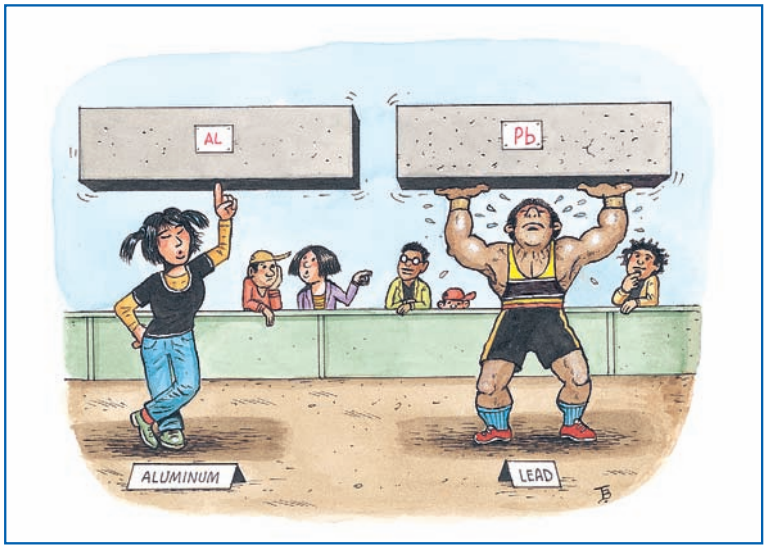
Activity 5 Mass and Volume



GOALS

In this activity you will:

- Determine the densities of various liquid and solid materials.
- Make measurements in the laboratory to the precision of the instruments used.
- Learn the difference between accuracy and precision in experimental measurements.
- Retain significant figures in calculations involving experimental measurements.
- Use density measurements to determine the identity of a material.
- Locate sources of the variation in the class's experimental results.

What Do You Think?

A piece of steel sinks in water, but a steel boat floats. A tiny rock sinks in water, but a large log floats.

- **Since a kilogram of feathers and a kilogram of lead have the same mass, how do they appear different and why?**

Record your ideas about this question in your *Active Chemistry* log. Be prepared to discuss your responses with your small group and the class.

Investigate

Part A: Mass and Volume of Liquids

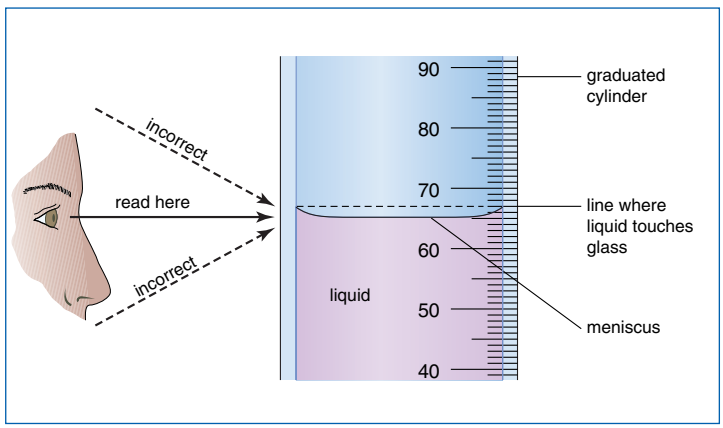
1. In your *Active Chemistry* log create a table to record your data for this part of the activity. You may wish to use a table similar to the one on the opposite page.

a.

Volume and Mass of Water

Mass of graduated cylinder (g)	Volume of water (mL)	Mass of graduated cylinder and water (g)	Mass of water (g)	Mass / Volume (g/mL)

2. Measure the mass of an empty, dry, graduated cylinder.
   a) Record the mass of the cylinder in your *Active Chemistry* log.
3. Add 10 mL of water to the graduated cylinder. Remember when reading the volume, take the reading at the lowest part of the meniscus, as shown in the diagram.



   a) Record the volume of water in your table. Remember to consider the precision of your measurement when recording your data.
4. Measure the mass of the graduated cylinder and 10 mL of water.
   a) Record the measurement in your log.
   b) Calculate the mass of the water and record this in your table.
5. Add another 10 mL to the graduated cylinder and measure the mass. Calculate the mass of 20 mL of water.

   Repeat this step for 30 mL, 40 mL, 50 mL, and so on up to 100 mL.

   a) Record all your measurements and calculations in the table in your log.

6. Use the data you obtained.

   a) Plot a graph of the mass versus the volume of water. Plot volume on the *x*-axis (horizontal axis) and mass on the *y*-axis (vertical axis).

   b) As the volume of the water increases, what happens to the mass?

