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Heat is a form of energy that can be transformed and transferred. These processes can be explained using the particle theory of matter.

There are many sources of heat.

Heat has both positive and negative effects on the environment.
On the way home from a trip to Ottawa, Tara and her mom, Gatleen, stopped in Brockville to visit some friends. Their friends, the Narangs, were building a new home. Soon after arriving at the apartment, Tara and Gatleen were ushered into the Narang family car and taken to the construction site. When they arrived, Tara was surprised by what she saw. On a patch of muddy ground was a framework of walls made entirely of pure white foam. There were none of the typical building materials that Tara had seen before on construction sites—no bricks, no cement blocks, and no wood frames. It looked as if the Narangs were going to live in a giant foam cooler!
Fascinated by what she saw, Tara watched as a construction worker built a wall. He stacked foam blocks, one on top of the other. The blocks were about the size of backpacks, and they were light enough for the worker to stack them with one hand. Tara wondered why the Narangs were building their home with such lightweight materials. Could such a house ever withstand strong wind, rain, and heavy snow?

The Narangs explained that the workers were using Polystyrene Block Form Construction to build the house. They said that this type of construction would help keep the house warm in the winter and cool in the summer. Mr. Narang explained that the blocks are hollow. They are filled with concrete once the wall is built.

Tara was not sure how the foam and concrete walls would help keep the Narangs’ house warm in winter and cool in summer. She did remember learning in science class that polystyrene is a plastic that may harm the environment. She asked the Narangs why they were using so much plastic in the construction of their home. The Narangs explained that the environmental benefits of using less fuel and electricity to heat and cool their home justified the use of the foam blocks in the walls. Tara thought about that, but was not convinced. How could having foam walls be so good for the environment? She planned to do some research on the Internet when she got home to find out if the Narangs were right.

**LINKING TO LITERACY**

**Asking Questions**
When you do not know the answer to something, you ask a question. The same is true for reading. But in reading, you end up answering most of the questions yourself. Questions can be asked before you start reading, while you are reading, or after you are finished reading.

1. Talk to a partner about the questions you had when you were reading about the Narangs’ new home.
   - Which questions were answered for you as you read more?
   - What questions do you still have?
   - Pick one question that you can do further research on to find the answer.
Feeling Cool

During this activity, you will explore the effect of heat on ice when the ice is placed on two different surfaces. You will then be asked to describe your observations in an expository paragraph. An expository paragraph is one that presents information, explains facts, or provides an opinion. This textbook contains many expository paragraphs. For example, see the paragraphs on page 10. The list of science terms on the right has been provided to help you write your paragraph.

**Equipment and Materials:** dry metal surface (metal kitchen sink); dry plastic surface (plastic countertop or plastic plate); 2 ice cubes

1. Place yourself so that a dry metal surface (for example, a metal kitchen sink) and a dry plastic surface (for example, a plastic countertop) are both within reach.

2. Touch your fingers to the metal surface and the plastic surface at the same time (Figure 1). Do they feel different?

3. Predict which ice cube will melt faster if you place one ice cube on the metal surface and another on the plastic surface at the same time. Using your observations from Step 2, state your prediction in the form of a hypothesis.

4. Test your prediction by placing one ice cube on the dry metal surface and the other ice cube on the dry plastic surface. Observe both ice cubes for 3 min, especially where the ice cubes touch the surfaces.

A. Describe what you felt in Step 2.

B. Brainstorm possible reasons why the two ice cubes melted at different rates.

C. Write an expository paragraph to describe your observations from Step 2, your hypothesis from Step 3, and your observations from Step 4.

D. Evaluate your hypothesis. Did your observations support your prediction, and your reasons for it?

E. Use what you have just discovered to predict whether hot chocolate will remain hot longer in a plastic cup or in a metal cup. Give reasons for your prediction.

**Science Terms**
- warm
- cold
- heat
- steel
- plastic
- conductor
- insulator
- temperature
- melt
Most living things need to stay warm in the winter and cool in the summer. Humans, in particular, control the transfer of energy to stay comfortable year round. As you progress through this unit, you will learn about different sources of energy and how we can control them.

The K-9 Doghouse Company is interested in building a new doghouse that it can sell to dog owners in Ontario. The company is holding a competition to come up with a new doghouse design. Specifically, the company is looking for a doghouse that will keep a dog comfortably warm outdoors during the winter and cool during the summer.

To enter the competition, you must build a prototype (scale model) of a doghouse. The prototype will be tested in hot and cold conditions to see how long the inside of the doghouse will stay at a comfortable temperature. The K-9 Doghouse Company would like the designers to present the prototype to its Board of Directors. The designers need to point out the pros and cons of their design, and convince the Board that the prototype deserves to be mass-produced.

**Unit Task** By the end of the Heat in the Environment unit, you will be able to demonstrate your learning by completing this Unit Task. As you work through the unit, continue to think about how you might meet this challenge. Read the detailed description of the Unit Task on page 82, and look for the Unit Task icon at the end of selected sections for hints related to the task.

**Assessment** You will be assessed on how well you

- identify several possible designs
- develop a plan for building a prototype based on one of your possible designs
- build a prototype based on one of your designs
- test your prototype and make modifications that improve its effectiveness
- use the concepts and terminology of the unit to communicate the development and testing of your prototype
Chapter 7 • Heating and Cooling

KEY QUESTION: How does heat affect matter?

Looking Ahead
- Heating and cooling are important in everyday natural and artificial processes.
- The particle theory explains heating and cooling.
- Heat is the transfer of energy from warmer substances to cooler substances.
- Most materials expand when they are heated and contract when they are cooled.
- Investigation skills can be used to learn about expansion and contraction of different materials.

VOCABULARY
- particle theory of matter
- heat
- kinetic energy
- temperature
- thermal energy
- thermal expansion
- thermal contraction
Warm and Cold

It is a freezing cold winter morning and I am waiting for a bus at a crowded bus stop. Although I am wearing thick wool gloves, my hands feel cold.

As I look around, I notice that people are pacing. I realize that everyone is breathing out puffs of white mist. Why does this happen in the winter, but not in the summer? As the bus arrives, I notice that the windows are frosted and white smoke is coming out of the bus’ exhaust pipe. I wonder what the white smoke is made of, and what it could be doing to the environment.

