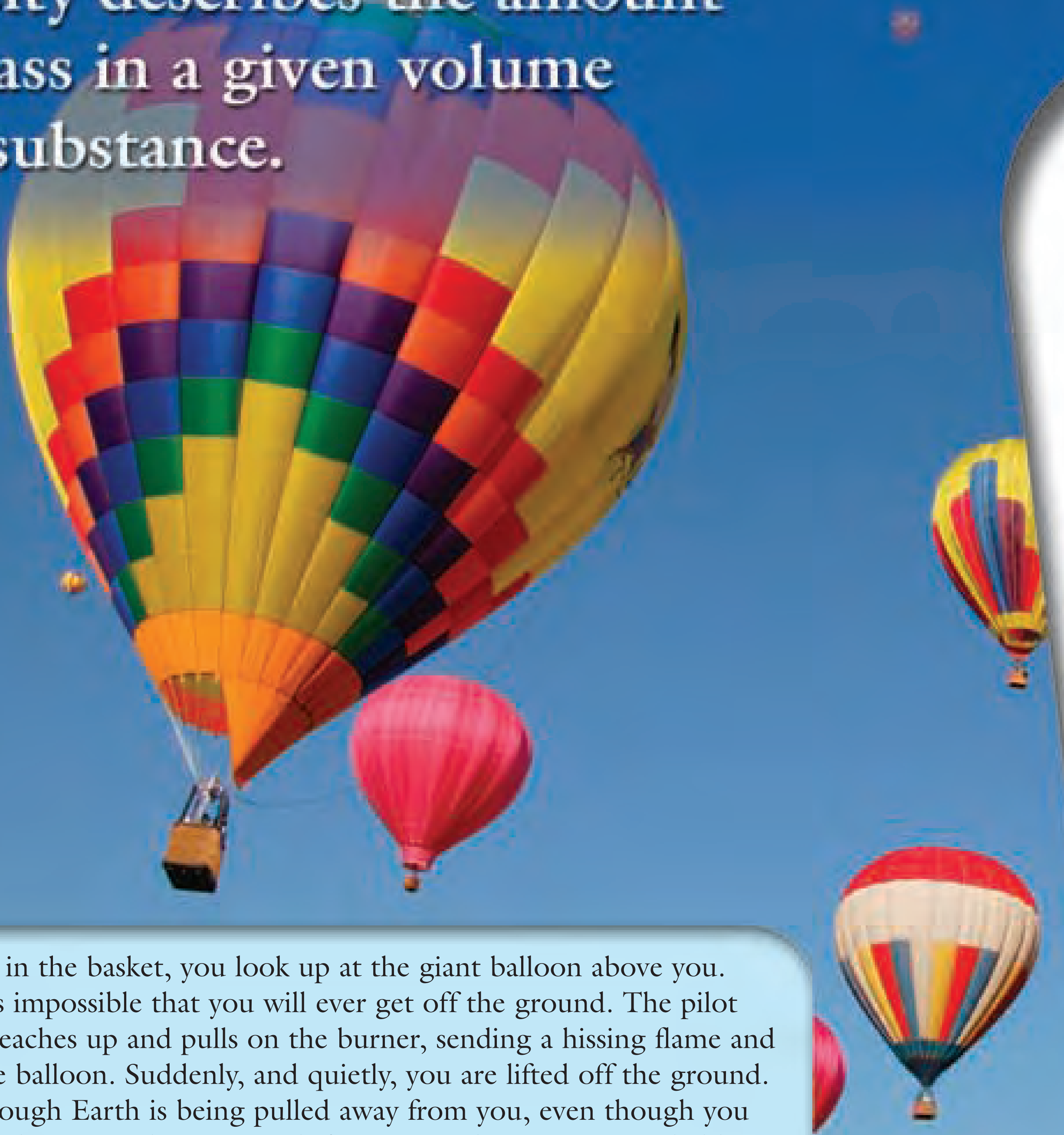
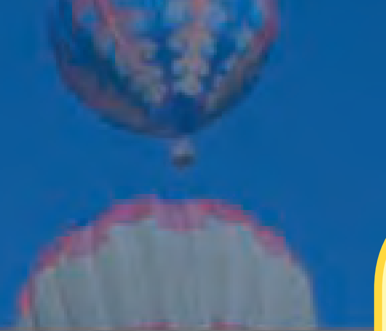
Chapter 8

Density describes the amount of mass in a given volume of a substance.



Standing in the basket, you look up at the giant balloon above you. It seems impossible that you will ever get off the ground. The pilot beside you reaches up and pulls on the burner, sending a hissing flame and heat into the balloon. Suddenly, and quietly, you are lifted off the ground. It feels as though Earth is being pulled away from you, even though you are the one who is quietly moving, drifting upward as you are guided by the wind.

Without jet engines and propellers how do these hot-air balloons float upward? The answer has to do with the density of the air inside the balloon. In this chapter, you will learn about the property of density and how it is unique to each individual substance. You will also explore how density helps to explain how certain substances interact with one another.



What You Will Learn

In this chapter, you will
- **Describe** the difference between mass, volume, and density
- **Explain** the relationship between mass, volume, and density using the particle theory
- **Predict** how temperature will affect the density of a substance

Why It Is Important

Density is a property that can help identify a specific substance. Understanding density can also help us understand the way things work around us.

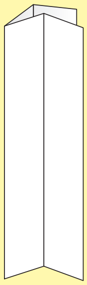
Skills You Will Use

In this chapter, you will
- **Determine** mass-to-volume ratios of different amounts of the same substance
- **Measure** density of fluids and solids
- **Observe** how temperature and density affect our everyday lives

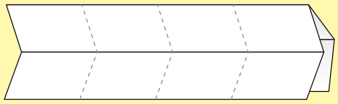
FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 8.

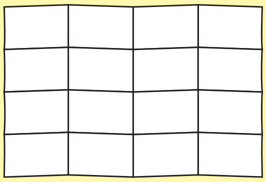
STEP 1 **Fold** a vertical sheet of legal-size paper from left to right two times. Unfold.



STEP 2 **Fold** the paper in half from top to bottom two times.



STEP 3 **Unfold** and draw lines along the folds.



STEP 4 **Label** the top row and first columns as shown below.

	Define States	+ Heat	– Heat
Liquid Water			
Water as a Gas			
Water as a Solid (Ice)			

Read and Write

As you read the chapter, define the states of matter in the *Define States* column of your Foldable. Write what happens when heat is added to or lost from each state.

8.1 Defining Density

Density is a measure of the mass contained in a given volume. Substances with a lower density will float on substances with a higher density.

Key Terms

density

One property that is useful in understanding both fluids and solids is density. **Density** is the amount of mass in a certain unit volume of a substance. In other words, density describes how closely packed together the particles are in a material.

You might think of density in terms of vehicles on a highway. A traffic jam like the one on the left in Figure 8.1A is a model of high density. The photograph of free-flowing loosely packed traffic on the right in Figure 8.1B is a model of low density.

Figure 8.1(A) When traffic gets very dense, it is difficult for vehicles to move. **(B)** When the density of traffic is lower, cars can move more easily.

Word Connect

The word density comes from the Latin word *densus*, meaning "thick or crowded".

Density and the Particle Theory

According to the particle theory, different substances have different-sized particles. The size, shape, and mass of the particles determine how many particles and how much mass can "fit into" a given space. Therefore, each substance has its own unique density, based on particle size, shape, and mass.

