Inquiry Activity

ACTING OUT THE PARTICLE MODEL

The Question

How can you and your classmates move and arrange yourselves to act like the particles that make up solids, liquids, and gases?

The Procedure

1. You will work in groups. Each group will work in a separate area. Treat each separate area as if it is a large container.
2. With your group, develop a way to represent a solid state of matter. Decide how to arrange yourselves and how to move to be particles of a solid.
3. Imagine that heat is being added to you. Your solid group is becoming a liquid.
4. Now add more heat and change your positions and movements to represent gas particles.
5. Keep working together until your group is satisfied with the way you represent particles in the three states of matter. Then present one of these states to the rest of the class without saying what it is. Show yourselves changing from that state to another state.

Figure 2.4a) Solid

Figure 2.4b) Liquid

Figure 2.4c) Gas

Collecting Data

6 Draw two rectangles on a sheet of paper. The rectangles represent "containers." Use them to sketch the two states of matter your group represented. Draw arrows to show your movement. Include other information about the way and the speed that you (as particles) were moving.

Analyzing and Interpreting

7 As a class, judge each group's presentation based on the following criteria.
- How easy was it to infer the state of matter being represented? What were the best clues? How accurately did the group represent the state of matter?
- How well did the group's actions represent the level of kinetic energy of the particles? How accurate was this action?
- How well did the group's actions show changes in volume?

Forming Conclusions

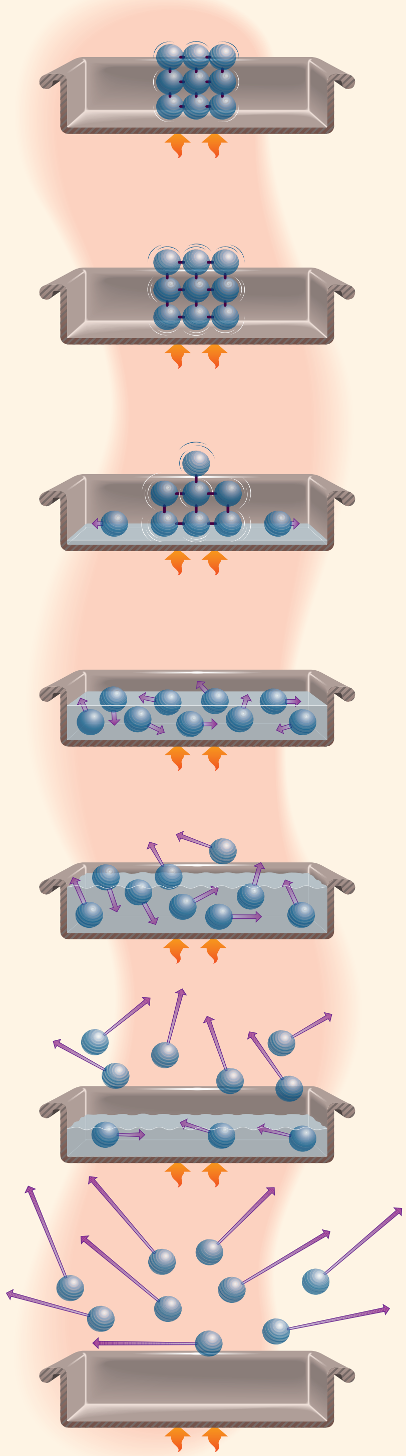
8 Review the scores that you gave your classmates' presentations. Write three paragraphs that describe the best presentation for each state of matter: solid, liquid, and gas.

Applying and Connecting

Sketch three diagrams that illustrate how adding heat affects the motion of particles. Use one real-life example for each of the three states.

How the Particle Model Explains Changes in State

The following chart shows what happens to the particles in a solid when heat is transferred to them. As the solid substance melts, becomes a liquid, and then a gas, the activity level of the particles and the amount of space between them changes.



1 Solid

- *Solid particles are packed closely together.*
- *Strong attractions, or bonds, hold the particles together.*
- *Solids have a fixed shape.*
- *The particles vibrate, or shake back and forth, in a fixed position.*

2 Heating a Solid

- *Transferring heat to a solid makes the particles vibrate more energetically.*
- *Some of the particles move farther away from one another.*
- *The solid expands—its volume increases.*

3 Melting a Solid

- *As more heat is transferred to a solid, the particles vibrate even more.*
- *The particles bump against one another.*
- *Some of the particles break loose.*
- *The solid structure begins to break down—the solid melts.*

4 Liquid

- *The particles have more kinetic energy to move about.*
- *The bonds that hold the particles together are weak.*
- *Liquids take on the shape of their containers.*

5 Heating a Liquid

- *Transferring heat to a liquid makes the particles move more vigorously.*
- *The particles move farther apart.*
- *The liquid expands—its volume increases.*

6 Boiling a Liquid

- *As more and more heat is transferred to a liquid, the particles bump and bounce around even more.*
- *Some of the particles are "kicked" out of the liquid.*
- *The liquid boils—it changes to a gas.*

7 Gas

- *Gas particles move about very quickly in all directions.*
- *Bumping and bouncing keep them far apart.*
- *Gas particles will fill up the space of any container.*
- *On heating, gas particles spread out even more—the gas expands.*

Check and Reflect

1. a) Below are pictures of three pure substances; one solid, one liquid, and one gas. Their melting and boiling points are also listed. Use the data to answer the questions below each picture.

Sulfur
- changes from the solid state to the liquid state at a temperature of 113°C
- changes from the liquid state to the gas state at a temperature of 445°C

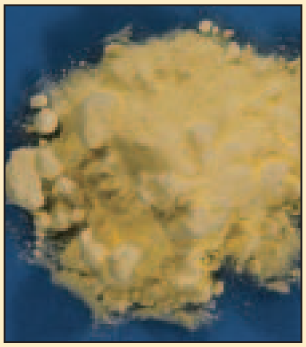


Figure 2.5a)

Sulfur is most often found in the solid state. What happens to the state of sulfur when the temperature changes from 20°C to 100°C? from 100°C to 120°C?

Mercury
- changes from the solid state to the liquid state at a temperature of −39°C
- changes from the liquid state to the gas state at a temperature of 357°C

Figure 2.5b)

Mercury is most often found in the liquid state. It is the only metal existing in the liquid state at room temperature. In what state is mercury at −50°C? −20°C? 200°C? 400°C?

Chlorine
- changes from the solid state to the liquid state at a temperature of −101°C
- changes from the liquid state to the gas state at a temperature of −35°C

Figure 2.5c)

Chlorine is most often found in the gas state. What would you have to do to make chlorine gas change into a liquid? to make solid chlorine change into a liquid?

b) Make a table or a graph that illustrates the melting and boiling points of the three substances shown above.

2. Create a cartoon strip with captions that illustrates the changes in particles from a solid state to a gas. Be sure to represent changes to both the kinetic energy and volume.

3. Design a chart that highlights the main ideas in the particle model. You may wish to use the one shown here, or create your own.