   Since the graph you created is a straight line (or close to a straight line), you should draw the best fit line through the data points. Do not connect the points with small segments but draw one line that comes closest to all of the individual points.

   c) From your graph predict the mass of 55 mL of water. What would be the volume of 75 g of water? Predicting values from within a graph is called interpolation.

   d) An important attribute of a straight line graph is its slope. How steep is the graph? Calculate the slope of the graph you plotted. Remember to calculate slope you divide the "rise" by the "run." What does the "rise" of the graph represent? What does the "run" represent?

   e) Divide the mass of each sample of water by the volume. What do you notice about the relationship between the mass and the volume?

   How does the slope of the graph compare to the values you calculated in this step?

7. Your teacher will provide you with a sample of a liquid.

   Use the procedure you used to find the mass and corresponding volumes of water to determine the slope of this liquid's mass/volume graph.

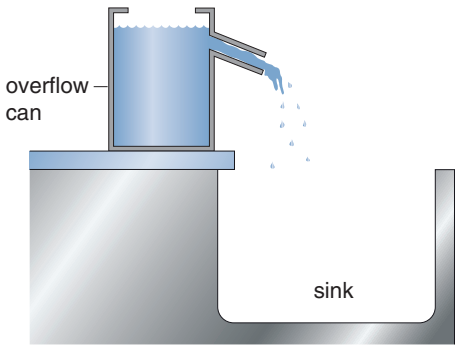
   a) Record all your data and calculations in your *Active Chemistry* log.

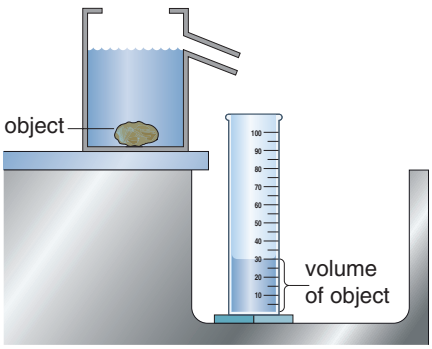
8. Dispose of your liquid sample as directed by your teacher. Clean up your work station.

Part B: Mass and Volume of Solids

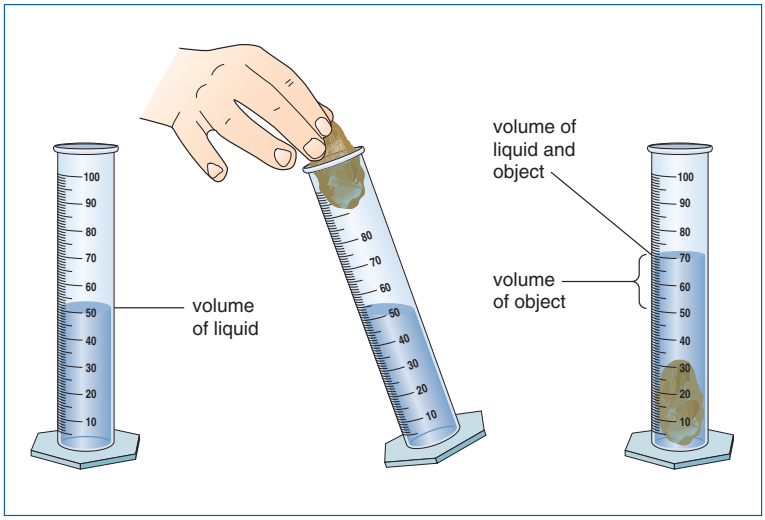
1. Your teacher will provide you with three samples of two different solid materials.

2. As a group, decide on a procedure to calculate the mass/volume ratio and slopes of the graph of each material.





You can consider using either method shown in the diagrams on the preceding page and at right for measuring the volume of each solid. Volume of solids is usually expressed in cubic centimeters. One milliliter is equivalent to one cubic centimeter ($1\ mL = 1\ cm^3$).



a) Record your procedure in your *Active Chemistry* log. Be sure to include what measurements you need to make, what equipment you will need, what safety precautions you must use, and what calculations you have to do.

3. When your teacher has approved your procedure, carry out your activity.

   a) Carefully record all your data.

4. Use the data you collected.

   a) Plot a mass versus volume graph for each solid. Plot both solids on the same graph.

   b) How do the slopes for the two solids compare? Which solid is more dense?

   c) Use the table in the **ChemTalk** reading section to identify the two samples of materials.

5. The mass of a unit volume of a material is called its density. You found the density of water by calculating the slope of the mass versus volume graph. You can also calculate density by dividing the mass of a sample of a material by the volume.

$$\text{Density } (D) = \frac{\text{Mass } (m)}{\text{Volume } (V)}$$

   a) Find the densities of water, the other liquid, and the two solid materials.

   b) Compare your answers with another lab group.

