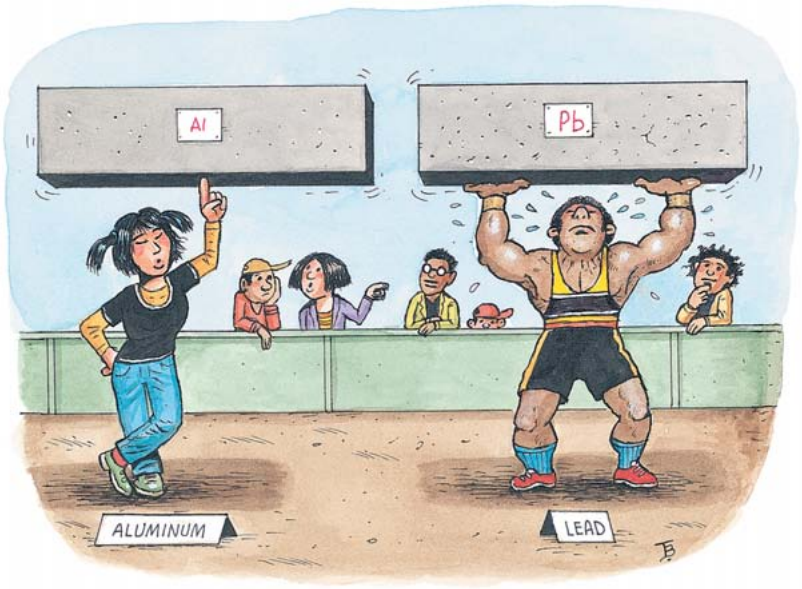
Section 5 Mass and Volume

Florida Next Generation Sunshine State Standards:
Additional Benchmarks met in Section 5

SC.912.N.2.5 Describe instances in which scientists' varied backgrounds, talents, interests, and goals influence the inferences and thus the explanations that they make about observations of natural phenomena and describe that competing interpretations (explanations) of scientists are a strength of science as they are a source of new, testable ideas that have the potential to add new evidence to support one or another of the explanations.

MA.912.S.1.2 Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.

What Do You See?



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.

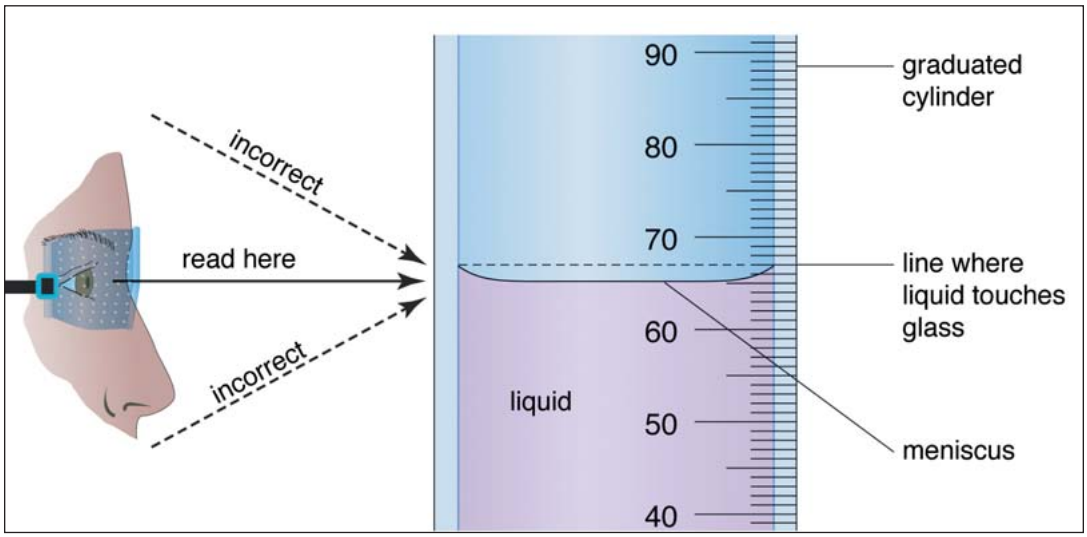
Investigate

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 investigation. You may wish to use a table similar to the one shown below.

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)	$\frac{\text{Mass}}{\text{Volume}}$ (g/mL)



2. Measure the *mass* (the amount of material and what gives it weight) 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*, the measure of how much space is taken up by the material, 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 uncertainty 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 the table 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 five more volumes of water.

