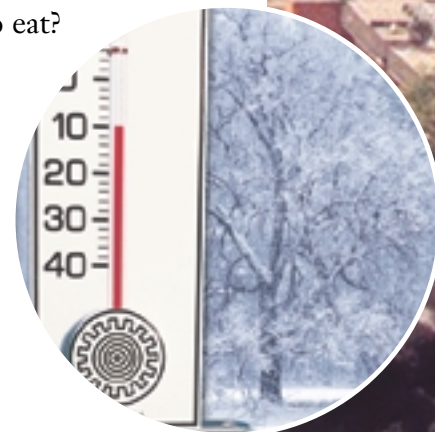


# Heat and Temperature

Imagine a world where people had not learned how to warm or cool anything. Without furnaces or air conditioners, homes and schools would get uncomfortably hot or dangerously cold. No one would ever enjoy a hot meal (no stoves) or an ice-cream treat (no freezers). Almost nothing would be made of metal or glass because these materials require intense heat for shaping. Automobiles, trucks, buses, and even bicycles would not exist. Most of the comforts and conveniences we now enjoy would not exist.

There is no question that devices that use heat and control temperature make our homes more comfortable and our lives more convenient. However, what happens to heat when you open the refrigerator door and stand gazing inside, wondering what to eat? How many hours in a month or a year is your refrigerator door open? How does that affect the amount of energy it uses? If you decide what you want to eat before opening the refrigerator door, will that make a difference? What if your whole class or your whole school decides to limit the amount of time their refrigerator doors stay open? What would be the impact of such an action? In this unit you will investigate some scientific principles that will help you make knowledgeable decisions about energy use.







