LESSON

4 Mass Communication

Mass and Volume

Think About It

Suppose you have two samples of gold, a gold ring and a gold nugget. Is there more gold in the ring or in the nugget? They feel similar in weight, and they look fairly similar in volume. While your senses can give you valuable information, they can't tell you exactly how much gold you have in each sample.

How do you determine the masses and volumes of different substances?

To answer this question, you will explore

1. Measuring Volume
2. Comparing Mass and Volume

Exploring the Topic

1 Measuring Volume

As you learned in Lesson 3, volume is a measure of size, or how much space each sample takes up.

There are two common ways of measuring the volume of solids: (1) by measuring their dimensions and using a geometric formula, and (2) by water displacement. The first method is convenient if the object has a regular shape. The second method is more convenient for irregularly shaped objects.

Using Geometric Formulas to Determine Volume

If a solid is rectangular, you can find its volume by measuring its three dimensions—length, width, and height—and multiplying these three values. Volume measured in this way is reported in *cubic* units such as cubic centimeters, cm^3; cubic meters, m^3; or cubic inches, in^3. The formula for volume is

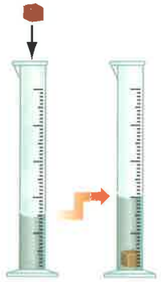
$$V = lwh$$

Consider these two solid blocks. You can use the formula to figure out their volumes.

$$\begin{aligned} V &= lwh \\ &= 1.0 \text{ cm} \cdot 1.0 \text{ cm} \cdot 1.0 \text{ cm} \\ &= 1.0 \text{ cm}^3 \end{aligned}$$

$$\begin{aligned} V &= lwh \\ &= 1.0 \text{ cm} \cdot 0.5 \text{ cm} \cdot 2.0 \text{ cm} \\ &= 1.0 \text{ cm}^3 \end{aligned}$$

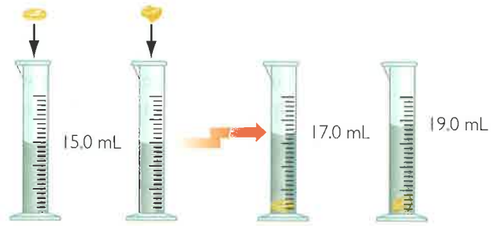
Notice that the two solids have different dimensions, but they have the same volume, 1.0 cubic centimeter.



The water level rises by 5.0 mL because the cube has a volume of 5.0 cm^3.

Using Water Displacement to Determine Volume

The second method of measuring the volume of a solid object is called **water displacement.** First, pour water into a graduated cylinder. Next, add the object whose volume you are measuring. An object takes up space, so it displaces some of the water when it is placed in the graduated cylinder. This causes the water level to rise by an amount equal to the volume of the object. If you read the volume of water in the graduated cylinder before you submerge the object and again after submerging it, the volume of the object is the difference between these two volumes.



Imagine you place a gold ring and a gold nugget in graduated cylinders partly filled with water. The graduated cylinder is marked in milliliters, mL. You observe that the water level in one container rises by 2.0 mL and by 4.0 mL in the other. The ring has a volume of 2.0 mL or 2.0 cm^3 and the nugget 4.0 mL or 4.0 cm^3.

Important to Know One milliliter is exactly equal in volume to one cubic centimeter: 1 mL = 1 cm^3. ◀

Of course, the water displacement method works only for solids that do not dissolve in water! The solid object also needs to sink so that it is completely submerged. If the object floats, the volume reading will not be accurate.

2 Comparing Mass and Volume

Imagine you have two objects with the same volume that are *not* made from the same material. You can compare their masses using a balance. The masses of 1.0 cm^3 of gold and 1.0 cm^3 of plastic are given in the table below along with the masses of the same volumes of wood, glass, and copper.

Material	Volume	Mass
gold	1.0 cm^3	19.3 g
plastic	1.0 cm^3	0.9–1.5 g
glass	1.0 cm^3	2.2–3.1 g
copper	1.0 cm^3	9.0 g
wood	1.0 cm^3	0.2–1.4 g

1.0 cm^3 of gold has much more mass than 1.0 cm^3 of plastic.

The mass of plastic, glass, and wood varies depending on the type.

Notice that 1.0 cm^3 of gold is heavier than the same volume of any of the other materials. Thus, two objects can have exactly the same volume but different masses.

