7.2 Fluids and Density

Fluids are forms of matter that can flow. 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
displacement
fluid

What do pancake syrup, water in a mountain stream, and lava flowing from a volcano have in common? They are all fluids (Figure 7.7). A **fluid** is any form of matter that can flow. Liquids and gases are able to flow because they do not have a fixed shape. Solids have a fixed shape and cannot flow. Therefore solids are not fluids. Your body contains many fluids, such as blood and the watery cytoplasm inside cells. Air flows into your lungs each time you inhale, and out of your lungs when you exhale.

Figure 7.7 Lava flows from an erupting volcano, water flows in a mountain stream, and pancake syrup flows from its container.

7-5 Fluids Can Flow

Think About It

Liquids and gases are fluids, forms of matter that can flow. In this activity, you will share your knowledge of fluids.

What to Do

Divide a piece of notebook paper into quarters. Label the sections Box A, Box B, Box C, and Box D.

1. In Box A, list all the fluids you can think of.
2. In Box B, suggest more than one way you can make a fluid flow more quickly.
3. In Box C, suggest several applications (uses) where heating fluids is important.
4. In Box D, suggest several applications where cooling fluids is important.
5. Share your information with a partner.

Solid, Liquid, and Gas Density

One property that is useful in understanding both fluids and solids is density. **Density** is the mass of a given volume. 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 7.8 is a model of high density. The photograph of free-flowing loosely packed traffic on the right in Figure 7.8 is a model of low density.

Did You Know?

There is space between grains of sugar. When you melt sugar to make candy, the sugar becomes a fluid. After the sugar cools, it contracts, making the candy even more dense than the original sugar.

Figure 7.8 When traffic gets very dense, it is difficult for vehicles to move.

Using what you already know about particles and the state of matter, predict which is likely to be the densest, a solid, a liquid, or a gas. Take a look at Figure 7.9. Aluminum (a solid), is denser than water (a liquid), and water is denser than air (a mixture of gases)—but why? The key to density is the spacing of the particles. The particles of a piece of solid aluminum are tightly packed, while liquid water particles have enough room between them to change position. The particles of air are free to move independently and have a large amount of space between them. Less densely packed particles will "float" on more densely packed particles. As temperature increases, a substance will change from solid, to liquid, to gas. According to kinetic molecular theory, the particles of a substance spread out as they gain energy when heated. The particles will take up more space, which means that the density of the substance decreases.

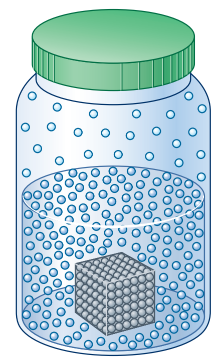
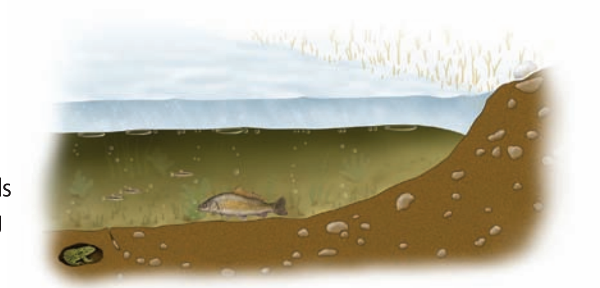


Figure 7.9 A sealed container holds air, water, and an aluminum block.

Most substances are denser in their solid form than their liquid form, but water is an exception. 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 (see Figure 7.10).

Figure 7.10 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.



Connection

Section 10.2 has more information about the density of water and ice.

7-6 Dense, Denser, Densest

Think About It

Generally speaking, solids are denser than liquids, and liquids are denser than gases. In this activity, you will discover whether a fluid could be denser than a solid.

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

What to Do

The approximate densities of some common substances at 20°C are listed in the table. The higher the number, the denser the substance. Use the information in the table to answer the following questions.

1. Which substance in the table is the densest?
2. Which substance is the least dense?
3. Which fluid is denser than lead?
4. Water is denser than which three solids?
5. (a) Which substances would float in water?
   (b) Which substances would sink in water?
6. Which common metals are less dense than mercury?

Layers of Fluids

Imagine two beakers, one filled with water, and one filled with corn syrup. Does the water or corn syrup have the greater mass? Which has the greater density? Recall that density is the mass of a given volume. When you compare the masses of equal volumes of different kinds of matter, you are comparing their densities.

