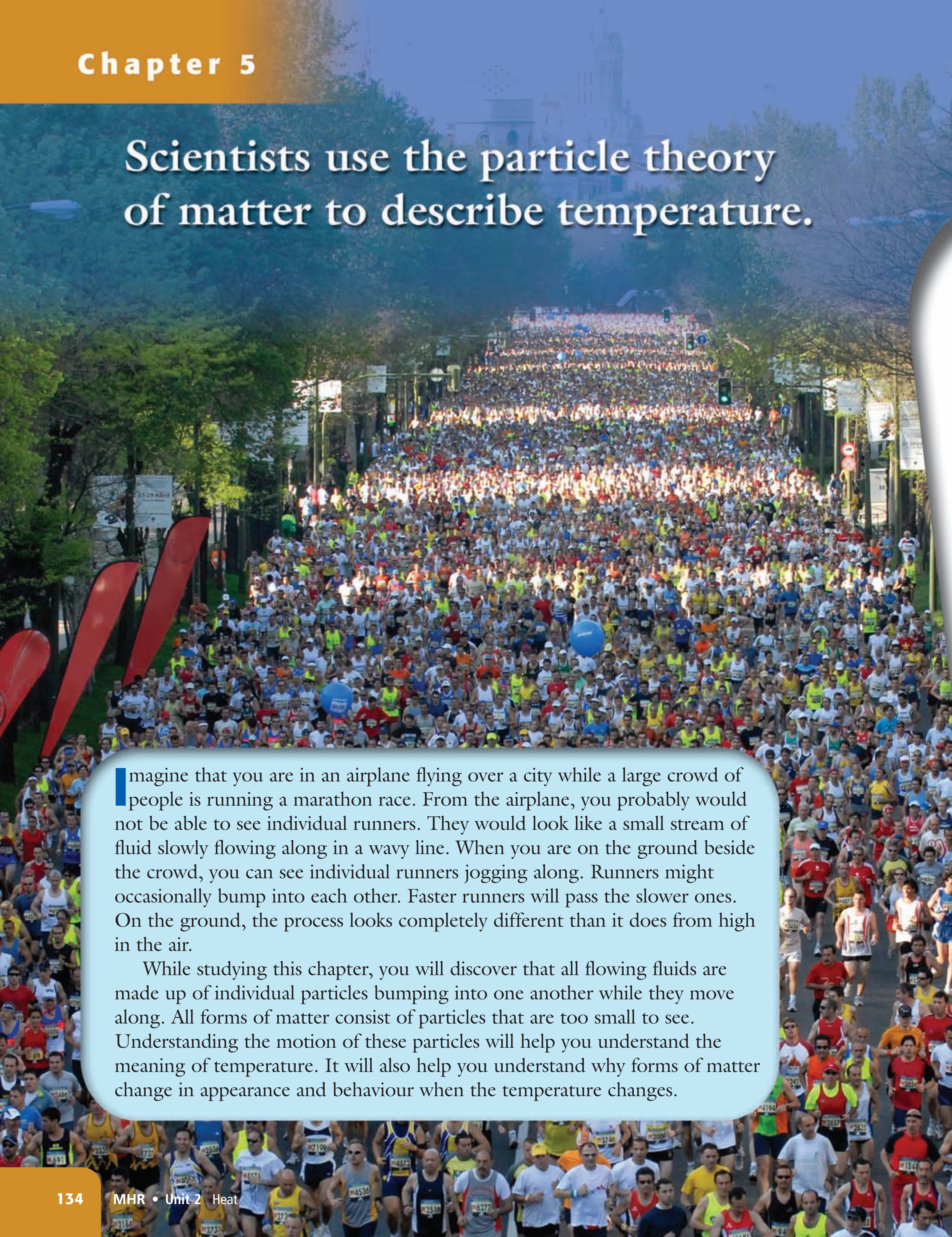
Chapter 5

Scientists use the particle theory of matter to describe temperature.



Imagine that you are in an airplane flying over a city while a large crowd of people is running a marathon race. From the airplane, you probably would not be able to see individual runners. They would look like a small stream of fluid slowly flowing along in a wavy line. When you are on the ground beside the crowd, you can see individual runners jogging along. Runners might occasionally bump into each other. Faster runners will pass the slower ones. On the ground, the process looks completely different than it does from high in the air.

While studying this chapter, you will discover that all flowing fluids are made up of individual particles bumping into one another while they move along. All forms of matter consist of particles that are too small to see. Understanding the motion of these particles will help you understand the meaning of temperature. It will also help you understand why forms of matter change in appearance and behaviour when the temperature changes.

What You Will Learn

In this chapter, you will
- **explain** the particle theory of matter
- **describe** the three states of matter
- **describe** the relationship between kinetic energy and temperature
- **explain** how each state of matter reacts to changes in temperature
- **use** the particle theory to explain expansion and contraction of matter

Why It Is Important

Understanding the particles that make up matter will help you understand why substances freeze, thaw, and evaporate. Knowing how materials expand and contract when the temperature changes is important for building safe structures such as buildings and bridges. Knowing how thermal energy is passed from one substance to another is necessary for designing insulation for homes and for cooking food.

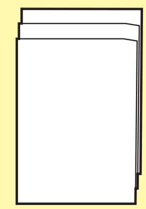
Skills You Will Use

In this chapter, you will
- **use** and **read** a thermometer safely and properly for collecting data
- **compile** and **display** data using tables and graphs
- **state** a prediction based on background information

FOLDABLES™
Reading & Study Skills

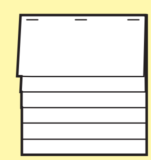
Make the following Foldable to take notes on what you will learn in Chapter 5.

STEP 1 **Stack** three sheets of 8.5″ × 11″ paper so that the back sheet is 2 to 3 cm higher than the middle sheet, and the middle sheet is 2 to 3 cm higher than the front sheet. (**Hint:** From the tip of your index finger to your first knuckle is about 2.5 cm.)

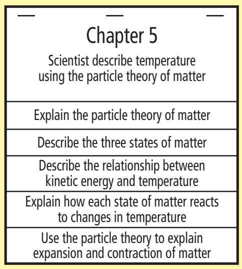


STEP 2 **Bring** the bottom of the sheets upward and **align** the edges so that all of the layers or tabs are the same distance apart. **Fold** the paper and **crease** well.

STEP 3 **Staple** the papers along the fold.



STEP 4 **Label** the Foldable with the chapter title and the five key points found in "What You Will Learn", as shown.



Organize As you read through the chapter, use the space under the tabs to record new terms and their definitions, and use the particle theory to explain temperature and its effect on matter.

5.1 Particle Theory of Matter

Did You Know?

The number of particles in one drop of water is about 3 000 000 000 000 000 000 000.

Matter is anything that takes up space and has mass. The particle theory of matter says that all matter is made up of tiny particles. The particles are always moving, have space between them, and are attracted to one another. The energy of motion is called kinetic energy. Temperature is a measure of the average kinetic energy of the particles that make up an object or a substance.

Key Terms

kinetic energy
matter
particle theory of matter
temperature

Matter is anything that takes up space and has mass. This book is matter. The water you drink is matter. Even though you cannot see it, the air you breathe is matter. Light from the Sun is not matter. It is a form of energy that your eyes can detect. Sunlight also helps plants grow but sunlight is energy and not matter.

The buildings in the photograph in Figure 5.1 are matter. Although it might be hard to believe, the buildings in photograph A are made entirely of Lego® blocks like those in photograph B. Each block had to be carefully attached to the others in exactly the right place to create these models of buildings.

Figure 5.1 Imagine the time and care it would take to build these buildings (A) from individual Lego® blocks (B).

You could think of buildings made up of Lego® blocks as models for all forms of matter. All matter is made up of particles. The particles of matter, however, are so small that you cannot see them. The type of particles and the way they are attached to one another determines what the substance is and how the substance functions. For example, the particles that make up water are different from the particles that make up salt or sugar.

5-1A Modelling the Particle Theory

Find Out ACTIVITY

All forms of matter are made up of very small particles and these particles have spaces among them. In this activity, you will model the particle theory to find evidence of the spaces among particles.

Safety

- Ethanol is poisonous.
- Be careful to wipe up any spills.

Materials

- funnel
- water
- 2 100 mL graduated cylinders
- 250 mL graduated cylinder
- 50 mL ethanol
- marbles
- 50 mL sand
- stirring rod

What to Do

1. Copy the following data table. Predict the total volume for each trial and record your prediction in your table.

Trial	Volumes	Predicted Total Volume (mL)	Actual Total Volume (mL)
1	50 mL water 50 mL water		
2	50 mL water 50 mL ethanol		
3	50 mL marbles 50 mL sand		
4	Trial 3 plus 50 mL water		

Trial 1 Water and Water

2. Use a funnel to carefully measure 50 mL of water into each of the two 100 mL graduated cylinders.
3. Add one of the volumes of water to the other. Stir with a stirring rod. Record the total volume.

Trial 2 Water and Ethanol

4. Carefully measure 50 mL of water into one 100 mL graduated cylinder and 50 mL of ethanol into the other cylinder.
5. Add one of the volumes to the other. Stir with the stirring rod. Record the total volume.

Trial 3 Marbles and Sand

6. Add marbles to the 250 mL graduated cylinder until they reach the 50 mL mark.
7. Add sand to a dry, 100 mL graduated cylinder until it reaches the 50 mL mark.
8. Add 50 mL of sand to the marbles. Record the new volume. (Save the mixture for Trial 4.)

Trial 4 Marbles, Sand, and Water

9. Carefully measure 50 mL of water in one of the 100 mL graduated cylinders. Add the water to the mixture of marbles and sand. Record the new volume.
10. Clean up and put away the equipment you have used.

What Did You Find Out?

1. If the 50 mL of water and the 50 mL of water did not add up to 100 mL, explain why.
2. If the 50 mL of water and the 50 mL of ethanol did not add up to 100 mL, explain why.
3. If the 50 mL of marbles and the 50 mL of sand did not add up to 100 mL, explain why.
4. If the 50 mL each of marbles, of sand, and of water did not add up to 150 mL, explain why.
5. If you added the substances in Trial 3 to the cylinder in reverse order, would the total volume be greater or less? Explain.

Word Connect

The word "kinetic" comes from a Greek word, *kinetikos*, which means motion or movement. The same Greek word is the basis of the word "cinema" (moving pictures).

Figure 5.2 The amount of kinetic energy that a ball has will determine how hard the ball hits the glove. Fastballs can sting your hand even if you are wearing a catcher's mitt.