The particle theory also suggests that there is empty space between the particles of matter. If you look back at Figure 8.1B, you can see that not as many cars can fit on the highway if there are large spaces surrounding each vehicle. The density of the traffic is reduced. Therefore, the more space that exists between particles of a substance in a certain unit of volume, the less dense the substance will be.

Density of Solids, Liquids, and Gases

How is the density of a substance related to the substance's physical state? Imagine filling a container with liquid water and another container of the same size with water vapour. Both liquid water and water vapour are the same substance, and therefore have particles of the same size and mass. According to the particle theory, however, gas particles have more space between them than do liquid particles. Therefore, the water vapour in the container would have fewer particles than the liquid water. You can then conclude that the density of the water vapour is less than the density of liquid water.

How are density and state of matter related to the physical properties of a substance? Solid objects can move easily through liquids and gases. For example, a diver can jump from a platform and move smoothly through the air and then the water in a pool, as shown in Figure 8.2. According to the particle theory, the fluid properties of water and of air allow water particles and air particles to move out of the way of the solid body of the diver.

Why do solid particles tend to hold together while fluid particles tend to move apart? The answer has to do with the attractive forces between particles. In solids, particles cannot be easily pushed apart. To understand why, imagine that you and a few friends are together. You want to prevent anyone else from pushing your group apart and moving between you. What would you do? First, you would have to stand quite close together. Then, you would probably hold on to each other very tightly. If you do not let go of one another, no one can move between you. Particles in a solid act much the same way. Attractive forces among the particles of a solid are stronger than those between fluid particles. Therefore, particles in a solid cannot slide past each other or move between each other.

If you were to place a rock on the surface of a lake, the water would not support the rock. Instead, the rock would go right through the water, and would continue to fall through the water, pushing water particles out of its way until it reached the bottom. Liquids cannot support

Did You Know?

Could the solid state be less dense than the liquid state of the same substance? The answer is yes for some substances. You have probably seen ice cubes floating in a glass of water. As solid ice forms from liquid water, the ice expands. This means that there is more empty space trapped in a chunk of ice than in the same amount of water. Therefore, solid ice is less dense than liquid water.

Figure 8.2 The particles of a fluid move apart easily when a solid object, such as a diver, travels through the fluid.

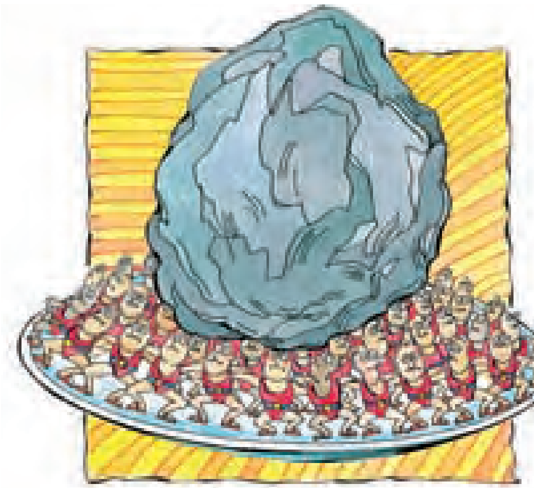


Figure 8.3 The cartoon weightlifters represent the tightly packed particles of the solid plate. The plate can hold its shape and support materials such as the large rock because the weight-lifters (plate particles) are holding on to each other very tightly.

Did You Know?

"Empty space" does not mean "air." Empty space means a separation between two objects with nothing between those objects, not even air particles. Simply because empty space and air look the same does not mean they are the same! For example, outer space is mostly empty space, but it has no air. Astronauts would suffocate if they were to venture outside their spacecraft without masks and air tanks, because there is no oxygen in outer space.

objects in the same way that solids can, because the particles of a liquid move apart easily, allowing a dense, solid object, such as a rock, to pass through the liquid. The attractive forces between liquid particles are not strong enough to prevent a rock from pushing them apart.

Similarly, a rock falls through air because gases are even less dense than solids or liquids. When you move through air, you are moving through mostly empty space. A solid object does not have to move as many particles of air out of the way as it would travelling through water. This explains why running through air is much easier and faster than running through water. In general, *gases are less dense than liquids* and *liquids are less dense than solids.*

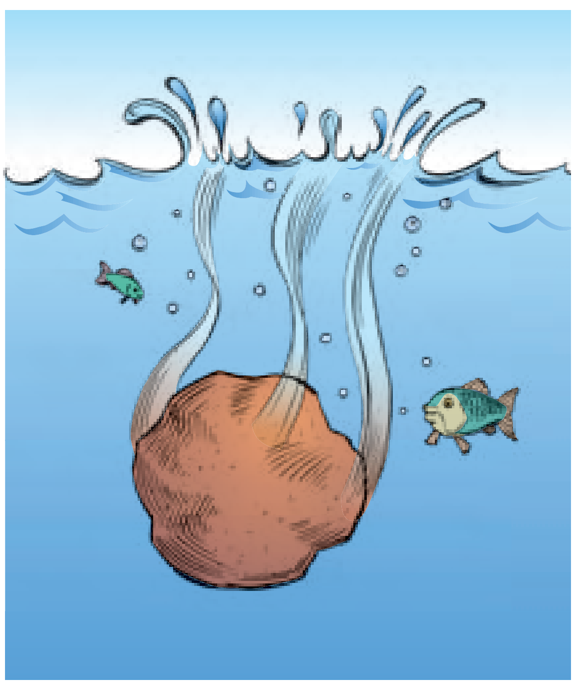


Figure 8.4 Although liquid particles are sometimes quite closely packed together, they cannot support objects in the same way that solids can, because the particles do not have a strong enough attraction for each other. Therefore, liquid particles move apart easily.

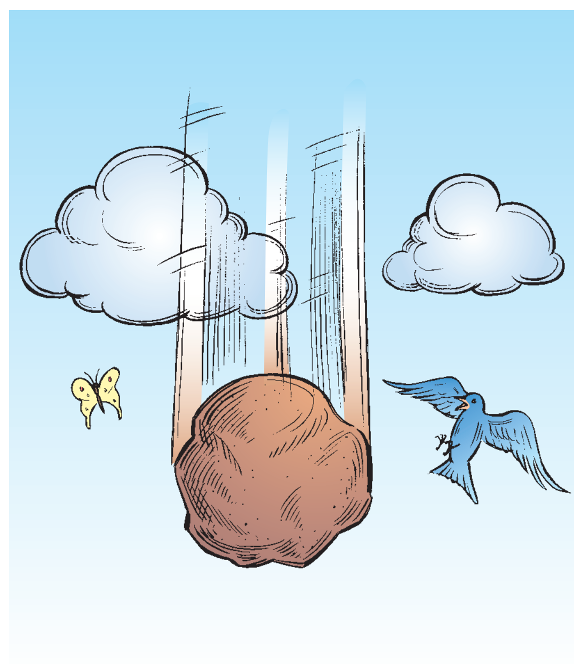


Figure 8.5 When a solid object moves through air, it does not have to move as many particles of air out of the way as it would when passing through a liquid, since gases are usually less dense than liquids. Gas particles are even less attracted to each other than particles in liquid.

8-1A Differing Densities

Using your knowledge of the particle theory, what inferences can you make about the densities of different substances?