State of Matter	Distance between Particles	Volume and Shape	Particle Movement
Solid			
Liquid			
Gas			

Figure 2.6 Question 3

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Chugging Along

The *Dorchester* was the first ever steam-powered locomotive built for travel on Canadian railways. Its first trip was on July 31, 1836, along an 80-km track in eastern Canada. It travelled at about 23 km/h. Find out what happened to this locomotive and what technology replaced it.

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All-Time Low

In theory, the lowest possible temperature is "absolute zero" or −273.15°C. Scientists have come close to reaching "absolute zero" in a lab, but it has never actually been achieved.

2.2 Heat and Temperature

Temperature is a term we're all familiar with. When you get up in the morning, you might listen for the temperature on the radio so you know whether you have to wear a sweatshirt or a warm jacket to school. When you want to heat up some leftovers in the oven, you have to set the temperature so you don't burn them.

Temperature is a measure of how hot or cold matter is. Recall that heat energy transfers from hotter substances to colder ones. If you put a pot of soup on a hot stove burner, the soup will slowly heat up. Heat is transferring from the burner to the soup. Suppose you measured the temperature of the soup before you heated it and then again after it had been on the burner for a while. What do you think you would find?

If your soup came out of a can stored in the cupboard, it was probably at room temperature, about 20°C. After a few minutes of heating, its temperature would be several degrees higher. Heat energy has transferred from the burner to the soup. The soup now has more heat energy, and its temperature went up. Does that mean that heat energy and temperature are the same?

Total Kinetic Energy

So far in this unit, we have been using the term *heat energy* to describe the kinetic energy of particles in matter. However, to understand better how matter changes temperature and what this change means, we should use the scientific meanings of the terms *thermal energy*, *heat*, and *temperature*.

The **thermal energy** of a substance is the total kinetic energy of all the particles the substance contains. If you measured the thermal energy of a cup of water, for example, you would be measuring the total amount of kinetic energy of all the water particles in the cup.

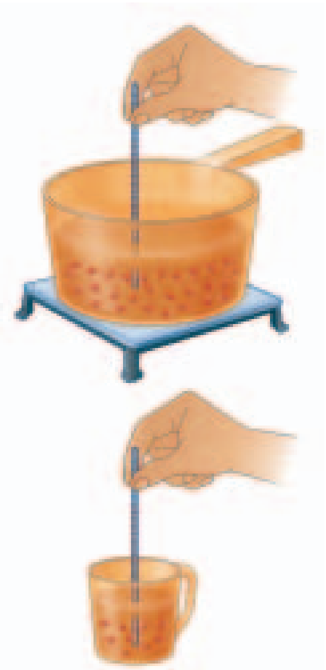


Figure 2.7 The soup in the pot has more thermal energy than the soup in the cup. But both are the same temperature.

Think about your soup example again. You heat the soup in a pot, and then pour a small amount of it into a cup. The temperature of the soup is the same in the pot and in the cup. But the soup in the pot has more thermal energy than the soup in the cup. This is because the amount of soup in the pot is greater than the amount of soup in the cup. A larger amount of soup contains more particles. If you added up the kinetic energy of all soup particles in the pot, you would find that it was greater than the total kinetic energy of the soup particles in the cup.

Energy Transfers

Scientists use the word **heat** to mean the energy that transfers from one substance to another because of differences in kinetic energy. So, in our soup example, the soup became hot because kinetic energy transferred from the particles in the hot stove burner to the cooler soup. A scientist would say that heat transfer had occurred.

The Difference between Heat and Temperature

Earlier in this unit, you learned how the particle model explains changes in state. The particle model also explains changes in temperature. Look at Figure 2.8. The kinetic energy of the water particles in the spoon increases as energy transfers from the flame to the water. The temperature of the water increases. Then, the spoon is placed in the freezer. Heat energy transfers from areas where particles have greater kinetic energy to areas where particles have less kinetic energy. In this case, kinetic energy transfers from the water particles in the spoon to the particles of the cold air in the freezer. The kinetic energy of the water particles in the spoon has decreased, and so the temperature has gone down.

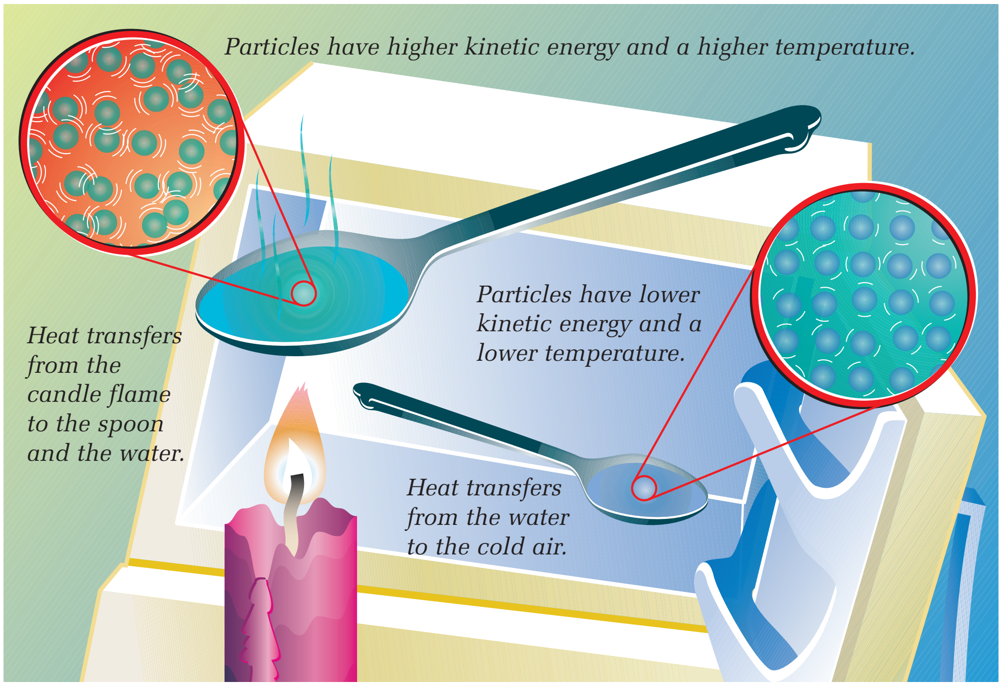


Figure 2.8 The temperature of the water in the spoon changes when heat transfers to it or from it.

Earlier, we said that temperature is a measure of how hot or cold a substance is. From the particle model, you know that the coldness or "hotness" of an object represents the kinetic energy of the particles it contains. Temperature then is more than simply a measure of how hot or how cold a substance is. It is a measure of the average kinetic energy of the particles in a substance.

Understanding the Difference

So thermal energy, heat, and temperature are different.

- Thermal energy is the total kinetic energy of all the particles in a substance.
- Heat is the energy that transfers from a substance whose particles have a higher kinetic energy to one whose particles have lower kinetic energy.
- Temperature is a measure of the average kinetic energy of the particles in the substance.