Some liquids float on top of others. Liquids will layer in order of density—the less dense liquid floats on the denser liquid if the two liquids do not mix together. How would corn syrup and water be layered if they were placed in the same beaker? Even though the two liquids are of the same volume, the corn syrup has more mass, and therefore it has a greater density than the water. Placing them together in the same container would result in the water floating on top of the corn syrup.

This layering according to density can even occur within the same substance. Air is an excellent example; differences in air density contribute a great deal to weather. When air is heated near the ground on a hot summer day, the particles gain energy and move farther apart. The warm air has a lower density than the air around it, and as a result, it begins to rise (see Figure 7.11 on the next page). As the warm air rises, cooler air rushes in beneath it, and a breeze is created.

Connection

Section 5.1 has information about air layers and mirages.

Air is a mixture of many types of particles, but it is mostly made of nitrogen and oxygen. Air particles are relatively dense close to Earth's surface. If we increase our altitude, we encounter areas of lower air density. The higher we go, the farther apart the air particles are spread out, making it harder for us to get enough oxygen particles into our lungs with every breath (see Figure 7.12).

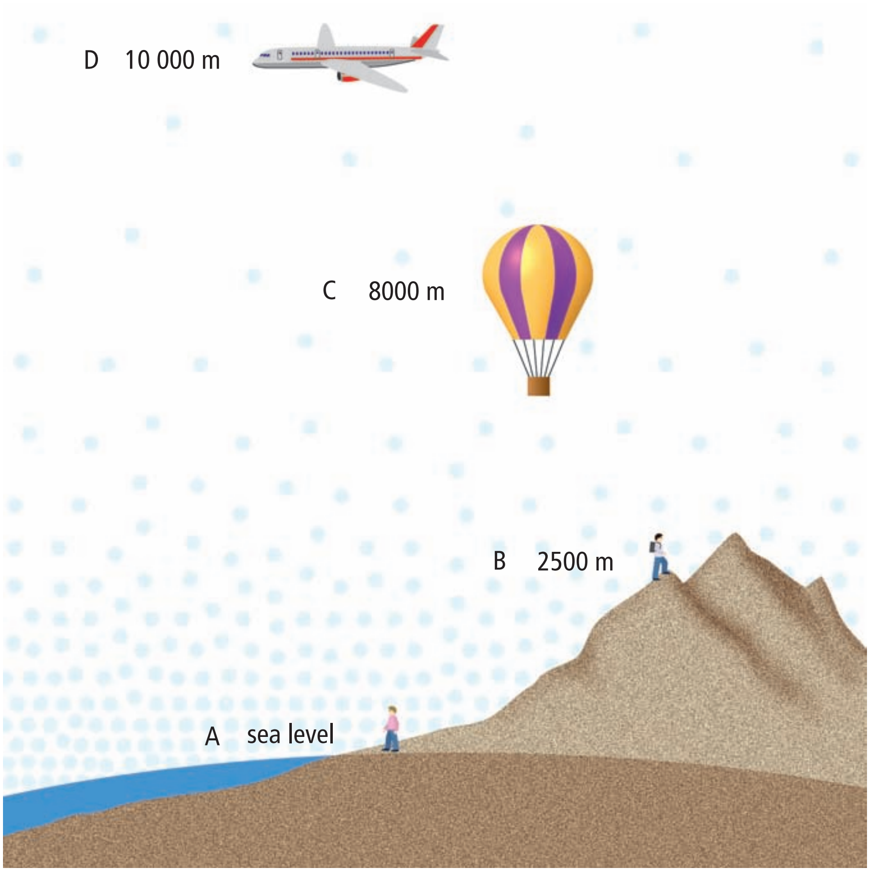


Figure 7.12 At sea level (A), there are more than enough oxygen molecules for us to breathe. Most people can climb to 2500 m with no ill effects (B). But going higher will likely lead to symptoms of lack of oxygen. Oxygen masks are needed at this air density (C). Large airplanes fly at high altitude because the air density is very low (D). With so much empty space between the particles, the airplane encounters less air friction, making flying more efficient and requiring less fuel.

Figure 7.11 As low-density warm air rises, it can carry water vapour with it. When the water vapour reaches the cooler higher atmosphere, it condenses into tiny droplets that we see as clouds.

Did You Know?

The cabins in large airplanes are pressurized so that the air density in the airplane is similar to the density on the ground. If the airplane loses cabin pressure, oxygen masks drop to the passengers, providing them with the oxygen they need.