The Particle Theory

The concept that all matter is made of particles is called the **particle theory of matter**. The important points of the particle theory of matter are listed here.

- All matter is made up of tiny particles.
- These particles are always moving—they have energy.
- There are spaces among particles.
- There are attractive forces between the particles.
- The particles of one substance differ from the particles of other substances.

Kinetic Energy

All particles of matter are moving and, therefore, have energy. The energy that an object has due to its motion is called **kinetic energy.** What properties of an object affect its kinetic energy?

Imagine that you are playing baseball in the position of catcher (see Figure 5.2). Which would sting your hand more when you caught it, a slow ball or a fastball? Whether you have ever played catcher or not, you probably know that a fastball will sting your hand more than a ball that is moving slowly. As the speed of an object increases, its kinetic energy increases, making it harder to stop.

Now think about bowling as shown in Figure 5.3. When you throw a strike, the pins fly away from the ball. What would the pins do if you rolled a baseball down the bowling lane at the same speed that you roll the bowling ball? The pins would probably wobble but they might not even fall down. A bowling ball moving at the same speed as a baseball has much more kinetic energy. When any two objects are moving with the same speed, the one with the larger mass has more kinetic energy. Mass and speed affect the kinetic energy of an object.

Figure 5.3 When a bowling ball is thrown well, the pins fly in all directions. How would the pins react if hit by a rolling baseball or a golf ball travelling at the same speed?

Average Kinetic Energy

Sports and games involving the motion of balls make excellent models for studying the motion of particles. Billiards allows you to analyze the motion of many balls at the same time. When a player makes the first shot and breaks the racked balls, the balls move out in all directions. Each ball has kinetic energy, but it is unlikely that any two balls have the same amount of kinetic energy. You could describe the energy of the balls by finding the average kinetic energy of all of the balls. An example of finding average kinetic energies is given in the following Think About It activity.

Figure 5.4 Even if you do not play billiards, you can learn a lot about motion by studying the speed and direction of the balls.

5-1B Average Kinetic Energy

Think About It

You will discover that the average kinetic energy of the particles in a substance is an important characteristic of matter. You can practise calculating the average kinetic energy of billiard balls to learn about finding averages.

Note: The unit of kinetic energy is the joule (J).

What to Do

1. Study the following example of finding an average.

   The kinetic energies of 15 billiard balls just after the racked balls were hit by the cue ball are given here.

0.95 J	1.21 J	1.10 J	0.90 J	0.82 J
0.86 J	0.79 J	1.35 J	1.08 J	1.03 J
1.05 J	0.91 J	0.77 J	0.88 J	1.11 J

   Find the average kinetic energy of all of the balls by adding the energies of all 15 balls and then dividing by the number of balls, or 15.

   0.95 J + 0.86 J + 1.05 J + 1.21 J + 0.79 J + 0.91 J + 1.10 J + 1.35 J + 0.77 J + 0.90 J + 1.08 J + 0.88 J + 0.82 J + 1.03 J + 1.11 J = 14.81 J

   $\frac{14.81\text{ J}}{15} = 0.99\text{ J}$

   The average kinetic energy of the balls is 0.99 J.

2. Find the average kinetic energy of the balls if their individual energies are:

0.92 J	1.09 J	1.23 J	0.94 J	0.85 J
0.89 J	0.81 J	1.04 J	1.02 J	1.14 J
1.12 J	0.72 J	0.74 J	0.85 J	0.91 J

What Did You Find Out?

1. How large is the average kinetic energy compared with the individual kinetic energies of the balls? Is it larger, smaller, or in the middle?
2. How long do you think it would take to calculate the average kinetic energy of 100 particles?

Reading Check

1. Describe the particle theory of matter.
2. When an object is moving, what type of energy does it have?
3. Name the two characteristics of an object that determine the amount of kinetic energy the object has.

Kinetic Energy and Temperature

If it is cool outdoors and you are not wearing gloves, you sometimes rub your hands together to make them warmer. Because your hands are moving, they have kinetic energy. The rubbing of your hands together causes the particles of skin on your hands to move more rapidly. How does this motion, or kinetic energy, cause your hands to feel warm? Some more clues about the connection between kinetic energy and temperature are given in the following Think About It activity.

5-1C Detect a Connection

Think About It

While analyzing the images in this activity, think about the motion of the particles that make up matter. According to the particle theory, particles are always moving, even when the object itself is not moving. You do not see the motion because the particles in the object are moving randomly and in different directions. How can you measure the motion of tiny objects that you cannot see?

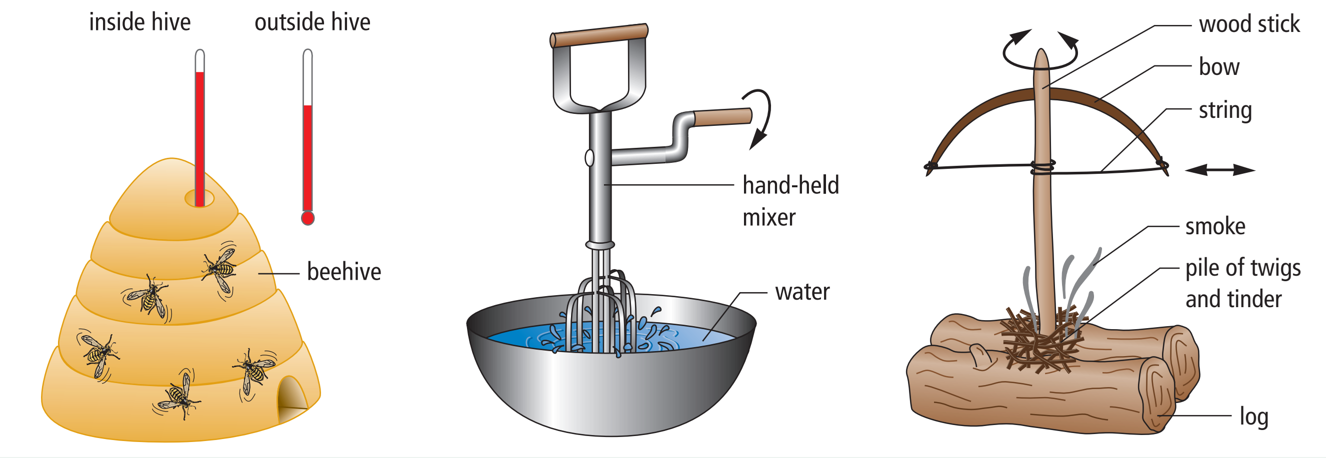
What to Do

Carefully examine each picture. Then, answer the following questions.

1. One way that bees control the temperature in their hive is by beating their wings vigorously. Explain what happens to:
   (a) the motion of the air particles in the hive
   (b) the air temperature in the hive
2. In a famous experiment, James Joule observed the temperature of water as a mechanical mixer stirred it vigorously. Explain what happened to:
   (a) the motion of the water
   (b) the temperature of the water
3. To start a fire, early people used a fire drill to twirl a stick pressed against a piece of wood.
   (a) What happened to the temperature at the pointed end of the drill?
   (b) What do you think caused the particles of wood to change temperature?

What Did You Find Out?

1. What common feature caused the changes in temperature in each example you examined?



When a large object such as a bowling ball or a billiard ball has kinetic energy, it moves from one place to another. When the particles that make up a solid object such as a billiard ball have kinetic energy, they do not move from place to place. Instead, the particles vibrate back and forth while remaining near the same location within the object. The particles are constantly colliding with one another and, therefore, changing direction.

Now think about rubbing your hands together again. When you rub your hands together, you cause the particles in your skin to vibrate faster and your hands feel warm. The temperature of your skin actually increases. Temperature is directly related to the kinetic energy of the particles in an object.

The particles in any object or substance do not all have the same amount of kinetic energy. However, you can describe their average kinetic energy just as you did with the billiard balls. Fortunately, you do not have to measure or calculate the kinetic energies of any of the particles to describe their average kinetic energy. The **temperature** of a substance is a measure of the average kinetic energy of its particles. Figure 5.5 illustrates the relationship between temperature and kinetic energy. When particles are the same size, the faster moving particles have more kinetic energy than the slower moving particles. The substance having the particles with the higher average kinetic energy has a higher temperature.

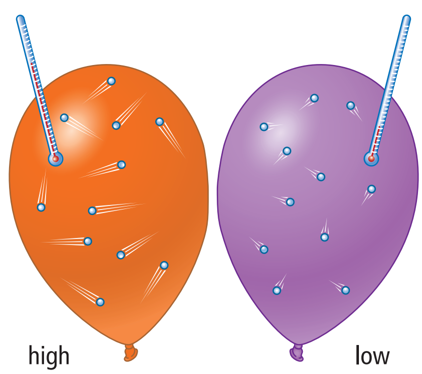


Figure 5.5 The air in the orange balloon is at a higher temperature than the air in the purple balloon because the particles have more kinetic energy.

Reading Check

1. Explain how particles in an object can be moving if the object is not moving.
2. What is the connection between the kinetic energy of the particles in an object and the temperature of the object?
3. Explain how to find the average of a set of numbers.

internet connect

You cannot see the motion of the particles in an object or substance, so it might be difficult to understand their motion. There are animations on the Internet that illustrate the motion of particles in relation to temperature. To find an animation, start your search at **www.discoveringscience.ca.**

Did You Know?

When scientists were developing the temperature scales, they had not yet discovered the relationship between temperature and average kinetic energy of particles in a substance. Temperature and energy are different quantities, measured in different units, and they cannot be equal to each other. Temperature is related to the average kinetic energy of the particles in a substance but it is *not* equal to it.

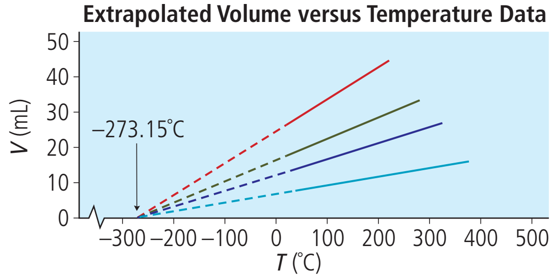
Science Watch

Absolute Zero: As Cold as It Gets

In Chapter 4, you read that the lowest possible temperature is –273.15°C. Why is it impossible for anything to get any colder than –273.15°C? You have learned that temperature is a measure of the average kinetic energy of the particles that make up a substance. Therefore, when the particles have no kinetic energy, the temperature is as low as it can possibly get.