Safety

What You Need

3–5 class sets of lettered containers (prepared by your teacher), filled to the brim with various "mystery substances"

What to Do

1. Make a table with the following headings:

Sample (letter)	Rank (ordered heaviest to lightest)	Substance	
		Your prediction	Actual

2. With a partner, pick up each container and observe how heavy or how light each one feels. Decide on the order of the containers from heaviest to lightest. Give the heaviest container rank number 5 and the lightest container rank number 1. In your table, record the ranks of the containers, from heaviest to lightest.
3. Predict what the substance inside each container might be. Record your predictions.
4. Find out what the substances are by checking your teacher's master list. Record the actual substances in the table.

What Did You Find Out?

1. Which substances did you predict correctly (or closely)? Which substances, if any, surprised you?
2. The volumes of the substances were identical because each container was filled to the top. Why is it important to keep the volumes equal in this activity?

In some cases, the densities of two pure substances can be so different that the liquid state of one is denser than the solid state of the other. One example of this is shown in Figure 8.6A. Many solid metals, such as copper, nickel, and silver, can float on liquid mercury, one of the densest substances known. Another example of water being denser than a solid is shown in Figure 8.6B.

Figure 8.6A Liquid mercury is so dense that it can support a solid iron bolt. A layer of oil has been placed on top of the mercury to prevent vapour from escaping into the surrounding air, as mercury is very poisonous.

Figure 8.6B A solid block of wood floats easily on the surface of liquid water.

Reading Check

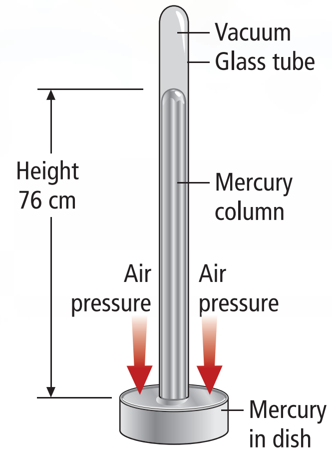
1. Explain what density means in your own words.
2. Explain why solids can support objects more easily than fluids can. You may use diagrams to help in your explanation.
3. How can the density of a pure substance change? Provide an example.
4. Using the particle theory, explain why some liquids can support a solid.

Wild, Weird, Wonderful

www Science

The Mercury Barometer

If you watch a weather forecast, you will often hear the meteorologist talk about high or low pressure systems. Our weather changes as systems of high and low atmospheric pressure are carried by winds and move over the land. Atmospheric pressure is measured by an instrument called a barometer. Although digital and other types of barometers now exist, the original and most common barometers work because of the unique properties of liquid mercury.



Mercury is a dense metal that is liquid at room temperature.

In 1643, Evangelista Torricelli developed the first mercury barometer, and it has changed very little in design since then. The air is removed from a glass tube (about 76 cm in length) that has one closed end and one open end. The open end is then placed into a reservoir of liquid mercury. As atmospheric pressure increses, it presses down on the reservoir and forces the mercury up into the tube. The mercury rises until the weight of the mercury in the tube balances the atmospheric force that is exerted on the reservoir. The higher the pressure, the higher the mercury will rise in the tube.

Why Use Mercury?

You may wonder why water was not used in these original barometers. The answer has to do with the high density of mercury. For a column of water to create as much pressure as the standard atmospheric pressure (101.325 kPa), it would have to be 10 m high. That would not be very practical, as you would have to have a glass tube that was over 10 m in height! Because mercury is much denser than water, but is still a liquid, it only takes 76 cm of mercury to make a column that exerts one atmosphere of pressure.

The End of the Mercury Barometer?

There are some very important problems with mercury that could mean that mercury barometers will stop being made. Scientists discovered that liquid mercury is highly toxic to humans and animals. Many countries have banned the use of mercury in manufacturing industries in order to prevent it from entering the environment.

Science Watch

Icebergs

Each spring, tourists and residents of Newfoundland and Labrador alike gather along the shores to watch white, silent giants slowly drift past in the ocean. The sheer size of these ancient icebergs boggles the mind, especially when we know we are only seeing "the tip of the iceberg." The area from the northern tip of Labrador down to the Grand Banks of Newfoundland is called Iceberg Alley. It is through this alley that many icebergs flow from the Arctic on their journey to warmer waters.

Iceberg Alley is known as one of the best places in the world to see icebergs.

Where do the Icebergs in Iceberg Alley come from?

The icebergs were originally part of Greenland's glaciers. Breaking off from one of the glacier's edges, an iceberg is caught in the Labrador Current and is carried into the alley along the shores of Labrador and then Newfoundland. But do not be tricked into thinking that this is a quick journey. It takes an iceberg about two to three years to reach the Grand Banks of Newfoundland from Greenland!

The "Tip of the Iceberg"

You have probably heard the saying that 90 per cent of an iceberg remains below the surface of the water. Considering that the average weight of an iceberg off the Grand Banks is one to two hundred thousand tonnes, it is hard to believe that these giants can float at all! Icebergs float because the density of ice is approximately 0.9 g/mL, which is lower than that of seawater (around 1.03 g/mL).

It is hard to imagine that 90 percent of this giant is hidden from view underneath the water.

Iceberg Lingo

Iceberg scientists and enthusiasts use words that a tourist might find strange!

- "growler" – very small chunk of floating ice that rises only about one metre out of the water
- "bergy bits" – small icebergs that rise one to four metres out of the water
- "calving" – when part of an iceberg splits away and falls into the ocean
- "tabular," "wedged," "pinnacled," "domed," "blocky," and "drydocked" – shapes of icebergs

Global Warming—The End of Icebergs?

Since the late 1990s, there has been a decline in the number of icebergs that pass through Iceberg Alley. Many scientists believe that this decline has to do with global warming—the increase in the average temperature of the Earth's near-surface air and oceans. As the air and ocean temperature increases even a few degrees, more icebergs are created from Greenland's glaciers, but they are melting before they reach Iceberg Alley. A lack of icebergs is good news for ships that pass through the alley and for oil rigs such as the Hibernia. However, it is bad news for tourists who come to see the icebergs, and for the province that enjoys the benefits of the tourism industry. The decline could also possibly be a warning for the future of Earth's environment.

Check Your Understanding

Checking Concepts

1. Imagine that you have two equal-sized containers. One is filled with liquid gold, and the other is filled with solid gold. Using the particle theory, explain why each physical state of gold will have a different density, despite the fact that they are both gold.
2. Using the particle theory, explain why dolphins can move easily through the air and the ocean when they jump.

3. Find some small items in the classroom (for example, pencils or paper clips) and determine whether these items are denser than water by dropping them into a container full of water. Organize your observations in a table.
4. The density of molten lava increases as it cools and hardens. List other examples of natural changes in density.
5. Explain why the attractive forces of particles make the densities of solids, liquids, and gases so different?

Understanding Key Ideas

6. Explain why "air" and "empty space" are two different things.
7. Many people take water aerobics classes because it is a good physical activity to stay in shape. Why would doing some exercises, such as running through water, be harder than doing it through the air?

Pause and Reflect

If an oil spill occurs, cleaning up the oil can be a challenge. One technique is the towing of booms that contain the oil within an area. Use what you have learned about density to explain why this technique can help clean up an oil spill.

8.2 Determining Density

How can you measure the density of a substance? You can determine a substance's density if you know how much of a substance occupies a certain space.

Key Terms

displacement
mass
mass-to-volume ratio
volume

Recall that density is the mass of a given volume. To find the density of a substance, you need to know its mass and its volume. **Mass** is the amount of matter in a substance (see Figure 8.7). **Volume** is a measurement of the amount of space occupied by the substance. Figure 8.8 shows how the volume of a solid can be measured. The volume of a liquid can be measured using a measuring cup or a graduated cylinder. The volume of a gas can be determined by measuring the volume of the container that holds it.