I start to feel warm as soon as I get on the bus. I notice that I can no longer see everyone’s breath. As the bus pulls away from the stop, I look out the window and see a bright yellow sign on the side of the road that says “Danger Bridge Ices.” Soon, the bus goes over a bridge, and I feel several bumps and hear some thumping noises. Why are bridges always bumpy? And why are there special signs warning motorists about ice on bridges? It is cold enough outside for ice to form on all roads, whether the roads go over bridges or not. I wonder …

Cold hands, cloudy breath, icy bridges, and frosty windows are some of the signs of cold weather that I have noticed all my life. I have often wondered why certain things happen in cold weather but not in warm weather.

Verifying Understanding

After reading, effective readers verify their understanding by reflecting on the ideas presented and discussing what they have read. They may even research some aspect of the topic.

1 The story you read introduced some of the ideas that will be discussed in Chapter 7. Create and complete a 3-2-1 table (Table 1). On the table, record three things that you discovered by reading the story, two interesting things, and one question that you have after reading the story. Discuss your table with a partner.
Warmth and Coldness

Living things are sensitive to warmth and coldness. They need a certain amount of warmth to survive. Humans keep warm by wearing clothes, performing physical activities, and burning various fuels in fireplaces and furnaces. Many birds fly south when it gets cold in northern regions (Figure 1(a)). Snakes and lizards bask in the sun to keep their bodies warm (Figure 1(b)).

However, living things avoid excessive warmth because it is dangerous for their health. Animals that overheat can suffer damage to their internal organs and can even die. Different types of living things have developed different ways of dealing with excessive warmth. For example, dogs cool off by panting (Figure 2). Honeybees flap their wings to cool their hives in hot weather. People use electric fans and air conditioners to cool their homes and other buildings when the weather is too warm.

Heating and Cooling Our Buildings

Homes and buildings are designed to keep their interiors warm in winter and cool in summer. In fact, heating, ventilation, and air conditioning (HVAC) is a $12 billion industry in North America. About 250 000 people have jobs in the HVAC industry. It is not easy to keep homes and other buildings comfortable during the hot, humid summers and cold winters of Ontario (Table 1).

<table>
<thead>
<tr>
<th>Table 1 Average Monthly Temperatures for Ottawa, Ontario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
</tr>
<tr>
<td>Average temp (°C)</td>
</tr>
</tbody>
</table>

Figure 1 Animals such as geese (a) and lizards (b) need warmth in order to survive.

Figure 2 A dog pants to cool down.
For thousands of years, people have warmed their homes in winter by burning wood in fireplaces. They have cooled their homes in the summer by placing blinds on windows and planting shade trees in their gardens. In ancient Rome, some buildings were sometimes cooled by running cold river water through the walls. Other buildings were cooled by installing a shallow indoor pool. In ancient China, some palaces had raised floors. This design permitted servants to tend fires beneath the floors during the winter. In the early 1800s, a few wealthy people began to install central heating systems in their homes. These systems consisted of furnaces that moved warm air or water to the rooms of a building. Modern electric air conditioners were first used in North America in the early 1900s (Figure 3).

Today, most Ontario homes are built with central heating systems. Some also contain central air conditioners (Figure 4). The furnaces in these systems typically burn fuels like oil (petroleum) or natural gas. Oil and natural gas are found in limited supplies deep within Earth's crust. If we continue to use these fuels at our current rate, scientists estimate that we will run out of them within a few decades. In some cases, buildings are heated with electric heaters, which use electricity to produce warmth. Electric heaters may consume fuels indirectly, depending on the electricity source.

Figure 3 Air conditioners are often fitted into building windows, where they draw in outside air, cool it, and blow it back into the building.

Figure 4 A typical home central heating and cooling system. The furnace heats the home in the winter; the air conditioner cools it in the summer. The same air ducts are used for both heating and cooling.
TRY THIS: Conduct a Heating and Cooling Survey

In this activity, you will survey people to find out how they keep their homes, or businesses, warm in the winter and cool in the summer. You may ask about the heating and cooling methods they currently use, or have used in the past. You may also ask about methods they may have used in other parts of the world.

Equipment and Materials: writing instruments (pencils, pens); paper

1. Think of 6 to 10 questions that ask participants how they keep (or kept) their homes or businesses warm in cold weather and cool in hot weather. Your questions may ask about the types of devices used, the sources of energy used to run the devices, the effectiveness of the methods used, or effects on the environment.

2. Organize your questions into a questionnaire.

3. Ask at least six people to answer your questionnaire. Collect their responses.

A. Analyze the answers. Write a brief report describing your findings. You may organize your findings using tables and graphs if appropriate.

B. Exchange reports with a classmate. Read your classmate’s report and note any differences and similarities in your findings. Together with your classmate, write a brief expository paragraph that summarizes your joint findings. Your paragraph should answer the following questions:

- What methods do people use to heat and cool the buildings in which they live?
- How effective are the methods that people use to heat and cool their buildings?
- How do the heating and cooling methods employed affect the environment?

CHECK YOUR LEARNING

1. (a) Give two examples of ways in which animals keep themselves warm or cool.
   (b) Give one example each of ways in which people keep themselves warm and cool.

2. Describe how home heating and cooling has changed over time, and how it has remained the same.

3. Why do buildings have chimneys?

4. List two costs, or drawbacks, of using an electric air conditioner, and two benefits.

5. Why should we try to use less oil, natural gas, and electricity?

Wood, coal, oil, and natural gas release energy and gases as waste when they burn. Some of these waste gases are toxic and must be removed from the building. Chimneys are vents that carry these gases to the air outside (Figure 5).

In the summer, buildings can be cooled by fans, window air conditioners, or central air conditioners. These devices do not normally produce toxic fumes during their use, but they do consume electricity. Air conditioners use much more energy than fans do.