The Kelvin scale was proposed in 1848. How did scientists of the time discover that absolute zero was –273.15°C? They did not even have refrigerators! They used a mathematical technique called *extrapolation.* Extrapolate means to extend the line in a graph past the data points. The scientists performed experiments on gases and collected and plotted the data from the experiments.

As the kinetic energy of gas particles gets lower and lower, the particles do not hit the walls of the container as often or as hard. If the walls are flexible, the container will get smaller. Therefore, as the temperature of a gas decreases, its volume also decreases. So, scientists measured the volume of samples of gases at many different temperatures. Then, they plotted the data on a graph like the one shown here. They drew a line through their data points and extrapolated the line to zero volume. No matter how large the sample was or what type of gas they used, the line ended at the same temperature, –273.15°C. The four lines on the graph below represent four different samples of gases tested under different conditions.



Today scientists want to get as close to absolute zero as possible. They have developed techniques involving magnetism and lasers that can cool particles to very near absolute zero. In 2001, three physicists, Carl Wieman, Eric Cornell, and Wolfgang Ketterle won the Nobel Prize in Physics for a project in which they brought a few very small particles down to a temperature of 0.000 000 170 K. As scientists study matter at these extremely low temperatures, they will learn more about the tiniest particles of matter and also develop new technologies. Some of the instruments used by these Nobel award-winning scientists are shown here.

Questions

1. Explain why it is not possible to cool a substance below absolute zero.
2. Is there a highest possible temperature? Do research on the Internet to find out.
3. What is the coldest temperature that you have ever experienced?

Check Your Understanding

Checking Concepts

1. State the definition of matter. Give an example of something that is not matter.
2. List the main points of the particle theory of matter.
3. How does the kinetic energy of the particles that make up a bowling ball differ from the kinetic energy of the ball as it rolls down the lane?
4. Two identical baseballs are hit with a baseball bat. One baseball is travelling at a speed of 35 m/s and the other is travelling at 23 m/s. Which baseball has more kinetic energy? Why?

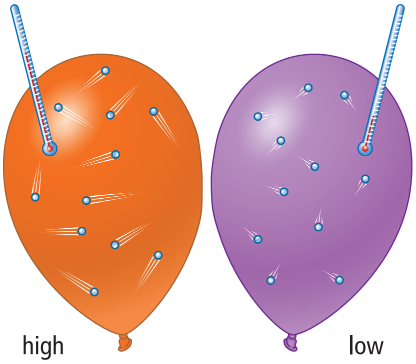
5. A billiard ball and a Ping-Pong™ ball are travelling at the same speed. Which ball has more kinetic energy? Why?
6. What is wrong with the following statement? "The temperature of an object is a measure of its kinetic energy." Rewrite the statement correctly.

Understanding Key Ideas

7. At the beginning of this section, you saw pictures of buildings made up of Lego® blocks. These were used as models of the particle theory of matter. Think of another way to model the particle theory of matter. Write a paragraph about your model.
8. Explain why rubbing your hands together makes them feel warmer. In what other way could you use motion to make yourself feel warmer?
9. One golf ball has been lying in the sun and another one has been in the shade. The particles of which ball have a larger average kinetic energy? Explain.

Pause and Reflect

The balloons from Figure 5.5 are shown again here. Analyze the image to find something that you think might be drawn in a more accurate way. Think about the number of particles in the balloons and the speed of the particles in each balloon. Think about the volumes of the balloons. Explain why the figure might be inaccurate. Draw the balloons in a way that corrects the figure.



5.2 States of Matter

The three common states of matter are solid, liquid, and gas. The particle theory explains the states of matter. Matter in any state will expand upon warming and contract upon cooling.

Key Terms

gas
liquid
solid
thermal contraction
thermal expansion

Figure 5.6 When you first look at this picture of an iceberg, you might just think of its beauty. However, by analyzing the picture, you can learn some very important features of matter.

Did You Know?

When learning about states of matter, you usually read about solid, liquid, and gaseous states. However, there are two additional states of matter. When matter becomes extremely hot, the positive and negative charges in the particles come apart and form an electrically charged gas. This state of matter is called plasma. When matter becomes extremely cold—very close to absolute zero—the small particles collapse and combine with one another to form another state of matter called a Bose-Einstein condensate.

Can you describe all of the forms of water that are shown in the photograph in Figure 5.6? The iceberg is made up of solid water. The ocean water is, of course, liquid water. The clouds in the sky are also liquid water. Clouds are made up of droplets of water that are so small that they do not fall to Earth. The presence of clouds indicates that there must also be water vapour in the air. Water vapour is the gaseous form of water. Three states of water—solid, liquid, and gas—are all present at the same time.

Did you know that water is the only substance that is naturally found in all three states at the same time on Earth? What causes some substances to be solid and others to be liquid or gaseous over the range of temperatures normally found on Earth? In this section, you will learn how to define solids, liquids, and gases. As well, you will learn how the particles of a substance cause them to be solids, liquids, or gases. Then, you will find out how changes in temperature affect matter in the three different states.

5-2A Is It a Solid, Liquid, or Gas?

Find Out ACTIVITY

You will analyze some objects and substances and classify them as solids, as liquids, or as gases. Then, you will discuss any uncertainties with the class.

Materials

- rock
- marshmallow
- a square of gelatin dessert
- glass of milk
- whipped cream from an aerosol can
- jar with lid
- glass of water
- vegetable oil

Safety

Do not taste any of the objects that you are analyzing.

What to Do

1. Inspect each item and classify each one as a solid, liquid, or gas.
2. If you were not sure about any of the items, explain why you were unsure.
3. For each state of matter (solids, liquids, and gases) write the characteristics that allow you to classify an item as that particular state of matter.
4. As a class, discuss any problems you had in classifying the items or defining the characteristics of a particular state of matter.

What Did You Find Out?

1. Describe any difficulties you had in defining what makes something a solid, a liquid, or a gas.
2. Was there any object that the class could not agree on? If so, what was it?

Describing the States of Matter

When you look at the photographs in Figure 5.7, you can easily identify each one as a solid, a liquid, or a gas. However, if you were asked to describe what you mean by a solid, a liquid, or a gas without referring to a picture, would you be able to give clear descriptions?

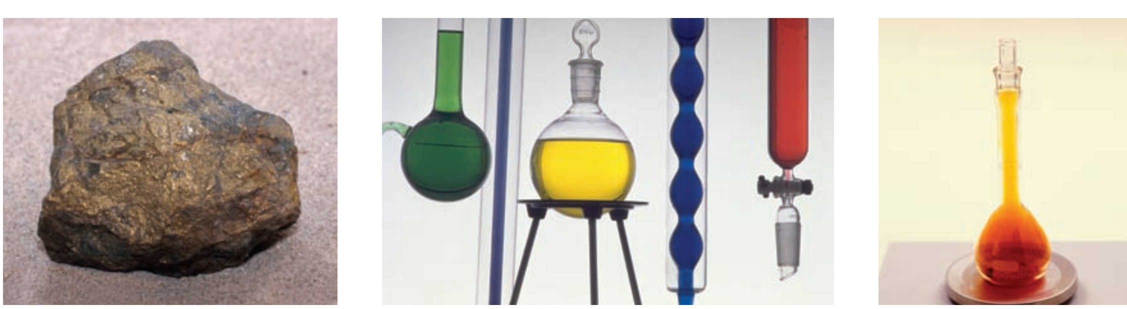


Figure 5.7 (A) You might have heard the expression, "solid as a rock." What do you think it means? (B) Does this photograph help you to describe the shape of a liquid? (C) Many gases are invisible but this gas has a reddish-brown colour.

Did You Know?

Scientists have found evidence to show that most of the giant planet, Jupiter, just below its cloudy surface, is made up of a strange substance. It is made up of liquid metallic hydrogen. At pressures of more than 4 000 000 times that of Earth's atmosphere, hydrogen not only flows like a liquid but also conducts electric current like a metal.

A **solid** is the form of matter that has a fixed shape. The shape of a solid will not change when you put it into a container or place it on a table. You might be able to break a solid such as the rock in Figure 5.7A by hitting it with a hammer. Then, you would just have smaller pieces of a solid. A solid also has a constant volume. You could try to press on it but its volume would not change. You might be able to change the shape of a solid such as bending a piece of plastic. You might be able to squeeze air bubbles out of something like a sponge, but you are not actually changing the volume of the solid itself.

A **liquid** has no shape of its own. When you pour a liquid into a container, it takes the shape of the container and forms a flat surface in the container. Figure 5.7B shows how the liquid takes on some interesting shapes. What are the shapes of the milk and juice containers in your refrigerator? Liquids also have an unchanging volume as long as the temperature does not change. You can exert pressure on the liquid but its volume will remain almost exactly the same. You might sometimes think you have compressed a liquid but you probably just squeezed out air bubbles.

A **gas** has no shape and no volume of its own. A gas takes the shape of any container and completely fills the container. The gas in Figure 5.7C has a reddish-brown colour so you can see that it fills the container. Gases can easily expand or contract to fit the volume of any container. Figure 5.8 summarizes the characteristics of solids, liquids, and gases.

solid state | liquid state | gas state

Figure 5.8 These definitions should help you identify the states of matter. Use these definitions to check your classifications in Find Out Activity 5-2A.

Solid
- A solid has a fixed shape.
- Its shape does not change to fit its container.

Liquid
- The shape of a liquid changes with the shape of its container.
- A liquid forms a surface inside its container.

Gas
- The shape of a gas changes with the shape of its container.
- A gas does not form a surface inside its container because it fills its container completely.

If you compared the amount of mass in a specific volume of a solid, a liquid, and a gas, what would you expect? For example, how would the masses of a litre of a gas, a liquid, and a solid compare? Since the amount of space between the particles of a gas is very large, the mass in a litre of gas would be very small. The amount of mass in a litre of a solid or a liquid is much larger than the mass in a litre of a gas when the temperature and pressure are the same. The mass in a litre of solids and liquids depends on the types of substances you are comparing. For example, a ball made up of solid lead would have much more mass than a ball made up of aluminum that is the same size.

The Particle Model and the States of Matter

The particle theory of matter might help you to understand why some substances are solids, others are liquids, and still others are gases under the same conditions. Examine Figure 5.9 to see how particles combine to make solids, liquids, and gases.