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. The line you draw should pass through or close to the zero.

c) From your graph predict the mass of 55 mL of water. What would be the volume of 25 g of water? Predicting values from within a graph is called interpolation. Predicting values beyond the measured values is called extrapolation.

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

Safety goggles and a lab apron must be worn *at all times* in a chemistry lab.

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 and the mass to volume ratio?

f) 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 such as ethanol. Use the procedure you used to find the mass and corresponding volumes of water to determine the slope of the ethanol's mass/volume graph and the mass to volume ratio.

Ethanol is very flammable and is a poison. Keep it away from sparks or flames. Do not ingest!

Wash your hands and arms thoroughly after the investigation.

Safety goggles and a lab apron must be worn *at all times* in a chemistry lab.

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

8. Dispose of your ethanol sample as directed by your teacher. Clean up your workstation.

9. Someone tells you the mass and volume of a liquid that is either water or ethanol.

a) Would you be able to determine what the liquid was?

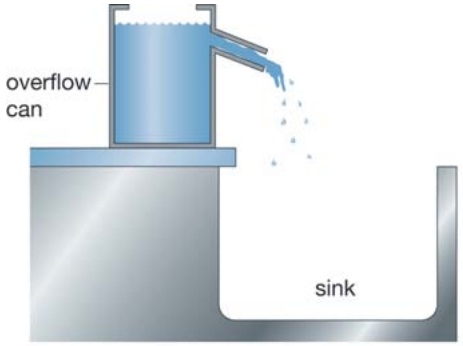
b) How would you make that determination?

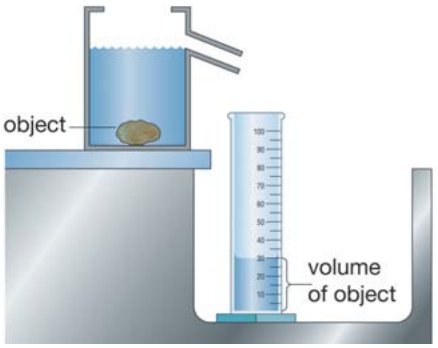
Part B: Mass and Volume of Solids

1. Your teacher will provide you with three samples each of two different solid materials or a sample of a material like clay that can easily be divided into pieces.

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

You can consider using either method shown in the diagrams on this and the next page 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.

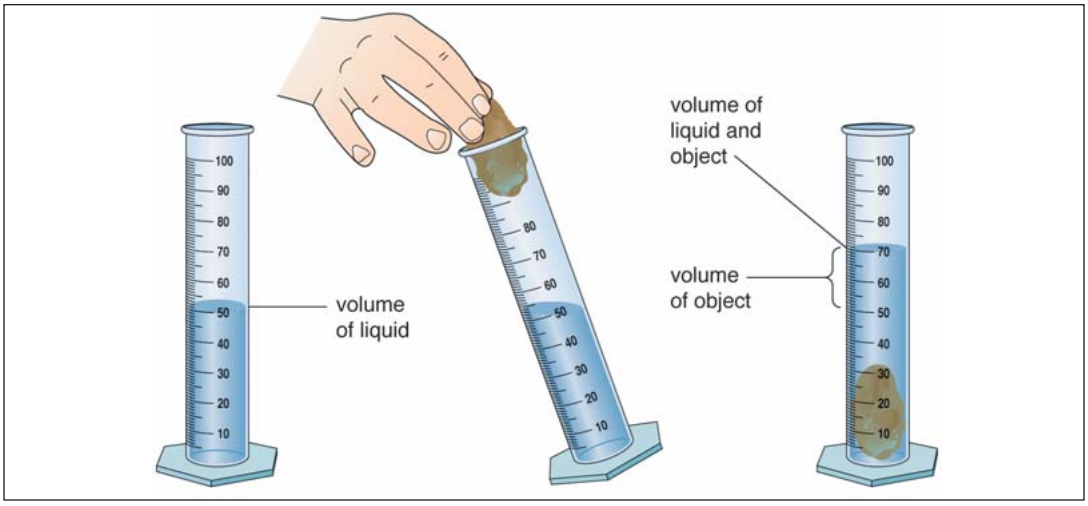
3. When your teacher has approved your procedure, carry out your investigation.

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 has the larger mass for the same volume?



5. You are given the mass and volume of a mystery material. How could you determine if the material is one of the liquids or solids that you used in this investigation?

6. 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. You will now try to make a plastic pen cap float in liquid.

a) Place the pen cap in a beaker of distilled water. Does the pen cap float or sink?

b) Place the pen cap in a beaker of ethanol. Does the pen cap float or sink?

c) Slowly add distilled water to the ethanol until the pen cap rises.

