both more usual and more convenient for this work.
The specific gravity of a solid heavier than water may be easily determined by the application of this principle. The body is weighed in air; then it is weighed in water, that is, suspended by a thread from the arm of a balance so as to be completely submerged (see Fig. 13.2). The loss of weight in water is \( W - W_1 \), where \( W \) is the weight in air and \( W_1 \) is the weight in water. But this loss of weight must be just the buoyant force, which, by Archimedes' principle, is equal to the weight of the water displaced, or the weight of an equal volume of water. Thus, the specific gravity \( S \) will be

\[
S = \frac{W}{W - W_1} = \frac{Mg}{Mg - M_1g} = \frac{M}{M - M_1}
\]  

(13.1)

where \( M \) is the body's mass in air and \( M_1 \) its apparent mass (from the apparent weight measurement) in water.

The specific gravity of a liquid may be found by measuring the loss of weight of a convenient solid body when immersed in that liquid and the loss of weight when immersed in water. The procedure is as follows: A heavy body is weighed in air; this weight is called \( W \). Then it is weighed in water; this weight is called \( W_1 \). Finally, it is weighed in the liquid whose specific gravity is to be determined; this weight is called \( W_2 \). The specific gravity of the liquid will then be

\[
S = \frac{W - W_2}{W - W_1} = \frac{M - M_2}{M - M_1}
\]  

(13.2)

since this expression represents the weight of a certain volume of the liquid divided by the weight of an equal volume of water. Here \( W - W_1 \) is the loss of weight in water, and \( W - W_2 \) is the loss of weight in the given liquid.

In order to find the specific gravity of a solid lighter than water, it is necessary to employ an auxiliary body, or sinker, of sufficient weight and density to hold the other body completely submerged. The specific gravity of a solid lighter than water, as obtained by the sinker method, is given by

\[
S = \frac{W}{W_1 - W_2} = \frac{M}{M_1 - M_2}
\]  

(13.3)

where \( W \) is the weight of the solid in air; \( W_1 \) is the weight of the solid and the sinker, with the sinker alone immersed; and \( W_2 \) is the weight when both solids are immersed in water.

The hydrometer is an instrument designed to indicate the specific gravity of a liquid by the depth to which it sinks in the liquid. To measure the specific gravity of a liquid by means of a hydrometer, it is only necessary to let the hydrometer float in the liquid and to read the specific gravity directly on the calibrated scale. The reading is taken, if possible, by placing the eye below the liquid surface and seeing where this surface cuts the hydrometer scale.

**APPARRATUS**

1. Triple-beam balance with hook for suspending weights
2. Metal cylinder
3. Wooden cylinder
4. Lead sinker
5. Distilled water
6. Alcohol
7. Hydrometer
8. Hydrometer jar
9. 1000-cc Pyrex beaker
10. Fine thread

**PROCEDURE**

1. The triple-beam balance is set up with a fine thread attached to the underside of the pan carrier so that you can weigh bodies by hanging them on the thread rather than placing them in the pan. Make sure that the thread is of the proper length so that a body attached to its end will hang completely submerged in the fluid in the beaker (see Fig. 13.2). Also check that the beam balance balances with no body attached and adjust it accordingly. Then weigh the
metal cylinder in air by suspending it on the end of the thread. Note that the balance is calibrated in grams, so that you will be recording the mass of the cylinder.

2. Fill the beaker with water and place it on the floor with the metal cylinder submerged in it as shown in Fig. 13.2. Be sure the cylinder is completely submerged and not touching the sides of the beaker. In this way, obtain the weight of the metal cylinder in water. Again, you will be reading in grams so that you will be observing an "apparent reduction in mass." When you have completed this measurement, remove and dry off the metal cylinder.

3. Empty the beaker, dry it thoroughly, and refill it with alcohol. Then repeat Procedure 2. When you are finished, pour the alcohol into the hydrometer jar and rinse out the beaker with distilled water.

4. Weigh the wooden cylinder in air as you did with the metal cylinder in Procedure 1.

5. Refill the beaker with distilled water. Attach the sinker to the wooden cylinder and weigh the combination with the sinker alone immersed in water.

6. Now weigh the two solids when they are both immersed in water.

7. Measure the specific gravity of the alcohol with the hydrometer. See that there is enough alcohol in the hydrometer jar and let the hydrometer float in the alcohol. Read the specific gravity directly.

**DATA**

<table>
<thead>
<tr>
<th>Mass of metal cylinder in air</th>
<th>Specific gravity of alcohol from Table IV at the end of the book</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent mass of metal cylinder in water</td>
<td>Percent error</td>
</tr>
<tr>
<td>Apparent mass of metal cylinder in alcohol</td>
<td>Mass of wooden cylinder in air</td>
</tr>
<tr>
<td>Specific gravity of metal cylinder</td>
<td>Apparent mass of cylinder in air and sinker immersed in water</td>
</tr>
<tr>
<td>Specific gravity of metal cylinder from Table IV at the end of the book</td>
<td>Apparent mass of cylinder and sinker, both immersed in water</td>
</tr>
<tr>
<td>Percent error</td>
<td>Specific gravity of wooden cylinder</td>
</tr>
<tr>
<td>Specific gravity of alcohol</td>
<td>Specific gravity of alcohol by using the hydrometer</td>
</tr>
</tbody>
</table>

**CALCULATIONS**

1. From the data of Procedures 1 and 2, calculate the specific gravity of the metal cylinder.

2. From the data of Procedures 1–3, calculate the specific gravity of the alcohol.
3. From the data of Procedures 4–6, compute the specific gravity of the wooden cylinder.

4. Compute the percent error of your measurements by comparing your results for the specific gravity of the metal cylinder and of the alcohol with the accepted values.

5. Compare your measurement of the specific gravity of alcohol using the hydrometer with the accepted value and note whether this latter value falls within the limits of precision on the hydrometer reading.

QUESTIONS

1. (a) Explain how you can obtain the volume of an irregular solid insoluble in water. (b) How can you obtain the weight of an equal volume of water?
2. (a) When a block of wood is completely submerged in water, why does it apparently lose more than its entire weight in air? (b) Given the block of wood’s weight and density, find an expression for the minimum weight of a sinker made of a material of density \( \rho_s > 1 \) that will completely submerge the combination.

3. Suppose there were a bubble of air on the bottom of the metal cylinder immersed in water. How would this affect the calculations of the density of the metal?

4. A piece of cork having a mass of 25 g in air and a specific gravity of 0.25 is attached to a lead sinker whose mass is 226 g in air. What will be the apparent mass of the two solids when they are both immersed in water?

5. The cork in Question 4 is allowed to float in water. What fraction of its volume is above the surface?

6. Derive Equation 13.3.
7. Look up Pascal's principle, state it in your own words, and tell how it was applied (without our saying so) in the derivation of Archimedes' principle given in the Theory section.

8. (a) Explain the apparent loss of weight suffered by an object when immersed in a liquid. (b) Suggest a modification of the apparatus shown in Fig. 13.2 that will demonstrate your answer to Part (a). (c) If your instructor suggests it and time permits, carry out the experiment you proposed in Part (b) and state your results below.