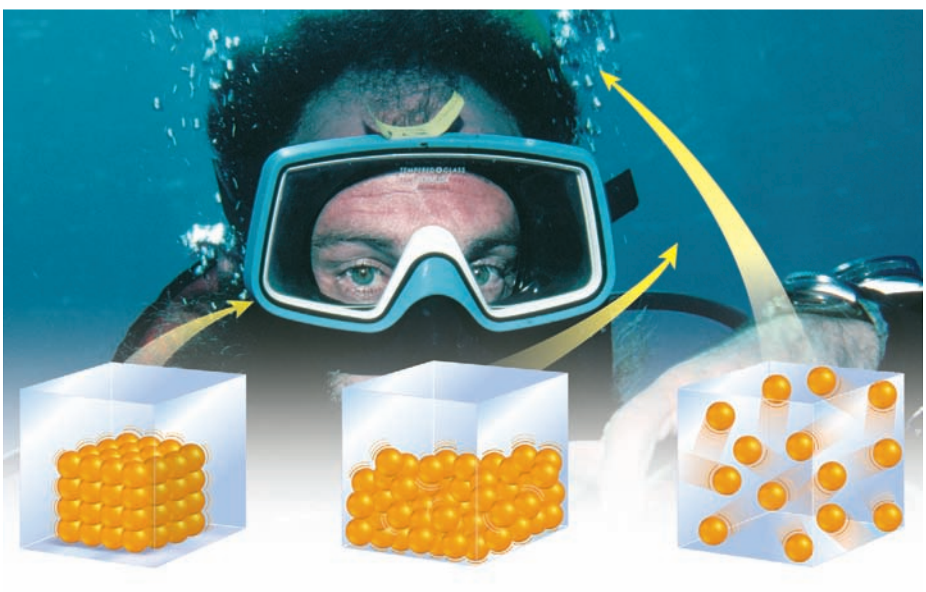


Figure 5.9 In solids, the particles are tightly packed. In liquids, the particles can slide around and past each other. In gases, the particles are very far apart. They collide with each other then bounce away.

In solids, particles are closely packed together. Each particle is attracted to the particles on each side by a strong force. The particles stay beside the neighbouring particles like children holdings hands (see Figure 5.10). The particles can move with small vibrations but they do not separate from the closest particles.

Figure 5.10 The children's hands held together represent the strong attractive forces that act between the particles in a solid. As long as they hold hands, the children can move around but they will always be holding hands with the same friends. The particles in a solid can move slightly but the forces will not allow particles to be separated from the particle beside it.

Figure 5.11 These square dancers are taking hands then letting go to take another hand. However, each person is always holding hands with someone as they move around the circle.

In liquids, particles are packed closely together and are attracted to each other by a force. However, particles can slide past each other and move around. You might picture the motion as similar to the square dancers in Figure 5.11. The dancers are constantly changing partners or moving past each other, but they are always holding hands with at least one other person.

In gases, the particles are not touching one another. There are large distances between them. The particles collide and bounce off the walls and off one another. The attractive forces between the particles are very small. You might compare particles in gases to children playing tag as shown in Figure 5.12. The children are running in all directions but are rarely touching each other.

Figure 5.12 When children play tag, they try to stay as far as possible from the child who is "it." They are each running in a different direction and never holding hands.

Did You Know?

If the amount of water that would fill this pitcher became a gas at standard atmospheric pressure, it would fill about four refrigerators.

Reading Check

1. (a) List two features of solids that help you to classify something as a solid.
   (b) List two features of liquids that help you to classify something as a liquid.
   (c) List two features of gases that help you to classify something as a gas.
2. Describe the arrangement of particles in a solid.
3. Explain one way in which the particles in a liquid differ from the particles in a solid.
4. Explain how children playing tag can make a good model for the particle theory of gases.

Expansion and Contraction of Matter

When you read about solids, liquids, and gases on page 146, you read that solids and liquids cannot be compressed. It is true that pressure has almost no affect on the volume of liquids and solids as long as the temperature stays the same. However, when you change their temperature, all forms of matter can expand and contract to some extent. In fact, many thermometers are based on the expansion of a liquid or solid with an increase in temperature as shown in Figure 5.13.

The term **thermal expansion** means that the volume of an object or substance increases when the temperature increases. When an object or substance cools, it contracts. That is, its volume decreases. The term **thermal contraction** applies to the reduction in volume with a decrease in temperature.

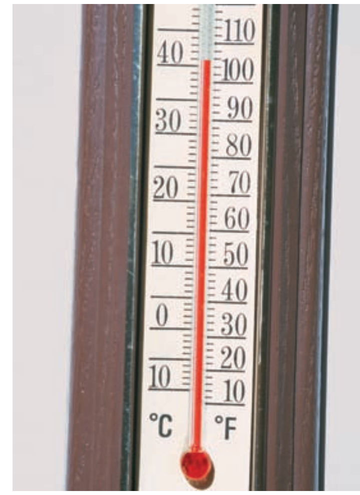


Figure 5.13 The red liquid in this thermometer expands when the temperature increases. It contracts when the temperature decreases.

Expansion, Contraction, and the Particle Theory

In Section 5.1, you read that the particles of an object or substance are always moving, so, they have kinetic energy. You also read that temperature is a measure of the average kinetic energy of the particles of a substance. If you add energy to a substance, or heat the substance, the kinetic energy of the particles increases. How does this increase in kinetic energy cause the substance to expand?

Figure 5.14 represents the particles of a gas (A) at a cool temperature and (B) at a warm temperature. The lengths of the arrows represent the speed of the particles. When the temperature of a gas increases and the kinetic energy of the particles increases, the particles collide with the walls of the container with a greater force. If the walls of the container are flexible, the increased force on the walls causes them to move out and the volume of the gas becomes greater.

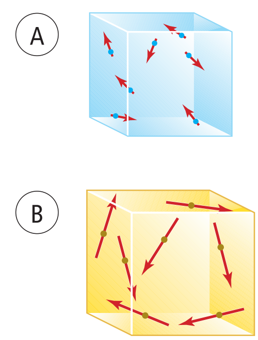


Figure 5.14 As the temperature rises and the kinetic energy of the gas particles increases, the particles collide with the walls with a greater force. This force causes the walls to move outward and the volume of the container increases.

A similar process occurs in liquids and in solids when the temperature of the substance increases. The particles move faster and collide with each other with a greater force. However, the attractive forces between the particles in liquids and solids prevent them from moving as far as the particles in gases move. Nevertheless, the particles collide with greater forces when they are at higher temperatures and particles push each other farther apart. As a result, the volumes increase somewhat.

Suggested Activity

Investigation 5-2B on page 151.

You might wonder how a particle in a solid can move more rapidly and with more energy but does not move away from the

Suggested Activity

Investigation 5-2C on page 152.

particles beside it when the temperature increases. You can imagine the particles in solids as being attached to each other by springs as shown in Figure 5.15. The springs represent the attractive forces between the particles. The particles can vibrate and stretch the springs, but the springs still prevent the particles from "letting go" of each other.

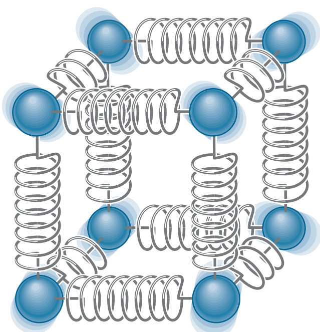


Figure 5.15 Particles are not really attached by springs, but the forces that hold them together cause the same effect that springs would cause.

The thermal expansion of solids is very small. For example, if you had a lead bar that was exactly 1.0000 m long at 0°C, it would expand to 1.0029 m long at 100°C. That is, the amount of expansion, or 0.0029 m, is about equal to the thickness of the cover of this textbook. This amount of expansion might not seem important, but for very large objects it can be critical. Engineers who design large buildings, bridges, and railroads must plan ahead for thermal expansion or the structures could be damaged. Figure 5.16 shows what can happen if railroad tracks are not designed to allow for thermal expansion. Correctly placed tracks have spaces between them as shown in Figure 5.16A. If the space is not large enough and the tracks expand on a very hot day, the tracks can bend as shown in Figure 5.16B. Bent tracks could cause a train to derail.

Suggested Activity

Investigation 5-2D on page 154.

Figure 5.16 (A) Notice the space between each piece of iron track. The space is necessary so that, when the track expands in the heat, the rails will not push on each other and cause bending. (B) This is what happens if not enough space was left between the pieces of track.

Reading Check

1. Define the term, *thermal expansion*.
2. How do the particles of a gas cause the volume of a container to increase when the temperature of the gas increases?
3. Describe a practical use for the expansion of liquids with an increase in temperature.

5-2B Bulging Balloons

Conduct an INVESTIGATION

SkillCheck
- Observing
- Predicting
- Controlling variables
- Evaluating information

Materials
- 2 identical balloons
- refrigerator or freezer
- hair dryer or electric heater

To observe the expansion and contraction of a gas, it must be in a flexible container. In this investigation, you will use balloons to "contain" a gas and observe any changes in the volume of the balloons.

Question
How can you demonstrate the effect that a change in temperature will have on a gas?

Prediction
Predict what will happen to a balloon that is cooled and to a balloon that is heated.

Procedure
1. Blow up both of the balloons several times to stretch them. Then, blow up both of the balloons to the same size and tie them so that no air can escape.
2. Put one balloon in the refrigerator or freezer to cool it. Leave the other balloon at room temperature.
3. Near the end of the class period, compare the size of the two balloons.
4. Warm the cold balloon by blowing warm air from a hair dryer over it or by holding it in the warm air from an electric heater. Continue to warm the balloon until it feels much warmer than room temperature.
5. Compare the size of the balloons.

Analyze
1. Describe what you observed using the words "expand" and "contract."
2. How well do your observations support your prediction? (completely, partially, or not at all)
3. Describe any differences between what you expected to happen and what did happen.
4. In this activity, one balloon is called the *control* and the other is called the *test*. Which is which? Why?

Conclude and Apply
5. At which point in this activity were the air particles in one balloon the farthest apart? When were they the closest together?
6. Describe another situation in which you are able to observe the expansion and contraction of a gas.

5-2C Race for the Top

Skill Check

- Observing
- Predicting
- Controlling variables
- Evaluating information

Safety

- Ethanol is poisonous. Be careful to wipe up any spills.
- Be careful when handling hot water.