Part C: Density and Special Effects

1. Your teacher will display a set of four colored liquids that float on one another. The densities of each of the liquids were measured. The top layer has a density of 0.8 g/mL. The next layer has a density of 0.9 g/mL. The following layer has a density of 1.1 g/mL. The bottom layer has a density of 1.3 g/mL.

   a) What do you notice about the densities of the liquids and their position in the display?

2. Your teacher will drop an ink-pen barrel into the liquids.

   a) What would you predict will happen to the ink-pen barrel? Write your prediction in your *Active Chemistry* log.

   b) Observe the movement of the ink-pen barrel as your teacher places it in the liquid. Record your observation in your log.

3. You will now make an ink-pen barrel float in liquid.

   Place the ink-pen barrel in a beaker of ethanol.

   Next place the ink-pen barrel in a beaker of distilled water.

   Return the ink-pen barrel to the beaker of ethanol. Slowly add distilled water to the ethanol until the ink-pen barrel floats.

   a) Before you begin, predict what you think will happen in each part of this step. Give a reason for your prediction.

Chem Talk

DENSITY

Density as a Property of Matter

If you were to compare a 1 cm^3 cube of iron to a 1 cm^3 cube of wood, you would probably say that the iron is "heavier." However, if you compared a tree trunk to iron shavings, the tree trunk is obviously heavier. As you discovered in this activity, a "fair" comparison of the "heaviness" of two materials is a comparison of their densities. **Density** is the mass per unit volume of a material. In this activity you measured the density of water and other liquids. You found that each sample of the same liquid had the same density and each different liquid had its own characteristic density. You also found that each solid material you investigated had its own characteristic density. Density can be expressed in grams per milliliter (g/mL) or grams per cubic centimeter (g/cm^3). The table on the next page shows the densities of some common liquids and solids.

You used the slope of the mass versus volume graph of a material to calculate density. You also calculated density using the equation:

$$\text{Density } (D) = \frac{\text{Mass } (m)}{\text{Volume } (V)}$$

Chem Words

density: the mass per unit volume of a material.

Density and Flotation

In this activity you further observed that materials with a greater density than a given liquid will sink, and materials with less density than a given liquid will float. In the column of colored liquids, the liquid with the highest density was on the bottom, and the liquid with the lowest density was on the top. The ink-pen barrel sank in ethanol and floated in water. When you added ethanol to the water you created just the right density to have the ink-pen barrel float within the liquid. This position of floating is where the density of the ink-pen barrel is equal to the density of the ethanol/water. The ink-pen barrel "found" the place where the density of the liquid was identical to the density of the ink-pen barrel.

Approximate Densities of Some Common Liquids and Solids

Material	Density (g/cm^3)
wood (balsa)	0.12
wood (birch)	0.66
gasoline	0.69
isopropanol	0.79
vegetable oil	0.92
distilled water	1.00
glycerol	1.26
magnesium	1.70
aluminum	2.70
iron	7.90
copper	8.90
nickel	8.90
silver	10.50
mercury	13.50
gold	19.30

The most famous story about density is when Archimedes jumped out of the bath, ran through the town naked, and shouted "Eureka!" As the story supposedly goes, Archimedes was asked by the king to determine if his crown was solid gold. Archimedes knew the density of gold. He also knew that he could correctly determine if the crown were gold if he knew the density of the crown. The mass of the king's crown was easy to measure. The volume posed a real problem because it had such an unusual shape, and of course the king did not want his crown altered. When Archimedes submerged himself in the bathtub, he realized that the displacement of water would provide him with the volume. *Eureka* is Greek for "I found it."

MAKING MEASUREMENTS AND USING THE MEASUREMENTS TO MAKE CALCULATIONS

Uncertainty of Measurements

Every measurement that you make involves some uncertainty. When you measured the volume of water using a graduated cylinder, you used the division of units marked on the side of the cylinder to make your measurements. Suppose the smallest precision division marked on the graduated cylinder was a milliliter. This means that you can estimate the measure to the nearest tenth of a milliliter, because you can see if the level of the water is at, above, or below the mark. When you record your measurement of volume, you can record it as 10.0 mL, because you can see whether the level of the water is at, above, or below the 10 mL mark.

Remember to always look at the instrument that you are using and determine the smallest precision mark it has. When you make your measurement using the instrument you can only estimate to the next place. If you are using an electric balance to measure mass, it will do the estimating work for you. Most school balances will measure to the tenth, or the hundredth of a gram.