Reading Check

1. Explain why gases and liquids are called fluids, but solids are not.
2. What happens to the density of matter when the matter is heated?
3. Why does ice float on water?
4. Why does water float on corn syrup?
5. How is a breeze created over land on a hot summer day?
6. Why is there more oxygen available to breathe at sea level than there is higher in the atmosphere?

Suggested Activity

Find Out Activity 7-8 on page 268

Figure 7.13 The SuperBall® sinks in the oil, but floats on the water!

Measuring Density

Layering is a useful technique for comparing densities (see Figure 7.13). When an object is placed in a less dense fluid, the object will sink down toward the bottom. If the fluid is denser than the object, the object will float. If the object has the same density as the fluid, the object will "hover" in place. Layering allows you to determine whether one substance is denser than another substance. However, layering does not provide a specific measurement of density, and layering cannot be used with solids. Solids do not flow, and their particles are so close together that other substances cannot move through them. How can you measure the density of a substance?

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 can be determined using an electronic scale or balance (see Figure 7.14).

The volume of a solid is often measured in cubic centimetres (cm^3). A cubic centimetre is the volume of a cube that measures 1 cm on each side. In other words, the volume of an object equals the number of 1 cm cubes it takes to fill that object. The volume of an object that has a simple shape can be determined mathematically (Figure 7.15).

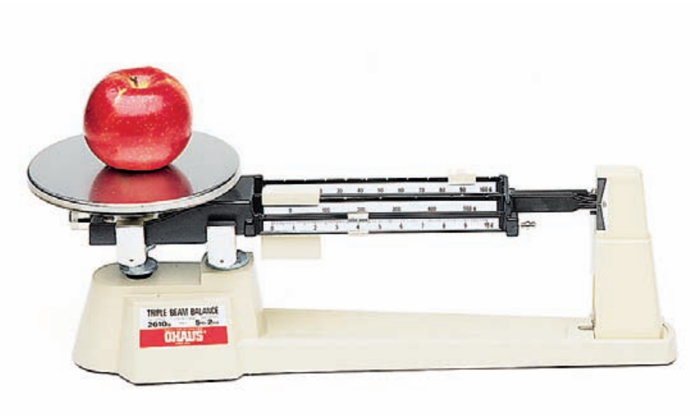


Figure 7.14 This triple beam balance indicates the apple has a mass of 94 g.

Figure 7.15 For objects that are block-shaped, volume can be calculated mathematically by using the equation: volume $=$ length $\times$ width $\times$ height.

Reading Check

1. How can you find the volume of a rectangular solid?
2. How can you find the volume of an irregularly shaped solid?
3. What two measurements do you need in order to calculate density?
4. What is the volume of a rectangular box that is 10 cm long, 5 cm wide, and 2 cm high?

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.

Calculating Density

Once you know the mass and the volume of a substance, you can calculate the density. You can calculate the density of both fluids and solids. The units for density depend on how you measure the mass and volume of your objects. The density of fluids is usually measured in g/mL, while the density of solids is usually measured in g/cm^3 (1 mL has the same volume as 1 cm^3).

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

Read the question:

1 mL of glycerol has a mass of 1.26 g. What it the density of glycerol?

Use the formula:

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

$$= \frac{1.26 \text{ g}}{1 \text{ mL}}$$

State your answer:
The density of glycerol is 1.26 g/mL.

Practice Problems

1. What is the density of a 2 cm^3 sugar cube that has a mass of 3.18 g?
2. A 3 mL sample of oil has a mass of 2.64 g. What is the density of the oil?
3. 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?

Explore More

Density and Dinosaurs

The densest substance that occurs in nature is iridium, a hard, brittle, whitish-yellow metal, with a density of 22.65 g/cm^3. Iridium has a special connection to the end of the reign of dinosaurs on Earth. Find out more about iridium and its connection to dinosaurs. Start your search at **www.bcscience8.ca.**

Answers

1. 1.59 g/cm^3
2. .88 g/mL
3. lead

7-7 Density Mystery

SkillCheck

- Measuring
- Classifying
- Explaining systems
- Evaluating information

Safety

- Handle balances with care and use them as instructed by your teacher.
- Avoid spilling fluids and solids on the balances.
- Do not pour materials down the drain. Dispose of them as instructed by your teacher.
- Use only fluids that are foods or mild dish detergents. Do not use any fluids that have any type of danger symbol on their labels.

