2. Density

Objectives

Determine that density is an intensive property of a substance independent of the shape or size of an object. Through this investigation, students:

- ♦ Determine the volume of regular- and irregular-shaped objects using geometric calculations and water displacement methods
- ♦ Use mass and volume data to calculate density using the formula, $\text{density} = \frac{\text{mass}}{\text{volume}}$
- ♦ Distinguish between intensive and extensive properties
- ♦ Learn that density is an intensive physical property that can be used to identify unknown substances

Procedural Overview

Students conduct the following procedures:

- ♦ Determine the volume of regular-shaped objects through geometric calculation
- ♦ Determine the volume of irregular-shaped objects through water displacement
- ♦ Measure the mass and volume of various objects and calculate the density by dividing the two values
- ♦ Identify the material a plastic cylinder is made from when given a list of substances and their corresponding densities

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	25 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- ♦ PASCO density set
- ♦ Beaker, 150-mL
- ♦ Overflow can
- ♦ Metric ruler (or calipers)

- Graduated cylinder, 50- or 100-mL
- Balance (2 to 3 per class)
- Water, 500 mL
- String

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Mass measurements
- Volume measurements
- Length measurements
- Physical properties
- Geometric mathematical formula for a cube and a cylinder

Related Labs in This Guide

Labs conceptually related to this one include:

- Significant Figures
- Density

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Note: There are no Tech Tips to list in this section as this activity does not use a data collection system.

Background

A substance can often be identified by its physical properties. For example, a substance that melts at 0ºC and boils at 100ºC might very well be water, especially if that substance is a clear, colorless, odorless liquid at room temperature. Boiling point, melting point, color, and odor are examples of intensive properties. Intensive properties are those that are independent of how much of the substance is being measured. All water, from a small amount contained in a glass to a large amount contained in a swimming pool or a fresh water lake, freezes at 0°C and boils at 100ºC.

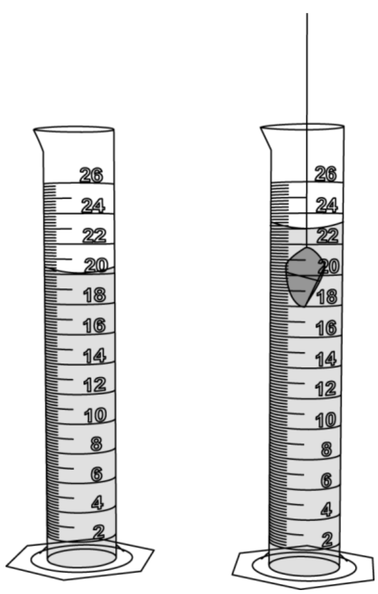
Some properties, however, depend on the amount of substance present. An extensive property changes as the amount of the substance being measured changes. Mass (weight) and volume are both examples of extensive properties. The water in a glass takes up less space and is not as heavy as the water in a swimming pool, even though both contain the same chemical substance.

Objects of the same size might not necessarily have the same mass. For example, an object made from foam weighs less than a lead object of the same size. Density is an intensive physical property of a substance that relates an object's mass to its volume. It is not an extensive property dependent on size because as a sample's mass increases, the sample's volume also increases proportionately. Many substances have similar densities, so density should be used along with other properties to positively identify a substance.

An object's density (ρ, "rho") determines whether it floats in a particular substance. To float, the density of the substance must be less than the density of the fluid in which the object is placed. At room temperature and to two significant figures, water has a density of 1.0 g/mL. This means that objects with densities less than 1.0 g/mL float in water. The fluids are not limited to liquids. For example, helium (ρ_{He} = 0.18 g/L) floats when trapped in a balloon because the density of the surrounding air is much greater (ρ_{Air} = 1.19 g/L).

To calculate density, both the mass and volume of an object must be known. Mass can be found directly using a balance (triple-beam or electronic). To calculate an object's volume, you have two options: 1) If the object has a regular shape, such as a cube or a cylinder, the volume can be calculated using the corresponding mathematical formula for that shape. 2) If the object has an irregular shape, the volume must be determined through other methods, such as water displacement.