Figure 2.9 John Locke performing experiment

Measuring Temperature with Thermometers

More than 300 years ago, an English scientist, John Locke, did an experiment to try to prove that our sense of touch was not a very accurate way to measure temperature. He filled three pans with water: one with water that was as hot as he could stand to touch, one with very cold water, and one with lukewarm water. He placed his left hand in the hot water, and his right hand in the cold water for one full minute. He then set both hands into the lukewarm water. To his left hand, the lukewarm water felt cool. To his right hand, the same lukewarm water felt warm. This proved to Locke that we needed a more reliable way to measure temperature. Such thinking led to the invention of the modern-day thermometer.

math Link

In Canada, we report temperatures in degrees Celsius. In the United States, temperature is reported in degrees Fahrenheit. The conversion equation is: $°C = 5/9(°F-32)$. If you were watching an American weather forecast, and the temperature was 75°F, what would the temperature be in degrees Celsius? How would you convert 30°C to degrees Fahrenheit?

Thermometer Scales

Galileo Galilei, an Italian scientist, invented the first device for measuring temperature in the 1590s. But it was not until the early 1700s that an accurate way to measure temperature was developed by a German physicist, Gabriel Daniel Fahrenheit. The scale that he created became known as degrees Fahrenheit, and this is still used in many countries today—including the United States.

In 1742, Swedish astronomer Anders Celsius came up with a different scale for measuring temperature. This is the one that we now use in Canada, measuring temperature in degrees Celsius.

Inquiry Activity

INVESTIGATING TEMPERATURE MEASUREMENT

Materials & Equipment

- 400-mL beaker
- ice
- water
- unmarked alcohol thermometer
- stirring rod
- felt pen
- hot plate
- oven mitts
- ruler

The Question

How can you make a thermometer to measure temperature?

Procedure

1. Fill the beaker with ice and water. Place the unmarked alcohol thermometer into the ice and water. Use a stirring rod to stir the mixture. Mark the level of the alcohol on the thermometer with a felt pen. Remove the thermometer from the beaker.
2. Place the water on a hot plate and bring it to a boil. Carefully place the thermometer in the water. Once the level of the alcohol stops changing, mark the stable level on the thermometer. Remove the thermometer from the water. Turn off the hot plate and use the oven mitts to remove the beaker.
3. Using the ruler, measure the distance between the two farthest marks on the thermometer. Divide this distance into 10 equal sections and mark these divisions on the thermometer. Mark another point in the middle of each division.
4. Your teacher will give you a "mystery" liquid at an unknown temperature. Place your thermometer into the solution and record the level.

Caution!
Use oven mitts to remove the beaker from the hot plate. Be careful not to splash any hot water.

Figure 2.10 Step 1 and step 2

Collecting Data

5 Make a table or chart in your notebook to record the temperatures that you measure for the water and for the unknown liquid.

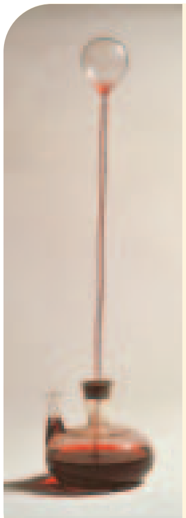
Analyzing and Interpreting

6 Knowing that water freezes at about 0°C and boils at 100°C, determine how many degrees each division on your thermometer represents.

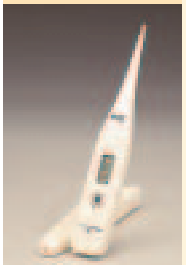
7 How close was your measurement of the temperature of the unknown liquid to the reading that your teacher had recorded? If there was a difference, why do you think this occurred?

Forming Conclusions

8 Describe how you constructed a thermometer and how it can be used to measure a range of temperatures. Explain any limitations to this device.



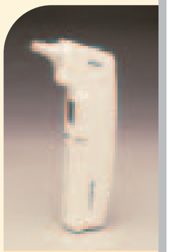
Galileo's thermoscope



Digital thermometer

History of the Thermometer

200 B.C.	A device, now generally known as a thermoscope, was used to show the expansion of air with an increase of temperature. Although the device did not have a scale, it is the oldest form of thermometer known.
1590s	Air thermometers, which used trapped air to measure temperature, were invented. These were, in fact, a form of thermoscope. One such thermometer, Galileo's thermoscope, is shown at left.
1630s	Use of water expansion thermometers was recorded.
1650s	The first sealed liquid thermometer was perfected. It was more accurate than the thermoscope.
1714	Gabriel Daniel Fahrenheit developed the first widely used measuring scale for temperature. He also perfected the use of mercury in liquid thermometers.
1742	Anders Celsius developed the centigrade scale. It was later renamed the Celsius scale.
1852	The modern form of the mercury-in-glass clinical thermometer was patented.
1861	The electrical-resistance thermometer was invented in Germany. It uses an electrical current to measure temperature.
1970s	The digital thermometer was introduced to consumers for home use. This instrument works in the same way as the electrical-resistance thermometer but has a digital scale.
1990s	The infrared thermometer was introduced to consumers for home use. It uses an infrared sensor to measure temperature. A small tip at one end of the thermometer inserted into a human ear measures the body temperature within seconds; this instrument is particularly useful with infants.



Infrared thermometer

Check and Reflect

1. Use Figure 2.11 to help you explain the difference between heat and temperature.

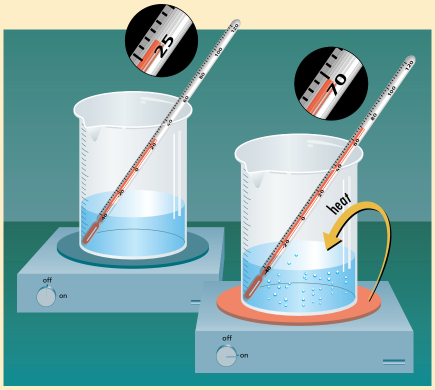


Figure 2.11 Question 1

2. According to its definition, temperature is a measurement of the average kinetic energy of the particles in a substance.
   a) Explain "average kinetic energy" in your own words.
   b) Why is the word "average" important?
3. Describe three major changes to thermometers during the history of their development.

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Canadian Contributions

How have Canadians added to our understanding of heat and temperature? What inventions or ideas have Canadians thought of to share with the rest of the world?

2.3 Heat Affects the Volume of Solids, Liquids, and Gases

When heat transfers from one object to another, the volume of each object is affected. If only a small amount of heat is transferred, you may not notice the difference. But if the difference is great enough, it can affect everyday life. This change in volume caused by heat transfer is an example of the particle model at work.

Observing the Effect of Heat

Think about the following examples. Work with a partner to develop a scientific explanation for what happened in each situation.

1. A large area of concrete is poured as a single slab to create a new outdoor basketball court for your school. The work is done in August before the new school year starts. A very cold winter follows. When spring comes and you and your friends want to use the court, you notice several large cracks in the concrete. It looks like the concrete will need replacing.