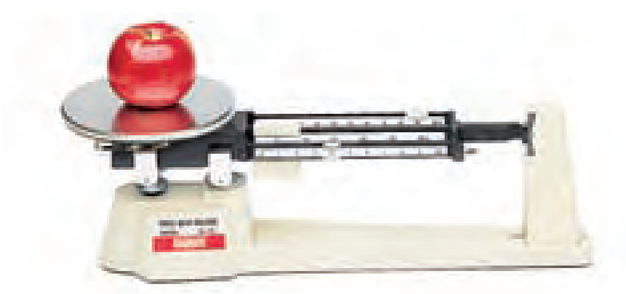


Figure 8.7 A balance is used to measure mass in grams (g) or kilograms (kg). This apple has a mass of 102 g.

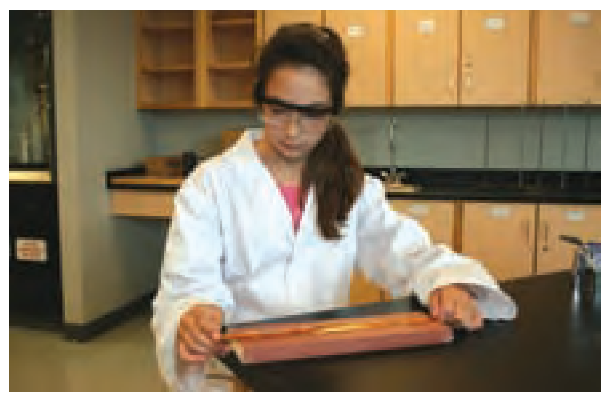


Figure 8.8 If an object has a regular shape, such as the block of wood in this picture, you can measure the length, width, and height and then use the mathematical formula, $V = l \times w \times h$, to calculate the object's volume.

Figure 8.9 The volume of an irregularly shaped object can be found by measuring the volume of the water that spills out of an overflow can.

Displacement

How would you measure the volume of an object with an irregular shape? **Displacement** is the amount of space that an object takes up when placed in a fluid. Have you ever noticed how the water level rises in a bathtub when you get into it? The amount of water you are displacing is the volume of your body that is in the water. So, by measuring the displacement of an object, you can measure the volume of the object.

Suggested Activity

Conduct an Investigation 8-2A on page 315.

Calculating Density

The density of a substance can be determined by calculating its **mass-to-volume ratio**. You can do this by dividing the object's mass by its volume. Therefore, the formula for density is:

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

The volume of a solid is often given in units of cm^3. Therefore, the density of solids is often given in g/cm^3. The volume of liquids, however, is often given millilitres (mL). Therefore, the density of liquids is often given in units of g/mL.

Did You Know?

Forensic scientists use density calculations to solve crimes! The density of glass fragments found at a crime scene or on a suspect's clothing can be compared to the density of other samples of glass. This may provide evidence that a particular suspect was present at the crime scene. What information would scientists need to calculate the density of the glass fragments? How might they gather this information?

Figure 8.10A The salt and sugar shown here both have a mass of 0.5 kg and are the same colour. However, their densities are different. Seawater may look like regular water (B) , but its density is closer to that of milk—1.03 g/mL.

As long as the temperature and pressure stay the same, the mass-to-volume ratio, or density, of any pure substance is a *constant*, meaning it does not change. If the mass of a pure substance increases, the volume will also increase. Similarly, if the volume of a pure substance increases, the mass will also increase. According to the particle theory, the size of the particles in a substance do not change when the mass or volume of the substance changes. A certain number of particles of a particular size and mass will always occupy a certain amount of space. Density is a property of matter that is unique to a specific pure substance. Table 8.1 on the following page lists the approximate densities of some common substances.

Suggested Activity

Investigation 8-2B on page 316.

Table 8.1 Approximate Densities of Common Fluid Substances and Solid Substances

Fluid	Density (g/mL)	Solid	Density (g/cm^3)
hydrogen	0.00009	styrofoam	0.005
helium	0.0002	cork	0.24
air	0.0013	oak	0.70
oxygen	0.0014	sugar	1.59
carbon dioxide	0.002	salt	2.16
ethyl alcohol	0.79	aluminum	2.70
machine oil	0.90	iron	7.87
water	1.00	nickel	8.90
seawater	1.03	copper	8.92
glycerol	1.26	lead	11.34
mercury	13.55	gold	19.32

Scientists determined the values in Table 8.1 by making very careful measurements of the mass and volume of samples of the substances and using the formula for density. Learn how scientists make these calculations by studying the sample problem below. Then, develop your problem solving skills by completing the practice problems that follow.

Sample Problem

Find the density of a 10 g mass of a substance that has a volume of 2.0 cm^3.

- Write the formula for density. $D = \frac{m}{V}$
- In place of *m* for mass, write 10 g. $D = \frac{10\text{ g}}{V}$
- In place of *V* for volume, write 2.0 cm^3. $D = \frac{10\text{ g}}{2.0\text{ cm}^3}$
- Carry out the division. That is, divide 10 by 2.0. $D = 5.0\ \frac{\text{g}}{\text{cm}^3}$

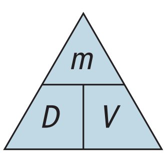
The density of the substance is 5.0 g/cm^3.

Practice Problems

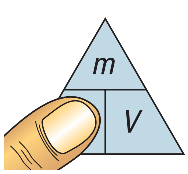
1. A piece of metal has a mass of 8.1 g and a volume of 3.0 cm^3. What is the density of the metal? Look at the densities of the solids in Table 8.1. What type of metal do you think was described in this problem?

Did You Know?

You can place the density formula in a triangle graphic to make it easier to manipulate:



By using your thumb to cover up the variable for which you wish to solve, you will be able to see the formula required.
If you wish to find the density (solve for *D*), cover up the *D*:



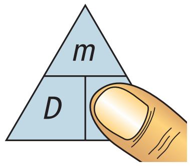
The formula can be read as "*m* over *V*", or mass divided by volume.

2. Imagine that you poured a liquid into a measuring spoon that holds 2.5 mL. When you measured the mass of the liquid, you discovered that its mass was 3.15 g. What is the density of the liquid? Was this liquid water? Explain how you could check if the liquid was water.
3. You collect 1000 mL of a gas in a balloon. If the gas in the balloon has a mass of 2.0 g, what is the density of the gas? Use Table 8.1 to identify the gas.

If you know the density of a substance and are given the mass of a sample of the substance, you can predict the volume of the sample. To do this, you use a different form of the formula. If you rearranged the formula, you would find that $V = \frac{m}{D}$. Learn how to use this form of the formula by studying the sample problem below. Then, complete the Practice Problems.

Did You Know?

Use the triangle graphic technique to find the volume by covering up the *V* in the triangle:



The formula can be read as "*m* over *D*", or mass divided by density.

Sample Problem

You want to put 10.0 g of salt into a container. What is the volume of the container if the salt completely fills it?

- Write for formula for volume when you know the mass and density. $V = \frac{m}{D}$
- Look up the density of salt in Table 8.1. $D = 2.16 \text{ g/cm}^3$
- In place of *m* for mass, put 10.0 g. $V = \frac{10.0 \text{ g}}{D}$
- In place of *D* for density, put 2.16 g/cm³. $V = \frac{10.0 \text{ g}}{2.16 \text{ g/cm}^3}$
- Carry out the division. That is, divide 10.0 by 2.16. $V = 4.63 \text{ cm}^3$

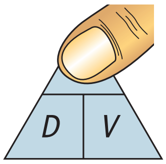
The volume of 10.0 g of salt is 4.63 cm³. The container holds 4.63 cm³.