CONSUMER CONNECTION

There are many different types of plastic. Soft drink bottles are made of polyethylene terephthalate, also called PETE. Plastic pipes and outdoor furniture are made of polyvinyl chloride, also called PVC. Styrofoam cups are made of polystyrene.

The mass of the plastic depends on the type of plastic being considered. The mass of a 1.0 cm^3 sample of plastic varies between 0.9 g and 1.5 g. Wood and glass also show variations. For instance, if you compare a 1.0 cm^3 sample of solid wood from an oak tree with a 1.0 cm^3 sample of solid wood from a pine tree, they will have different masses. The oak sample will be considerably heavier than the pine. A 1.0 cm^3 sample of pure gold will always have a mass of 19.3 g because there is only one type of pure gold.

Example 1

Try to work out the answers yourself before reading the solutions.

Cubes of the Same Volume

Suppose you have two cubes. One cube is made of solid gold and the other cube is made of solid plastic. The sides of the cubes each measure 2.0 cm in length.

a. What is the volume of each cube?

b. How much water will each cube displace?

Solution

a. The volume of a cube is equal to length times width times height.

$$V = lwh$$
$$= 2.0\text{ cm} \cdot 2.0\text{ cm} \cdot 2.0\text{ cm}$$
$$= 8.0\text{ cm}^3$$

b. Because 1 cm^3 = 1 mL, you can reason that 8.0 cm^3 = 8.0 mL. So each cube will displace the same amount of water, or 8.0 mL.

Important to Know The rise in the water level does not depend on how heavy the cube is. The water-level rise depends only on the volume of the object. ◀

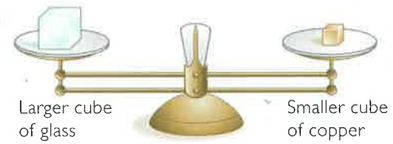
Example 2

Cubes of the Same Mass

One cube is made of solid copper and another cube is made of solid glass. They have exactly the same mass. How do their volumes compare?

Solution

If you look at the table of masses on page 14, you will see that 1.0 cm^3 of copper has much more mass than 1.0 cm^3 of glass. Thus, in order for the two cubes to have the same mass, the copper cube must be much smaller than the glass cube.



The small cube of copper exactly balances the mass of the larger cube of glass.

Key Term

water displacement

Lesson Summary

How do you determine the masses and volumes of different substances?

The volume of a solid object is determined either by water displacement or by measuring its dimensions and using a geometric formula for volume. The mass of any solid sample is found by weighing it on a balance, or scale. The relationship between mass and volume depends on the type of material being considered. Two objects may have the same volume but different masses, or two objects may have the same mass but different volumes.

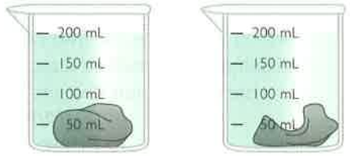
EXERCISES

Reading Questions

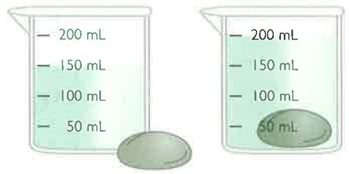
1. Describe two ways to determine the volume of a solid object.
2. If you have two objects with equal volume, do they have the same mass? Explain your thinking.

Reason and Apply

3. Can you predict the volume of an object just by looking at it? Explain.
4. Can you predict the mass of an object just by looking at it? Explain.
5. If you stretch a rubber band, does it still have the same mass? Explain.
6. You submerge a piece of clay in water and measure the total volume. You change the shape of the clay and put it back into the same amount of water.



   a. The total volume does not change. Explain why.
   b. Does the total mass change? Explain.
7. Describe how you might find the volume of these items:
   a. pancake mix
   b. hair gel
   c. a shoe box
   d. a penny
   e. lemonade
8. Draw two things with the same mass, but different volumes.
9. Draw two things with the same volume, but different masses.
10. Use the illustrations to complete these statements.



    a. What is the volume of the liquid inside the container?
    b. What is the volume of the rock in mL? In cm^3?
11. Suppose that you have two cubes of exactly the same volume. You weigh them and find a mass of 8.91 g for one cube and 8.88 g for the other cube even though they are made of the same material. How is this possible?

LESSON 5

All That Glitters

Density

Think About It

Gold and lead are metals that are soft and bendable. They are easy to tell apart at a glance because lead is dull gray. But suppose someone tried to trick you by coating a block of lead with a thin layer of gold. How could you prove that this block was a fake?

How can you use mass and volume to determine the identity of a substance?