2. Use the concept of density.

a) Explain the results of your observations of the pen cap in water, ethanol, and the mixture of the two.

3. Your teacher may display a set of four colored liquids that float on one another or have you refer to a picture. The densities of each of the liquids were measured. The top layer has a density of 0.8 g/cm^3. The next layer has a density of 0.9 g/cm^3. The following layer has a density of 1.26 g/cm^3. The bottom layer has a density of 1.37 g/cm^3.

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

4. Your teacher will drop a pen cap into the liquids.

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

b) Observe and record the movement of the pen cap as your teacher places it in the liquid.

Wash your hands and arms thoroughly after the investigation.

Dispose of all substances and materials as directed by your teacher.

Chem Talk

Derived SI Units

In the *Investigate*, you calculated the density of a liquid and a solid. The units you used were grams per milliliter (g/mL) and grams per cubic centimeter (g/cm^3). Note that the units are made up of a combination of SI units. These are called derived units. In this case, the derived units have compound names. Later you will learn about derived units that have special names.

Other units also can be used for density. For example, the density of a gas might be given as grams per liter (g/L).

Chem Words

mass: the measure of the amount of matter an object contains.

volume: a measure of how much space an object occupies.

density: the mass per unit volume of a material.

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 investigation, a "fair" comparison of the "heaviness" of two materials is a comparison of their densities. Every material that exists has **mass** and **volume**. **Density** is the mass of the same volume of each material. In this investigation, you measured the density of water and ethanol. 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 units g/mL and g/cm^3 are equal, since 1 mL = 1 cm^3. The table shows the densities of some common liquids and solids.

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	1.74
aluminum	2.70
iron	7.86
nickel	8.90
copper	8.96
silver	10.50
mercury	13.50
gold	19.30

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

$$\text{density } (D) = \frac{\text{mass } (m)}{\text{volume } (V)}$$

Symbols for Physical Quantities

Symbols for SI units are unique and precise. There is only one symbol for each SI unit. For example, "m" stands for meter and "s" stands for second. The same SI symbol is used in every language.

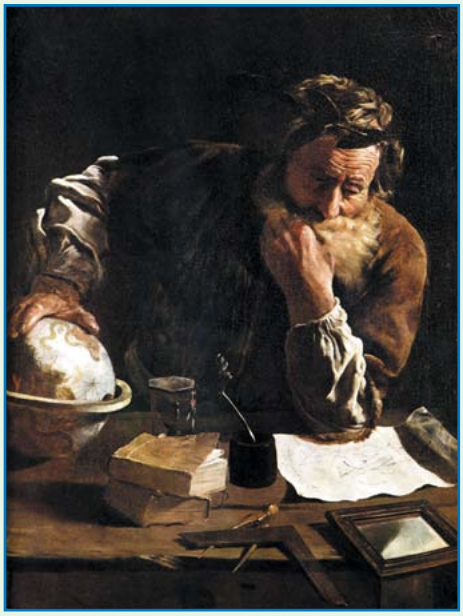
When writing equations in science, there is a need for other symbols, too. Symbols are needed for quantities such as density, mass, and volume. Letters that are used to represent such quantities are called "quantity symbols." These symbols are not a part of SI, and they are not always unique. For example, "*V*" can stand for volume or voltage. However, as much as possible, scientists try to use standard symbols for quantities.

When writing equations, you should use the same symbols used in the *Active Chemistry* book. To distinguish the two types of symbols in printed materials, sloping (*italic*) type is used for quantity symbols and upright (roman) type is used for SI symbols.

Density and Flotation

In this investigation 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 a column of colored liquids, the liquid with the highest density will be on the bottom, and the liquid with the lowest density will be on the top. The pen cap sank in ethanol and floated in water.

When you added ethanol to the water you created just the right density to have the pen cap float within the liquid. The point at which the pen cap will neither rise nor sink is where the density of the pen cap is equal to the density of the ethanol/water. The pen cap "found" the place where the density of the liquid was identical to the density of the pen cap. 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."