Practice Problems

1. A piece of gold has a mass of 9.66 g. What is its volume?
2. What volume is taken up by 15 g of helium?
3. What is the volume of 250 g of sea water? Would the same mass of pure water have a larger volume or a smaller volume than the sea water? Explain.

Did You Know?

Use the triangle graphic technique to find the mass (solve for *m*) by covering up the *m* in the triangle.



The formula can be read as *D* times *V*, or density multiplied by volume.

By rearranging the formula for density in another way, you can calculate the mass of a given volume of a substance if you know its density. The formula for calculating mass is $m = VD$ or mass equals the volume times the density. Study the following sample problem, and then complete the practice problems.

Sample Problem

What is the mass of 1500 mL of helium?

- Write the formula for mass when you know the volume and density. $m = VD$
- Look up the density of helium in Table 8.1 . $D = 0.0002$ g/mL
- In place of *V* for volume, write 1500 mL. $m = (1500 \text{ mL})D$
- In place of *D* for density, write 0.0002 g/mL. $m = (1500 \text{ mL})(0.0002 \text{ g/mL})$
- Carry out the multiplication. That is, multiply 1500 by 0.0002. $m = 0.3$ g

The mass of 1500 mL of helium is 0.3 g.

Practice Problems

1. What is the mass of 20 000 mL of oxygen?
2. When you lower an irregularly shaped piece of copper into water in a graduated cylinder, the volume of the water increases by 6.5 mL. What is the mass of the copper?
3. What is the mass of 7.0 mL of machine oil?

Reading Check

1. What two measurements do you need to determine the density of a substance or object?
2. What is the formula for density?
3. Describe how to measure the volume of an object with an irregular shape.
4. If the mass of a pure substance increases, what happens to the volume of the substance?

8-2A What is the Density of a Pencil?

Find Out ACTIVITY

You need two measurements to calculate the density of a pencil. What are they?

What You Need

- balance
- 100 mL graduated cylinder
- water
- pencil

What to Do

1. Use the balance to measure the mass of a pencil in grams.
2. Pour 90 mL of water into a 100 mL graduated cylinder.
3. Lower the pencil, eraser end down, into the cylinder. Continue to push the pencil down until it is completely underwater, but be sure your finger is not also submerged.
4. Read and record the new volume of water.
5. Determine the volume of the pencil by calculating the amount of water displaced. You can calculate this value by subtracting the original volume of water from the final volume of the water after you submerged the pencil.
6. Calculate the pencil's density by dividing its mass by its volume.

What Did You Find Out?

1. Is the density of the pencil greater or less than the density of water? How do you know?
2. How does the method you used to determine the density of the pencil differ from the method you would use for an object with a regular shape, such as a cube or a sphere?

Extension

Use the same method to find out the density of another object, such as a rubber stopper or a cork. Make a prediction, and then carry out the activity to see if you were correct.

8-2B Determining Density

Core Lab

SkillCheck

- Predicting
- Measuring
- Calculating
- Graphing

Safety

- Handle balances with care and use them as instructed by your teacher.
- Avoid spilling liquids and sand on the balances.
- Do not pour substances down the drain. Dispose of them as instructed by your teacher.

Materials

- 500 mL beaker (or 500 mL cup)
- balances (or one shared by the class)
- 5 different coloured pencil crayons or markers
- 500 mL (per trial) of each of the following substances: water, oil, glycerol, molasses, sand
- graph paper for each student

The following investigation will show, by means of accurate measurements, how mass and volume can be used to determine density.

Question

How can measurements of mass and volume be used to determine the density of a substance?

Part 1

Mass-to-Volume Ratios

Procedure

1. Before beginning the investigation, predict how the substances will rank according to density. Rank the substances from the least dense (1) to most dense (5). Record your hypothesis and a brief note explaining your ranking order.
2. (a) Your teacher will divide the class into groups and will assign one substance to each group. Subdivide each group into smaller groups or partners to provide multiple trials for each substance.

   (b) Copy the data table below into your notebook.

Individual Results

Substance Tested:

A	B	C	D	E
Volume (mL)	Mass of Beaker Only (g)	Mass of Beaker and Substance (g)	Mass of Substance Only (g)	Ratio of Mass to Volume (g/mL)
100				
200				
300				
400				
500				

3. Measure the mass of the empty beaker. Record this value in column B of your table.

Step 3.

4. Pour 100 mL of your substance into the beaker. Be as accurate as possible.

Step 4.

5. Measure the mass of the beaker plus the substance. Record this value in column C in your table.
6. Subtract the mass of the beaker (column B) from the mass of the beaker and the substance together (column C). Record the difference in column D.
7. Repeat steps 3 to 5 four more times, each time adding 100 mL of your substance to what is already in the beaker. (The last time, you will be measuring 500 mL.)

Step 5.

Continued on next page

SkillCheck
- Predicting
- Measuring
- Calculating
- Graphing

8. The mass-to-volume ratio is the relationship between mass and volume expressed as a quantity of the mass divided by its volume. To find the mass-to-volume ratio for each amount of each substance, divide the mass (column D) by the volume (column A). Show your calculations and results in column E. Wash your hands.
9. When each group has finished, your teacher will display a set of class results for all the substances in a summary chart with the following headings:

Class Results

Substance	Mass (g)	Volume (mL)	Mass-to-Volume ratio (g/mL)

Copy these results into your notebook. (If there were two or more trials for each substance, calculate the averages for the mass, volume, and mass-to-volume ratio values for each substance.)

Part 2
Graphing

Procedure

1. Make a line graph of the class results recorded in Part 1. Place the volume scale along the horizontal axis (x-axis), and the mass scale along the vertical axis (y-axis).
2. Plot the (average) results for the first substance on the graph. Draw a line through these points in one colour. Record this colour in a legend on the graph, and write the name of the substance beside it.
3. *On the same graph*, plot the results for the next substance. Draw a line through these points using another colour. Record this colour in the legend, and write the name of the substance beside it.
4. Repeat step 3 for the three remaining substances.
5. Give your graph a title.

Analyze

1. Describe the lines on your graph. Are they straight or curved? Are some lines steeper than others? Are some lines closer together than others?
2. Look back to the data table you made for your substance. What happens to the mass-to-volume ratio for each volume measurement of your substance? Why do you think this happens?
3. Compare your hypothesis to the final results.
4. There is a chance of error in every experiment. Suggest ways to improve (a) how you performed the investigation (more accurate measurement, avoidance of spilling, etc.), (b) how you calculated results (possible math errors), and (c) how you graphed your results.

Conclude and Apply

5. Why are some lines in the graph similar to each other while some are different?
6. How can you tell from your mass-to-volume ratios and your graph which substance is the least dense? Which substance is the most dense?
7. Look at the mass-to-volume ratios in the Class Results table in Part 1. Compare these values with the steepness of the lines in the graph that correspond to them. How does the steepness of a line change as the mass-to-volume ratio changes?
8. Add a sixth line to your graph for a substance that is denser than water but less dense than sand. Between which values would its mass-to-volume ratio be?
9. Use the particle theory to explain the relationship between the mass, volume, and density of the substances you examined in this investigation.

Extend Your Skills

10. From your observations, do you think that density and viscosity are related? Explain your answer.
11. Use the particle theory to predict the effect of temperature on mass-to-volume ratios.