To answer this question, you will explore

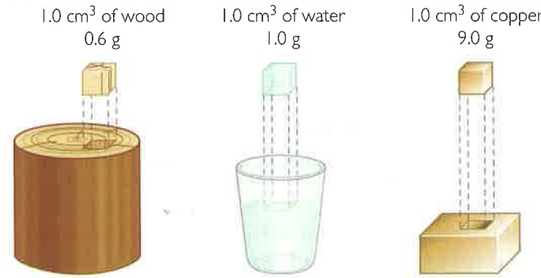
1. The Definition of Density
2. Calculating Density
3. Identifying Matter Using Density

Exploring the Topic

1 The Definition of Density

Which is heavier, gold or copper? It depends on the amount of each that you have. If you compare a tiny gold earring and a large copper pipe, the copper will be heavier. If you compare the same volume of each, gold is *always* heavier than copper. That is because there is more matter in 1.0 cm^3 of gold than in 1.0 cm^3 of copper. You could also say that gold is *denser* than copper. The mass of a substance per unit of volume is called its **density.**

Imagine comparing 1.0 cm^3 cubes of oak wood, water, and copper from larger samples of each material. All three cubes have the same volume, but each cube has a different mass and a different density.



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INDUSTRY CONNECTION

Most substances will expand when temperature increases and contract when temperature is decreased. For this reason, there are special joints built in between sections of sidewalks, bridges, railroad tracks, and other structures to prevent cracking or breaking when the volume of the materials changes due to temperature.

Example 1

Differences in Density

Consider the objects on balances shown in these illustrations. How can differences in density account for what you observe in these pictures?

The balance is uneven. The two solid cubes have the same volume but different masses.

The balance is level. The two solid cubes have the same mass but different volumes.

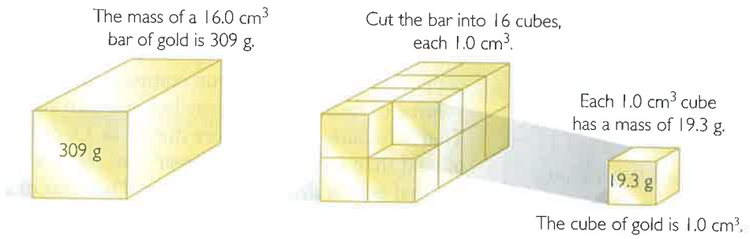
Solution

Because the cubes on the first balance are exactly the same size, one cube must be denser than the other. So the two cubes are made of different materials.

On the second balance the larger cube must have a lower density than the smaller cube. Again, the two cubes are made of different materials.

2 Calculating Density

You can determine the density of a substance without actually cutting out a cubic centimeter sample. Suppose a large chunk of gold has a mass of 309 g and has a volume of 16.0 cm^3. Divide the mass of the gold by its volume to find its mass *per* cubic centimeter. This is equal to the density.



$$309\ g \div 16.0\ cm^3 = 19.3\ g/cm^3$$

The density of gold is 19.3 grams per cubic centimeter, or 19.3 g/cm^3. This answer is rounded to three significant digits. [For review of this math topic, see **MATH** ***Spotlight: Accuracy, Precision, and Significant Digits*** on page 617.]

Density

The mathematical formula for density is

$$D = \frac{m}{V}$$

where D is the density, m is the mass, and V is the volume.

Example 2

Density of a Gold Ring

Suppose you have a gold ring that weighs 7.50 g and has a volume of 0.388 mL. Does it have the same density as a big piece of gold?

Solution

Use the formula to find the density of the ring.

Start with the formula. $D = \frac{m}{V}$

Substitute the values of m and V. $D = \frac{7.50\ g}{0.388\ mL}$

Solve for D. $= 19.3\ g/mL = 19.3\ g/cm^3$

The ring has the same density as any other sample of gold, big or small. The density of a material does not depend on the shape or size of the sample.

Important to Know The density of a substance does not change with its size or its shape. A solid gold bracelet will have the same density as a solid gold brick, and the density of one penny is the same as the density of two pennies. ◀

Densities of Some Metals

Metal	Density
copper	9.0 g/cm^3
zinc	7.1 g/cm^3
gold	19.3 g/cm^3
lead	11.4 g/cm^3
aluminum	2.7 g/cm^3
brass	8.4 g/cm^3

3 Identifying Matter Using Density

Every substance has certain properties, such as color, hardness, melting point temperature, and density, that depend on the type of matter, not on the amount or size of the sample. These properties are called **intensive properties.** Intensive properties do not change if the quantity of the substance changes. Therefore, they can be used to help identify that substance.