## Unit Contents

### TOPIC 1

Using Energy  
from Heat **188**

### TOPIC 2

Measuring  
Temperature **192**

### TOPIC 3

The Particle Model,  
Temperature, and  
Thermal Energy **202**

### TOPIC 4

Expansion and  
Contraction **210**

### TOPIC 5

The Particle  
Model and  
Changes of State **218**

### TOPIC 6

Transferring  
Energy **226**

### TOPIC 7

Sources of  
Thermal Energy **238**

### TOPIC 8

Conserving  
Our Fossil  
Fuels **248**



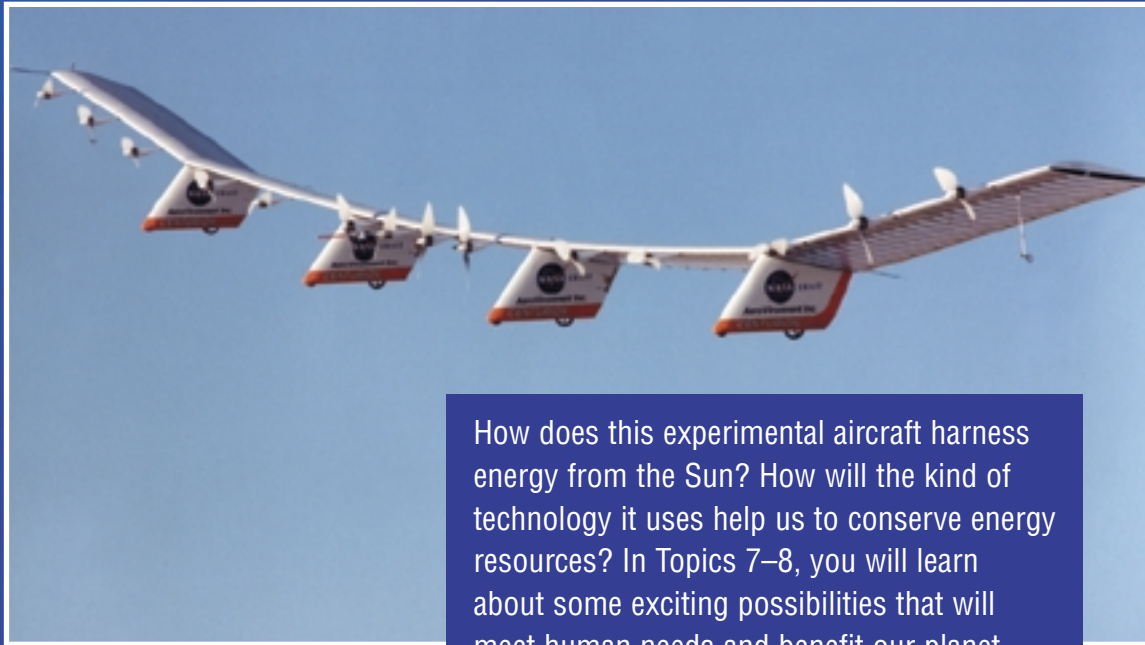
**Focussing  
Questions**

- How do you use energy every day?
- What happens to materials when they are heated?
- How can we reduce the amount of energy we use?

How does the energy that keeps us warm and cooks our food get out of control? What do we do then? Topics 1–3 will introduce you to the basics of heat and temperature. You will then move on to find out how to control this energy and how to use it efficiently.



Up and away! Heat technology enables hot air balloons like this one to take off, float through the air, and come back to land. Heat affects other substances, besides air. In Topics 4–6, you can find out what they are and how controlling them benefits us.



How does this experimental aircraft harness energy from the Sun? How will the kind of technology it uses help us to conserve energy resources? In Topics 7–8, you will learn about some exciting possibilities that will meet human needs and benefit our planet.

A tablet device is shown at an angle, displaying a list of activities. At the top right of the tablet is a circular icon with the text "Looking Ahead" and a green arrow pointing right. The text on the tablet is as follows:

Read the Unit Issue Analysis on pages 260–261. Will there be enough energy resources to last throughout your lifetime? your children’s lifetime? your grandchildren’s lifetime? How can you get ready for your issue analysis? Here are some ways:

- Start a Solar Centre for material you find about solar energy.
- Become Super Savers by making an energy-saver poster.
- Become Internet Experts. Research and bookmark solar energy sites on the Internet.
- Become Energy Sleuths. Find out about energy and how it “works” by doing the activities and investigations in this unit.





# 1 Using Energy from Heat



**Figure 3.1A** Open fires cook food, but they are hard to control, dangerous, and messy.

Since ancient times, people have needed thermal energy (heat) to cook their food and to keep them warm. And since the beginning of time, uncontrolled heat has scorched and spoiled the taste of food and has destroyed buildings and homes. In what ways have humans made thermal energy work for them?

Look at the following photographs to see some of the ways in which this form of energy has been used throughout history.



**Figure 3.1B** Open wood-burning fireplaces (at right) draw the warmth from a room. Modern gas fireplaces (above) use energy efficiently, directing warm air back into the room.



**Figure 3.1C** Pioneer stoves did double duty heating the home and cooking the food.



**Figure 3.1D** Modern stoves are attractive, easy to control, and relatively safe to use.



**Figure 3.1E** This Inuit hunter has built an igloo shelter. When he perspires inside the igloo, the moisture will condense when it hits the ice, sealing the igloo.



**Figure 3.1F** Sod houses provided protection from the weather, and the soil helped to prevent heat from escaping.

- ☀ Initiating and Planning
- ☀ Performing and Recording
- ☀ Analyzing and Interpreting
- ☀ Communication and Teamwork

# Using Energy



## Think About It

How are your home and school heated? What cooking devices do people in your community use most often—stoves, microwave ovens, toaster ovens, or other appliances? What sources of energy heat buildings and cook food, and power other daily activities where you live? Do people you know rely on solar energy, electricity, natural gas, propane, or fuel oil? Use your skills of communication, organization, and interpreting data to find out.