Keeping interiors comfortable all year long is important to consider in the construction and maintenance of all buildings. Heating and cooling are expensive processes. They are also harmful to the environment. We should use them as little as possible. Imagine if we only had to turn on the air conditioner for a few minutes once a day to cool a building. The building would then stay at a comfortable temperature for the rest of the day. Think how much electricity we could save! Understanding more about heating and cooling may help people keep buildings comfortably warm or cool, while minimizing negative effects on the environment.
Explaining Hot and Cold

We use the word “heat” to describe something that produces warmth. But what is heat? How does heat affect matter? Scientists have tried to understand the causes of warmth and coldness for a long time. Eventually, they developed several explanations for these ideas. Today, scientists explain heat using a theory called the particle theory of matter.

The Particle Theory of Matter

In the early 1800s, scientists suggested that warmth is caused by the motion of the small, invisible particles that make up matter (Figure 1). The faster the particles move, the warmer the material feels. The slower the particles move, the colder the material feels. This explanation of warmth and coldness eventually became part of the particle theory of matter (also shortened to “the particle theory”). The main points of the particle theory are listed below:

- All matter is made up of invisible particles.
- Particles have spaces between them.
- Particles are moving all the time.
- Particles move faster when they are heated.
- Particles attract each other.

Heat

The particle theory helps us explain many characteristics of matter, including how matter warms up and cools down. When an object is heated, its particles move faster. When an object is cooled, its particles move slower.

Figure 1 The particle theory applies to all matter, including the water in this bottle and the bottle itself.
When a warm object comes into contact with a cold object, the faster-moving particles of the warm object bump into the slower-moving particles of the cold object. As a result, energy is transferred. This causes particles of the cold object to speed up and the particles of the warm object to slow down. If you watch a game of billiards being played, you will see a similar transfer of energy. When a fast-moving billiard ball (the white cue ball in Figure 2(a)) collides with a stationary ball, some energy is transferred. The stationary ball starts to move and the white ball slows down (Figure 2(b)).

To heat an object means to transfer energy to the particles of that object. Heat is not a thing or substance that an object can contain. Instead, heat is the transfer of energy from warmer things to cooler things.

You should be careful about how you use the word “heat.” In an investigation, you may be instructed to “Heat the water in the beaker by placing it on a hot plate.” You should not, however, say, “Water absorbs heat when it is placed on a hot plate.” A substance cannot absorb heat. When water is heated, it absorbs energy, not heat.

CHECK YOUR LEARNING

1. (a) Describe a key idea about heat that you understood from this section. (b) How does the scientific definition of heat compare to the use of the word “heat” in conversational English? (c) Discuss this idea of heat with a classmate or with your teacher. Write an explanation of heat in your own words. If you like, you may use diagrams or pictures.

2. Summarize the key ideas of the particle theory in your own words or with labelled diagrams.

3. How does the particle theory help to explain the difference between a drop of cold water and a drop of hot water?

4. Explain what is wrong with the statement: “A mug of hot chocolate contains more heat than a glass of cold water.”
Kinetic Energy, Heat, and Temperature

Warmth and coldness involve the motion of the particles of matter. Since they are always moving, the particles of matter possess a form of energy called kinetic energy. All moving objects, large and small, possess kinetic energy (Figure 1). Flying airplanes, the flapping wings of a bird, and invisible vibrating particles all possess kinetic energy.

Figure 1  All objects that move have kinetic energy. There are even moving particles inside of a balloon.

All of the particles in a substance are attracted to each other. So, why do the particles not stick together and stop moving? Particles have a lot of kinetic energy, which keeps them moving. When the environment gets colder, they slow down and come closer together. They never slow down enough to come to a complete standstill.

If you could see the particles of an object, you would notice that they are not all moving at the same speed. Particles of matter collide with each other much like bumper boats in an amusement park ride. Bumper boats collide randomly as they move from place to place (Figure 2). Sometimes, several boats collide in such a way that some slow down and some speed up. Particles of matter also move and collide randomly, some speeding up and some slowing down. Particles do not all possess the same amount of kinetic energy at any given time. Some particles have more kinetic energy than others.

Temperature

If you could see the particles of a hot object and the particles of a cold object, you would see that most of the particles of the hot object move faster than most of the particles of the cold object. Thus, the average kinetic energy of the particles of a hot object is higher than the average kinetic energy of the particles of a cold object.

Temperature is a measure of the average kinetic energy of particles. If most of the particles of air in your kitchen are moving faster than most of the particles of air in your bedroom, then the temperature of the air in your kitchen is higher than that of the air in your bedroom.
**Particle Theory and the States of Matter**

Matter exists in three common states: solid, liquid, or gas (Table 1). The particle theory can be used to explain the characteristics of solids, liquids, and gases.

<table>
<thead>
<tr>
<th>State of matter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>The shapes and volumes of solids do not change because the particles of a solid vibrate. They cannot move past each other. The kinetic energy of the particles is too low to overcome the forces holding the particles together. The particles are packed close together, and are difficult to squeeze into a smaller space.</td>
</tr>
<tr>
<td>Liquid</td>
<td>Liquids take the shape of their containers and have fairly constant volumes. The particles of a liquid move faster than the particles in a solid of the same substance. The particles vibrate, rotate, and move past one another. The speeds of the particles prevent the forces of attraction from holding them in one place. However, there is still enough attraction between the particles to keep them from separating completely. The particles of a liquid are slightly more spread out than the particles of a solid. The particles of liquids strongly resist being squeezed closer together.</td>
</tr>
<tr>
<td>Gas</td>
<td>Gases expand to fill an empty container. This means that both their volume and shape can change. The particles of a gas vibrate, rotate, and move past one another much more than the particles of solids and liquids. The fast motions of the particles prevent their forces of attraction from holding them close together. Gas particles have very large spaces between them. Their movement is only limited by the size of the container. Gases are relatively easy to compress.</td>
</tr>
</tbody>
</table>

**Particle Theory and Changes of State**

According to the particle theory, particles of matter are constantly moving and are attracted to each other. The motions of the particles of a substance (their kinetic energies), and their attraction for each other, determine whether the particles form a solid, a liquid, or a gas. The kinetic energy of the particles and the energy of attraction between them are called thermal energy. We can increase the thermal energy of a substance by heating it, and we can decrease the thermal energy by cooling the substance. Changes in thermal energy can also cause a substance to change state (Figure 3 on the next page). For example, increasing the thermal energy of a solid may cause it to melt, becoming a liquid.
Thermal Expansion and Contraction

When solids, liquids, and gases are heated, their volumes usually increase. This process is called thermal expansion (Figure 4). Heating a substance speeds up its particles, so they have more kinetic energy. The faster-moving particles travel greater distances, so they occupy more space.