On the other hand, **extensive properties,** such as mass or volume, do change depending on the amount of matter. Extensive properties alone can't be used to help identify a type of matter. For example, knowing that a metal earring has a mass of 3 g doesn't help you identify what the earring is made of.

Because density is an intensive property, it can be used to help identify the type of matter that an object or sample is made of. First, determine the density of the object and then compare it with known density values in a reference table like this one to help identify the type of matter.

BIG IDEA Each specific type of substance has a particular density. You can identify a substance by its intensive properties, including density.

The Fake Bar of Gold

If someone tried to trick you by coating a block of lead with a thin layer of gold, how could you prove the bar is a fake?

One approach would be to scratch the bar to reveal that the inside isn't gold. Another method would be to use density to prove that the bar is or isn't gold.

If the block is pure gold, it should have a density of 19.3 g/cm^3.

Key Terms

density
intensive property
extensive property

Lesson Summary

How can you use mass and volume to determine the identity of a substance?

To identify substances, you examine their intensive properties, qualities that do not depend on size or amount. Intensive properties include color, hardness, and density. Density is the mass of a substance per unit of volume. If two substances have different densities, then they are probably made of different types of matter.

EXERCISES

Reading Questions

1. In your own words, define density.
2. Explain how density can be used to determine if the golden penny is made of solid gold.

Reason and Apply

3. How does the density of aluminum compare with the density of gold? What does this tell you about the amount of matter within each?
4. If two objects have the same mass, what must be true? Choose the correct answer(s).
   - **A.** They have the same volume.
   - **B.** They are made of the same material.
   - **C.** They contain the same amount of matter.
   - **D.** They have the same density.
5. Two objects each have a mass of 5.0 g. One has a density of 2.7 g/cm^3 and the other has a density of 8.4 g/cm^3. Which object has a larger volume? Explain your thinking.
6. A piece of metal has a volume of 30.0 cm^3 and a mass of 252 g. What is its density? What metal do you think this is?
7. A glass marble has a mass of 18.5 g and a volume of 6.45 cm^3.
   - **a.** Determine the density of the marble.
   - **b.** What is the mass of six of these marbles? What is the volume? What is the density?
   - **c.** How does the density of one marble compare with the density of six of the marbles?

HISTORY CONNECTION

Sacagawea was a Shoshone woman who guided Lewis and Clark in their exploration of the western United States between 1804 and 1806. The U.S. Mint began making the Sacagawea dollar in the year 2000. It is called the Sacagawea Golden Dollar, but it is made of 88.5% copper, 6% zinc, 3.5% manganese, and 2% nickel. The golden color is due to a coating of brass, which is made by combining copper and zinc.

SECTION

I

Key Terms

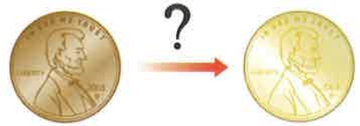
hypothesis
property
chemistry
matter
mass
volume
meniscus
water displacement
density
intensive property
extensive property

SUMMARY

Defining Matter

Alchemy Update

Can a copper penny be turned into gold through chemical processes?



The "golden" penny looks like gold and has essentially the same volume as a true gold penny. However, the golden penny has a much lower mass than a true gold penny. This means the density of the "golden" penny is less than the density of gold. It cannot be a solid gold penny.

The concept of density has provided the evidence needed to confirm that the gold-colored penny is not actually made of gold. But if it is not gold, then what is it? Many questions remain to be answered. Is it still possible to make gold some other way? And, what is it about gold that makes it gold?

Review Exercises

1. Explain how you would determine the volume of a powdered solid, a liquid, and a rock.
2. Use your own words to define *matter.*
3. Will an object with a higher density displace more water than an object with a lower density? Explain why or why not.
4. How does the density of one penny compare with the density of two pennies?

1 Penny
Mass = 2.6 g
Volume = 0.36 cm^3

2 Pennies
Mass = 5.2 g
Volume = 0.72 cm^3

5. A small pebble breaks off of a huge boulder. The pebble has the same density as the boulder. In your own words, explain how this can be true.
6. Archeologists discover a silver crown in an ancient tomb. When they place the crown in a tub of water, it displaces 238.1 cm^3 of water. The density of silver is 10.5 g/cm^3. If the crown is really silver, what should its mass be?