Materials

- 3 liquids (coloured water, ethanol, and cooking oil)
- 3 large test tubes
- 3 one-hole stoppers with 50 cm pieces of glass tubing inserted
- laboratory stand and clamps
- rubber bands
- markers
- 2 large tin cans or 500 mL beakers
- very hot water
- ice-cold water

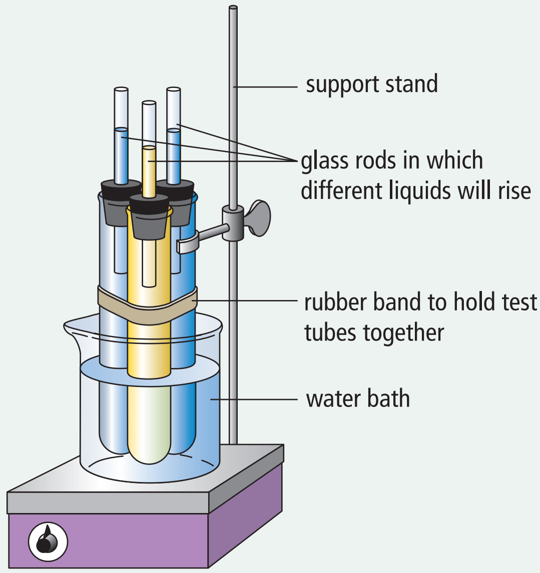
You already know that liquids expand when heated. You have used laboratory thermometers that can measure temperature because the liquid expands by a known amount. Thermometers are calibrated so that the degree marks match the amount of increase in the volume of the liquid when the temperature increases by one degree. Do all liquids behave in exactly the same way? (Your teacher may choose to demonstrate some or all of the steps for you.)

Question

Do all liquids expand by the same amount when they are heated?

Hypothesis

Make a hypothesis about the expansion of different liquids when they are heated to the same temperatures.



Procedure

1. Completely fill one test tube with coloured water, the second with ethanol, and the third test tube with cooking oil. Insert a stopper in each test tube so that there are no air bubbles and the liquid rises a few centimetres up the glass tubing.
2. Hold the test tubes together with the rubber band so that the liquids are at the same level in the glass tubing.
3. Arrange the apparatus as shown in the diagram.
4. Use the markers to mark the starting height of each liquid on the glass tubing.

Inquiry Focus

5. Pour the hot water into the beaker around the test tubes. Watch the heights of the liquids closely as the liquids warm.
6. Before the liquids overflow the glass tubes, lift the apparatus out of the hot water and put it into the ice-cold water.
7. Continue to watch the height of the liquids as they cool.

Analyze

1. Did all of the liquids expand by the same amount as they warmed? If not, answer the following questions.
   (a) Which liquid expanded the most?
   (b) Did the liquid that expanded the most as it warmed also contract the most as it cooled?
2. At the end of the activity, did the liquids return to their original heights in the tubes? Did you expect them to do so? Explain.

Conclude and Apply

3. Based on your observations, do all liquids expand and contract the same amount when they are heated and cooled?
4. Explain which of the liquids that you tested would be most suitable for making a thermometer that could be used to
   (a) show small changes in temperature clearly
   (b) measure large changes in temperature without the thermometer being too large
   Explain the reasoning for your answers to (a) and (b).
5. Examine the laboratory thermometer and the home thermometer below. Have you noticed that all liquid thermometers have a large bulb of liquid at the bottom?
   (a) What do you think is the purpose of the bulb of liquid?
   (b) What part of your apparatus performs the same function as the bulb on thermometers?
   (c) Why do you think that the diameter of the tube in which the liquid rises affects the accuracy of the thermometer?

5-2D Expanding Solids

Skill Check

- Observing
- Measuring
- Evaluating information
- Explaining systems

Materials

- long copper or iron wire
- small mass with a hook (200 g or 500 g)
- metre stick
- ball and ring apparatus
- laboratory burner
- candles
- matches
- cold water

Changes in the size of solids are so small that you usually cannot see them. In this investigation, you will observe two special situations that allow you to see the effects of the expansion and contraction of solids.

Question

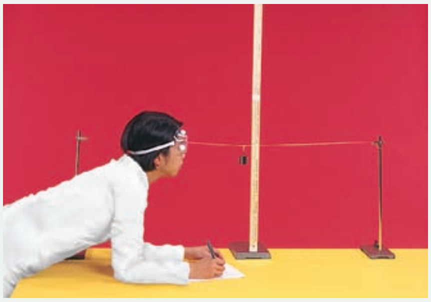
What evidence can you observe of solid materials expanding as they are warmed?

Safety

- Be careful working with an open flame and hot objects.

Part 1

The Sagging Wire



Procedure

Time of Heating or Cooling	Height of Mass Above the Table

1. Prepare a table like the one on the left for recording your data. Make at least 12 rows.
2. Stretch the wire tightly between firm supports. Place the small mass in the middle of the wire. Put the metre stick behind the mass and record its height.
3. Light the candles and use them to warm the entire length of the wire for several minutes. As you do, observe and carefully record the height of the mass after each 30 s of heating.
4. Stop warming the wire. Observe and record what happens to the height of the mass during the next 2 or 3 min.

Analyze

1. (a) If the wire sags, the mass moves down. Does this mean that the wire is getting longer or shorter?

   (b) What is happening to the length of the wire if the mass moves up?
2. If the wire sags, are its particles getting farther apart or closer together? Explain why they would do this. (Hint: Think about their motion.)

Problem-Solving Focus

Part 2

Your teacher will do the heating in Part 2 as a demonstration.

The Ball and Ring

1. Observe whether the brass ball fits through the brass ring when both the ball and the ring are at room temperature.
2. Warm only the ring in a hot flame for 30 s. Does the ball fit through the ring when only the ring is heated?
3. Allow the ring to cool.
4. Heat only the ball for 30 s in a hot flame. Does the ball fit through the ring when only the ball is heated?
5. Heat both the ring and the ball. Does the ball fit through the ring when both the ball and the ring are heated?
6. After the ball and ring have both cooled, test once more whether the ball will fit through the ring.

Analyze

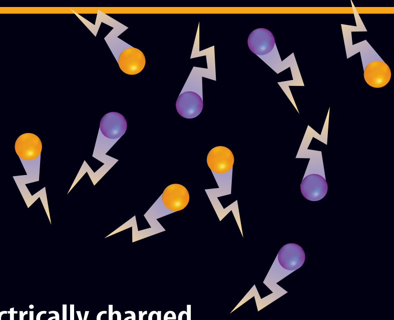
1. As a class, brainstorm possible reasons that can explain your observations. If possible, propose an experiment that will test your ideas.

Conclude and Apply

2. How did the demonstration give evidence that solids can expand? Explain what you did to cause the expansion and which part of the apparatus (the ball, the ring, or both) expanded.
3. Explain precisely what you think happens to the particles that make up the apparatus when the ball and ring are heated. How does this change in the individual particles, due to heating, bring about a change in the overall structure of the ball and ring? How does the change in the structures cause the outcomes that you observed when testing whether the ball would fit through the ring?
4. What do you think happens to the particles when the apparatus is cooled?

VISUALIZING STATES OF MATTER

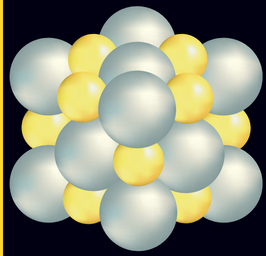
NATIONAL GEOGRAPHIC

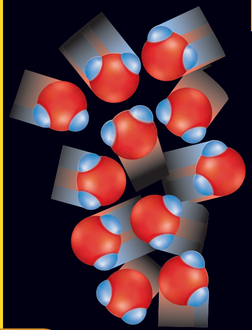


Matter on Earth exists naturally in four different states—solid, liquid, gas, and plasma—as shown here. The state of a sample of matter depends upon the amount of energy its particles possess. The more energy that matter contains, the more freely its particles move, because they are able to overcome the attractive forces that tend to hold them together.

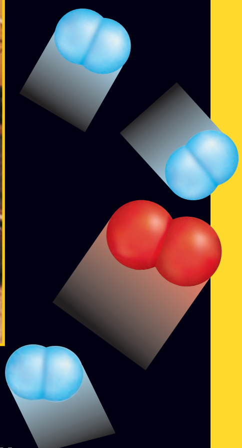
D PLASMA Electrically charged particles in lightning are free moving.

A SOLID In a solid such as galena, the tightly packed particles lack the energy to move out of position.





B LIQUID The particles in a liquid such as water have enough energy to overcome some attractive forces and move over and around one another.



C GAS In air and other gases, particles have sufficient energy to separate from each other completely and move in all directions.

Checking Concepts

1. How are the three states of water unique when compared to other substances?
2. State one way in which solids and liquids are similar and one way in which solids and liquids are different.
3. State one way in which liquids and gases are similar and one way in which liquids and gases are different.
4. According to the particle theory of matter, why can the particles of a liquid slide past one another but the particles of a solid cannot? Why must the particles of a solid remain beside each other?
5. Compare the attractive forces among the particles of gases, liquids, and solids.
6. Compare the thermal expansion of gases to the thermal expansion of solids and liquids. How are they similar and how do they differ?
7. Explain how a solid can expand while the individual particles in the solid always remain beside the same particles.
8. Give one reason why it is important for engineers who design buildings and bridges to understand thermal expansion and thermal contraction of materials.

Pause and Reflect

On the road surface of bridges, you often see structures like the one in the photograph on the right. Why do you think these structures are built into the roadways of bridges? Predict whether this photograph was taken in the winter or in the summer. Explain your reasoning.

Understanding Key Ideas

9. Describe how you would use Styrofoam™ balls to model the three states of matter. Use sketches if you would like to.
10. A metal lid on a jar is stuck on very tight. Use the particle theory to explain whether heating or cooling the lid would make it easier to remove the lid.
11. Imagine that you were given a balloon and a bottle. Design an activity that would demonstrate the thermal expansion of gases.

5.3 Changes of State

The changes of state are melting, freezing, evaporation, condensation, sublimation, and deposition. Each pure substance has its own unique freezing point and boiling point. The strength of the attractive force among particles determines the freezing and boiling points of a pure substance.

Key Terms

boiling point
change of state
condensation
deposition
evaporation
freezing
heating curve
melting
melting point
sublimation

Have you ever heard a car owner talk about "winterizing" the car? To winterize a car simply means to prepare it for winter. One of the most important things to do is to be sure that the water in the radiator will not freeze. The water circulates through the engine to keep it cool while the engine is running. When the car is not running, however, the water in the radiator will become as cold as the outdoor temperature. If the water freezes, it will crack the radiator and possibly even the engine. The repair is very expensive. Therefore, car owners add antifreeze to the water in the radiator as shown in Figure 5.17. The car owner or auto mechanic can also check the antifreeze (Figure 5.17B) to see how cold the weather can become before the coolant will freeze.