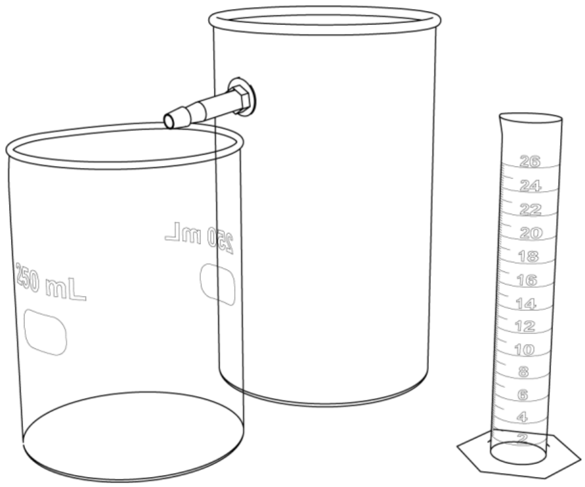
Based on the fact that two objects cannot occupy the same space at the same time, an object that sinks in water displaces a volume of liquid that is equal to its own volume. By submerging an irregular-shaped object in water, it is possible to deduce its volume by measuring the increase of the water level.



In this diagram a small rock caused the water volume to increase from 20 mL to 23 mL. The volume of the rock, therefore, is 3 mL.

Measuring volume of an irregular-shaped object using water displacement.

If the object does not fit into a graduated cylinder, the object can be placed into an overflow container. The water spills out of the container and into a collection beaker. The volume of the water collected in the beaker can then be measured using a graduated cylinder.



Overflow container with a beaker and graduated cylinder.

When the mass and volume have been determined, the density can then be calculated by dividing the two quantities.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Pre-Lab Discussion and Activity

Intensive and Extensive Properties

Use two bottles of soda (same brand and flavor) to demonstrate intensive and extensive properties. Show a small bottle (500-mL) next to a large bottle (2-L). Explain that extensive properties depend upon the amount of substance being measured—larger quantities produce greater values for the extensive property. Intensive properties, however, do not depend upon how much substance is being measured—the value of the property remains constant regardless of how large the quantity.

1. Look at the contents in the two bottles of soda. Are they the same?

If the brand and flavor are the same, the contents should be identical in all regards: taste, sweetness, color, carbonation, and so on.

2. Does the amount of soda you have matter when you decide how large a bottle should be used to contain it?

Yes. The more soda you have, the larger the bottle needs to be.

3. Is volume an intensive or extensive property of soda?

Because the volume increases as you increase the amount of soda you have, volume is an extensive property.

4. Think about the taste of the soda inside the bottles. Does the flavor of the soda change depending on the amount of soda you drink?

No. The taste remains the same no matter how much you pour into a glass.

5. Is flavor an intensive or extensive property of soda?

The taste remains the same no matter how much you drink; therefore flavor is an intensive property.

Density and Archimedes

Relate the following story of Archimedes: Around 250 B.C., King Hiero II wanted a new crown. He gave a block of gold to a goldsmith to use for the crown. The king was suspicious that the goldsmith might keep some of the gold and substitute a less expensive metal, coating only the outside of the crown with gold. The king asked the famous Greek philosopher, Archimedes, to determine if the crown was gold without damaging it. Archimedes knew if it were made of pure gold, the crown would have the same intensive properties as a bar of gold. Archimedes thought long and hard about the problem knowing he couldn't scratch the surface of the crown or melt any part of it. One day, as he stepped into his bathtub, the water spilled over the edge of the bathtub and onto the floor. This helped Archimedes figure out the solution to his problem. He was so excited he jumped out of the tub and forgot to get dressed! He ran through the streets without his clothes shouting "Eureka!" ("I have found it!") on his way to tell the king his idea.

Simulate Archimedes' problem by wrapping same sized blocks of aluminum, iron, and lead with masking tape (or paint these blocks with gold-colored paint). The masking tape or paint represents a thin layer of gold coating the less expensive metal inside. Inform the students they are not allowed to scratch through the surface coating.

6. What is the same about the blocks?

The blocks have the same size (volume) and they have the same outside appearance.

7. What is different about the blocks?

The blocks have different masses (weigh different amounts).