8-2C Comparing Densities

When you compare the masses of equal volumes of different kinds of matter, you are comparing their densities. Scientists have recorded the densities of many substances. Does knowing how the density of a substance compares with the densities of other substances tell you something about the characteristics or behaviour of the substance? Find out in this investigation.

What to Do

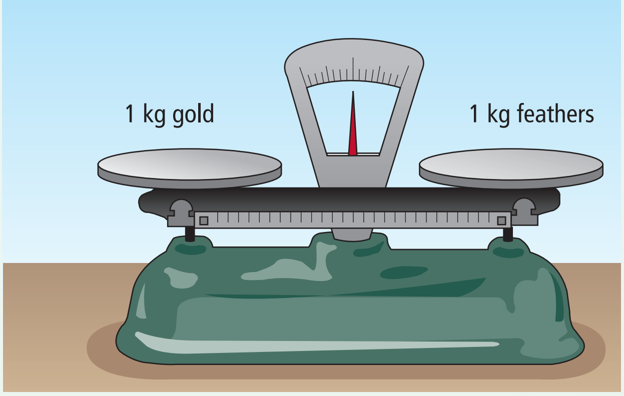
Use the information in Table 8.1 on page 312 to answer the following questions:

1. Which substance in the table is the most dense? Is it a solid, a liquid, or a gas at room temperature?
2. Which substance is the least dense? What is its physical state at room temperature?
3. Write a conclusion about which physical state tends to be the most dense.
4. Name the substance that is denser than mercury.

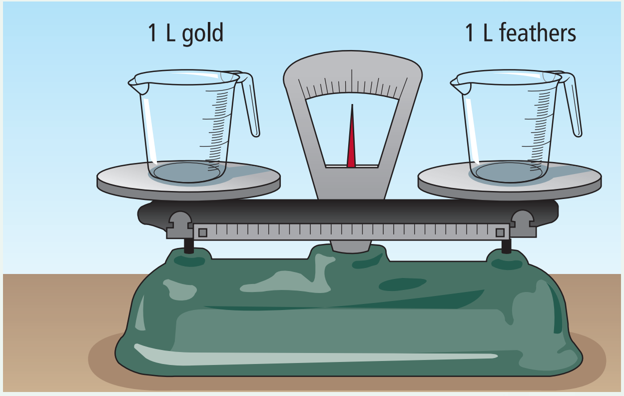
Analyze

1. Which substances would float in water?
2. Which substances would sink in water?

Extension



1. Copy and complete the diagram above by adding a sack of gold and a sack of feathers. If both sacks have the same mass, which one will have the larger volume?



2. Copy and complete the diagram above. Add the gold and the feathers to the measuring cups, and show how the balance would tip as a result. If both substances have the same volume, which one will have the larger mass? Record your answer. Comment on how a knowledge of density helped you with your answers.

Wild, Weird, Wonderful

www Science

The Galileo Thermometer

Walking into your friend's home, you see a large glass tube with several colourful glass balls that are suspended in liquid. While it may look like a strange piece of art, chances are you are looking at a Galileo thermometer!

In the early 1600s, Galileo Galilei knew that the density of water changes as its temperature increases or decreases. He also realized that different objects that had slightly different densities would rise or sink depending on the density of the water around them. Putting these ideas together, Galileo created the thermoscope, which eventually changed into the Galileo thermometer.

Modern Galileo thermometers consist of a glass tube filled with a liquid that undergoes a greater density change with temperature than water does. Also in the tube are several hollow glass balls that have been filled with coloured water. Because the glass balls are different sizes, they each have varying amounts of liquid to make them equal in weight. Attached to each glass ball is a small metal tag that has a temperature engraved on it. (For example, the red ball may be 20°C, and the blue ball may be 25°C.) If you could take these tags off and weigh them, you would find that each tag is a little different in weight. The result is that each glass ball has a slightly different density.

As the temperature of the air rises, the temperature of the liquid inside the thermometer also rises. As the density of the liquid changes with the increase in temperature, it causes the weighted glass balls to either rise or sink, depending on their density. The temperature of the air can be read on the tag of the lowest ball that is still suspended in the liquid.

The glass balls filled with coloured liquid all have slightly different densities. Depending on the temperature of the liquid around them, they will rise or sink.

Science

Math connect

Working With Density Measurements

Density is an example of a property that can be used to identify pure substances. Therefore, you could measure the density of a pure substance to help determine its identity.

In the science lab, you collect all sorts of measurements. Taking these measurements and turning them into numbers that allow for analysis and comparison is very important. In the case of density, we need to convert a variety of mass and volume measurements to decimal values that make comparison of densities easy and make it possible to identify substances.

Density is really a ratio of mass to volume. For example, a 155 mL sample of glycerol is placed on a scale and records a mass of 195 g.

(a) This would be a mass-to-volume ratio of 195 g : 155 mL.

(b) This ratio can be expressed as a fraction $\frac{195\text{ g}}{155\text{ mL}}$

(c) You can convert this fraction to a decimal by dividing the numerator by the denominator:
$\frac{195\text{ g}}{155\text{ mL}} = 1.26\text{ g/mL}$

Practice Problems

Try it yourself. First convert the following measurements into:
(a) a mass-to-volume ratio
(b) a fraction
(c) a decimal

To be consistent, round each of your answers to two decimal places. Then, compare your decimal values to Table 8.1 on page 312 to identify each mystery substance.

1. Mystery substance A has a mass of 1780 g and a volume of 200 cm^3. What substance is it?

2. Mystery substance B has a mass of 972 g and a volume of 360 cm^3. What substance is it?

3. Mystery substance C has a mass of 132.79 g and a volume of 9.8 mL. What substance is it?

4. Mystery substance D has a mass of 1404 g and a volume of 650 cm^3. What substance is it?

5. Mystery substance E has a mass of 1422 g and a volume of 1800 mL. What substance is it?

Check Your Understanding

Checking Concepts

1. What is the density of a 2 cm^3 sugar cube that has a mass of 3.18 g?
2. The mass of 1 cm^3 of lead is 11.34 g. The mass of 1 cm^3 of iron is 7.87 g. Which solid has the greater density?
3. Using information from Table 8.1 on page 312, copy the table below and fill in the missing information.

Substance	Mass (g)	Volume (cm^3)	Density (g/cm^3) (Mass-to-Volume Ratio)
aluminum	5.40		
	6.48	3.0	
		5.0	8.92
oak	0.33		
salt		4.0	

4. The picture shows that a can of diet soft drink floats in water, but a can of regular soft drink sinks. What does this tell you about the relative densities of water, the can of regular soft drink, and the can of diet soft drink?

5. Explain why the lines representing pure substances on a mass vs. volume graph are straight.

Understanding Key Ideas

6. How do you measure the volume of a liquid? Of a solid? Of a gas?
7. What does the mass-to-volume ratio tell you about a substance?
8. Why is the process of displacement a good tool for measuring volume?
9. Liquid mercury (13.55 g/mL) is denser than solid copper (8.92 g/mL). When a drop of mercury is placed on solid copper, it stays on top. If mercury is denser than copper, why does the mercury not move down through the copper?

Pause and Reflect

Dissolving substances such as salt into water increases the density of water. Salt water has a greater density than distilled (pure) water. Considering the formula you have learned for calculating density, offer an explanation for why salt water is denser than distilled water.

8.3 Changes in Density

Just as changes in temperature affect the viscosity of fluids, changes in temperature also affect the density of a substance. By learning about the effects of temperature on density, you will begin to understand how these two factors are linked together in the world around us.