## Procedure

- 1 With your group, prepare a survey similar to the one shown here. Use it to find out from family and community members the different ways of cooking food and heating homes and workplaces that are used in your community. Find out how often each method is used and why it is chosen.
- 2 From your group, select one member to be part of a class delegation. The delegation will interview people at your school who look after the heating and ventilation system and any cooking facilities. The delegation can arrange one meeting with the appropriate person(s) and then report back to the other groups.

- 3 Use library or Internet research to try to find out which energy source is most commonly used in Alberta for:
  - (a) heating
  - (b) cooking
- 4 Chart the class results of your survey and research.

Respondent	Source of energy to heat building	Source of energy to cook	Method	Why chosen?
Person 1				
Person 2				
Person 3				

## Analyze

1. According to your results, which source(s) of energy are used most commonly for heating buildings and cooking food in your community?
2. How well do the results of your survey agree with your findings about the most common energy choices across Alberta? Suggest reasons for any differences.

## Extend Your Knowledge

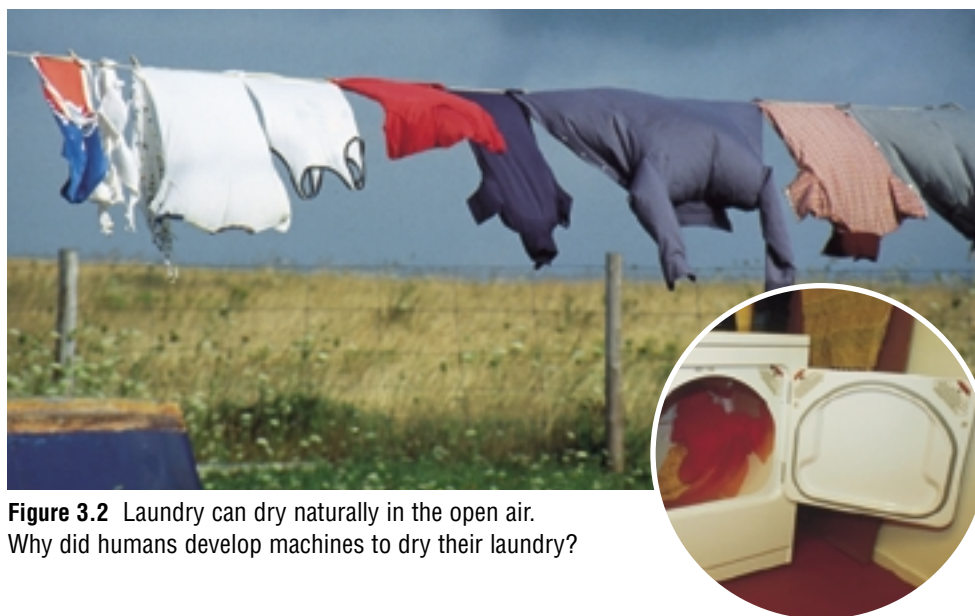
Find out what sources of energy are commonly used in other provinces. Why might the use of these particular sources of energy sometimes result in problems for the users? (You might find out, for example, about the source of energy that is used in the province of Québec. Why did it pose a problem during the Ice Storm of January 1998?)



New technology in electric blankets can help warm up your cold feet without scorching the rest of your body. These blankets have micro-sensors that work like invisible thermostats. They measure the temperature of different parts of your body and generate heat accordingly.

## More Uses of Energy

Over the years we have learned a great deal about efficient ways of heating our homes and cooking our food. The pan of water that boiled dry over the cookfire has been replaced by a whistling kettle on a gas or electric stove. Even more advanced technology has given us “cordless” electric kettles that shut themselves off when the water they contain reaches boiling point. Many other technologies also use thermal energy to make our lives easier or more comfortable.



**Figure 3.2** Laundry can dry naturally in the open air. Why did humans develop machines to dry their laundry?

As people’s ways of life, needs, and wants change, we learn new ways to change and improve technology. As a result, we often can choose among several ways of doing a task. For example, you might sometimes wash your hair and let it dry naturally. If you wash it before you come to school, you might need to dry it more quickly, especially in winter. To do so, you can choose to use a hair dryer.