Science Skills

Go to Science Skill 7 for help with measuring mass and volume. Go to Science Skill 5 for help with drawing a graph.

In this investigation, you can make and use accurate measurements to determine density and predict layering.

Question

What are the densities of various fluids and solids?

Materials

- various fluids, such as water, vegetable oil, corn syrup, molasses, dish detergent
- various granular solids, such as sand, sugar, flour, aquarium rocks
- various solid objects, such as an eraser, pencil sharpener, block
- large graduated cylinder
- overflow can
- water
- 250 mL beaker
- clear plastic disposable drinking cups
- electronic scale or triple beam balance
- medicine dropper
- ruler
- calculator

Procedure

Part 1 Calculating Density

1. Copy the data table below to use in recording your experimental data.

Material	Mass of Graduated Cylinder (g)	Mass of Graduated Cylinder and Material (g)	Mass of Material (g)	Volume (mL or cm^3)	Density (g/mL or g/cm^3)

2. Use measurement A, B, or C to determine the mass and volume of each material.

Measurement A: Use for fluids and granular solids.

(a) Place the empty graduated cylinder on the scale. Record its mass.

(b) Fill the graduated cylinder to the 25 mL mark. Use the medicine dropper if necessary. Record the volume of the fluid or granular solid as 25 mL.

(c) Place the filled graduated cylinder on the scale and record the mass of the fluid or granular solid and cylinder.

(d) Subtract the mass of the empty graduated cylinder from the mass of the filled graduated cylinder. This is the mass of the fluid or granular solid. Record the mass in your table.

Measurement B: Use for solids that are cubic or rectangular.

(a) Place the solid on the scale. Record its mass.

(b) Use the ruler to measure the length, width, and height of the solid in centimetres.

(c) Multiply the length, width, and height values together. This is the volume of the solid. Record the volume in your table.

Measurement C: Use for irregularly shaped solids.

(a) Place the solid on the scale. Record its mass.

(b) Position the beaker to catch water from the overflow can. Fill the overflow can with water. Empty the beaker of any water that has overflowed and place it back into position to catch water.

(c) Push the solid into the water of the overflow can so that it is just underwater. Pour the beaker overflow water into the graduated cylinder. The reading on the cylinder is the volume of the solid. Record the volume in your table.

3. Divide the mass of each material by its volume. This is the density of the fluid or solid. Record this density in your table.

Part 2 Comparing the Materials

4. Examine the densities of the materials in the data table. Create a bar graph that compares all the densities.

5. Examine your bar graph. Predict how these fluids would layer if you put them into the same clear plastic cup. Make a sketch that illustrates how you think the fluids would layer.

6. Carefully pour each fluid you tested into a clear plastic cup in the order you predicted in step 2. Start with the fluid at the bottom. Use only enough fluid to create a layer approximately 1 cm deep. Tilt the cup as you pour to allow the fluids to layer and avoid splashing.

Analyze

1. (a) What parts of this density experiment could have caused experimental error?

   (b) How might you do the experiment differently to reduce that error?

2. Compare your density results and layering test to the predictions you made. If you were wrong on any prediction, offer an explanation why.

Conclude and Apply

1. (a) Write a short paragraph that describes how you can determine the density of a fluid or solid. Include an evaluation of two different density-determining techniques.

   (b) Is one technique better than the other? Why?

7-8 Layers of Water

Find Out ACTIVITY

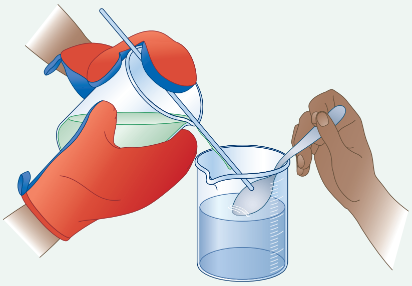
In this activity, you can find out how the temperature of a liquid affects its density.

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. Offer a particle explanation as to why the layers sometimes do not form.
3. How does the kinetic energy 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.
5. Examine the lamp in this photograph. The heat from the light at the bottom of the lamp causes a solid at the bottom to turn into soft lumps of fluid. Explain why the lumps of fluids in the lamp rise and 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 the table in Think About It 7-6 on page 262 to identify each mystery substance.