2. You are working on your bike on a hot summer afternoon. You need to replace a metal bolt, and you find that it fits inside a metal nut. Leaving most of your tools and the bike sitting in the sun, you take a break for an hour. When you come back, you pick up the bolt and find that it's hot to the touch. You grab the right size of metal nut that has been sitting in the shade. It doesn't fit. You use an identical nut that had been sitting in the sun, and it fits!

3. After getting caught in a summer thunderstorm, you decide to make yourself a mug of hot chocolate. The biggest mugs are in your kitchen freezer, chilled and ready for lemonade on the next hot day. You take one, noticing that the thick glass is covered with a light layer of frost. As you pour the boiling water into the mug, you hear and see it crack.

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Balloon Brothers

Thermal energy can be converted into flight. In 1783, Joseph and Jacques Montgolfier lit a fire under a large balloon made of paper and silk. The fire heated the air inside the balloon, causing it to expand. Since the heated air was less dense than the surrounding air, the balloon was able to rise into the sky.

Figure 2.12 The concrete cracks after a cold winter.

Figure 2.13 Fitting the nut to the bolt

Figure 2.14 Boiling water cracks the chilled mug.

Inquiry Activity

Heating and Cooling a Copper Wire

The Question

What will happen to copper wire when it is heated and cooled?

The Hypothesis

Form a hypothesis based on the question. (See Toolbox 2 if you need help with this.)

Caution!
Always use caution around an open flame.

Materials & Equipment

- 2 retort stands
- about 130 cm of thin copper wire
- metre-stick
- aluminum foil
- paper clip
- steel nut (not galvanized) or any mass of 20–25 g
- candle
- candleholder
- matches

Figure 2.15 Step 3. Adjusting the paper clip and nut

Figure 2.16 Step 7. Heating the copper wire

Procedure

1. Wind and tie the copper wire around the two retort stands. Set the stands about 1 m apart so that the copper wire is taut.
2. Place a sheet of aluminum foil on a tabletop so that it is under the wire.
3. Carefully bend part of the paper clip into a hook shape. Hang the hook from the middle of the copper wire. Hang the nut on the open end of the paper clip.
4. Measure the distance from the bottom of the nut to the aluminum foil on the table. Record this distance.
5. Place the candle in the candleholder, and place the candle and candleholder on the aluminum foil below the wire. Carefully light the candle.
6. Write your prediction of what will happen when you heat part of the wire with the candle. Let the lighted candle heat part of the wire for about 2 min.
7. After 2 min of heating, carefully blow out the candle. Measure and record the distance from the bottom of the nut to the aluminum foil. Let the wire cool. Do not touch it as it will be very hot.
8. After about 10 min, measure and record the distance again from the nut to the aluminum foil.

Collecting Data

9. Make a chart like the one shown below to record your data.

Distance of Nut from Tabletop (mm)		
Step 4	Step 7	Step 8

Analyzing and Interpreting

10. How did the distance from the nut to the aluminum foil change as heat transferred to the wire? How did it change as heat transferred from the wire?

Forming Conclusions

11. Use the particle model to explain what happens to a copper wire when it is heated and cooled. Include a diagram to help make your explanation clear.

Expansion and Contraction of Solids

The particle model of matter tells us that when the thermal energy of a solid increases, so does its volume. We say that the solid **expands**. This occurs when heat transfers to a solid. When the thermal energy of a solid decreases, its volume decreases, and the solid **contracts**. This occurs when heat transfers from the warmer solid to cooler matter.

This is critical information for people who work in a variety of professions. Engineers designing bridges and buildings need to consider this information in their plans. Steel beams will bend or even break if the plans do not allow for expansion and contraction. This process of expansion of a substance caused by an increase in thermal energy is called **thermal expansion**. Expansion joints were invented to deal with this and are used on bridges, highways, and between railroad tracks.

Figure 2.17a) When temperatures are low the space between metal joints is large. When temperatures rise the space between the metal joints closes up.

People who lay pipes for the gas pipelines, construction workers, and steelworkers are only a few examples of people who use the science of expansion and contraction in their jobs.

Figure 2.17b) Workers installing a gas pipeline

Heat Affects the Volume of Liquids and Gases

Like solids, matter in the liquid and gas states will also expand when their thermal energy increases. That is, when heat transfers to them from warmer matter. And they will contract when their thermal energy decreases. That is, when heat transfers from them to cooler matter. Liquids usually expand more than solids do, but not as much as gases do.

Expansion and Contraction in Liquids and Gases

We can see a simple example of expansion and contraction of a liquid in the thermometer. Liquid, usually alcohol, is placed in a narrow glass tube. As the liquid becomes warmer, it expands and rises in the glass tube. As it cools, contraction takes place and the liquid drops down.

Similar principles are at work when there is a change in the heat energy of a gas. Imagine that you are invited to a party in the month of January. At the end of the celebration, you take home a cluster of helium balloons tied to ribbons. It is a very cold night, and you walk quickly. The farther you go, the more the balloons seem to be "wilting." They no longer pull at the ribbons, but now bob near your shoulders. By the time you reach home, the balloons are noticeably smaller and look a bit wrinkled. However, after they have been in your bedroom for an hour, the balloons are in the same condition as when you left the party. Both contraction and expansion have been at work!

Figure 2.18 Why are the balloons wilting?

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Full Steam Ahead!

Steam-powered automobiles were popular in the late 1800s. Some cars could go very fast. In 1906, one car was clocked at 205 km/h! However, by the 1930s, because the internal combustion engine had become popular, steam cars had all but disappeared. How did the steam car work? What was the science behind this invention?

Check and Reflect

1. You and your family give your grandmother a ring for her birthday. Unfortunately, it is too small to fit her finger. How can the concepts of heat and temperature help make the ring her proper size?
2. Write a hypothesis to explain how the particle model of matter explains expansion and contraction. Write your ideas in a paragraph and include a diagram to illustrate your explanation.
3. Use Figures 2.19a)–d) and your understanding of thermal energy, heat, and thermal expansion to answer each question.

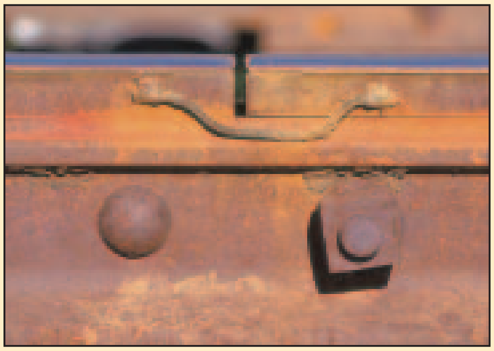

Figure 2.19a) Train tracks span great distances. Spaced many metres apart are small gaps between the rails. What's the purpose of these gaps? What might happen if the gaps weren't there?

Figure 2.19b) Workers set up these electrical cables during the summer. You'll notice that the cables are not stretched tightly. They sag. What is the advantage of leaving some slack when installing electrical cables like these? What might happen if the cables were installed tightly with no slack?