8. Why was the overflowing bathtub important to Archimedes' problem?

The amount of water that overflowed was equal to his volume. He reasoned that the crown's volume could be determined the same way. Finding the crown's mass was straightforward. By finding the ratio of the mass and the volume of the crown, Archimedes could compare the densities of the crown with a sample of real gold.

Regular Soda and Diet Soda

Use four bottles of soda (500-mL and 2-L of soda along with 500-mL and 2-L of diet soda) to demonstrate the concept of density. Record the weights of the different bottles and assist the students in calculating density by dividing the masses by their respective volumes. Record and display the results. Explain that for an object to float in water, it must have a density less than water (ρ_{water} = 1.0 g/mL). Ask the students to predict what will happen to each bottle (float or sink) as it is being placing into a large container of water, such an aquarium. Discuss the results by discussing the similarities and differences between the bottles.

Teacher's Tip: Avoid using the terms heavy and light when describing density. Instead, the terms more dense and less dense are more appropriate. Remember: "What weighs more, a kilogram of lead or a kilogram of feathers?" (Neither: they are both one kilogram of material.) Even though aluminum is not very dense (ρ_{Al} = 2.70 g/cm^3), a 500-kilogram block of aluminum is still very heavy. (It weighs 500 kilograms.)

9. How are the bottles of soda similar?

The bottles of soda all contain a carbonated liquid soda beverage.

10. How are the bottles of soda different?

The bottles of soda are different sizes and contain either regular or diet soda.

11. How is diet soda different from regular soda?

Regular soda contains more calories than diet soda. Regular soda contains sugar while the diet soda contains different types of sweeteners.

12. Which bottles float in water? Why?

Both bottles containing diet soda float. The diet soda has a density less than water. The regular soda sinks in water because its density is greater than water. The difference is in the sweeteners that are used in the soda. Regular soda generally contains between 35 to 45 grams of sugar, but diet soda only contains about 0.1 to 0.2 grams of artificial sweeteners. The regular soda has a much greater amount of sugar within the same volume of liquid, making it more dense.

13. The 2-L bottle of diet soda weighs more than the 500-mL bottle of regular soda, but it still floats while the other sinks. Explain.

Density is an intensive property, independent of the amount of substance present. Density is the ratio of mass to volume; as a sample's mass increases, its volume also increases proportionately to keep density constant for that substance.

Determining Volume

Hold up a box, a cylinder, and an irregular-shaped object (such as a rock) and ask how the volume of these objects could be found. Review the mathematical formulas for calculating volume of regular-shaped objects and demonstrate how to calculate the volume of an irregular-shaped object. Introduce the water displacement method by dropping a rock into an overflow can and then measuring the displaced water using a graduated cylinder.

14. How can the volume of the box be determined?

Measure the length, width, and height of the box and multiple the three measurements together.

Volume of a box = length × width × height

15. How can the volume of the cylinder be determined?

Measure the height of the cylinder as well as the diameter, then divide the diameter by two to find the radius.

Volume of a cylinder = height × πr^2

16. How can the volume of the rock be determined?

Because the rock is an irregular-shaped object, its volume is difficult to determine mathematically. It is much easier to determine the volume of the rock using water displacement. Place the rock in a container and measure the volume of water that is displaced. The volume of water displaced is equal to the volume of the rock.

17. **Can the volume of regular-shaped objects be determined using water displacement?**

Yes. The volume determined from water displacement should be the same as the volume calculated using the mathematical formulas.

Lab Preparation

Although this activity requires no specific lab preparation, allow 10 minutes to gather the equipment needed to conduct the lab.

Safety

Follow all standard laboratory practices.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

1	5	2	4	3
Before taking any quantitative measurements, list some qualitative properties of the object being studied.	Identify the object's material based on its density.	Measure the object's dimensions and mass.	Determine the object's density.	Calculate the object's volume.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Collect Data

Part 1 – Brass Objects

1. ☐ List at least two qualitative observations about the brass objects.

Brass is golden in color and has luster (shiny).

2. ☐ Predict how the density of the brass block compares to the density of the brass cylinder.

Because density is an intensive property of the substance, the density of the block should be the same as the density of the cylinder because both shapes are made of brass.