### Looking Ahead

Ask adults you know whether they feel energy conservation is important. If any can suggest ways to conserve energy for cooking and home heating, add their ideas to your Super Saver poster.

As you work through this unit, you will understand how some of these methods work (or why they do not work!).



**Figure 3.3** Hair dryers are made to meet various kinds of needs. Why are the buttons necessary?

### INTERNET CONNECT

[www.mcgrawhill.ca/links/sciencefocus7](http://www.mcgrawhill.ca/links/sciencefocus7)

Find out about “soddies.” Click on **Web Links** to find out where to go next. Write a story about a day in the life of a “soddie” dweller.





## How Was It Made?

Heat technology has been used extensively in industry, as you will see in this activity.

### Materials

access to the Internet (if available)

library resources

audiovisual materials

writing materials

### Procedure



Performing and Recording

Communication and Teamwork

1. With your group decide which of the following areas involving the use of heat-related technologies you would like to investigate:

- ceramics
- metallurgy (working with metals)
- use of engines

You will be finding out about the history of each industry and presenting an audiovisual report on your findings.

2. Decide how to divide the tasks among your group members.
3. Use as many research resources as you can to find out information such as the following:
  - When did this industry begin?
  - Why did it begin? (What needs led to its start and development?)

## Find Out ACTIVITY

- What does it produce? If the product is used in a further process or to produce another product, what is the process?
  - Were there times when the industry grew especially slowly or quickly?
  - What other events in history might have affected its growth or lack of growth?
  - How has the technology changed over time?
  - What has brought about those changes?
- Add your own questions to investigate.

4. When you have completed your research, prepare an audiovisual presentation about what you have learned. Use charts and graphs wherever possible. Be sure to indicate the sources of the information you found.
5. Complete your report by suggesting (with reasons) what your group thinks the future holds for this industry.

### What Did You Find Out? Analyzing and Interpreting

1. What kinds of events slowed or speeded up growth in the industry you investigated? Why do you think that was the case?
2. Will future changes in the industry be based on changing needs or on the availability of newer technology — or are the two really the same thing?

## TOPIC 1 Review

1. What problems have people experienced in using energy from heat? Give some examples from the text and from your own experience of ways people have tried to resolve these problems.
2. **Apply** What need can you identify in your own life that current technology does not meet? Share your ideas with a partner or with your group and try to think of a new device that will benefit you and your group. Prepare a computer graphic to describe and advertise it.





*“Ooh, that wind is as cold as ice. Better stir up the campfire to get those red-hot coals burning again. There, that feels a lot warmer. I hope my hot chocolate hasn’t cooled down too much.”*

You probably think of temperature as a number that tells you how hot or cold something is. That is a practical, everyday definition. As you work through this Topic and the next, you will learn more about the scientific picture of temperature.

Everyday life is full of descriptions of temperature; that is, how warm or cool things are. One way to estimate temperature is just to touch something. Some nerve endings in human skin are quite sensitive to different temperatures, so people can learn to recognize the feeling of particular temperatures by experience. Health-care workers can recognize dangerous body temperatures by touching a patient’s forehead with the back of a hand. People who work with very hot, glowing materials can estimate the temperature of the materials by the colour of the light they give off. Welders and glass blowers can estimate when a flame is hot enough to soften metal or glass. Astronomers judge the temperature of stars by the colour of the light they emit.

Estimating temperatures with your eyes or skin is not always safe or reliable, however. Even if glass and metal are not glowing, they can be hot enough to burn you badly. In the winter, when the air temperature rises above freezing after a cold snap, people feel warm and take off their heavy clothing. In the summer, cool winds before a thunderstorm can make people shiver and reach for sweaters, even though the temperature is still far above freezing.

