Purpose
To determine the densities of unknown metals.

Background
An old riddle asks “Which is heavier, a pound of feathers or a pound of lead?” The question is nonsensical, of course, since a pound of feathers and a pound of lead both weigh the same, one pound. Nevertheless, there is a clearly something different about a small lead brick and a large bag of feathers, even though they weigh the same. The key to answering the riddle is understanding the relationship that exists between a substance’s mass and the volume it occupies. This relationship is expressed by the physical property called density. Density is defined as the ratio of a substance’s mass to the volume it occupies.

\[
\text{Density} = \frac{\text{mass of substance (g)}}{\text{volume of substance (mL)}}
\]

In this experiment, you will measure the mass and volume of several unknown materials. You will then use your data to explore the relationship between the mass and volume of the materials and to calculate their density.

After performing this lab, if someone asks you the riddle about feathers and lead, you can explain to them the difference between weight and density.

Materials (Per Pair)
- safety goggles
- ruler
- centigram balance
- metal samples
- 25-mL graduated cylinder
- paper towels

Safety First!
In this lab, observe all precautions, especially the ones listed below. If you see a safety icon beside a step in the Procedure, refer to the list below for its meaning.

Caution: Wear your safety goggles. (All steps.)

Note: Your teacher will properly dispose of the materials.
Students will determine the mass/volume ratios for samples of two different metals. Class data will be combined and graphed. Students should learn that the mass/volume ratio is constant for a particular metal and that this constant ratio is called density. If time permits, students can test and analyze additional samples.

Analyses and Conclusions
Remind students that the measurement with the least number of significant figures determines the number of significant figures in a calculated answer (multiplication and division). The number of significant figures in a volume measurement made in a graduated cylinder generally depends on the size of the cylinder in the following way:

- 100 mL = ± 1 mL
- 25 mL = ± 0.5 mL
- 10 mL = ± 0.2 mL

Refer students to the graphing review section in Appendix C of the textbook.

Provide students with clear plastic rulers for use in drawing the “best fit” line through their data points. The y-intercept for this line should be 0.
## OBSERVATIONS

### DATA TABLE 1: INDIVIDUAL DATA AND CALCULATIONS

<table>
<thead>
<tr>
<th></th>
<th>Metal A</th>
<th>Metal B</th>
<th>Additional Metal Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass (g)</td>
<td>10.10 g</td>
<td>33.41 g</td>
<td></td>
</tr>
<tr>
<td>volume of water alone (mL)</td>
<td>12.0 mL</td>
<td>19.7 mL</td>
<td></td>
</tr>
<tr>
<td>volume of water + metal (mL)</td>
<td>15.8 mL</td>
<td>23.5 mL</td>
<td></td>
</tr>
<tr>
<td>volume of metal (mL)</td>
<td>3.8 mL</td>
<td>3.8 mL</td>
<td></td>
</tr>
<tr>
<td>density of metal (g/mL)</td>
<td>( \frac{10.10 \text{ g}}{3.8 \text{ mL}} ) = 2.7 g/mL</td>
<td>( \frac{33.41 \text{ g}}{3.8 \text{ mL}} ) = 8.8 g/mL</td>
<td></td>
</tr>
</tbody>
</table>

All sample data is for aluminum (Metal A) and brass (Metal B).

### DATA TABLE 2: CLASS DATA: MASS AND VOLUME OF METAL SAMPLES

<table>
<thead>
<tr>
<th>Lab Pair</th>
<th>mass (g)</th>
<th>volume (mL)</th>
<th>mass (g)</th>
<th>volume (mL)</th>
<th>mass (g)</th>
<th>volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.10</td>
<td>3.8</td>
<td>33.41</td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.31</td>
<td>1.7</td>
<td>34.62</td>
<td>3.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8.05</td>
<td>3.0</td>
<td>27.63</td>
<td>3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8.21</td>
<td>3.1</td>
<td>21.00</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>10.35</td>
<td>4.1</td>
<td>20.92</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>8.22</td>
<td>3.2</td>
<td>26.92</td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4.51</td>
<td>1.7</td>
<td>34.00</td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>9.93</td>
<td>3.7</td>
<td>21.22</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>4.70</td>
<td>1.8</td>
<td>27.15</td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ANALYSES AND CONCLUSIONS

1. Compute the volume of each metal sample, using data from Data Table 1. Compute the density of each metal sample, showing your work (including units), in Data Table 1. Remember,

\[
\text{density} = \frac{\text{mass (g)}}{\text{volume (mL)}}.
\]

2. Complete Data Table 2 by recording the mass and volume data collected by you and your classmates.

3. Using the class data, plot a graph of mass versus volume. Represent the plotted points for each metal with a different symbol. Draw a “best fit” straight line through each group of plotted points.

4. Determine the slope of each of the lines on your graph. Record the slope of each line and your method of calculation in Data Table 3. (Hint: The general equation for a line is \( y = mx + b \) where \( m \) is the value for the slope and \( b \) is the value for the \( y \)-intercept.) Pay special attention to the units of the slope.