When solids, liquids, and gases are cooled, their volumes usually decrease. This process is called thermal contraction. Cooling a substance slows down its particles, so that they have less kinetic energy. The slower-moving particles travel shorter distances, so they occupy less space.

During thermal expansion and contraction, the mass of the object stays the same. The change in volume is not due to an addition or removal of particles, or to a change in the size of the particles. The change in volume is due to an increase or decrease in the spaces between particles. In general, for a given change in temperature, gases expand and contract more than liquids and solids, and liquids expand and contract more than solids.

Figure 3 Changes of state involve changes in thermal energy.

**Thermal Expansion**

- **Thermal expansion**: an increase in the volume of a substance caused by heating

**Thermal Contraction**

- **Thermal contraction**: a decrease in the volume of a substance caused by cooling

Figure 4 Thermal expansion occurs when particles move farther apart.

**CHECK YOUR LEARNING**

1. Name and briefly describe the two kinds of energy that all particles possess.
2. Describe the relationship between temperature and energy.
3. List the three states of matter in order of decreasing kinetic energy.
4. (a) Which state of matter is most easily compressed to take up a smaller volume?  
   (b) Write a sentence explaining this observation.
5. When a substance is cooled, what happens to its particles? How does cooling affect the volume of the substance?
Expanding and Contracting

All forms of matter change when they are heated or cooled. In this investigation, you will study the effect of heat on the volume of a liquid (water), a gas (air), and a solid (brass).

Testable Questions

Part A: Read Part A of the Experimental Design and the Procedure, then write a testable question for Part A.

Part B: Read Part B of the Experimental Design and the Procedure, then write a testable question for Part B.

Part C: Read Part C of the Experimental Design and the Procedure, then write a testable question for Part C.

Hypothesis/Prediction

Part A: Make a hypothesis regarding your testable question for Part A. Your hypothesis should include a prediction and reasons for it.

Part B: Make a hypothesis regarding your testable question for Part B. Your hypothesis should include a prediction and reasons for it.

Part C: Make a hypothesis regarding your testable question for Part C. Your hypothesis should include a prediction and reasons for it.

Experimental Design

Part A: Coloured water in a test tube fitted with a narrow plastic tube is warmed up, and then cooled down. Any change to the water level in the tube is measured and recorded.

Part B: A glass bottle with an empty rubber balloon stretched over its mouth is warmed up, and then cooled down. Any changes to the balloon are observed and recorded.

Part C: A brass ball that barely passes through a brass ring is warmed up, and then cooled down. Any changes to the ball are observed by attempting to stick the ball through the ring.

Equipment and Materials

- eye protection
- apron
- test tube
- rubber stopper with plastic tubing
- glass marking pen
- 2 large beakers
- glass bottle with narrow neck
- empty rubber balloon
- brass ball and ring
- water
- food colouring
- ice

Be careful when handling glass. Report any breakages to your teacher immediately.
**Procedure**

**Part A: Heating a Liquid**
1. Put on your apron and eye protection.
2. Add room temperature water to a beaker.
   Add a few drops of food colouring and swirl the water to mix the colour in. Fill a test tube with the coloured water and then rinse the beaker.
3. Insert a stopper with plastic tubing into the test tube. Ensure that there is no air trapped in the test tube. The coloured water should move up the tube. Use the glass marking pen to mark the water level.
4. Add 300 mL of hot tap water to a beaker. Be careful not to scald yourself with the hot water.
5. Add 200 mL of cold tap water to a second beaker. Add ice to the water, bringing its volume to 300 mL.
6. Place the test tube in the hot water bath. After 3 min, mark the water level on the plastic tubing and record your observations.
7. Transfer the test tube to the cold water bath. After 3 min, mark the water level on the plastic tubing and record your observations.
8. Remove the test tube from the cold water.

**Part B: Heating a Gas**
9. Add new hot water and ice to the water baths.
10. Stretch the opening of an empty rubber balloon over the mouth of a glass bottle.
11. Place the glass bottle in a hot water bath for 5 min. Observe any changes in the balloon, and record your observations.
12. Remove the bottle from the hot water bath and place it in a cold water bath for 5 min. Observe any changes in the balloon, and record your observations.

**Part C: Heating a Solid (Demonstration)**
13. Your teacher will show you a brass ball and ring apparatus.
14. Your teacher will attempt to pass a brass ball through a brass ring when both are at room temperature. Record your observations.
15. Your teacher will heat the brass ball, and attempt to pass it through the cooler brass ring. Record your observations.
16. Your teacher will cool the brass ball to room temperature, and attempt to pass it through the brass ring. Record your observations.

**Analyze and Reflect**
(a) Did the evidence you obtained in Part A support your hypothesis? Explain.
(b) Did the evidence you obtained in Part B support your hypothesis? Explain.
(c) Did the evidence you obtained in Part C support your hypothesis? Explain.
(d) Answer your Testable Questions.
(e) How confident are you about your answers to your Testable Questions? Explain.
(f) In Part B, what happened to the air in the glass bottle when it was placed in the cold water bath? Provide evidence and explain the results using the particle theory.
(g) In Part C, what happened to the brass ball when it was heated? What happened when it was cooled? Provide evidence and explain the results using the particle theory.

**Apply and Extend**
(h) State an everyday example in which you observe
   (i) a gas expanding when heated
   (ii) a solid contracting when cooled
(i) Materials do not expand by the same amount when heated. What problems might this cause when designing products? Give an example.
7.5 Living with Thermal Expansion and Contraction

Materials in our world are exposed to changing temperatures. Computer chips warm up when a computer is turned on and cool down when it is turned off. Buildings and bridges warm up during the day, and then cool down again at night. Buildings also have to withstand the changes that occur between the seasons. Materials expand and contract, sometimes dramatically, during temperature changes. When different materials are used to build a structure, designers must understand how the materials behave when they are heated or cooled.