### DidYouKnow?

The record Canadian low temperature of  $-62.8^{\circ}\text{C}$  was recorded at Snag, in the Yukon Territory. The Canadian record high temperature of  $45^{\circ}\text{C}$  was recorded in Sweetgrass, Saskatchewan. Try to locate Snag and Sweetgrass on a map of Canada. Then try to find the record high and low temperatures in your area and the dates they were recorded.

## Find Out **ACTIVITY**

### Baffle Your Skin


How hot something seems to be when you touch it depends on how warm your skin already is. You can experience this for yourself.

#### Materials

3 bowls of water, large enough to dip a hand in  
hot (not burning) tap water  
room-temperature water  
cold tap water

#### Procedure **Performing and Recording**

1. Put one hand in the bowl of cold water and the other hand in the bowl of hot water. Hold them there for 1 min.
2. Quickly put both hands in the bowl of room-temperature water. Notice how each hand feels.

3. Repeat steps 1 and 2, but switch hands in step 1.
4.  In clear sentences, record how warm the room-temperature water felt to each hand in step 2 and in step 3.

#### What Did You Find Out? **Analyzing and Interpreting**

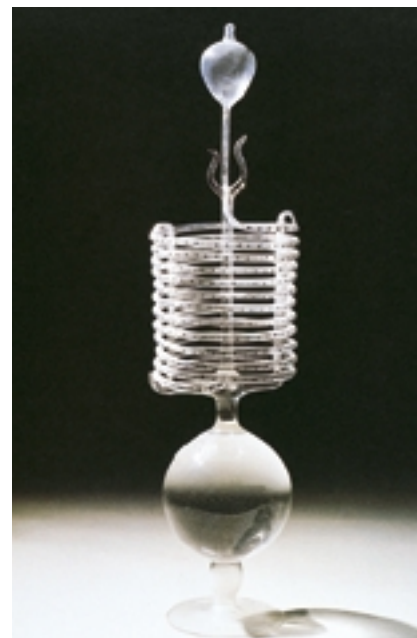
1. Was there any difference in your observations in steps 2 and 3? If there was, suggest a reason why.
2. Use your observations in this activity to explain how the same air temperature can seem warm in the winter and cool in the summer.

## Thermometers

Your senses are easily fooled, but **thermometers** are more reliable. Thermometers are mechanical or electrical devices for measuring temperature. A thermometer similar to the one in Figure 3.4A was constructed by the Italian scientist Galileo in the early seventeenth century. One hundred years later, the design was improved, as Figure 3.4B shows. However, an important part of modern thermometers was still missing. Examine the photographs carefully to find out what it was.



**Figure 3.4A** Galileo invented his air thermometer around 1600. As the air in the upper bulb cooled or warmed, a bubble of liquid moved up or down in the tube.



**Figure 3.4B** More portable thermometers, like this liquid thermometer invented around 1700, were made by putting the liquid in the bulb and part way up the stem.



## Temperature Scales

When you examined Figures 3.4A and 3.4B, you probably noticed that these early thermometers do not have **scales**. That is, they have no markings with numbers to indicate a precise temperature. As scientists discovered more and more about the effects of temperature, they needed to measure temperatures precisely. Modern thermometers, such as the one in Figure 3.4C, have gradations or evenly spaced lines that allow you to read exact temperatures.



**Figure 3.5** Anders Celsius suggested his temperature scale in 1742.



**Figure 3.4C** A modern laboratory thermometer has a smaller bulb and a much narrower opening in the glass stem.

For any form of measurement, someone has to decide on a unit and a standard for comparison. Today, the temperature scale commonly used in Canada and many other countries is called the **Celsius scale** in honour of Anders Celsius (1701–1744). He used the “degree” as the unit of temperature. He based his standards for comparison on the properties of water, the most abundant liquid on Earth. Celsius assigned zero degrees to the temperature at which ice melts at sea level. He assigned a value of one hundred degrees to the temperature at which liquid water boils at sea level. Then he separated the region between these temperatures into 100 evenly spaced units or degrees. (The degrees below zero and above 100 are also evenly spaced.)