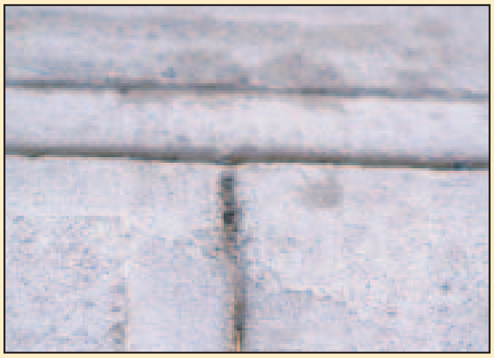

Figure 2.19c) Did you ever notice that sidewalks are made of slabs with gaps between them? What is the advantage of leaving these gaps? What might happen if the slabs were placed right up against each other?

Figure 2.19d) Pop and juice bottles are never filled all the way to the top. What is the advantage of leaving some space in these bottles? What might happen if the bottles were filled completely?

TRY This at Home

ACTIVITY

HOMEMADE HOT-AIR BALLOON

Have you ever watched a hot-air balloon drift across the horizon on a warm evening? You can create your own balloon with a friend or family member by following these steps.

- Find a plastic bag, such as a large garbage bag.
- Check for and seal any holes in the bag.
- Using paper clips, gather parts of the open edge of the bag to make the opening smaller, about 10 cm in diameter. Spread the paper clips evenly around the opening.
- Ask your friend to hold the hair dryer so that the hot-air nozzle is pointed upward. Make sure that the air intake vent of the hair dryer is not blocked. This will prevent the hair dryer from overheating.
- Turn the hair dryer on to its highest heat setting. Be very careful when handling the hair dryer to avoid a burn.
- Gently bring the open end of your bag over the hair dryer, keeping it at least 10 cm away from the nozzle. Hold the bag in place until it appears to be full of hot air. Turn off the hair dryer. Release the bag and watch what happens!

Caution!
Be careful when using plastic bags, especially around younger children.

Materials & Equipment

- large plastic garbage bag
- paper clips
- hair dryer (blow dryer)

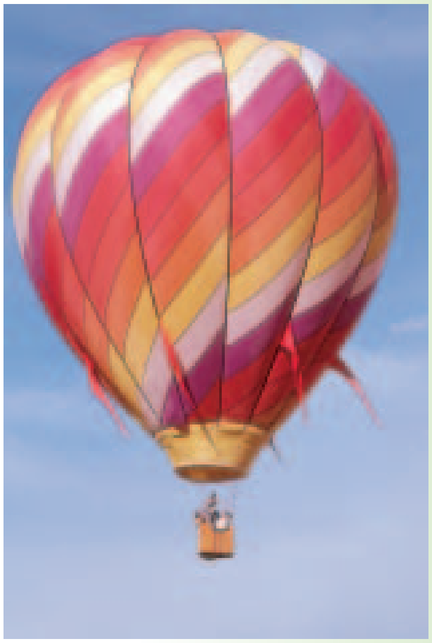

Figure 2.20 A hot-air balloon

Things to Think About

- Did your balloon go straight up or did it have a crooked flight?
- What could you add to your balloon to give you more control over its flight?
- Would using different types of bags make any difference to the results? Why or why not?
- Could you use more than one hair dryer?
- Would using different heat settings on the hair dryer make a difference to the flight of your balloon?
- How could you redesign your hot-air balloon so that it could carry an object like a pen or small toy into the air?

2.4 Heat Transfers by Conduction

If you have ever had the experience of roasting hot dogs or marshmallows over a fire using a wire coat hanger, you have probably noticed that the metal will heat up very quickly and burn your hand if you are not careful. When taking a metal tray from the oven, you need to use oven mitts to avoid a burn. In each of these cases, heat has transferred from the source to another substance.

Figure 2.21 Oven mitts help prevent this person's hands from getting burned.

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Space Insulation

A special thermal protection system prevents space shuttles from burning up on re-entering Earth's atmosphere. The shuttle's high speed compresses the air, which creates intense heat. NASA designers developed a special ceramic tile that can withstand temperatures of nearly 1400°C. Approximately 33 000 of these special tiles are attached to the underside of a shuttle.

Conduction

One way that heat transfers through matter is by **conduction**. Conduction is the transfer of heat energy between substances that are in contact with each other. Here's how it works. Figure 2.22 shows a metal spoon in a cup of hot chocolate. The particles in the hot chocolate are moving rapidly, and they bombard the particles in the parts of the spoon that are in the hot liquid. The spoon's particles that are being pushed around start to move faster, vibrating back and forth. The faster they move, the greater the thermal energy in that part of the spoon. The spoon begins to warm up.

The parts of the spoon that are not in the hot chocolate become warm because of the movement of other particles within the spoon. The fast moving particles in the part of the spoon that had been warmed by the hot chocolate now bump into their neighbours in the spoon's handle. These particles speed up and bump into those next to them. And so on, until all the particles in the spoon are moving faster. Think of it as a chain reaction. None of the particles move from one end of the spoon to the other. The particles stay in the same part of the spoon. They simply transfer the energy by bumping into each other.

Figure 2.22 A metal spoon in a mug of hot chocolate. Heat is transferred from the hot liquid to the spoon. The particles in the spoon speed up and the spoon becomes hot.

Problem Solving
Activity

THE BUTTER TEST

Recognize a Need

You are doing research for a company that makes electrical appliances. These appliances generate a lot of heat, so designers want to use materials that will enable the heat to be removed. At the same time, they have to consider the cost of the materials. You have been asked to recommend the best conductor based on performance and cost. You will make your recommendation using data from the "butter test" and the cost information provided. The butter test involves placing a small amount of butter at one end of a piece of each material. You then place the other end of the material in hot water. The faster the butter melts, the better conductor the material is.

Materials & Equipment

- beaker or other suitable container for hot water
- butter or margarine
- assorted materials for testing
- paper towels

The Problem

What material will be best to use in the appliances based on cost and conducting ability?

Criteria for Success

For your recommendation to succeed, you must meet the following criteria:

- You must design a butter test for the materials provided to determine which material will melt the butter the fastest.
- You must base your recommendation on the butter test and the information you are given about the cost of each material.
- You must communicate your results using diagrams, charts, or graphs.

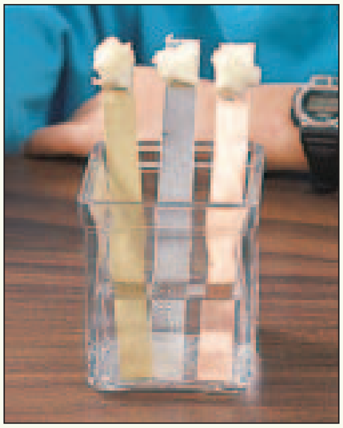

Figure 2.23

Brainstorm Ideas

1. Your teacher will tell you what materials are available and the cost of each.
2. Working with your group, determine which variable is the manipulated variable and which one is the responding variable in your test. What variables will you be controlling (or keeping constant)? Record your ideas.
3. Determine how you will set up your butter test to ensure your variables are all controlled.
4. Create a plan and have it approved by your teacher before continuing.