5. What does the slope of the line for each metal represent? (Hint: Look back at Data Table 1.)

The slope is the density. If you use the origin as one of the points in the slope formula, then the slope equals the ratio of the mass to volume.

6. Looking at your graph, what does this experiment demonstrate about the density of a metal? What does it demonstrate about the densities of different metals?

This experiment indicates that the density of a specific metal is constant. It also indicates that the densities of different metals can be quite different.
7. Calculate the percent error in the density calculations for the two samples. (See Analyses and Conclusions, Step 1.) Your teacher will provide the accepted value for the density of each metal.

\[
\text{percent error} = \frac{|\text{experimental value} - \text{accepted value}|}{\text{accepted value}} \times 100\%
\]

Densities of suggested metals are Al (2.70 g/cm³), brass (8.44 g/cm³), Zn (7.04–7.16 g/cm³), Fe (7.85–7.88 g/cm³), stainless steel (7.75 g/cm³). For the examples of aluminum (Metal A) and brass (Metal B) used here, a sample calculation follows, based on the sample density data provided.

- experimental density (Al) = 2.7 g/cm³
- experimental density (brass) = 8.8 g/cm³

\[
\text{percent error (Al)} = \frac{|2.7 \text{ g/cm}^3 - 2.7 \text{ g/cm}^3|}{2.7 \text{ g/cm}^3} \times 100\%
\]
\[
= \frac{|0 \text{ g/cm}^3|}{2.7 \text{ g/cm}^3} \times 100\%
\]
\[
= 0\%
\]

\[
\text{percent error (brass)} = \frac{|8.8 \text{ g/cm}^3 - 8.4 \text{ g/cm}^3|}{8.4 \text{ g/cm}^3} \times 100\%
\]
\[
= \frac{|0.4 \text{ g/cm}^3|}{8.4 \text{ g/cm}^3} \times 100\%
\]
\[
= \frac{0.4}{8.4} \times 100\%
\]
\[
= 0.048 \times 100\%
\]
\[
= 4.8\%
\]

8. Calculate the percent error in the values of density obtained from the slopes of the lines in your graph. (See Analyses and Conclusions, Step 4.)

\[
\text{percent error (Al)} = \frac{|2.7 \text{ g/cm}^3 - 2.6 \text{ g/cm}^3|}{2.7 \text{ g/cm}^3} \times 100\%
\]
\[
= \frac{0.1}{2.7} \times 100\%
\]
\[
= 3.7\%
\]

\[
\text{percent error (brass)} = \frac{|8.5 \text{ g/cm}^3 - 8.4 \text{ g/cm}^3|}{8.4 \text{ g/cm}^3} \times 100\%
\]
\[
= \frac{0.1}{8.4} \times 100\%
\]
\[
= 0.012 \times 100\%
\]
\[
= 1.2\%
\]
9. Look back at the percent errors calculated in problems 7 and 8. Generally, the slope of the line will give a more accurate value for density than a single sample. Explain why this is usually true.

   Ordinarily, a number of determinations are better than a single determination;
   witness the results obtained for brass. The 0% error in the single determination
   for aluminum is probably the result of canceling measurement uncertainties.
   The 3.7% error found by using the slope method is more realistic.

10. Can you identify a metal if you know its density? Explain your answer. Try to identify the metals used in this experiment by referring to tables of density.

   Density can be used to identify a metal because density is constant for a particular
   metal and generally different for different metals. For the densities of some common
   metals, see the answer to problem 7 in the Analyses and Conclusions section.

11. Do you think that determining the volumes of your metal samples by measuring their dimensions and calculating would be more accurate or less accurate than determining these volumes by water displacement? Explain. Would measuring the dimensions of a solid always be possible? Explain.

   If the dimensions of a regular solid cylindrical sample of metal were measured more
   accurately (to more than two significant figures), the calculated value for the
   volume would be more accurate. This increased accuracy could be achieved by
   using a vernier caliper to make the measurements. If a cylinder is used, the
   following volume formula applies:

   \[ V = \pi r^2 h \]

   Measuring the dimensions of an irregularly shaped object is usually not possible.
12. How would you modify this experiment to determine the density of table sugar, wood chips, and milk?

- The sugar would dissolve in water; use a solvent in which it would not dissolve.
- Wood chips would float in water; use a metal cylinder of known volume to weigh down the wood chips. Since milk is a liquid, determine the mass of an empty 25-mL volumetric flask (or some container of known volume). Fill the flask with milk and remeasure the mass. The mass of the known volume of milk is the difference between the two mass measurements.

GOING FURTHER

Develop a Hypothesis
Based on the results of this lab, develop a hypothesis about how and why unknown substances can be distinguished from one another by measuring their densities.

Design an Experiment
Propose an experiment to test your hypothesis. If resources are available and you have your teacher's permission, perform the experiment.