### DidYouKnow?

It takes less time to make a mug of hot chocolate on top of a mountain. Water boils at lower temperatures the farther above sea level you go.



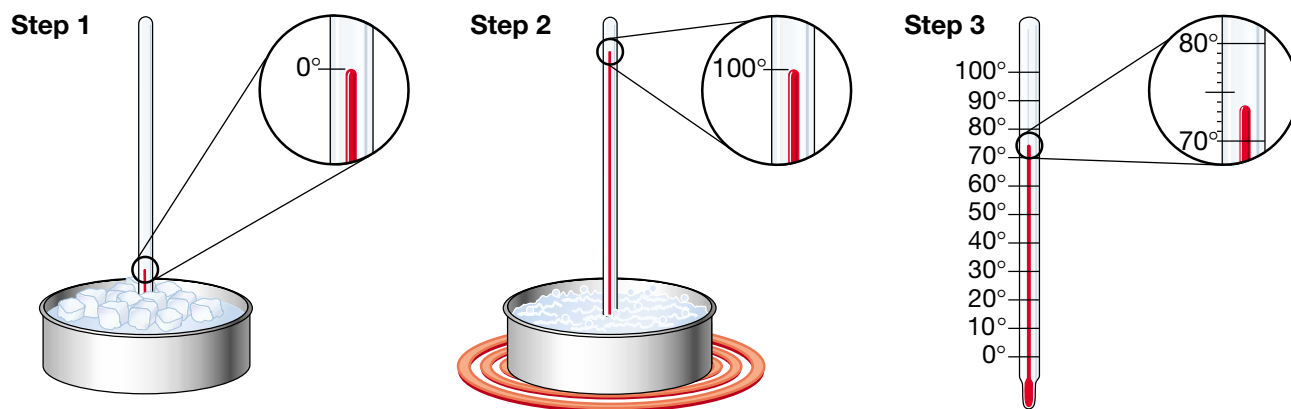
loose and packed snow

“firn”  
(snow/ice grains)

solid glacial ice

moving (plastic) ice

**Figure 3.6** The bottom layer of a glacier does not behave like solid ice. It acts more like a very stiff liquid! The tremendous weight pressing down on the base of the glacier slowly squeezes the ice crystals out of shape, causing the glacier to flow forward. High pressure also changes the nature of ice crystals in other ways. Light shining through the lower part of the glacier appears bluish-green even though ice itself is colourless.



The liquid level in an ice-water bath is marked as  $0^\circ$ .

The liquid level in boiling water is marked as  $100^\circ$ .

The scale is divided into 100 equal degrees and numbered.

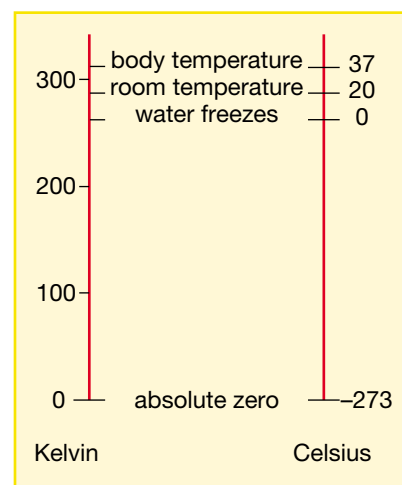
**Figure 3.7** Steps in calibrating a Celsius thermometer at sea level.

The two fixed temperatures that Celsius chose — freezing water ( $0^\circ\text{C}$ ) and boiling water ( $100^\circ\text{C}$ ) — can be used for calibrating thermometers. Study Figure 3.7 to find one way this can be done. To be accurate, this type of calibration must be done at sea level using very pure water. Impurities in water change its boiling and freezing points. Salt water, for example does not freeze until it is colder than  $0^\circ\text{C}$ .