Calculations

When you perform calculations using the measurements that you made in an investigation, you need to express the result of your calculations in a way that makes sense of the certainty of the measurements you made. For example, when calculating the density of a 10.1 mL sample of liquid with a mass of 9.8 g, you may obtain a value of 0.9702770… g/mL using a calculator. This value does not seem reasonable when considering limitations of your measurements.

There are rules that you can use when making your calculations:

Adding and Subtracting

When adding or subtracting numbers, arrange the numbers in columnar form lining up the decimal points. Retain no column that is to the right of a column containing a doubtful digit.

Multiplying and Dividing

In multiplication and division, the result should have no more significant digits than the factor having the fewest number of significant digits. To determine how many digits are significant, count all the digits excluding zeroes at the beginning or end (e.g., 0.00326 and 71800 each have 3 significant digits). (Exception: a zero at the end of a number is significant if the number contains a decimal point — for example, 0.00326 has 3 significant figures, 0.003260 has 4, and 3260 has 3.)

Checking Up

1. Explain the meaning of density.
2. Explain the difference between feathers and lead, using the concept of density.
3. Why is balsa instead of birch wood used in the construction of model airplanes?
4. In an investigation the volume of a material is measured as 80.0 cm^3 and its mass is measured as 253 g. Which calculation of density correctly uses the precision rules: 3.1625 g/cm^3, 3.163 g/cm^3, 3.16 g/cm^3, 3.2 g/cm^3, or 3 g/cm^3?

Reflecting on the Activity and the Challenge

In this activity, you discovered that the ratio of mass to volume (m/V) is a special number associated with each material. The ratio m/V is called the density and is a characteristic property of matter. You can identify whether a piece of metal is gold or gold-plated by measuring the density. You can distinguish one material from another by comparing densities. Objects of greater density than a liquid will sink, while objects of lesser density will float. Objects of the same density will appear suspended. You can make use of these conclusions in your challenge. For instance, you may want to have a movie special effect where a material appears suspended in space. The concept of density will help you create this special effect. You can compare the density of different materials and decide which materials will float and which materials will sink, and also how to make them appear to be suspended somewhere between the top and bottom of a liquid.

Chemistry to Go

1. Look at the table in the **ChemTalk** reading section. Use density to identify the liquid and solid samples you investigated in this activity.
2. Calculate the density of a solid from the following data:

Volume of water	48.4 mL (or cm^3)
Volume of water and solid	62.7 mL (or cm^3)
Mass of solid	123.4 g

3. Determine the density of a liquid from the following data:

Mass of the graduated cylinder	33.79 g
Mass of the cylinder and liquid	40.14 g
Volume of liquid	13.3 mL

4. Methanol has a density of 0.79 g/mL. How much would be the mass of 589 mL of methanol?
5. Copper has a density 8.90 g/cm^3. What would be the volume of a 746 g sample of copper?
6. In a well-known movie, there is a famous scene in which the hero tries to outwit the designers of a trap by replacing a gold statue with a bag of sand of about the same volume.
   a) Given the density of gold is 19.3 g/mL and sand is 3.1 g/mL, does this seem like a scientifically reasonable plan?
   b) In the movie, the hero grabs the gold statue with one hand and appears to handle it quite easily. Given that the volume of the statue appears to be about 1 liter, what would be the mass of the statue?
   c) A mass of 454 g has a gravitational weight of about 4.45 N (newtons) which is about 1 lb. How many pounds would the statue weigh?
   d) One gallon of milk has a mass of 3.7 kg and a weight equivalent of approximately 8 pounds. How many gallons of milk would be equivalent to the gold statue?
7. In each of the following pairs, which has the greater mass?
   a) 1 kg lead or 1 kg feathers?
   b) 1 L gold or 1 L water?
   c) 1 L copper or 1 L silver?

8. Which of the following has the greater volume:
   a) 1 kg lead or 1 kg feathers?
   b) 1 kg gold or 1 kg water?
   c) 1 kg copper or 1 kg silver?
9. Review the measurements you made for mass and volume. How certain were your measurements? If you were to make the measurements again, could you be more certain? Explain your answer.
10. In calculating density you divided the mass of the material by the volume. Review the calculations you made. Adjust the accuracy of your answers using the rule for division given in the **ChemTalk** reading section.

Preparing for the Chapter Challenge

Design a special effect in which an object is suspended in a liquid. Consider the density of the material you will suspend, and the density of the liquid you will use. Show the calculations that you used to make your choice of materials.

Inquiring Further

1. Is it real gold?

The new United States dollar coin has a golden color. Could it be made of real gold? Devise a method to determine if the new golden coin is any of the metals in the table in the **ChemTalk** reading section.

2. Density of gas

Devise an investigation that you could do to determine the density of air or gas.