Expansion and Contraction of Solids

It is important to choose the right materials when designing structures that are exposed to changing temperatures. Imagine that designers choose to use two solids that expand or contract differently when heated or cooled. The structure could be damaged by the different amounts of expansion and contraction. For example, the concrete used to build bridges and buildings is reinforced by steel rods (Figure 1). The steel used to make the rods is designed to expand at the same rate as the concrete. If the rods expanded at a different rate, the concrete would crack. The structure could, over time, crumble and fail. In the same way, when a dentist fills a decayed tooth, the filling material must change its volume to the same degree as the tooth itself. Some scientists specialize in the development of dental filling materials that expand and contract just like real teeth.

Bridges and sidewalks are built in segments. They have spaces called expansion joints between them. The expansion joints allow the concrete and steel to expand without buckling and cracking (Figure 2). The thumping sound you hear when you drive over a bridge in a car or bus is the sound of the tires going over the expansion joints.

Figure 1 The steel rods (at the worker’s feet) used to reinforce concrete are designed to expand and contract in the same way the concrete expands and contracts.

Figure 2 (a) The expansion joints narrow when bridge segments expand in hot weather. (b) Expansion joints in a bridge separate when the side-by-side segments of a bridge contract in cold weather.
Expansion and Contraction of Gases

When a gas in a container is heated, the kinetic energy of the gas particles increases. The particles of the warmer gas hit the walls of the container more often and with greater force. If the walls of the container are flexible, as in a balloon, the more frequent and faster collisions may cause the walls of the container to expand (Figure 3).

![Diagram of gas particles hitting walls of a balloon](image)

**Figure 3** The helium gas in a mylar balloon expands a great deal when the balloon is taken from the cold outdoors into a warm room.

(a) At a low temperature, the average kinetic energy of the particles in the balloon is low, so the frequency and force of collisions on the inside walls of the balloon are low.

(b) As the temperature of the gas inside the balloon rises, the particles collide more often with the walls of the balloon. They are also travelling faster. These stronger collisions cause the balloon to expand.

Thermal expansion and contraction affect the volume and pressure of tires, volleyballs, and basketballs. When cars are moving quickly, the rubbing between the tires and the road increases the temperature of the air in the tires. This causes the tires to expand. Tires must be inflated according to manufacturers’ recommendations. If they are over-inflated when cool, they can burst when they warm up. Volleyballs and basketballs left out in the cold become smaller and softer because of the thermal contraction of the air inside.
Expansion and Contraction of Liquids
Thermal expansion and contraction affect the volumes of liquids that are used every day. Cars provide a good example of this. Cold gasoline in a car’s gas tank expands in hot weather. If the tank is filled to the brim, the gas may overflow. Also, if a car engine is filled with cold liquid coolant, the coolant will warm up and expand when the car is running, and may overflow.

Studies over the past 100 years show that the average temperature of Earth’s oceans has been steadily increasing. As the ocean water warms up, its volume increases due to thermal expansion. The greater volume leads to rises in sea levels. This could lead to floods in coastal cities.
Sun Kinks, Breather Switches, and Train Disasters

Travelling by train is popular. Passenger trains carry people between towns and cities every day. Freight trains transport products over long distances.

Train cars glide on long parallel steel rails. Train tracks are manufactured in 20 m lengths that are welded together. This ensures a smooth, quiet ride. The continuous welded rail can be several kilometres long.

Railway tracks in Canada are exposed to extreme changes in temperature. These changes can cause a lot of thermal expansion of the rails in summer, as well as contraction in winter. To avoid these changes, the tracks are heated before being put together. Nevertheless, sudden bouts of extremely hot weather can cause a rail to buckle. This forms a twist in the rail that some people call a “sun kink.” Sun kinks are extremely dangerous, and have been linked to some serious train disasters.

On July 4, 2005, a train carrying 51 empty fuel cars derailed near Ottawa (Figure 1). It is believed that sun kinks were the cause. Luckily there were no injuries or deaths in this accident. However, the derailment disrupted normal passenger service between Montreal and Toronto for several days. Passenger train derailments involving sun kinks have caused many injuries and deaths. Scientists and engineers are working to develop rail technology that minimizes the possibility of sun kinks.

One method used to avoid sun kinks is to cut the rails at sharp angles. This leaves a small gap between the cut surfaces. These gaps are called “breather switches” (Figure 2). Engineers continue to work on methods that will improve train transportation safety.

To learn more about sun kinks and breather switches, Go to Nelson Science

Figure 1 If the cars had been filled with fuel, the derailment would have caused serious damage to wildlife and the surrounding environment.

Figure 2 A breather switch. The sharp angle at which rails are cut ensures a relatively smooth and quiet ride for passengers.
BIG Ideas

- Heat is a form of energy that can be transformed and transferred. These processes can be explained using the particle theory of matter.
- There are many sources of heat.
- Heat has both positive and negative effects on the environment.

Looking Back

Heating and cooling are important in everyday natural and artificial processes.

- All living things are most comfortable within a certain temperature range.
- Many animals adapt their behaviour to keep their bodies at a comfortable temperature.
- Humans adapt to their surroundings by using heating and cooling technologies.

The particle theory explains heating and cooling.

- All matter is made of invisible particles. Particles have spaces between them. Particles are moving all the time. Particles move faster when they are heated. Particles attract each other.
- Heating and cooling a substance affects the motion of its particles.
- Solids, liquids, and gases can be described in terms of the arrangement and motion of their particles.
- Moving particles possess kinetic energy. A faster-moving particle possesses more kinetic energy than a slower-moving particle.
- Thermal energy includes the kinetic energy of all the particles in a substance and the energy associated with the attractive forces between the particles in the substance.
Heat is the transfer of energy from warmer substances to cooler substances.

- Temperature is a measure of the average kinetic energy of the particles in a substance.
- The faster the particles of a substance move, the hotter the substance is; the slower the particles of a substance move, the colder the substance is.
- When a hot object comes into contact with a cold one, the fast-moving particles of the hot object bump into the slow-moving particles of the cold object. The fast-moving particles slow down as they transfer energy to the slow-moving particles.

Most materials expand when they are heated, and contract when they are cooled.