3. ☐ Measure the length, width, height, and mass of the brass block and the height, diameter, and mass of the brass cylinder. Record your results in Table 1 below.

Table 1: Dimensions and mass of brass objects

Object	Length (cm)	Width (cm)	Height (cm)	Diameter (cm)	Mass (g)
Brass block	2.59	1.88	1.58		66.10
Brass cylinder			6.38	2.20	208.16

Part 2 – Aluminum Objects

4. ☐ List at least two qualitative observations about the aluminum objects.

Aluminum is silver in color and has luster (shiny).

5. ☐ Predict how the densities of the three aluminum objects will compare to each other.

Density is an intensive property of the substance, therefore the densities of the three objects should be the same because all three objects are made of aluminum.

6. ☐ Measure the length, width, height and mass of the aluminum block and the height, diameter, and mass of the aluminum cylinder and record your results in Table 2 below.

Table 2: Dimensions and mass of aluminum objects

Object	Length (cm)	Width (cm)	Height (cm)	Diameter (cm)	Mass (g)
Aluminum block	4.88	3.12	1.55		64.85
Aluminum cylinder			6.35	2.20	66.44

7. ☐ Measure the mass of the irregular-shaped aluminum object.

Mass of irregular-shaped aluminum object: __________66.54 g________

8. ☐ Complete the following steps to measure the volume of the irregular-shaped aluminum object using water displacement.

a. Put the beaker under the overflow can spout.

b. Pour water into the overflow can until it overflows into the beaker.

c. Allow the water to stop overflowing on its own and empty the beaker into the sink.

d. Place the beaker back in its position under the overflow can spout without touching the overflow can.

e. Tie a string to the irregular-shaped object and gently lower the object into the overflow can until it is completely submerged.

f. Allow the water to stop overflowing and then pour the water from the beaker into the graduated cylinder.

g. Measure the volume that was displaced by reading the water level in the graduated cylinder.

h. Record the volume of water that was displaced in units of cm^3 (1 mL = 1 cm^3).

Volume of water displaced: 25.3 mL

9. ☐ Why do you need to use the water displacement method for the irregular-shaped object?

There is no mathematical formula for the volume of an irregularly-shaped object, so you must find the volume through other means.

Part 3 – Unknown Plastic Objects

10. ☐ List at least two qualitative observations about the plastic cylinder.

The plastic cylinder is white in color and is opaque.

11. ☐ Table 3 lists three common plastics and their densities. How might you determine the material that the plastic cylinder is made?

Table 3: Density of plastics

Types of Plastic	Density
Polypropylene	0.95 g/cm^3
Nylon	1.15 g/cm^3
Polyvinyl chloride	1.39 g/cm^3

Measure the volume and mass of the cylinder and then calculate its density. If the cylinder is made of one of these three plastics, its density should match one of the three densities given.

12. ☐ Measure the height, diameter, and mass of the plastic cylinder and record your results in Table 4 below.

Table 4: Dimensions and mass of a plastic cylinder

Object	Height (cm)	Diameter (cm)	Mass (g)
Plastic cylinder	6.35	2.20	23.43

13. ☐ Clean up your lab station according to the teacher's instructions.

Data Analysis

Part 1 – Brass Objects

1. ☐ Use the following equations to calculate the volumes of the brass block and brass cylinder. Show your work and record your results in Table 5 below.

Volume (block) = length × width × height Volume (cylinder) = height × πr^2

Table 5: Volume of brass objects

Object	Show Your Work Here	Volume
Brass block	Vol = 2.59 cm × 1.88 cm × 1.58 cm =	7.69 cm^3
Brass cylinder	Vol = 6.38 cm × 3.1416 × $(1.10\ cm)^2$ =	24.3 cm^3

2. ☐ Use the following equation to calculate the densities of the brass block and brass cylinder. Show your work and record your results in Table 6 below.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Table 6: Density of brass objects

Object	Show Your Work Here	Density
Brass block	Density = 66.10 g / 7.69 cm^3	8.60 g/cm^3
Brass cylinder	Density = 208.16 g / 24.3 cm^3	8.57 g/cm^3

3. ☐ Did the shape of the brass object have an effect on the resulting density?