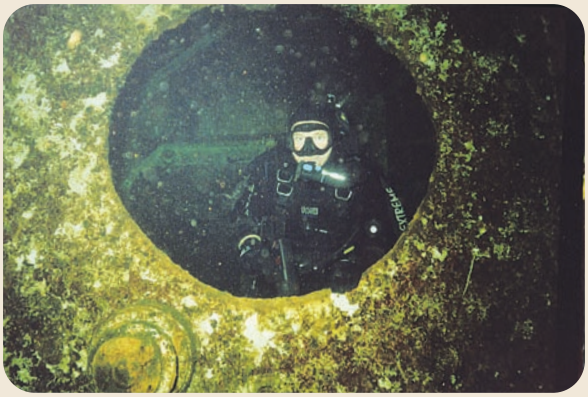
1. Mystery substance A has a mass of 1780 g and a volume of 200 cm^3. What substance is it?
2. Mystery substance B has a mass of 972 g and a volume of 360 cm^3. What substance is it?
3. Mystery substance C has a mass of 132.79 g and a volume of 9.8 mL. What substance is it?
4. Mystery substance D has 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?

Answers

1. nickel
2. aluminum
3. mercury
4. salt
5. ethyl alcohol

Career Connect

Diver



Tony Holmes looks through the window of the sunken ship *HMCS Chaudiere* and sees a sea lion swim by. At 39 m below sea level, this is just another day at work for Tony. As the owner of Suncoast Diving in Sechelt, British Columbia, Tony has turned his love of the ocean and scuba diving into a full-time business.

Q. How long have you been diving?

A. I did my first dive in a lake in Jasper about nine years ago. Since then I have completed over 3000 dives.

Q. What can divers see in the waters around British Columbia?

A. A huge number of species. British Columbia is rated as the number one cold-water dive spot in the world. The water is nutrient rich so we have abundant marine life, such as giant pacific octopus, sunflower stars, sea squirts, red coral, and sharks.

Q. What training do you need to become a scuba diver?

A. To get your scuba certification, you need to be at least 10 years old and complete some in-class background work. You learn to use the scuba equipment in a swimming pool or shallow bay. Then you do four ocean dives. To become a professional scuba diver, you need to do additional diving courses and at least 100 dives.

Q. What training do you need to dive the *HMCS Chaudiere*?

A. You need your advanced level diving qualification to dive around the outside of the ship as it is quite deep. To dive inside the ship, you need a wreck diving course. This course focusses on entry and exit of small places, special equipment use, carrying extra gas reserves, and special kicking techniques to minimize stirring up the silt.

Q. What science do you need to know to become a professional scuba diver?

A. If you want to be a divemaster, physics and physiology are both very important. You need to understand buoyancy to be able to lift things to the surface. You also need to be able to figure out the right amount of air to use, especially as the pressure is greater and the air and water denser, the deeper you dive. You need to understand how pressure affects the body and how gas acts on it.

Questions

1. What training do you need to become a scuba diver?
2. Why is physics important to a scuba diver?
3. What would you like most about being a professional diver?

Checking Concepts

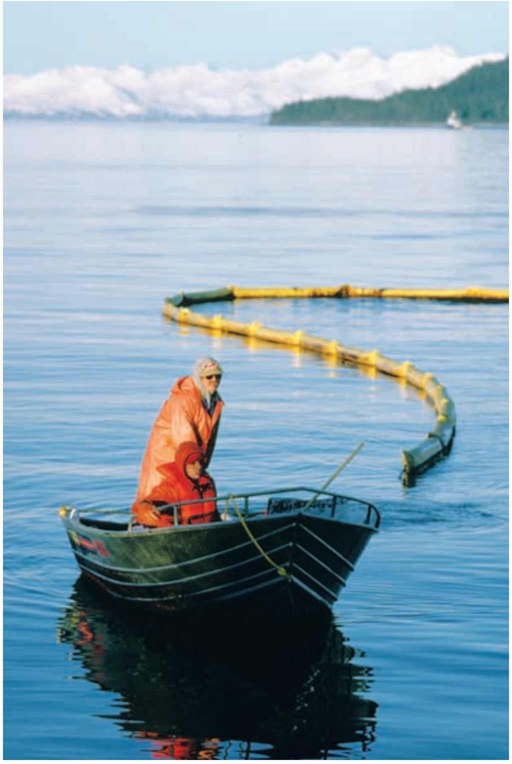
1. The photograph shows six substances—oil, corn syrup, water, plastic, Styrofoam®, and a grape—layered in a cup. Based on how they are layered, place these six substances in a list from lowest to greatest density.

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.
3. 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?