- When a material is heated or cooled, the motion of its particles is affected. When heated, the particles move faster and farther apart. When cooled, the particles move slower and come closer together.
- The expansion and contraction of solids, liquids, and gases must be considered when designing structures or devices that are subjected to changes in temperatures.
- When the temperature changes, solids expand and contract the least, gases expand and contract the most.

Investigation skills can be used to learn about expansion and contraction of different materials.

- Expansion and contraction of solids, liquids, and gases can be observed and analyzed.
- The particle theory can be used to explain observations made about expansion and contraction.
CHAPTER

What Do You Remember?
1. (a) Describe two things that humans do to warm up.
   (b) Describe two things that animals other than humans do to warm up.  
2. Briefly summarize the particle theory in your own words.  
3. Copy Table 1 into your notebook and complete it.  

Table 1 Descriptions of Three States of Matter

<table>
<thead>
<tr>
<th></th>
<th>Solid</th>
<th>Liquid</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shape</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>type of particle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>motion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>spaces between particles</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Use the particle theory to explain why gases expand more than liquids or solids when they are heated.  
5. Write a definition of “heat,” using your own words.  
6. From what you have seen or read, list two examples each of  
   (a) thermal expansion in solids  
   (b) thermal expansion in liquids  
   (c) thermal expansion in gases  

What Do You Understand?
7. (a) List five situations where heat plays a role in your daily life (for example, cooking an egg).  
   (b) Give three examples of state changes that you see happening in your daily life.  
8. Solids expand slightly when heated. For this reason, bridges and railway tracks are built with expansion joints. Use the particle theory to explain what might happen on a hot day if expansion joints were not used.  

9. Use diagrams and words to explain what happens to the particles of matter in each of the following situations (Figure 1(a) to 1(c)). Consider these questions: Are the particles moving faster or slower? Are the particles getting closer or farther apart? What change of state is occurring?  
   (a) Droplets of water form on the outside surface of a glass of water.  
   (b) Butter melts in a hot skillet.  
   (c) The red line in a liquid thermometer gets shorter as the temperature drops.  

10. Perspiration (sweat) helps a person cool down. What change of state is involved in sweating?  
11. You are boiling vegetables on the stove and notice the lid of the pot moving up and down. Use the particle theory to explain what is happening.  
12. Thermal expansion can be useful or it can be a problem. Research the effects and uses of thermal expansion. Choose one example of thermal expansion and write a summary paragraph about it.  

Go to Nelson Science
Solve a Problem!

13. (a) Many containers that hold food are made of glass sealed with a metal lid. These lids can be difficult to remove. Holding the lid of the jar under hot water for a short time makes the lid easier to remove. Explain why this works.

(b) An auto mechanic is having difficulty loosening the nut on a bolt using only a wrench and a pair of pliers. How can the mechanic use the ideas in this chapter to solve this problem?

14. (a) Some people hang wet clothing out to dry on warm, sunny days. Why does wet clothing dry in this weather?

(b) Some people hang wet clothing out to dry even on freezing cold days. Will wet clothes dry in this weather?

(c) What would happen to juicy vegetables left on a plate in a freezer for a long time? How can this be prevented?

15. A bimetallic strip is made of one type of metal on one side and a different metal on the other side (Figure 2). The strip bends one way when heated.

(a) Explain why the strip bends when heated.

(b) Conduct library or Internet research to determine how bimetallic strips are useful.

(c) How could a bimetallic strip be used to help you perform a practical task in everyday life?

Create and Evaluate!

16. Ice is lighter than water. Use the library or the Internet to research and explain what this statement means. Write a short script, story, or poem describing the implications of this effect for life on Earth.

17. Using the Internet, research the thermoscope. Write a short description of this instrument, indicating how it worked and what it was made of. Compare the thermoscope with thermometers used today. How useful would the thermoscope be in everyday tasks?

Reflect on Your Learning

18. Think back to the Key Question on the first page of this chapter.

(a) In a brief paragraph, answer the Key question. You may use diagrams.

(b) Write one or two more questions about the topic of this unit that you would like to explore.

19. Think about a new idea regarding heat that you have learned in this chapter. How may this idea change some of the things you do on a daily basis?

20. Which concept presented in this chapter did you find the most interesting? What new questions do you have about this concept?
Designing an Energy-Efficient Doghouse

Background
Choosing the best materials is important when you are planning a building project. Insulation can slow down the transfer of thermal energy through the walls of a building. If the designer wants to keep the building cool, she or he might choose to paint the building a light colour, or use a material on the outside walls that is shiny. The designer must consider form and function.

Scenario
The K-9 Doghouse Company is holding a design competition to develop a new doghouse. The company is looking for a doghouse that will keep a dog comfortably warm during the winter months and cool during the summer.

Design Brief
Designers must build a prototype of a doghouse that is designed to keep a dog warm during the winter and cool during the summer. The prototype must not exceed 15 cm × 15 cm in floor area, and 15 cm in height, inside. There must be a doorway. Designers are encouraged to use materials efficiently, to keep the doghouse affordable, and to minimize negative effects on the environment (Figure 1). All materials must be safe for use in the classroom and home.

Research and Consider
Before designing your doghouse, research different types of materials. Remember that energy can be transferred by conduction, convection, and radiation.

Figure 1  Your doghouse must be affordable, with minimal effects on the environment.

Plan and Construct
Choose one of your designs and build a prototype doghouse for the design competition. Before building, you should do the following:
• Complete a scale drawing of the doghouse.
• Produce a list of equipment and materials to be used during construction.
• Create a step-by-step plan for building the prototype.
• Produce a list of job responsibilities for each team member (if you are working in a team).
• Ask your teacher to approve the list of materials and the building plan before you begin.