Pressure also affects the boiling point and freezing point of water. Extremely high pressures, such as those under a glacier or a skate blade, cause ice to flow or even melt at temperatures below  $0^\circ\text{C}$  (Figure 3.6). Ice skaters actually glide on a thin layer of water! Under low pressure, water boils before it reaches  $100^\circ\text{C}$ . In Alberta, for example, the high altitude means that the weight of the air above you is smaller than it would be at sea level. As a result, water in Alberta boils at several degrees less than  $100^\circ\text{C}$ . At the top of Mount Everest, water would boil at only  $69^\circ\text{C}$ .

As scientists developed theories to explain the behaviour of gases at different temperatures, they realized that they needed a temperature scale that started at the coldest possible temperature, or “absolute zero.” This new temperature scale was named the **Kelvin scale**, in honour of William Thomson (1824–1907), who was given the title Lord Kelvin. Although no one has ever been able to cool anything down to absolute zero, scientists predict that the temperature is  $-273.15^\circ\text{C}$ .

The units of temperature on the Kelvin scale are not degrees but are simply called kelvins. For example, the freezing temperature of water at sea level is 273.15 K (read, two hundred seventy three point one five kelvins). When it is not necessary to be extremely precise, this temperature is usually rounded to 273 K.



**Figure 3.8** The Kelvin temperature scale is used by scientists. Try to use the diagram to express room temperature, body temperature, and other common temperatures in Kelvins.



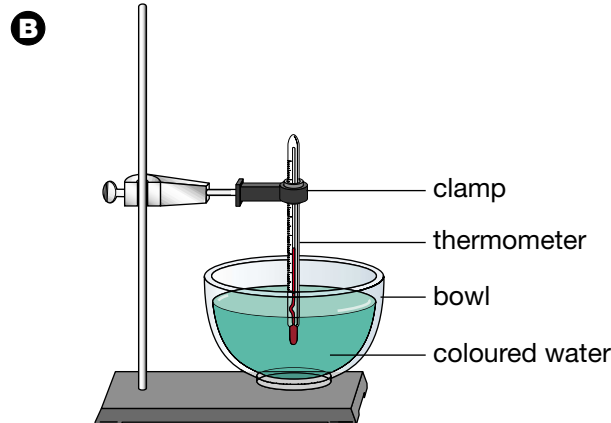
Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

# Make Your Own Thermometer



Today thermometers and other scientific instruments are mass-produced in factories. Early scientists, however, had to build their own measuring devices. Their clever designs used everyday materials, yet produced accurate measurements. Can you use modern materials to build a working model of one of the earliest thermometer designs?

## Challenge

Use everyday materials to build a thermometer that accurately measures temperatures in your classroom.

### Materials

small glass bottle with a narrow neck (for example, a small pop bottle)

drinking straw or length of tubing

one-hole stopper

laboratory stand and ring clamp

dishcloth

paper

pen

ruler

calculator

bowl of water with food colouring added

modelling clay or silicone glue

ice-cold water

The class also needs two calibration devices, assembled as in diagram B.

### Safety Precautions



Silicone glue does not wash off hands or clothing. It irritates skin and emits fumes as it hardens. If you use it, follow your teacher's directions carefully and work in a well-ventilated area. Wear gloves, eye protection, and an apron, and work on newspaper. Use craft sticks or wide toothpicks to apply and shape the smallest possible quantity of the glue. Roll up the craft sticks in the newspaper when you are finished, and discard them in the garbage.

### Specifications

- Thermometers built in Part 1 should detect increases in temperature when your teacher warms them gently with a hair dryer and decreases in temperature when they are cooled with a cold washcloth.
- At the end of Part 2, the thermometer will have a properly constructed scale with evenly spaced degree markings and suitable numbering.
- The thermometer must measure the temperature of the classroom accurately. The reading should be within  $2^{\circ}\text{C}$  of the temperature measured by a standard laboratory thermometer.