Changes in Temperature and Density

Suggested Activity

Find Out Activity 8-3B on page 328.

As you know, as temperature increases, a substance will change from a solid, to liquid, to gas. The particle theory states that the particles of a substance spread out as they gain energy when heated. Since they spread out, the particles take up more space, which means that the density of a substance decreases. It is almost always true that, for each pure substance (for example, silver), the density of its solid state is greater than the density of its liquid state. The substance's solid state and liquid state are, in turn, denser than its gaseous state.

Although most substances are denser in their solid form, water is an exception to this rule. When water freezes, the particles move slightly farther apart as they become fixed in position. This means that ice is actually less dense than liquid water, so it floats.

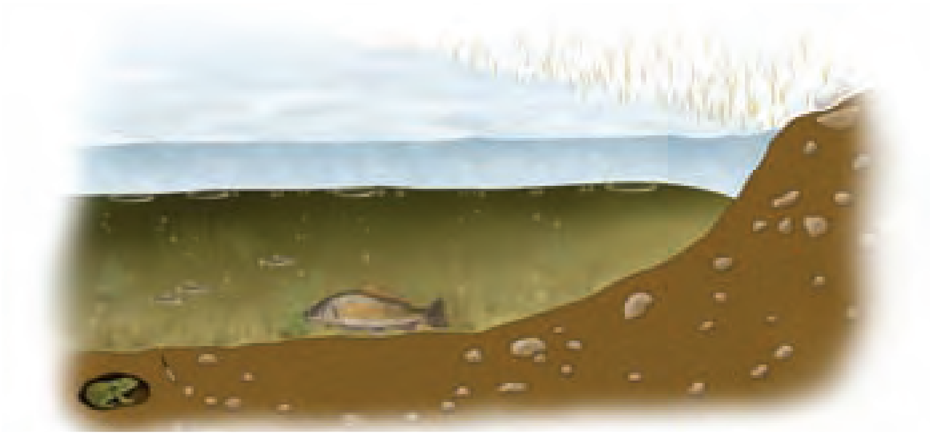


Figure 8.11 The property of ice floating on water makes life in freshwater lakes possible. If ice sank as it froze, lakes would freeze solid. Instead, the floating ice builds slowly from the top down, creating an insulating barrier against cold temperatures.

Temperature and Density in Everyday Life

You don't have to conduct an experiment in your science classroom to see the effects of temperature on density. All you have to do is look around you. For example, have you ever noticed that the tires on an automobile need more air during the winter than they do during the summer? As the temperatures decrease in the winter months, the particles inside the air in the tires lose energy, and therefore, take up less space. Therefore, the density of the air decreases, and the tire deflates a little. During the summer, however, increasing temperatures give the air particles more energy, meaning they require more space to move around. The air in the tire then expands, and the tire inflates.

A hot-air balloon is another example of the effect of temperature on density. When a balloon pilot is preparing to fly, you will notice that he or she turns on a gas burner that heats the air inside the balloon. As they gain energy from the heat, the air particles inside the balloon begin to move around more and spread further apart from one another. Eventually, the air particles move so far away from each other that some of them are forced out of the bottom of the balloon. As the density of the air inside the balloon decreases, it becomes less dense than the air surrounding the balloon, so it rises. The pilot can now control the altitude of the balloon by controlling the amount of heat that enters the balloon.

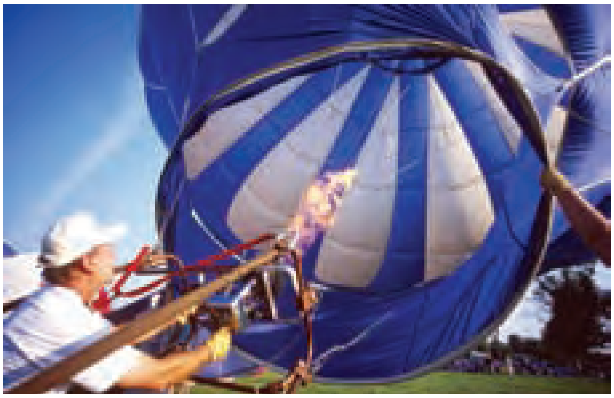
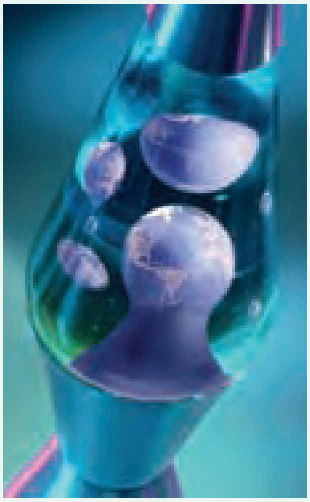


Figure 8.12 A hot-air balloon rises by adding heat to the air, and therefore decreasing the density of the air inside the balloon.

8-3A Lava Lamps

Think About It

In this activity, you will discover how the "lava" flows inside a lava lamp.



At the bottom of a lava lamp sits an incandescent bulb, which heats up the mixture of water and wax that sits at the bottom of the glass when it is cold. At room temperature, the wax is slightly denser than water. By answering the following questions and using your knowledge of density, see if you can figure out how the "lava" moves up and down.

1. What happens to the density of the wax in relation to the water when it is heated?
2. As the density of the wax changes, what happens to it?
3. Once the wax reaches the top of the lamp, it begins to flow back down. Why?
4. Using the particle theory, explain in your own words how a lava lamp works.

Did You Know?

Have you ever gone swimming in the ocean? If you have, then you know that it is much easier to float in salt water than in fresh water. The reason is that the density of salt water is greater than that of fresh water. Therefore, it can support more of your body weight, making it easier for you to float.

Changes in the density of a substance can also occur naturally. If you have ever stacked wood, you will know that freshly cut wood from a living tree is much heavier than wood that has been cut and dried in the air for a period of time. Why is this? A living tree, or one that has been freshly cut, contains a high quantity of water. In fact, the water in a living tree often has a greater mass than the wood itself. The density of a living or freshly cut tree is, therefore, high due to its high water content.

Once a tree has been cut and is left to dry, the water particles in the wood evaporate, and are replaced with air. Because air is much less dense than water, the dry wood is less dense than the moist wood. Therefore, the wood is lighter and easier to lift. As well, the absence of water makes the wood easier to burn.

Figure 8.13 Firewood is often stacked and left to dry before being used. As the water evaporates, the density of the wood decreases, making it lighter and easier to burn.

Wild, Weird, Wonderful

www Science

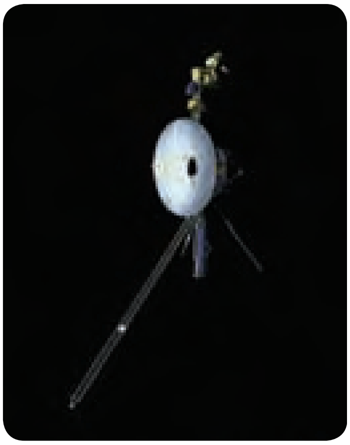
Iridium—The Densest Substance on Earth

Imagine a substance that is so resistant to heat, its melting point is at 2446°C and its boiling point is at 4428°C. What kind of uses can you think of for a substance like that? The substance is iridium, and it is the densest known substance on Earth. Discovered in 1803, iridium is a very hard and brittle metal that was named after the Greek word *iris*, meaning "rainbow." Although it looks silvery-white, the salts that are in iridium ore are many different colours. Canada is the primary source for iridium, which is a by-product of nickel mining.