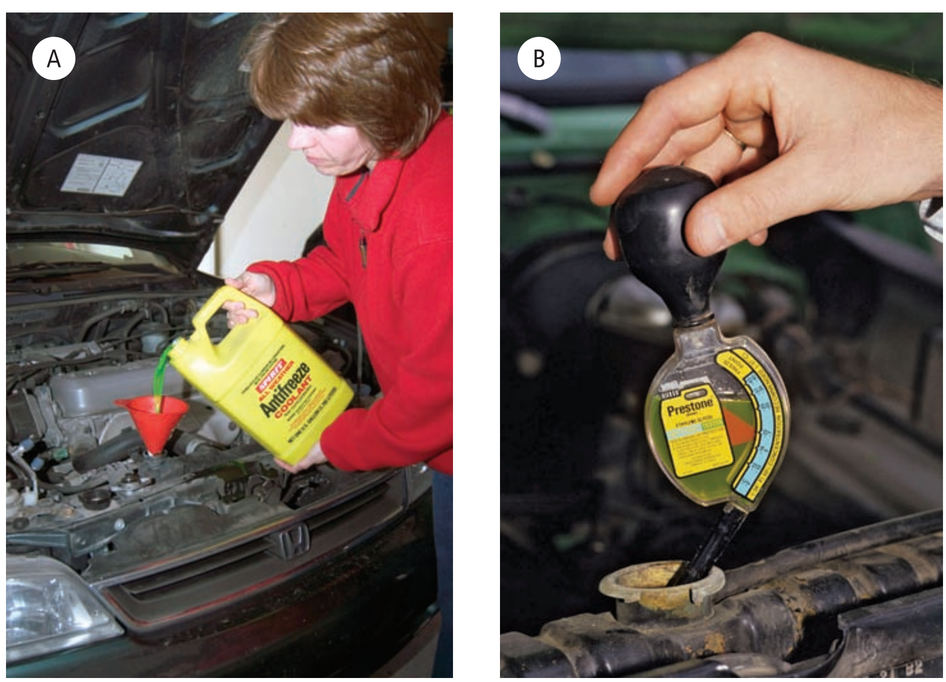


Figure 5.17 (A) The car owner is adding antifreeze to the car radiator. (B) To test the coolant, you squeeze the bulb then put the end into the coolant and release the bulb, drawing coolant into the tester. The dial will tell you the lowest temperature at which the coolant will still be liquid.

Did You Know?

Antifreeze contains ethylene glycol, which is very toxic to animals and people. It also has a sweet taste, which will tempt animals to lick up spilled antifreeze. Car owners should be extremely careful about cleaning up spills and carefully storing antifreeze. Also, humane societies are urging governments to pass laws to make manufacturers add a bitter tasting chemical to antifreeze to prevent animals from drinking it.

5-3A How Low Can It Go?

The instrument shown here is called a sling psychrometer. It has two thermometers, a dry bulb and a wet bulb thermometer. The technician using it, wets the cloth around the bulb of the wet bulb thermometer, holds it by the handle, swings it around rapidly, and then quickly reads the temperature on both thermometers. The motion causes the moisture in the cloth to evaporate at the maximum rate. The difference in the readings of the dry bulb and wet bulb thermometers allows the technician to calculate the relative humidity and the dew point.

In this Activity, you will observe the effects of evaporation of two different liquids on the temperature reading of a wet bulb thermometer. You will not swing the thermometers around but instead you will use an electric fan to increase the rate of evaporation. You might be surprised to discover how evaporation affects the temperature of an object. Try it and see.

Materials

- laboratory thermometer
- electric fan
- 2 strips of cloth or paper towel
- room-temperature water
- room-temperature alcohol

Safety

Pure alcohols are harmful to the body. Do not taste these chemicals and do not breathe in their vapours. Do not use alcohols near open flames as the alcohol vapours may catch fire or explode.

What to Do

1. Measure and record the temperature of the liquid water and alcohol.
2. Wrap the cloth strip around the thermometer bulb and soak it in the water. Hold the thermometer near the fan to speed up evaporation from the wet cloth. Record the temperature every 30 s until it stops changing.
3. Repeat step 2 using a second cloth strip and alcohol.
4. To compare your observations for the two liquids, draw a graph with temperature on the vertical axis and time on the horizontal axis. Plot both sets of data on the same graph.

What Did You Find Out?

1. In which liquid were the particles evaporating faster? How do you know?
2. Which of the two cloths would take longer to dry completely? What would happen to the temperature of the cloth after all of the liquid had evaporated?
3. In which liquid do you suppose the particles have a stronger attraction for one another? Why do you think so?

Science Skills

Go to Science Skill 1 for help with graphing.

Figure 5.18 You often see moisture on the outside of a glass of ice water. Why do you *not* see this on a glass or cup of a hot drink?

Describing Changes of State

A glass of ice water or other iced drink, like the one in Figure 5.18, is a common sight. You put ice in the drink to cool it. As the ice melts, the drink becomes cooler. Often, water vapour from the air condenses on the outside of the glass.

The melting of ice and the condensing of water vapour are called changes of the state of water. All substances can exist as solids, liquids, or gases. The gaseous form of water is often called vapour. However, for most substances, scientists use the term "gaseous state" instead of vapour. The change from any of the three states to any other state is called a **change of state.** Each change of state has a specific term that describes that change.

- **Melting** is the change from the solid state to the liquid state.
- **Freezing** is the change from the liquid state to the solid state.
- **Evaporation** is the change from the liquid state to the gaseous state.
- **Condensation** is the change from the gaseous state to the liquid state.
- **Sublimation** is the change from the solid state to the gaseous state.
- **Deposition** is the change from the gaseous state to the solid state.

These definitions are summarized in Figure 5.19.

Suggested Activity

Investigation 5-3C on page 166.

Connection

Section 7.1 has information on pure substances.

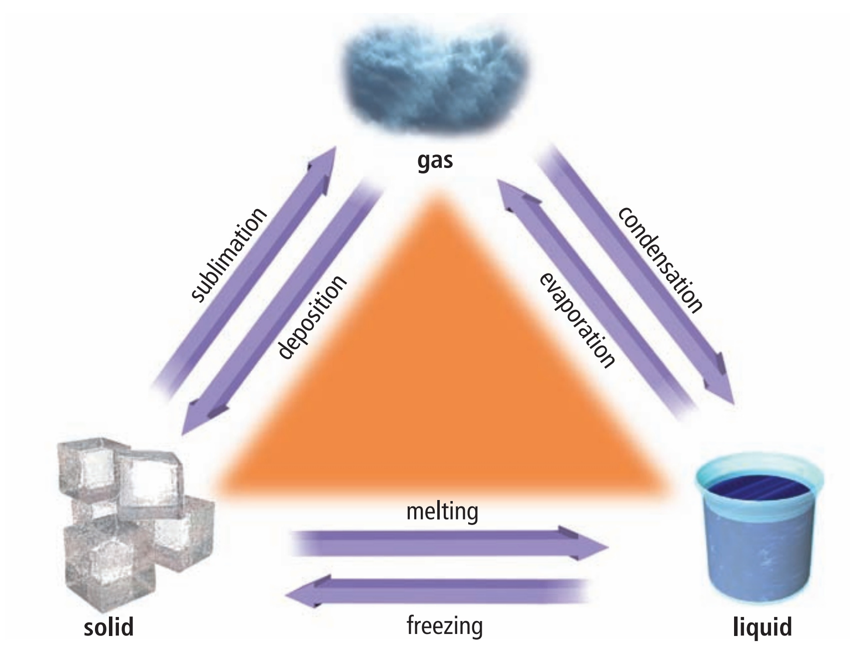


Figure 5.19 This diagram summarizes all of the changes of state.

Before you read the last paragraph, did you know that substances could go from the solid state directly to the gaseous state, or sublime? You might not have realized it but you have probably seen evidence of sublimation before. The substance that is called dry ice is really solid carbon dioxide. It is extremely cold, so you should never handle it with your bare hands. Your skin would freeze in just a few seconds. However, dry ice is often used for special effects in plays or at parties.

Under standard conditions, dry ice does not melt but it sublimes directly into carbon dioxide gas. If you put it in water, it looks as though the water is boiling. However, the dry ice is turning into gaseous carbon dioxide under water and making bubbles.

You might have seen effects such as those shown in Figure 5.20. The effects are created with dry ice, but the foggy substance that you see is not carbon dioxide gas. Carbon dioxide gas is colourless and, therefore, invisible. However, the carbon dioxide gas cools the air so much that water vapour in the air condenses to form the fog.

Figure 5.20 This halloween pumpkin looks like steam is coming from its mouth. Actually, there is dry ice inside the pumpkin. As the dry ice sublimes, it cools the air and causes water vapour to condense.

Melting Points and Boiling Points

You usually think of metals such as tin and lead as being solids. As well, you probably think of oxygen and nitrogen as being gases. These are the states in which you find these substances at room temperature. Nevertheless, if you heat tin and lead to very high temperatures, they will become liquids and then gases. If you cool oxygen and nitrogen to very low temperatures, they will become liquids and then solids.

Most pure substances have specific temperatures at which they melt and boil. The temperature at which a substance changes from a solid to a liquid is called its **melting point.** The temperature at which a substance changes from a liquid to a gas is called its **boiling point.** Table 5.1 lists some melting and boiling points for a few common substances. Remember, below its melting point, a substance is solid. At temperatures between its melting point and boiling point, a substance is a liquid. Above its boiling point, the substance is a gas.

Did You Know?

Water is a unique substance. The boiling point (100°C) and the melting point (0°C) of water are much higher than those of nearly all other substances that have particles about the same size as water particles. What does this information tell you about the attractive forces that hold particles of water together?

Table 5.1 Melting Points and Boiling Points of a few Pure Substances

Substance	Melting Point (°C)	Boiling Point (°C)
Oxygen	–219	–183
Nitrogen	–210	–196
Rubbing alcohol	–88	82
Mercury	–39	357
Water	0	100
Sulfur	115	445
Tin	232	2602
Lead	328	1740
Aluminum	660	2519
Table salt	801	1413
Silver	962	2162
Gold	1064	2856
Iron	1535	2861

5-3B State the State

Think About It

Different pure substances have different melting and boiling points. Scientists measured and used these temperatures to identify substances long before they could explain the differences. You can probably guess that modern explanations involve the strength of the forces that hold the tiniest particles of a substance together.