Test and Evaluate

5. Perform your test based on your plan.
6. Record your results.

Communicate

7. Based on cost, what is the cheapest material to use for the appliances?
8. Based on conducting ability, what is the best material?
9. Based on a combination of cost and conducting ability, what is the best material to use?
10. Illustrate your results using diagrams, charts, or graphs.

Conductors

One of the key characteristics of conduction is that heat transfers in only one direction—from areas of greater kinetic energy to areas of less kinetic energy. That is, heat transfers from areas having more thermal energy to areas having less thermal energy. One example is placing a hot water bottle next to cold skin. The hot water bottle contains more thermal energy than the skin does. So heat transfers from the hot water bottle to the skin. Although the temperature of the skin rises as conduction takes place, none of the matter from the hot water bottle moves to the skin. The skin becomes warm because of energy transfer between particles.

Conduction is most common in solids. It is less common in liquids, and it is rare in gases. Materials that allow easy transfer of heat are called **conductors**. Metals are examples of good conductors of energy.

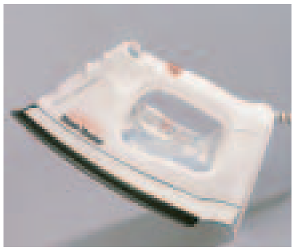

Figure 2.24 An iron

Figure 2.25 A metal pot and lid

Figure 2.26 A curling iron

Insulators

Insulators are materials that do not allow easy transfer of heat. They reduce the amount of heat that can transfer from a hotter object to a colder one. Plastic, cork, and wood are good insulators. This means that they are poor conductors of heat.

In household products that use heat, we often combine insulators with conductors to create safe tools. Look at Figures 2.24 to 2.26. Identify which parts of each device are conductors and which parts are insulators.

Check and Reflect

1. What are the three types of changes that may happen when heat transfers into or out of matter?
2. Explain the difference between a conductor and an insulator, and give at least three examples of each.
3. The sun heats a wooden door and a metal knob on the outside of the door. What happens to the metal knob on the other side of the door? Write a paragraph using the words *heat energy*, *kinetic energy*, *conduction*, and *insulation* to explain the situation.

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A Good Idea?

Use print or electronic resources to research what material is the best conductor, and list two of its uses. Prepare a diagram showing how it works in each situation, and a written summary of your results.

2.5 Heat Transfers by Convection and Radiation

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Burning Hot!
The average surface temperature of the sun is 5500°C. The temperature at the centre of the sun is thought to be 15 000 000°C. Less than one billionth of the sun's total energy output reaches Earth.

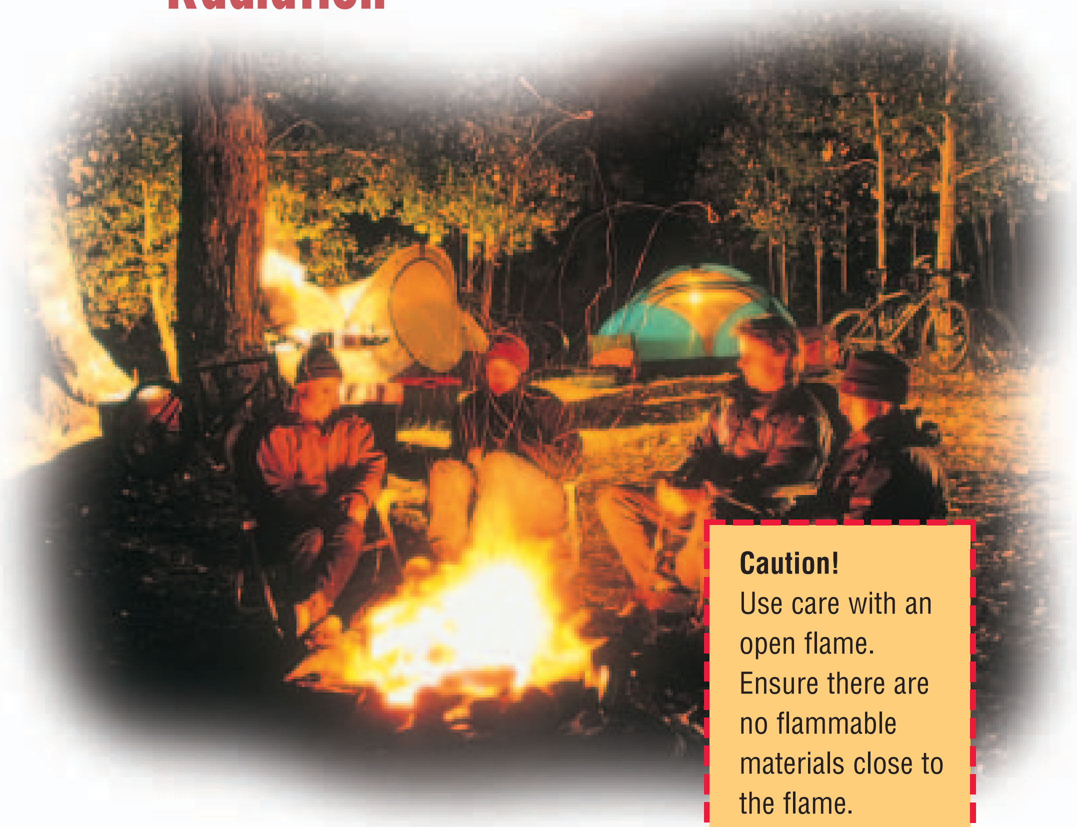

Figure 2.27 Sitting around a campfire

Caution!
Use care with an open flame. Ensure there are no flammable materials close to the flame.

If you have ever sat by a campfire on an evening when there was little wind, you may have noticed that the sparks from the fire did not simply go straight up into the air. Rather, they seemed to swirl and travel in an almost circular motion. If you added paper to the fire, you would have seen a similar motion as the embers (pieces of paper that are still glowing with fire) moved above the fire.

Give it a TRY ACTIVITY

CANDLE MAGIC

Work with a partner. Predict what the smoke will look like when you blow out a candle. Then, light a candle and let it burn for about 15 s. Gently blow out the flame. Notice what happens to the thin ribbon of smoke as it moves above the candle. Was your prediction correct?

Understanding Convection

Another way that heat transfers through matter is by convection. In convection, heat is transferred when liquid or gas particles move from one area to another. Recall that in conduction, the particles do not move—only the heat does. In convection, the particles themselves move. For this reason, convection occurs only in liquids and gases.

Convection Currents

Heat transfer by convection occurs when the particles in a liquid or gas move in circular patterns called **convection currents**. Convection currents form when heat transfers to liquids or gases. Figure 2.28 shows how convection currents form in a pot of water on the stove.

Heat first transfers to the bottom of the pot from the hot burner by conduction. In turn, heat transfers from the heated bottom of the pot to the water that is in direct contact with it. The kinetic energy of the water particles increases. They move faster and spread farther apart. In other words, the water at the bottom of the pot expands.