**Test and Modify**
Test the doghouse prototypes using the procedures in Table 1:

<table>
<thead>
<tr>
<th>Cold Weather test</th>
<th>Warm Weather test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Measure the temperature inside the doghouse at room temperature and record it as the initial (comfortable) temperature. Leave a thermometer inside the doghouse.</td>
<td>Repeat the procedure for the Cold Weather Test, except put the doghouse in direct sunlight for 10 min.</td>
</tr>
<tr>
<td>2. Put the doghouse prototype into a freezer for 10 min.</td>
<td></td>
</tr>
<tr>
<td>3. Remove the doghouse prototype from the freezer and quickly measure the temperature inside the doghouse. Record this temperature as the final doghouse temperature.</td>
<td></td>
</tr>
<tr>
<td>4. If the temperature of your doghouse changed to an uncomfortable temperature during the trial, work with your team to make modifications to the design.</td>
<td></td>
</tr>
<tr>
<td>5. Build your redesigned prototype and retest it.</td>
<td></td>
</tr>
</tbody>
</table>

**Evaluate**
Answer the following questions:

1. Which elements of the doghouse design prevented the inside temperature from dropping too quickly when the prototype was placed in the freezer?
2. Which elements of the doghouse design kept the inside temperature comfortable when the prototype was placed in direct sunlight?
3. Compare the test results from your doghouse with those of other prototypes. Give reasons for the outcome.

**Communicate**
Make an oral presentation to the “Board of Directors” of K-9 Doghouse Company that points out the pros and cons of your design. You need to convince the Board that the prototype deserves to be mass-produced. Create a poster that features a scale drawing of your doghouse design, highlights the ways in which the doghouse prevents heat loss and overheating, and displays the results of the Cold Weather and Warm Weather tests.

**Assessment**
You will be assessed on how well you

• state the design problem or challenge
• identify several possible design solutions
• make sketches of several possible designs
• develop a plan for building a prototype, based on one of your possible designs
• build a prototype based on one of your designs
• test your prototype and record observations, make modifications, or identify modifications that could be made to improve the effectiveness and efficiency of the prototype
• evaluate your prototype according to your observations and the criteria
• use the concepts and terminology of the unit to communicate the development and testing of your prototype
Heat in the Environment

Make a Summary
During this unit, you have learned many new concepts about heat and its effects on the environment. The Chapter Review for each chapter lists the new words and terms that you learned. In this activity, you will use those words to complete a series of activities.

Equipment and Materials
• markers
• sticky tape or glue
• sticky notes or small pieces of paper
• chart paper

Procedure
1. Form a team of three or four people.
2. Work together to write each of the vocabulary words on the sticky notes. Write one word (or one term) only on each note.
3. Place a piece of chart paper in the centre of your team. Share the vocabulary words equally among team members.
4. Organize the words into two to five logical groupings on the chart paper. You can use any criteria you like to put the words into groups.
5. Once your team agrees on how the words are grouped, stick the words in place on the chart paper.
6. Write a title above each group that describes why the words are in that particular group.
7. Below each list of words, write one sentence that describes an important idea from the unit that is associated with that group of words.
8. Use these sentences as the basis of a paragraph or two, summarizing your learning in this unit.

Unit C Review Questions

What Do You Remember?

1. Which of the following types of energy is most commonly used for home heating? ☑
   (a) chemical energy
   (b) mechanical energy
   (c) friction
   (d) solar energy

2. Which form of energy transfer is primarily responsible for thunderstorms? ☑
   (a) convection
   (b) conduction
   (c) friction
   (d) radiation

3. Which type of rock is formed as molten lava cools? ☑
   (a) metamorphic
   (b) sedimentary
   (c) igneous
   (d) all of the above

4. The radiant energy of the Sun is directly transformed into electrical energy in a
   (a) wind turbine
   (b) photovoltaic panel
   (c) geothermal heat pump
   (d) nuclear reactor ☑
5. Decide whether each of the following statements is true or false. If the statement is false, rewrite the statement to make it true.
(a) Heat is energy that is transferred from a cooler object to a warmer object.
(b) Heated liquids expand much more than heated solids.
(c) Visible light is a form of chemical energy.
(d) Wind is caused by the transfer of energy through conduction.

6. When a substance's particles absorb energy, what happens to the motion of the particles?

7. A cup of hot chocolate is set on a table before you drink it (Figure 1). Suggest two different ways in which energy is transferred away from the hot chocolate, allowing it to cool.

8. What invisible form of electromagnetic radiation is emitted by low-temperature objects like the human body?

9. Matter can exist as a solid, a liquid, or a gas. Which state(s) of matter
(a) has particles that are free to move long distances in all directions?
(b) has the most effective forces of attraction between the particles?
(c) efficiently transfers energy by conduction?
(d) has a fixed volume, but takes the shape of its container?

10. What causes lightning to form in a thunderstorm?

11. Rearrange the following phrases into an order that describes the production of energy by a hydro-electric power plant:
(a) Water flows into a river.
(b) A generator turns.
(c) Water is held in a reservoir.
(d) Electricity is produced.
(e) Water flows through a penstock.
(f) A turbine turns.

12. Radiant energy from the Sun can pass through the atmosphere to reach the surface of Earth, and some of the radiant energy from Earth passes back through the atmosphere toward space. How is some of the radiant energy from Earth prevented from escaping through the atmosphere?

**What Do You Understand?**

13. Explain how thermal energy is involved in each of the following situations:
(a) A cool breeze blows from a lake onto a beach on a sunny summer day.
(b) You clutch a cup of hot chocolate with your hands on a cold winter night.
(c) A large thundercloud rolls with thunder on a springtime afternoon.

14. The thermal expansion of materials can be an advantage or a drawback. Provide an example of each.

15. How can you prevent the unwanted transfer of thermal energy in your home by
(a) radiation?
(b) convection?
(c) conduction?
16. Scientists studying glaciers have found that the snow is contaminated with tiny specks of black soot released from factory smoke stacks.
(a) How could this observation help explain why glaciers are melting faster than predicted?
(b) Is the melting of glaciers an environmental concern? Explain.

17. When engineers design a device or structure composed of different materials, they consider how materials expand and contract. Why is this an important consideration? Provide an example.

18. On a particularly cold winter day, you hear a neighbour exclaim, “So much for global warming!”
(a) What does your neighbour mean by this statement?
(b) Is your neighbour’s exclamation reasonable? Explain.

Solve a Problem!
19. You have just been selected to join a field trip to the Arctic in January. What type of clothing will you pack? Describe the properties of the clothing that you will choose. Explain your choices.