What to Do

Use the information in Table 5.1 to answer each of the following questions.

1. In what state (solid, liquid, or gas) would each substance be at the given temperature?
   (a) oxygen at –50°C
   (b) aluminum at 800°C
   (c) table salt at 800°C
   (d) gold at 3000°C
   (e) iron at 2000°C
2. What change of state, if any, would each substance go through during the given temperature change?
   (a) mercury cooling from –10°C to –45°C
   (b) silver cooling from 1000°C to 950°C
   (c) tin warming from 2200°C to 2300°C
   (d) mercury warming from 300°C to 350°C
   (e) iron cooling from 1600°C to 1500°C

What Did You Find Out?

Compare the melting points of aluminum and tin. Which metal do you suppose has stronger forces holding its particles together? Explain your reasoning.

Reading Check

1. What is another name for water vapour?
2. What change of state is opposite to:
   (a) evaporation
   (b) melting
   (c) deposition
3. Define the term, *boiling point*.
4. At what temperature does sulfur boil?

Changes of State and the Particle Theory

In a solid substance, the particles are held tightly together. As you saw in Figure 5.15 on page 150, the particles have kinetic energy, so they vibrate. However, they remain attached to each other by forces that are represented by springs. As you add more energy in the form of heat, the kinetic energy of the particles increases and the temperature increases. Eventually, you reach a temperature at which the kinetic energy of the particles is great enough to break the attractive forces, or springs, that are holding the particles together (see Figure 5.21). This temperature is the melting point of the substance. As the particles break away from one another and have enough energy to slide past each other, the substance becomes a liquid.

As a liquid is heated, the particles gain kinetic energy. Eventually, many particles have enough energy to break away from the attractive forces of the other particles and escape from the surface of the liquid as shown in Figure 5.22. These high-energy particles are now in the gaseous state.

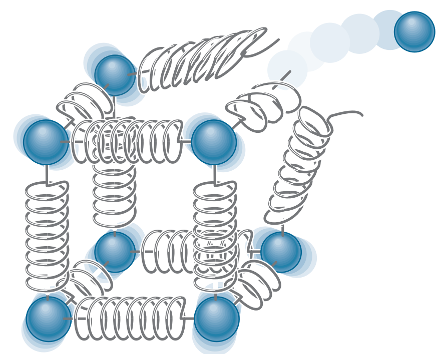


Figure 5.21 The forces that hold particles together in the solid state are quite strong. Nevertheless, particles can gain enough kinetic energy to break away from their neighbouring particles.

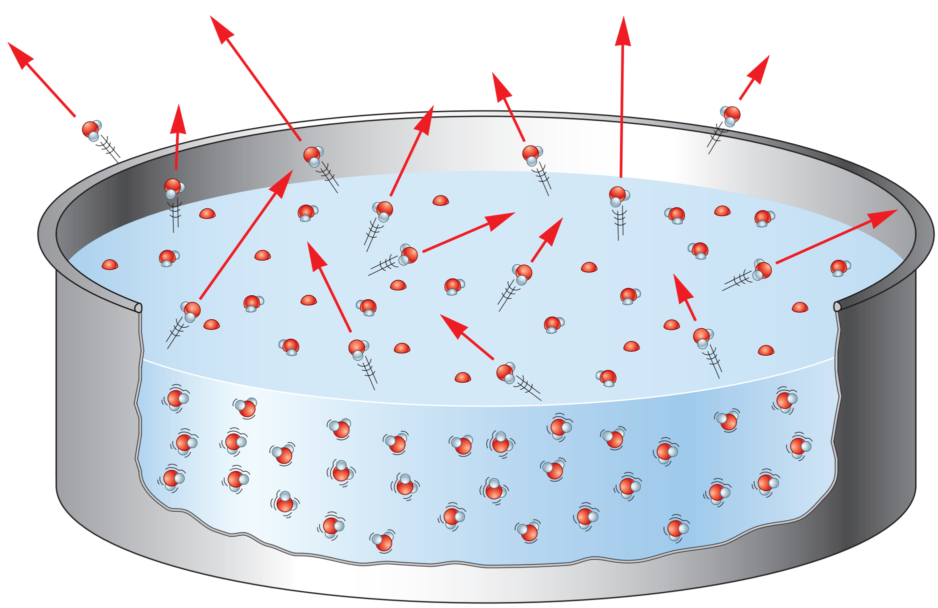


Figure 5.22 This diagram models the activity of particles as a substance evaporates (that is, as it changes from the liquid state to the gaseous state).

Did You Know?

Nearly all substances contract when they freeze, or change their state from a liquid to a solid. Water, however, expands when liquid water freezes and becomes ice. That is the reason that ice floats on water instead of sinking.

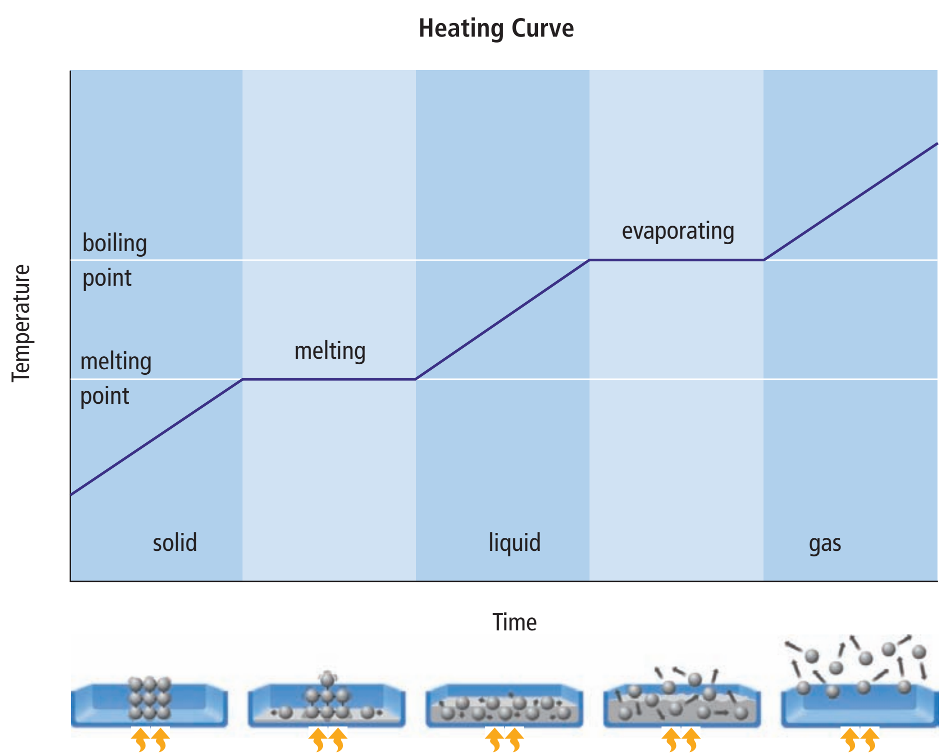
Why do different substances have such different melting points and boiling points? The melting point and boiling point of a substance depend on the strength of the attractive forces holding the particles together. If the forces are very strong, large amounts of energy are needed for a particle to break away from its neighbouring particles.

In order for the particles of a substance to have large amounts of energy, the temperature must be high. Therefore, the particles of substances that have high melting points and boiling points have very strong forces holding the particles together. For example, the melting point of table salt is 801°C while the melting point of sulfur is 115°C. Therefore, the attractive forces holding particles of table salt together are much stronger than the attractive forces between particles of sulfur.

Heating Curves

You can summarize the processes of changing states by using a heating curve. A **heating curve** is a plot of temperature and time. Energy is continuously being added to the substance. In Figure 5.23, a heating curve is drawn above diagrams that show what is happening during the various periods of time as energy is continuously being added to a substance.

Figure 5.23 The diagrams below the graph show how the particle theory explains what is happening as heat is being added to a substance during a period of time. The yellow arrows indicate that heat is entering the container.



To understand the heating curve, follow it from the time that the heating began on the left, to the end of the process on the right. The particles representing a solid are in a container that is being heated. The yellow arrows at the bottom of the container represent heat entering the system. When the process begins, the object is in its solid state and the temperature is low. As heat is added to the object, its temperature rises because the heat is giving the particles more kinetic energy. When the temperature reaches the object's melting point, the energy going into the object gives the particles enough energy to break away and start forming a liquid. Notice that the temperature stops going up for a while. During this time, all of the heat entering the object is used to overcome the attractive forces holding the particles together. They are not gaining kinetic energy. Eventually, the entire object has melted and is a liquid.

Now the heat that is entering the object gives the liquid particles more kinetic energy and the temperature rises again. A similar situation occurs when the liquid reaches its boiling point. Once again, the temperature stops going up for a while. All of the energy going into the liquid is used by the particles to break away from the liquid and go into the gaseous state. Finally, when all of the liquid has evaporated, heat entering the system increases the kinetic energy of the gas particles. The temperature once again rises.

Did You Know?

Some species of bacteria are able to live in water temperatures of 90°C and in water as acidic as vinegar.

Reading Check

1. What condition must occur for a solid to start melting?
2. Describe evaporation using the particle theory of matter.
3. Explain how heat can be added to a substance but the temperature of the substance remains the same.

Did You Know?

The white trails behind jet planes in the sky are often called jet trails. The correct term is contrail because they are a result of the condensation of water in the exhaust of the jet engines. The jet plane's exhaust is very hot and contains a lot of water vapour. When the hot vapour mixes with the cold air at these high altitudes, it condenses and forms a contrail.

5-3C The Plateau Problem

Core Lab

Skill Check

- Observing
- Controlling variables
- Graphing
- Working co-operatively

Safety

- Use oven mitts, hot pads, or tongs to handle the beaker of boiling water.
- Unplug the hot plate at the end of the investigation and let it cool before putting it away.

Materials

- 2 laboratory thermometers
- stirring rod
- hot plate
- kettle
- 2 beakers (250 mL)
- clock or watch
- crushed ice
- ice-cold water
- hot water (almost boiling)

Puddles of liquid water on the road can freeze on a wintry night but this does not happen instantly. Water boiling in a kettle is turning into water vapour but this takes time. What is happening while the water is changing state?

Question

What happens to the temperature of water while it changes state?

Hypothesis

Think about familiar situations in which ice is melting or liquid water is boiling. Then, form two hypotheses by completing the following two statements. Add reasons for your hypotheses.