As the water expands, it becomes less dense and rises up to the surface. The particles in the rising warm water push the cooler particles at the top aside. This cooler water sinks toward the bottom of the pot to fill the space left by the rising warm water. When the cooler water reaches the bottom, it too heats up and expands. It rises, leaving space for more water from the top to sink downward.

As the water moves away from the heat source, it cools down slightly. When it reaches the top of the pot, it comes in contact with the air. Energy from the water transfers to the air, and the water cools down even more. This cooler water is pushed to the sides by the warmer water rising underneath it. The cooler water drops down along the sides of the pot. Here, too, energy is lost through heat transfer from the water to the pot and the air outside.

This sets up a circular convection current. As long as heat continues to transfer from the hot burner, this pattern of convection currents continues to transfer heat throughout the water.

Figure 2.28a) *Heat from the hot element reaches the water particles at the bottom of the pot by conduction.*

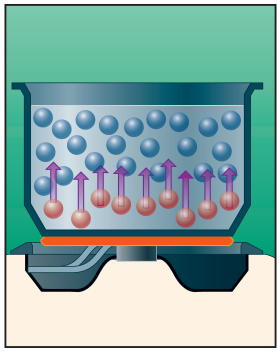

Figure 2.28b) *The heated water expands and becomes less dense. Hot particles begin to rise, pushing the cooler particles at the top to the sides.*

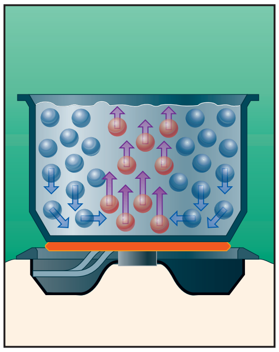

Figure 2.28c) *The cooler particles sink from the top to take the place of the rising particles.*

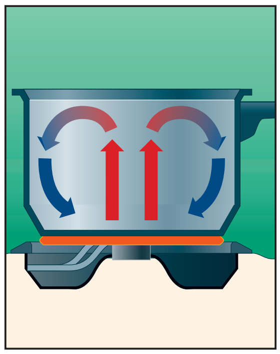

Figure 2.28d) *As the particles reach the bottom, they in turn are heated. The processes in Figures 2.28a)–c) repeat continually to result in a convection current.*

Inquiry
Activity

Investigating Convection

Materials & Equipment

Part 1
- smoke box
- small candle
- splint or incense stick to produce smoke
- fire safety equipment

Part 2
- small jar and lid with small hole in it
- warm water
- food colouring
- 70-cm string
- 2000-mL beaker
- cold water

The Question

How does convection transfer heat in fluids?

Procedure

Part 1 Convection in a Gas (Teacher Demonstration)

1. Set up the smoke box as shown in Figure 2.29.
2. Slide open the plastic front cover of the smoke box and light the candle. Slide the plastic cover back into place.
3. Wait for 1 min, and then light the splint or incense stick.
4. When the smoke from the splint or incense stick becomes visible, carefully hold the splint or incense stick at the top of the chimney on the side without the candle. Record your observations.

Figure 2.29 Set-up of smoke box

Part 2 Convection in a Liquid

5. Fill the jar to the top with warm water that has been coloured with food colouring. Screw the lid on tightly. Tie each end of the string around the top of the jar below the lid to create a handle.
6. Fill the beaker two-thirds full of cold water. Lower the jar into the beaker until it is completely submerged but not touching the bottom of the beaker.
7. Record your observations when you first submerge the jar and then at 30 sec, 60 sec, and 120 sec after submerging it.

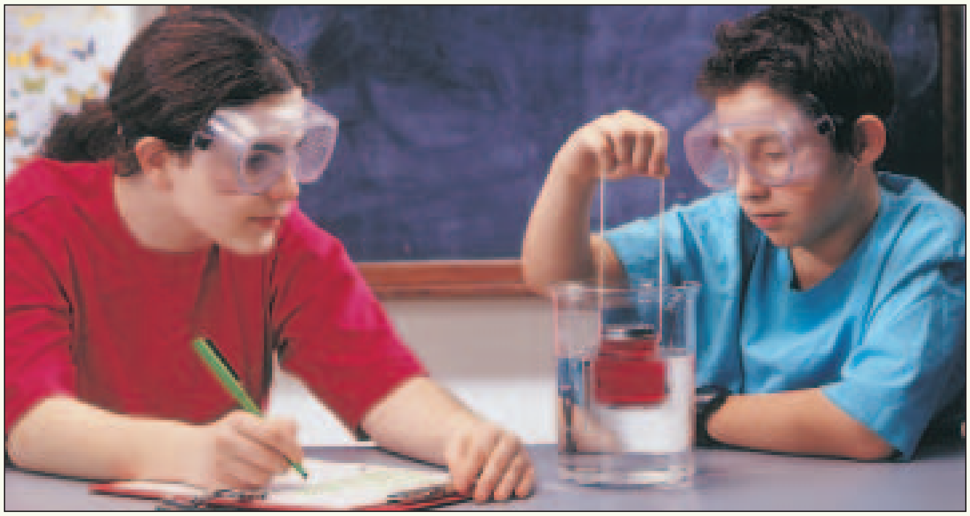

Figure 2.30 Observe what happens to the coloured water in jar.

Collecting Data

Part 1

8 Draw the smoke box set-up when the candle is lit.

9 On your drawing of the smoke box, draw the path of the smoke after the splint or incense stick is lit and held above the smoke box.

Part 2

10 Record your observations in words and diagrams.

Analyzing and Interpreting

Part 1

11 What path did the smoke from the splint or incense follow? Did you see any evidence that hot air rises? If so, what is this evidence?

12 What surprised you about the path of the smoke?

13 What effect do you think the heat from the candle is having on the air inside the smoke box directly above the candle?

14 As the candle heats up the air above it, what do you think is happening to the rest of the air inside the box? Outside the box?

Part 2

15 What happened to the warm water as it remained submerged in the cold water? Why do you think this happened?

16 Are there any similarities between your observations in part 2 of this activity and those in part 1? Provide examples to support your answer.

Forming Conclusions

17 Using your observations and discussions in class, describe how the process of convection transfers heat in a liquid and a gas.

Convection Currents in Air

As with conduction, heat transfers by convection move in only one direction. It moves from an area of greater kinetic energy to one of lesser kinetic energy. Think about being in a cold room that has a heater in one corner. When the heater is first turned on, the only part of the room that is warm is the space closest to the heater. As the air near the heater heats up, it expands, becomes less dense, and rises. Cooler air moves in to take its place near the heater. This air is then heated, and it rises. Convection currents form, and eventually the entire room becomes warm.

Energy Efficient Windows

Heat transfer by convection from a heater or in a cooking pot delivers heat energy where it is needed. However, convection can also cause heat loss. This used to be a problem in windows in houses. In the summer, people needed only one pane of glass in their windows. But our cold winters meant two panes of glass were needed to make houses feel more comfortable. Every fall, people would add another window called a storm window. These helped to keep houses warmer by reducing drafts and providing a bit of extra insulation. The extra insulation came from the air space between the inner and outer windows. Air is a poor conductor of heat.