No. The densities of the two brass objects were nearly identical.

Part 2 – Aluminum Objects

4. ☐ Calculate the volumes of the aluminum block and the aluminum cylinder. Show your work and record your results in Table 7 below.

Table 7: Volume of aluminum objects

Object	Show Your Work Here	Volume
Aluminum block	Vol = 4.88 cm × 3.12 cm × 1.55 cm =	23.6 cm^3
Aluminum cylinder	Vol = 6.35 cm × 3.1416 × $(1.10\ cm)^2$ =	24.1 cm^3

5. ☐ Calculate the density of the aluminum block, aluminum cylinder, and the irregular-shaped aluminum object. Show your work and record your results in Table 8 below.

Table 8: Density of aluminum objects

Object	Show Your Work Here	Density
Aluminum block	Density = 64.85 g / 23.6 cm^3	2.75 g/cm^3
Aluminum cylinder	Density = 66.44 g / 24.1 cm^3	2.76 g/cm^3
Irregular-shaped aluminum object	Density = 66.54 g / 25.3 cm^3	2.63 g/cm^3

6. ☐ Did the shapes of the aluminum objects have an effect on the resulting densities?

No. The densities of the three aluminum objects were nearly identical.

Part 3 – Unknown Plastic

7. ☐ Calculate the volume of the plastic cylinder. Show your work and record your results in Table 9 below.

Table 9: Volume of plastic cylinder

Object	Show your work here	Volume
Plastic cylinder	Vol = 6.35 cm × 3.1416 × $(1.10\ cm)^2$	24.1 cm^3

8. ☐ Calculate the density of the plastic cylinder. Show your work and record your results in Table 10 below.

Table 10: Density of plastic cylinder

Object	Show your work here	Density
Aluminum block	Density = 23.43 g / 24.1 cm^3	0.97 g/cm^3

9. ☐ From which plastic is the cylinder made?

The density of the cylinder is similar to that for polypropylene. Therefore, the plastic cylinder is most likely made from polypropylene.

Analysis Questions

1. Does the shape of an object affect its density?

No. Density is an intensive property and is always constant for the same substance. The shape and size of the object does not affect its density.

2. Is it possible for two objects to have the same volume and different densities? Explain your answer and provide evidence from this experiment to support your answer.

Yes, the three cylinders had essentially the same volume (~24 cm^3), but they had three different densities (ρ_{brass} = 8.6 g/cm^3, ρ_{Al} = 2.7 g/cm^3, $\rho_{plastic}$ = 0.97 g/cm^3). The cylinders had three different densities because they were made from three different substances.

3. Which material, brass, aluminum, or plastic, was the most dense?

The brass objects have the greatest density (ρ = 8.6 g/cm^3), followed by aluminum (ρ = 2.7 g/cm^3), and then plastic (ρ = 0.97 g/cm^3).

4. Research the accepted values for the densities of aluminum and brass. How do the accepted answers compare to the values you calculated in this experiment?

Aluminum has an accepted density of 2.70 g/cm^3. Brass has an accepted density between 8.4 to 8.8 g/cm^3. Brass is an alloy of variable amounts of zinc and copper, which explains the range of possible densities. These values are similar to those found in the lab.

Teacher Tip: Percent error may be calculated using the following formula:

$$\text{Percent error} = \frac{|\text{accepted value} - \text{experimental value}|}{\text{accepted value}} \times 100$$

Synthesis Questions

Use available resources to help you answer the following questions.

1. Will the brass, aluminum, or plastic cylinder float in water? Explain.

The brass and aluminum cylinders will both sink in water because their densities are greater than the density of water (ρ_{water} = 1.0 g/cm^3). The plastic cylinder will float because its density is less than that of water.

2. If a company buys 200 cm^3 of aluminum, how much would you expect the aluminum to weigh?

The aluminum would weigh 540 g. This value is calculated from the density:

$$200\ \text{cm}^3 \left(\frac{2.70\ \text{g}}{1\,\text{cm}^3}\right) = 540\ \text{g Al}$$

3. A 260-kg tree that is 10 m tall and 25 cm in diameter falls into a river. Explain mathematically why the tree floats, given that the density of water is 1000 kg/m³.