(a) While water melts from solid ice to liquid water, the temperature will (drop/stay the same/increase), because…

(b) While water boils from a liquid to a gas, the temperature will (drop/stay the same/increase), because…

Procedure

1. Prepare a table for data like the one shown here. You will need space for at least five observations (more if time permits).

Time (min)	Temperature of Melting Ice (°C)	Temperature of Boiling Water (°C)

2. Fill one beaker with hot water from the kettle and put it on the hot plate to boil.
3. In the other beaker, make a slush of crushed ice and a little cold water.
4. With a stirring rod, stir the contents of each beaker for several seconds. Then, measure and record the temperature. Lift the thermometer off the bottom of the beaker to ensure that you are measuring the temperature of the contents and not the container.

5. Repeat the temperature measurements every 3 min. For a fair test, make sure that you stir and measure exactly the same way each time. Record each result.
6. Stop heating the boiling water *before* it all boils away. Unplug the hot plate, and carefully set aside the hot beaker to cool.

Analyze

1. In this activity, you measured time and temperature.
   (a) What was your dependent variable? (Which value was unknown until after you made an observation?)
   (b) What was your independent variable? (What value did you select before making an observation?)
2. Draw two line graphs to show your temperature–time observations: one for the melting ice and one for the boiling water. Instead of joining the points dot-to-dot, draw a smooth line or curve that passes through or between the points (a best-fit line).
3. On your hot-water graph, mark the part where
   (a) the water was hot but not yet boiling
   (b) the hot water was boiling vigorously (called a "full rolling boil" in cooking)
4. Label any plateaus (flat, horizontal segments) on your graph.
5. Compare the temperature of your melting slush with the "official" temperature you saw in Chapter 4.
   (a) If the two temperatures are almost the same, any small differences might be caused by errors in your equipment or measurements. Suggest at least two specific errors of this sort that might occur.
   (b) If the two temperatures are quite different, the conditions in your laboratory or your sample might be responsible. Suggest at least two specific conditions that might cause this type of error.
6. Imagine that you combined both parts of this investigation. Sketch a third graph that shows what would probably happen if you heated one sample from ice to water and then to water vapour.
7. On the temperature scale of your third graph, mark the melting point and the boiling point of your samples, according to your observations.
8. Combine all the results from your class to find the average melting point and the average boiling point for water. Are they closer to the expected values than your individual group values? If they are closer, explain why.

Conclude and Apply

9. From your observations, write a clear answer to the question at the beginning of this investigation.
10. How well do your observations support your hypothesis?
11. (a) Identify any problems you had with the apparatus, procedure, or the way that you organized and worked together in your group.
    (b) Describe one improvement that your group could make the next time you work together.

Wild, Weird, Wonderful

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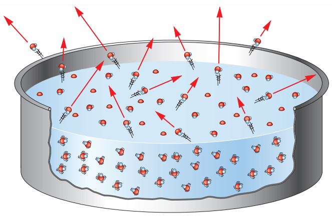


Evaporative Cooling

When you are playing a sport or doing hard physical work, you usually sweat a lot. Is sweating just annoying or is it doing something useful for your body? Actually, sweating helps cool your body. The process is called evaporative cooling.

Review the process of evaporation by analyzing the illustration in Figure 5.22 shown on page 163. Recall that the kinetic energies of the individual particles in a substance such as liquid water are all different. Even when water is well below the boiling point, some of the particles have a large amount of kinetic energy. These particles can escape from the liquid water. What happens to the average kinetic energy of the particles remaining in the liquid state? The following calculation will help you answer the question.

Before Evaporation

Kinetic energy of particles:

1.13 J 0.87 J 0.94 J
0.99 J 0.91 J 0.88 J
0.78 J 0.82 J 0.73 J
0.85 J 1.28 J 0.94 J
1.34 J 1.02 J 0.97 J

Average kinetic energy: 0.96 J

After Evaporation

The four particles with the most kinetic energy evaporate.

Kinetic energies of remaining particles:

0.99 J 0.91 J 0.73 J
0.78 J 0.82 J 0.94 J
0.85 J 0.94 J 0.97 J
0.87 J 0.88 J

Average kinetic energy of particles remaining: 0.88 J

The average kinetic energy of the particles remaining after the most energetic particles evaporated is lower than it was before the particles evaporated. Therefore, the temperature of the remaining liquid is lower—it is cooler!

Evaporative cooling is very effective and useful. Sweating makes you cooler. Not all animals sweat but they have other ways to make water evaporate from their bodies. You have probably seen dogs panting with their tongues hanging out. Evaporation from their tongue and their breath cools them.

Some animals lick themselves and the moisture they leave on their skin or fur evaporates and cools them. The wood stork, shown here, and the black vulture urinate on their legs. The evaporation of their urine cools their legs and cools the blood flowing just under their skin.

Elephants spray water on their bodies.

Check Your Understanding

Checking Concepts

1. Explain the meaning of the phrase "change of state."
2. How does sublimation differ from evaporation?
3. Refer to Table 5.1 to answer the following questions.
   (a) What is the state of nitrogen at –200°C?
   (b) In what state is rubbing alcohol at 90°C?
   (c) In what temperature range is tin a liquid?
4. Use the particle theory to explain melting.
5. How does the particle theory explain why different substances have different melting and boiling points?
6. What is a heating curve?

For question 8

Understanding Key Ideas

7. People often put salt on icy sidewalks or roadways. Give a possible explanation for why salt might cause ice to melt.
8. When you are holding a cold glass of water or other cold drink, the outside of the glass often becomes wet. Where did the liquid water come from?
9. Compare the strengths of the attractive forces between the particles of water and between particles of table salt.
10. A cooling curve is the opposite of a heating curve. When you start making observations, the substance is a gas and the temperature is warm. The substance loses energy, or cools, over a period of time. Sketch a cooling curve for rubbing alcohol. (Hint: the boiling point for rubbing alcohol is 82°C and the melting point is –88°C.)
11. When a liquid is heated, why do all the particles not break away and become gaseous at the same time?

Pause and Reflect

In the introduction to this section, you read about car owners adding antifreeze to the coolant in the radiators of their cars. Explain how you think that antifreeze prevents the coolant in a car from freezing.

Chapter Review

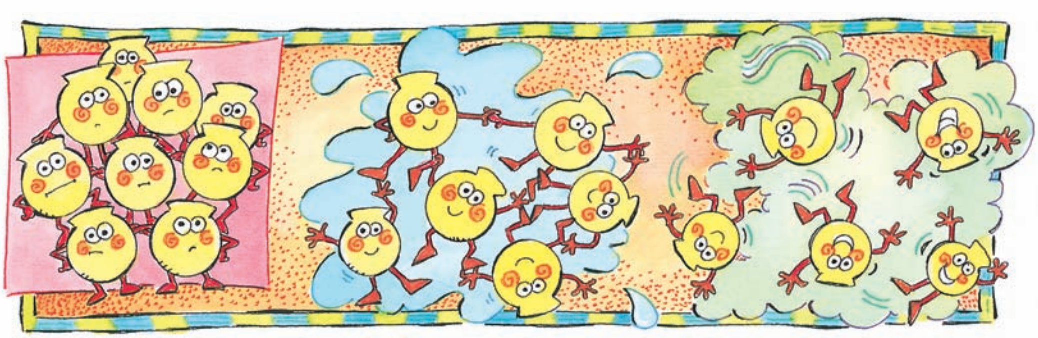
Prepare Your Own Summary

In this chapter, you investigated the particle theory of matter and the states of matter. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 9 for help with using graphic organizers.) Use the following headings to organize your notes:

1. The Particle Theory of Matter
2. Temperature and the Kinetic Energy of Particles
3. States of Matter
4. Expansion and Contraction of Matter
5. Changes of State
6. Melting Points and Boiling Points

Checking Concepts

1. In order for an object to have kinetic energy, it must be doing what?
2. What is a measure of the average kinetic energy of the particles that make up an object or a substance?
3. Explain how you can decide whether a substance is a solid, a liquid, or a gas.
4. Make a sketch to show how the particle theory can account for the three common states of matter. Explain your sketch.
5. How does an increase in the temperature of an object affect its volume? Which state of matter is affected the most?
6. How does the particle theory of matter explain the ability of a liquid to flow?
7. Name the following changes of state.
   (a) from a liquid to a solid
   (b) from a solid to a gas
   (c) from a gas to a liquid
8. How does the particle theory of matter explain evaporation?
9. What can you say about the forces among the particles of a pure substance if the melting temperature is –40°C?
10. What is happening to the temperature of a pure substance while it is melting?
11. The figure below can be used as a model to represent some concepts that you learned about in this chapter.
    (a) These figures are models for what concepts?
    (b) Explain how each part of the figure models the concept.
    (c) Are there any changes that you would suggest that would make the figure a better model? If so, what are those changes?



Understanding Key Ideas

12. Explain how Lego® blocks can be used to model the particle theory of matter.
13. If two golf balls are flying through the air, how can you tell which one has more kinetic energy?
14. Imagine you fall off a bicycle and your arm rubs against the ground. The injury is sometimes called a "burn." Explain why this could be a suitable description.
15. A classmate says that if something takes the shape of the container, it must be a liquid. How would you respond to that statement?
16. Mercury is the only metal that is a liquid at room temperature. All other metals are solids at room temperature. What can you say about the interactions among the particles of mercury when compared with the particles of other metals?
17. Imagine that you filled a glass to the very top with water directly from the refrigerator. You put it on the table and then answered the telephone. After a long conversation, you discover that there is water all around the glass on the table. Explain what happened.
18. Two drinking glasses are stuck together, one inside the other. Write a recommendation for a way to remove the outer glass without breaking either glass. Explain why your method works.
19. On a winter day, the wind blows briskly all day. At the end of the day, you notice that there is much less snow on your driveway than there was in the morning. However, you did not see any moisture on the pavement all day. Explain what happened to the snow.
20. If you wanted to heat a substance to 450°C, would you use a tin container or an aluminum container? Explain your reasoning.
21. Imagine that you put some eggs in a pot of water on the stove and turn it on to boil the eggs. Then, you go to your room to do homework. You were working so hard that you forgot that you had put the eggs on to boil. While you were doing homework, all the water boiled away and the eggs were badly burned. Explain why eggs do not burn when they are in boiling water but they do burn after the water boils away.

Pause and Reflect

Examine the photograph of the sidewalk shown here. Give a possible explanation why the sidewalk buckled and broke in this way.