20. An adventure company wants to design a new camp stove to be used by backpackers to boil water while out on the trail. Using a small candle as a source of thermal energy, suggest a design that will transfer the greatest amount of energy from the burning candle into the water in a kettle. Draw a detailed sketch of your camp stove design.

21. To help keep pizza hot during delivery, restaurants put the pizza boxes in a delivery bag (Figure 2).
(a) How does the design of the pizza bag help to keep the pizza hot?
(b) How could the delivery bag in Figure 2 be improved?

22. The Space Shuttle has a “Thermal Protection System” mainly consisting of thick dark tiles that line the bottom surface. These tiles protect the Shuttle and its occupants when it re-enters Earth’s atmosphere prior to landing.
(a) Why would the bottom surface of the Space Shuttle warm up as it descends through Earth’s atmosphere?
(b) What form of energy transfer do you think the tiles are designed to prevent?
(c) If you were a NASA engineer assigned the task of designing these tiles, what material would you use? What would influence your choice?
23. Methane is one of the greenhouse gases you read about in Section 9.3. Methane has a much higher global warming potential than carbon dioxide. One kilogram of methane warms Earth 25 times as much as 1 kg of carbon dioxide. Research the main sources of methane. How can you reduce the amount of methane released into the atmosphere as a result of your actions?

Create and Evaluate!

24. Most scientists believe that global warming is mainly caused by an increase of greenhouse gases, like carbon dioxide, in the atmosphere. Create a plan to make one change in your life that will reduce your greenhouse gas emissions. Evaluate your plan, and explain why it will have the desired effect.

25. Which devices in your home use the most energy? What can you do to reduce the amount of energy they use? Research more about the energy consumption of home devices by using the Internet or going to the library. Based on your research, evaluate which devices in your home would be best to replace or upgrade so that you can reduce your family’s energy consumption.

26. A scientist claims that “it takes more energy to make ethanol biofuel than you get out of it.” Evaluate this claim by researching and comparing the amount of energy needed to make a litre of ethanol from corn and the energy we can get from the litre of ethanol.

Reflect on Your Learning

27. Thermal energy has both positive and negative effects on the environment. Draw a table similar to Table 1 in your notebook. Complete the table by listing the positive and negative effects of thermal energy that you have learned. In the third column, list facts that you may have found particularly interesting or meaningful.

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative</th>
<th>Interesting/ Meaningful</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

28. Reread Section 9.3. Think about the issues presented in this section. Write a brief expository paragraph, a poem, or a lyric that expresses your feelings about these issues. If you prefer, you may draw a cartoon, compose a poster, or write a slogan. Share your composition with a classmate and discuss common interests and concerns.

29. The particle theory is a model that helps us visualize an idea.

(a) How did using a model (the particle theory) help you as you learned about how energy affects matter?

(b) What are the disadvantages of using a model like the particle theory?

(c) How have you used this model to help make sense of the things you see in the world around you?
A

active solar energy system  a device that harnesses radiant energy from the Sun and converts it into a more useful form of energy (p. 72)

alternative energy source  a source of energy that is not as common as conventional sources; alternative energy sources tend to be renewable and have few negative impacts on the environment (p. 70)

B

biofuel  [BYE-oh-fyoo-uhl] a liquid fuel, such as ethanol, produced from plant or animal material (p. 76)

C

conduction  [kun-DUK-shun] the transfer of thermal energy through a substance, or between substances in contact, by the collision of particles (p. 35)

convection  [kun-VEK-shun] the transfer of thermal energy from one part of a fluid to another by a circulating current of faster-moving and slower-moving particles (p. 38)

conventional energy source  a source of energy that has been widely used for many years (p. 62)

E

Earth’s energy balance  the balance between the energy lost by Earth into space and the energy gained by solar radiation trapped by Earth’s atmosphere (p. 66)

F

fossil fuels  concentrated sources of chemical energy such as coal, oil (petroleum), and natural gas that were formed deep in Earth’s structure over millions of years from decayed and compressed plant material (p. 64)

friction  [FRIK-shun] a force produced when objects rub against each other (p. 59)

G

geothermal  [jee-oh-THUR-muhl] energy  energy contained below Earth’s surface (p. 36)

global warming  an increase in Earth’s global temperature due to changes in the atmosphere that enhance the greenhouse effect (p. 68)

greenhouse effect  a rise in temperature resulting from certain gases in the lower atmosphere trapping radiant energy and warming Earth’s surface (p. 66)

greenhouse gases  gases such as water vapour, carbon dioxide, methane, and nitrous oxides that trap energy in Earth’s atmosphere (p. 66)

H

heat  the transfer of energy from the particles of a warmer object to the particles of a cooler object (p. 14)

I

igneous  [IG-nee-uhs] rock  rock formed from magma that has cooled and solidified (p. 36)
**K**

**kinetic** [ki-NET-ik] **energy** energy that all moving objects possess; a particle has more kinetic energy when moving faster and less kinetic energy when moving slower (p. 15)

**M**

**metamorphic** [MET-uh-MORE-fik] **rock** rock that is formed when heat and pressure change existing rock (p. 37)

**N**

**non-renewable energy resource** a source of energy that could eventually be used up (p. 63)

**P**

**particle theory of matter** a theory that explains what matter is made of, and how it behaves (p. 13)

**passive solar heating** heating caused by the passage of radiant energy through the windows of a building (p. 72)

**R**

**radiant energy** energy that travels in the form of electromagnetic waves through empty space; includes visible light, ultraviolet radiation, and infrared radiation (p. 42)

**radiation** [RAY-dee-AY-shun] the transfer of radiant energy by means of electromagnetic waves (p. 42)

**renewable energy resource** a source of energy that can be used indefinitely, without running out (p. 62)

**S**

**solar energy** radiant energy (mostly visible light and infrared radiation) produced at the Sun’s outer surface and radiated out into space (p. 58)

**T**

**temperature** a measure of the average kinetic energy of the particles of a substance (p. 15)

**thermal contraction** a decrease in the volume of a substance caused by cooling (p. 17)

**thermal energy** the total kinetic energy and energy of attraction of all the particles in a material (p. 16)

**thermal expansion** an increase in the volume of a substance caused by heating (p. 17)