Understanding Key Ideas

4. A student measures 1080 g from a sample of an unknown solid. If the volume of the sample is 500 cm^3, what is the identity of the solid?
5. Liquid mercury (13.55 g/mL) is denser than solid copper (8.92 g/mL). When a drop of mercury is placed on copper, it stays on top. If mercury is denser than copper, why does the mercury not move down through the copper?

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.

Chapter Review

Prepare Your Own Summary

In this chapter, you investigated how the kinetic molecular theory explains the characteristics of solids, liquids, and gases. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 10 for help with using graphic organizers.) Use the following headings to organize your notes:

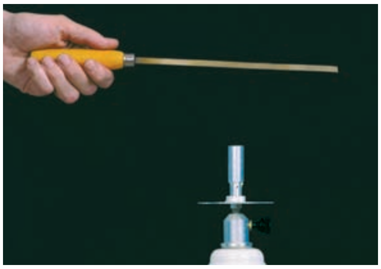
1. The Particle Model of Matter
2. The Kinetic Molecular Theory
3. Changing the State of Matter
4. Measuring Mass, Volume, and Density
5. Calculating Density

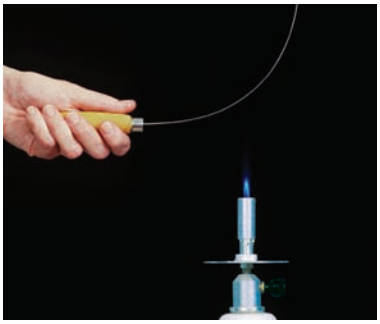
Checking Concepts

1. How does the particle model explain the difference between solids and gases?
2. (a) What is kinetic energy?
   (b) What happens to particles when their kinetic energy is decreased?
3. What is the difference between thermal energy and heat?
4. Describe how particles change as they change state from (a) solid to liquid (b) gas to liquid.
5. Explain the difference between condensation and evaporation.
6. Why are solids denser than gases?
7. How could density be used to determine the mass of a particular volume of a substance?
8. Fine sand can appear to flow like a fluid when it is dumped from a bucket. How can you prove to someone that sand is not a fluid?

Understanding Key Ideas

9. Examine the two demonstrations shown in the following photographs.
   (a) A bimetallic strip has two different metals bonded together. When heated, the strip curves. Use the kinetic molecular theory to explain the curving strip.





   (b) In the ball and ring demonstration, the ball is heated and then cooled. When hot, the ball will not fit through the ring, but when it is cool, it will. Use the kinetic molecular theory to explain the ball and ring demonstration.

10. On a very cold day, a car enters a carwash. As soon as the hot water strikes the windshield, it cracks. Explain this event in terms of kinetic molecular theory.

11. Nutritionists recommend limiting saturated fats in your diet. Saturated fats, such as butter, are solid at room temperature, while unsaturated fats, such as cooking oil, are liquid at room temperature. Which type of fat has the higher melting point? Explain.

12. Explain why hot water can float on top of cold water. Use the words "density" and "particles" in your answer.

13. A student obtains a measurement of 192 g for the mass of an 800 cm^3 solid sample of unknown material.
    (a) What is the density of the material? Show your calculations, including the formula.
    (b) Will the mass float on water?

14. A student performs an experiment with three unknown fluids and obtains the following measurements:
    Fluid A: $m = 2060$ g, $V = 2000$ mL
    Fluid B: $m = 672$ g, $V = 850$ mL
    Fluid C: $m = 990$ g, $V = 1100$ mL
    (a) What are the densities of the unknown fluids?
    (b) Draw how the fluids would be layered if they were combined in a beaker.

15. A 1000 cm^3 sample of an unknown substance has a mass of 917 g.
    (a) What is the density of the substance?
    (b) Would it float in water?

16. An atmospheric temperature inversion happens when warm air settles in a layer above cold air. When this condition occurs over cities, it can create a very stable air mass that traps pollution near Earth's surface. Why is the air mass in a temperature inversion so stable?

17. Reinforced concrete is concrete that has had metal bars added to increase its strength. Without the steel, concrete can tend to be brittle and crack. Engineers are careful to use steel when reinforcing concrete because it has almost the same rate of thermal expansion as concrete.
    (a) Why is it so important that the concrete and steel have similar expansion rates?
    (b) What would happen if metal bars with a different thermal expansion rate were used to reinforce concrete?

18. Describe a method by which you could make a substance that is more dense than water float. Explain how your method works.

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.