With such unique properties, iridium has many uses. It is an ingredient in crucibles, electrical contacts such as spark plugs, and platinum jewellery. It is also used in cancer radiation therapy.

Iridium and the Dinosaurs?

There is one theory that iridium may have caused the extinction of the dinosaurs. All over the world's surface, there is a layer of iridium in the sediment. As iridium is found in meteors, scientists believe that Earth was struck by a large meteor during the time of the dinosaurs. The impact of the meteor would have created clouds of dust all over the world that contained iridium. This dust would have also blocked out the Sun for a long period of time, bringing an end to many plant and animal species, including the dinosaurs.



Iridium is used in unmanned space probes, such as the Voyageur probes, to enclose electrical generators to protect them from high temperatures.

Because of its high tolerance for heat, iridium is often used in making crucibles that can be heated to high temperatures to melt metals.

Iridium is used as a hardening agent in platinum. This allows jewellery, such as these platinum rings, to be more durable.

8-3B Layers of Water

Find Out ACTIVITY

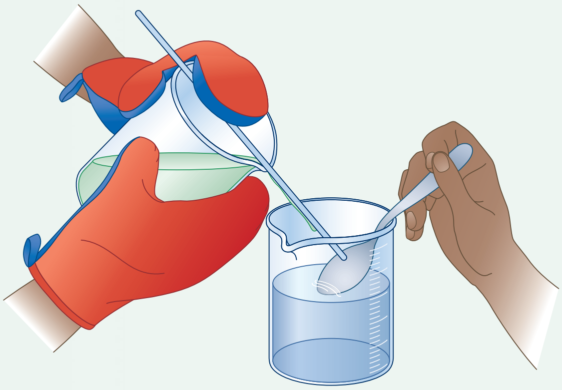
In this activity, you can find out how the temperature of a liquid affects its density.

Safety

- Be careful when handling hot water.

Materials

- two 250 mL beakers
- very cold water
- very hot water
- stirring rod
- large spoon
- food colouring



What to Do

1. Add 100 mL of water to a beaker. Use water as cold as possible from the tap.
2. Add 100 mL of water to the other beaker. Use water as hot as possible from the tap. Do not burn yourself. Use protective mitts to handle your hot water beaker.
3. Add a few drops of food colouring to the hot water and stir.
4. Put the stirring rod across the top of the hot water beaker, and very gently tip it so that the water runs along the stirring rod into the cold water beaker.
5. To make sure the hot water enters gently, have your partner hold the head of the spoon at the top of the cold water level. Pour the hot water into the head of the spoon. Continue pouring very slowly until the beaker is full.
6. Observe your beaker. If you have created two layers, look at them very carefully, especially where the two layers meet. If you do not have two layers, look at the beakers of other students in class.
7. Clean up and put away the equipment you have used.

What Did You Find Out?

1. How does the density of hot water compare to the density of cold water?
2. Occasionally this experiment is unsuccessful with the hot and cold water not forming layers. Provide an explanation, based on the particle theory, as to why the layers sometimes do not form.
3. How does the kinetic energy (energy of motion) and distance between particles compare between hot water and cold water?
4. If you repeated this activity by trying to pour the cold water on top of the hot water, what do you think would be the result? Explain.

Checking Concepts

1. The photograph shows six substances—oil, corn syrup, water, plastic, Styrofoam®, and a grape—layered in a cylinder. Based on how they are layered, place these six substances in a list from lowest to greatest density.

2. A balloon is filled with helium in a cold room. The balloon is taken to a warm room where, after some time, the balloon expands. Has the density of the helium changed? Explain.

Pause and Reflect

A weather balloon is a type of unmanned balloon that takes readings of atmospheric pressure, temperature, and humidity. Unlike hot-air balloons that are usually made of a type of nylon fabric, weather balloons are made with a flexible latex material. Why do you think weather balloons are made of this type of material rather than a nylon fabric?

3. In picture below is an outdoor thermometer. It is made of a small tube with a quantity of coloured alcohol. We can tell how warm or cold it is outside by reading the temperature that is next to the top of the coloured alcohol line. Using your knowledge about temperature and density, explain how the alcohol moves up or down, depending on the temperature.

Understanding Key Ideas

4. Use the particle theory to explain how temperature affects density.
5. Explain why the properties of water are critical for the survival of living organisms in the water during winter.

Chapter Review

Prepare Your Own Summary

In this chapter, you explored fluids by learning how to calculate their densities, and by examining factors that increase or decrease their density. Create your summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. Use the following headings to organize your notes:

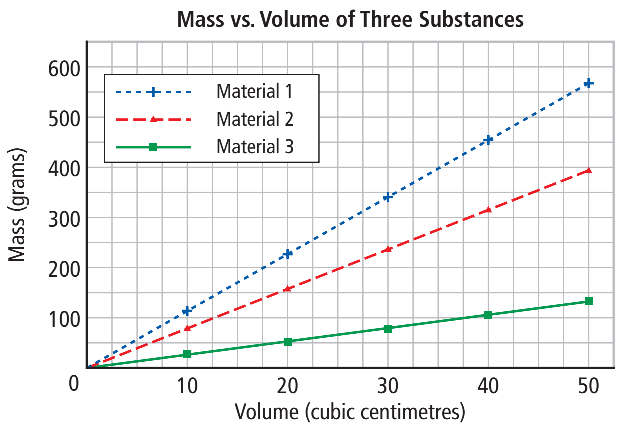
1. Densities of Solids, Liquids, and Gases
2. Calculating Density
3. Effect of Temperature on Density
4. Temperature and Density in Everyday Life

Checking Concepts

1. Define density.
2. Explain density using the particle theory of matter.
3. Why would the contents of two equal sized containers, one filled with water, and the other with water vapour, have two different densities?
4. Using the particle theory of matter, explain why solids can move easily through liquids and gases.
5. Give an example where the liquid state of one substance is denser than the solid state of another substance.
6. Why must the measurement of displacement of water be used in order to determine the density of some objects?
7. Compare and contrast *mass* and *density*.
8. What two factors must remain the same for the density of a pure substance to stay constant?
9. Changes in temperature can often change the density of a substance. Provide one example of this effect. Explain why the temperature change of the substance affects its density.

Understanding Key Concepts

10. The graph below shows the density of three different substances.



(a) Which substance has the largest mass when the volume is 50 cm^3?
(b) Which substance takes up the most space at 100 g?
(c) Calculate the mass-to-volume ratio for each material from the lines on the graph.

11. (a) Plot the following data on a line graph representing mass vs. volume:

Mass (g)	Volume (cm^3)	Mass-to-Volume Ratio (g/cm^3)
15.7	15.7	
39.3	39.3	
55.0	55.0	
82.9	82.9	
94.4	94.4	

(b) Calculate the mass-to-volume ratio for each mass.

(c) Be a sleuth and identify this mystery substance from the densities listed in Table 8.1 on page 312.

(d) Where would the line for a lower-density substance fit on your graph? For a higher-density substance? Indicate these lines on your graph.

12. Explain how you would measure the volume of water in its various states as ice cubes, in a water bottle, and as water vapour.

13. Why is a bag containing 1 kg of feathers much larger than a bag containing 1 kg of gold coins?

14. Do you think density and viscosity are related? Provide one example that demonstrates that they are related and one that demonstrates that they are not related. Use the particle theory of matter to suggest an explanation.

Pause and Reflect

In the human body, some materials are solids, and some are liquids. Gases are found in the lungs and respiratory system. How might you determine the density of at least three of the substances making up the human body?