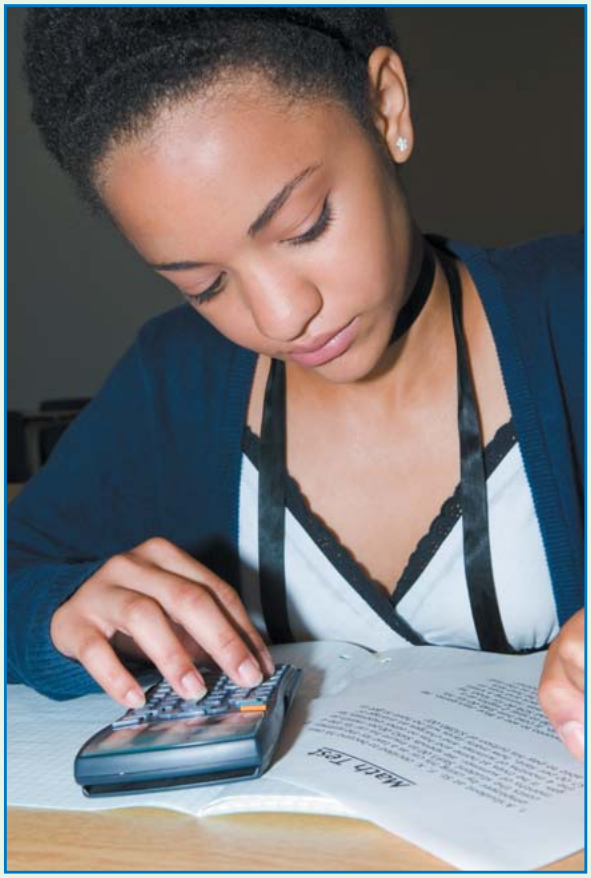


MAKING MEASUREMENTS AND USING THE MEASUREMENTS TO MAKE CALCULATIONS

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 that the meniscus is at the 10 mL mark.

Remember always to 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. The precision of 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 columns so that the decimals line up. Complete the addition or subtraction problem and draw a vertical line to mark the end of your least precise number. The final answer should have the same number of decimal places as the number with the least decimal places.

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. In order to determine the number of significant digits there are a few rules. First you must count all non-zero digits as significant (735 has 3 significant digits). Then all zeroes that are sandwiched by non-zero digits are significant (2008 has 4 significant digits). Finally, if zeroes are on the left they are not significant (00.0076 has 2 significant digits), and if they are on the right they are significant (820.00 has 5 significant digits). You can remember this rule with two words: "Not Significant." If the zeroes are on the left, they are not significant. If the zeroes are on the right, they are significant. (Exception: zeroes on the right are not significant if they do not have a decimal point. For example, 230 has only 2 significant digits and if you want 230 to have 3 significant digits, then write it in scientific notation, 2.30×10^2.) After you have determined the number of significant digits in each of your starting numbers, your final answer is limited to the least number of significant digits.

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?

What Do You Think Now?

At the beginning of this section you were asked the following:

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

You answered this question using density in *Checking Up*. If there were a statue made out of pure gold (density = 19.30 g/cm^3) and you built a replacement out of copper (density = 8.90 g/cm^3) and painted it gold, you know that the volumes would be identical. Discuss how you could tell the difference between the two statues.

Chem

Essential Questions

What does it mean?

Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your *Active Chemistry* log.

MACRO	NANO	SYMBOLIC
Describe what you would see when comparing liquids of different densities.	*In words, describe at the particle level the difference between two liquids of different densities.*	*How can you find density mathematically?*

How do you know?

Look at the graph of the mass and volume of a liquid. Use your data to show that density is an intensive property. An intensive property is one that does not depend on the amount of the material.

Why do you believe?

Everyone has experienced density at some point in his or her life. How have you experienced this property in the course of life? Explain how density related to this life experience.

Why should you care?

You will be writing a movie scene for your challenge in this unit. You can make objects appear to float by suspending them in a liquid of equal density. Alternatively, you can also create an object from a less dense material and make it appear like a dense material (for example, foam can be made to look like rocks). Write about an object that you could include for a special effect in your movie.

Reflecting on the Section and the Challenge

In this section, 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. Foam with its low density could also be made to look like dense rocks. The strength of a super-hero character can then be part of your special effect.

Chem to Go

1. Look at the table in the *Chem Talk*. Use density to identify the liquid and solid samples you investigated in this section.
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. What would be the mass of 589 mL of methanol?
5. Copper has a density of 8.96 g/cm^3. What would be the volume of a 746 g sample of copper?
6. In a well-known movie, *Raiders of the Lost Ark*, 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 that 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 one 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 lb. How many gallons of milk would be equivalent to the mass of 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 precision of your answers using the rule for division given in the *Chem Talk* reading section.
11. ***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 most recent United States dollar coins have a golden color. Could they be made of real gold? Devise a method to determine if the new golden coins have any of the metals in the table in the *Chem Talk* reading section.

2. Density of gas

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