The tree has a volume of 0.49 m^3.

$$V_{\text{cylinder}} = h \times \pi r^2$$

$$V_{\text{cylinder}} = 10\text{ m} \times \pi\left(\frac{0.25\text{ m}}{2}\right)^2 = 0.49\text{ m}^3$$

Its density is 530 kg/m^3.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$\text{density} = \frac{260\text{ kg}}{0.49\text{ m}^3} = 530\text{ kg/m}^3$$

The density of the tree is less than the density of the water, therefore the tree will float.

4. Can a very large object have the same density as a very small object? Explain.

Two different-sized objects can have the same density. Density is an intensive property. If the large object also has a large mass and the small object has a small mass, they could have the same density if their mass/volume ratio is the same. A small lead pipe will have the same density as a large lead pipe because it is made out of the same material.

5. A student has three silver cubes. Although the cubes look the same, one is made of zinc, another is made of lead, and third is made of aluminum. How can the student determine the material that was used to make each cube?

One way to identify the material in each cube is to determine the density of each cube by measuring its mass and volume. The calculated values can then be compared to literature values of these metals. Lead has the highest density (ρ_{Pb} = 11.34 g/cm^3) followed by zinc (ρ_{Zn} = 7.14 g/cm^3). The lowest density is aluminum (ρ_{Al} = 2.70 g/cm^3).

6. A rectangular object weighs 2445 g and its density is 12.9 g/cm³. When measured, its height is 7.43 cm and its width is 3.45 cm. How long is the object?

The object is 7.40 cm long.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$12.9\text{ g/cm}^3 = \frac{2445\text{ g}}{(7.42\text{ cm})(3.45\text{ cm})(\text{length})}$$

$$\text{length} = \frac{2445\text{ g}}{(7.42\text{ cm})(3.45\text{ cm})\left(\frac{12.9\text{ g}}{\text{cm}^3}\right)} = 7.40\text{ cm}$$

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Diamond has a density of 3.26 g/cm^3. What is the mass of a diamond that has a volume of 0.350 cm^3?

- **A.** 0.107 g
- **B. 1.14 g**
- **C.** 9.31 g
- **D.** None of the above

2. What is the volume of a sample of liquid mercury that has a mass of 76.2 g, given that the density of mercury is 13.6 g/mL?

- **A.** 0.178 mL
- **B. 5.60 mL**
- **C.** 1040 mL
- **D.** None of the above

3. Which statement about density is true?

- **A.** Two samples of nickel may have different densities
- **B.** Density is constant for all types of metals
- **C.** The density of a sample depends on its location on Earth
- **D. Density is a constant value for all objects made of the same material**

4. A zinc block has a mass of 20 g and a zinc cylinder has a mass of 40 g. How will the density of the two objects compare?

- **A.** The zinc block will be less dense than the zinc cylinder
- **B.** The zinc block will be more dense than the zinc cylinder
- **C. The zinc block and the zinc cylinder will have the same density**
- **D.** There is not enough information to answer the question

5. Density equals:

- **A. Mass / volume**
- **B.** Volume / mass
- **C.** Mass × volume
- **D.** Length × width × height

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. Properties that depend on the amount of material present are called **extensive** properties, and include **mass** and **volume**. Those properties that are independent of the amount of substance being studied are called **intensive** properties, and include color, **boiling point**, and **density**.

2. **Density** is the amount of matter in a particular amount of space. Density is the ratio of **mass** to **volume**. Substances with large densities feel **heavy** for their size. Substances with densities less than 1.0 g/mL **float** in water. To find an object's density, a **balance** is used to determine its mass. Volume is found either by using a **mathematical formula** or by **water displacement**. Density can be used to **identify** a substance.

Extended Inquiry Suggestions

Pennies produced before 1982 are mostly comprised of copper, while pennies produced after 1982 are mostly zinc covered with a thin layer of copper. The two types of pennies, therefore, have different densities. Determine the densities of pre-1982 pennies and post-1982 pennies. Use ten pennies of each type to get accurate measurements. Use the water-displacement method to find the volume of all the pennies of a particular type at the same time.

Repeat the experiment using only the method of water displacement to determine volume.