The problem with the old storm windows was that they weren't very efficient. They still lost a lot of heat because convection currents would form in the air space between the panes of glass. The convection currents would transfer heat from one pane of glass to the other. Energy efficient windows are designed to reduce heat transfer. They do this by preventing convection from occurring between the panes of glass. Some windows contain a gas such as argon or krypton to improve their performance in reducing heat transfer. These gases are better insulators than air. They do not move as easily in convection currents as air does.

Figure 2.31 An energy efficient window

Heat Transfers by Radiation

Conduction and convection are two ways that heat transfer occurs. **Radiation** is the third. Both conduction and convection rely on the movement of particles to transfer heat energy. Radiation does not. Think of all the energy we receive from the sun every day. It reaches us across millions of kilometres of space where there are very few particles. Radiation is the transfer of energy by invisible waves that can travel great distances. Energy transferred from its source by radiation is called **radiant energy**. Heat is only one type of radiant energy. It is transferred by invisible waves called **infrared waves**.

When the invisible radiant energy waves come in contact with an object, the particles in the object increase in kinetic energy. The particles move faster and the object becomes hotter. Every hot object produces some radiant energy. That's why your hand feels warm when you hold it near a hot object without touching it. The heat you feel is transferred to you by radiation.

Figure 2.32 Even on a cold day, the sun's radiation can heat the floor.

You get into a car that has been parked in the sun on a hot, sunny day. It is hot inside—the fabric seat feels quite warm. But try touching the dashboard. It's probably so hot that it can almost burn your hand! Part of the reason for this is that the different materials absorb the sun's heat to different extents. Now, think about the clothing you have worn on hot, sunny days. Do you recall how you felt when you wore light-coloured and dark-coloured clothing? How do you think the different colours affect the absorption of the sun's heat?

Inquiry
Activity

HEATING DIFFERENT COLOURED SURFACES

The Question

How do different colours of surfaces affect the absorption of heat transferred by radiation?

The Hypothesis

Restate the above question in the form of a hypothesis.

Materials & Equipment

- 2 large test tubes
- test-tube rack
- sand
- white paper
- scissors and tape
- 2 thermometers
- black paper
- 100-W light bulb (optional)
- timer

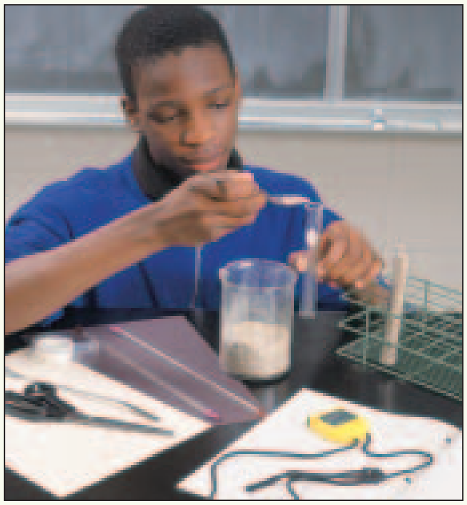

Figure 2.33a) Step 1. Filling the test tube with sand

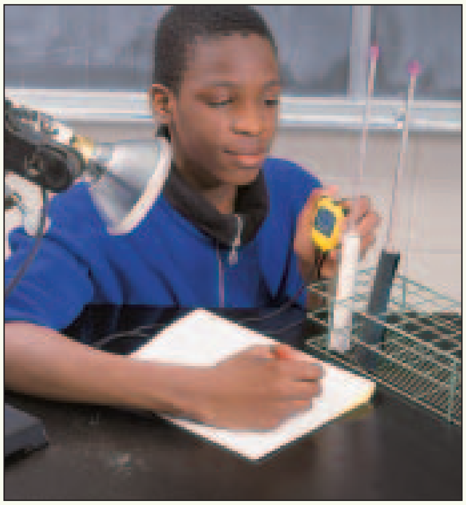

Figure 2.33b) Step 8. Using the stopwatch to keep track of time

Procedure

1. Fill each test tube with sand to the top.
2. Tape white paper around one test tube so that it is fully covered, including the top.
3. Cut a small hole in the top and carefully insert a thermometer about 5 cm into the sand. Gently tap the test tube to pack the sand as you insert the thermometer. Put the test tube back in the test-tube rack.
4. Repeat steps 2 and 3 with the other test tube using black paper. Make sure that the thermometers are inserted to the same depth in the two test tubes. Put the test tube in the same rack next to the white test tube.
5. Read the thermometers and record the temperature of the sand in the test tubes.
6. Place the test tubes in the rack in the sun on a window sill. If there is no sun, use a 100-watt bulb as a heat source and put the rack 20 cm in front of the bulb.
7. Predict which test tube will heat up faster in 15 min.
8. Read and record the temperature in each test tube every 3 min for 15 min.

Collecting Data

9 Record your temperature readings in a data chart like the one shown here.

White Tube		Black Tube	
Time (min)	Temperature (°C)	Time (min)	Temperature (°C)
0		0	
3		3	
6		6	
etc.		etc.	

Analyzing and Interpreting

10 Use your data to draw a graph showing how the temperature of the sand changed over time in each test tube.

11 Based on your graphs, which test tube heated up faster?

Forming Conclusions

12 Present your results in a summary in paragraph form. Your summary should answer the following questions:
- Which of the two test tubes absorbs more heat from the sun?
- What do you think your results would be if you had added a third and a fourth test tube and used orange paper on one and aluminum foil on the other to cover them? Explain your reasoning.

13 How did the results compare with your hypothesis?

Applying and Connecting

Clothing designers may use certain colours during one season but not the next. Most people wear white or other light colours in the summer to reflect the sun's heat. In winter, black or dark colours are the choice for many people since they absorb heat. Designers know this and keep it in mind when choosing fabrics.

Figure 2.34 Dressing for the different seasons

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Planets of the Solar System

Of the planets in the solar system, Mercury is closest to the sun. However, Venus, its neighbour, has a higher average surface temperature. Why?

Reflect or Absorb?

Matter can reflect or absorb radiant energy. Objects that are shiny and light coloured are good reflectors of radiant energy. So on a hot, sunny summer day, to stay cool, you would probably choose light-coloured clothing. Dark and dull objects are good at absorbing radiant energy. If you have been on a black sand beach such as those found in parts of Europe, the Caribbean, or the South Pacific, on a sunny day, then you know just how good dark colours are at absorbing radiant energy! At the hottest point in the day, the skin on the soles of people's feet will begin to burn if they run barefoot over a long stretch of sand.

Figure 2.35 A black sand beach in Spain

Check and Reflect

1. Explain how convection works to make your bedroom warm.
2. Use what you have learned about convection to explain why the floors in most homes are cold in winter.
3. Tanning studios have become popular in the past few years. How can you get a tan in a tanning studio?
4. If more radiant energy was allowed to reach the surface of Earth, what do you think might happen? Why?