OBJECTIVES

- To extend the concepts of proportional relationships to intensive properties of substances.
- To accurately measure the densities of common household substances
- To apply density relationships in problem solving.

INTRODUCTION

Remember the old joke, "Which is heavier a pound of lead or a pound of feathers?" Even though a pound is always a pound, we think of lead as being heavier than feathers because lead has such a large density.

Density is defined as mass per unit volume; mathematically, we would write:

\[
density = \frac{mass}{Volume} \quad \text{or} \quad d = \frac{m}{V}
\]

For any pure substance or homogenous mixture, density is an intensive quantity, which means that its value is the same no matter how much of the substance is present. Density expresses the proportional relationship between mass and volume of the substance. If the density of a particular substance is given in grams per milliliter, it indicates the number of grams present in 1 milliliter of that substance. Conversely, the reciprocal of density tells the number of milliliters present in one gram of the substance. For example, the density of copper is 8.94 g/cm³. This tells us that:

1. A sample of copper with a one cubic centimeter volume weighs ______ grams.

2. A one gram sample of copper occupies a volume of ______ cm³.
To determine density, the mass and volume of a sample of material must be measured. Figure 2.2 depicts a cylinder of lead that is 19 mm in diameter and 20 mm high. (Remember, the volume of a cylinder is \( V = \pi r^2 h \), where \( r \) is the radius and \( h \) is the height.)

3. What is the mass of the lead cylinder? ______

4. What is the volume of the lead cylinder? ______

5. What is the density of lead? ______

If a large mass is confined to a small volume, the density will be large. From a microscopic perspective, this means that the atoms or molecules are packed together closely, as they are in solids and liquids (incompressible phases). By contrast, when atoms or molecules are relatively far apart, as they are in gases, the density is much lower.

6. Compared to 500 g of solid lead, 500 g of nitrogen gas would have a (higher or lower) density and a (larger or smaller) volume.

Whether an object floats or sinks relative to another is directly related to its density, not its mass. As Figure 2.3 indicates, a cork weighing 12.5 grams floats on water, while a much lighter piece of lead (2.5 g) sinks to the bottom.
Liquids display a variety of densities. The five liquids displayed in the picture below are water, vegetable oil (polyunsaturated triglycerides), karo syrup (a concentrated solution of sucrose and water), rubbing alcohol (isopropanol) and dry cleaning solvent (trichloroethylene).

7. Circle the liquids that have a higher density than water.

Cooking oil  Karo syrup  Dry cleaning fluid  Rubbing alcohol

**EXPERIMENTAL**

In this experiment, you will explore the relationship between mass and volume for two liquids, karo syrup and cooking oil, by measuring the relationship between their masses and their volumes. In particular, you apply the proportional reasoning concepts demonstrated in the Balance experiment to the densities of these materials. Then you will practice using the densities relationships to determine masses and volumes.

- Balance from Experiment 1
- Primary and secondary mass standards
- Measuring cup
- Measuring spoons
- Canola oil
- Corn syrup
1. Carefully measure a tablespoon of canola oil using a measuring spoon.

2. Pour contents into the plastic cup on one side of the balance. Be sure to hold the cup so the balance doesn't tip and spill the oil.

3. Balance the oil by adding your primary and secondary mass standards to the other cup.

4. Compute the mass of the sample, and add the data to row 7, column D of the accompanying spreadsheet.

5. Repeat the measurement three times by adding three additional one-tablespoon increments. Then complete rows 8 - 10 of column D.

6. Repeat steps 1 - 5 using corn syrup, and fill in rows 7 - 10 of column E.

RESULTS & DISCUSSION

Although density relates two different types of measurements, mass and volume, it bears many of the characteristics of the proportional relationships between mass standards that were observed in the Balance Lab. As the graph on your spreadsheet has been constructed to illustrate, the mass/volume relationship for a specific substance (karo syrup or vegetable oil) at constant temperature is linear with a y-intercept of 0.

\[
\text{Slope} = \frac{\Delta Y}{\Delta X} = \frac{m_2 - m_1}{v_2 - v_1} = \text{(density)}
\]

This must be the case for any proportional relationship. The density of a homogenous mixture with a fixed composition (your karo syrup or vegetable oil), like the density of a pure substance, is an intensive property of the substance at a given temperature. This means that it does not vary as the amount of the substances is changed.

Let's use your experimental data to convert between mass and volume information for karo syrup and cooking oil. Begin by indicating the densities of cooking oil and karo syrup predicted from the best-fit straight lines obtained from your experimental data:

- Density of cooking oil: __________
- Density of Karo syrup: __________

These slopes represent proportional relationships between the masses of the materials. Use them to answer the following questions:

1. What is the volume of 125 g of cooking oil? __________
2. What is the mass of 5 L of Karo syrup? __________
3. What is the density of 3500 pounds of cooking oil? __________
4. If 26 g of cooking oil are carefully poured on 35 g of Karo syrup, what is the total volume? __________
# DATA SHEET

<table>
<thead>
<tr>
<th>Volume (Tbs)</th>
<th>Volume (ml)</th>
<th>Mass (g) cooking oil (oil)</th>
<th>Mass (g) corn syrup (syrup)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Volume vs. Mass**

```
<table>
<thead>
<tr>
<th>Mass (g)</th>
<th>Volume (ml)</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
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<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>
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**Note:** The data sheet shows the volume in tablespoons (Tbs) and the corresponding volume in milliliters (ml) along with the mass in grams for cooking oil and corn syrup. The graph illustrates the relationship between volume and mass for these substances.