### Skill

## FOCUS

For tips on scientific problem solving, turn to Skill Focus 7.

## Part 1

### Assembling the Thermometer

#### Plan and Construct

- 1 Using the materials your teacher provides, your group will design and assemble a thermometer like the one illustrated in diagram A. The straw or tubing needs to have an airtight seal against the bottle neck. Tape does not work very well. If necessary, put it in a one-hole stopper that fits the bottle. You could use modelling clay to make a good seal.
- 2 Warm the bottle with your hands. Record what happens in the dish at the end of the straw. Troubleshooting: If nothing happens, your hands are probably about the same temperature as the bottle. Try wetting a dishcloth with warm water, wringing it out, and draping it over the top of the bottle.
- 3 Wet a dishcloth with cold water, wring it out, and drape it over the bottle. What happens to the level of water inside the straw?
- 4 When you are sure that your thermometer is working correctly, have your teacher certify that it meets Specification A.

#### Evaluate

1. Which part of your thermometer responds to changes in temperature? Describe how it responds when the air in the bottle  
(a) warms up    (b) cools down
2. Why might you add marks and numbers to your thermometer? Where would you put them?

## Part 2

### Calibrating the Thermometer

#### Plan and Construct

- 1 Plan how to create a scale for your thermometer so that it can measure temperatures accurately. Here are some hints:

- (a) Your scale needs to be fastened to the thermometer, then taken off for measuring and marking, and then replaced on the thermometer in its original position.
- (b) Start by marking the scale at two known temperatures at least 10 degrees apart. You could use two wet washcloths or sponges. Soak one in water with a known cool temperature. Wrap it around the top of your thermometer and watch the liquid level fall. Mark the lowest level.
- (c) Repeat (b) using a washcloth soaked in water with a known warm temperature. Mark the highest level the liquid in your thermometer reaches.
- (d) You now have two markings on your scale, for two different temperatures. Take the scale off the thermometer and mark the proper temperatures beside each mark.
- (e) Measure the number of millimetres between the two marks.
- (f) Subtract to find the number of degrees between the two marks.
- (g) Divide to find how many millimetres on your scale stand for each degree celsius. Ask your teacher for help if necessary.

- 2 Use your calculations to finish marking your thermometer scale. Be sure to number the scale every 5 or 10 degrees.
- 3 Show your teacher or another lab group that your calibrated thermometer meets Specifications B and C.

#### Evaluate

1. Did your thermometer meet the design specifications? How could you improve it?
2. Describe the main problems that you had building your thermometer. How did you overcome each problem?
3. Why are thermometers designed like yours not very useful in everyday life?



# Boiling Hot, Freezing Cold

## Think About It

You can probably guess many familiar temperatures quite accurately. Other temperatures may surprise you! As you follow the directions, make sure that you learn the temperatures described in italics.

## Procedure

- 1 In your notebook, make a table with three columns labelled “Very cold,” “Everyday,” and “Very hot.” Give your table a title.
- 2 Copy each description from the table on the right into the proper column in your table.
- 3 For each description, choose the correct temperature from the right-hand column of the table. Write the temperature beside the description. Discuss your answers with your partner until you agree on each one.
- 4 Check your answers against the list your teacher has. Correct any mistakes you made.
- 5 Have your partner quiz you to make sure that you know the common temperatures, which are printed in italics.



This “Morning Glory Pool” is heated by energy from deep within Earth. The water remains about 95°C even with snow on the ground nearby.

	Description	Temperature (°C)
1	temperature of lava from Hawaiian volcanoes	4 to 10
2	temperature of ocean currents off Canada’s east coast	–5
3	temperature of ocean currents off Canada’s west coast	–87
4	world record coldest air temperature	–121 to –156
5	<i>comfortable room temperature</i>	92
6	body temperature of a budgie bird	15 000 000
7	temperature where the Space Shuttle flies in orbit	–10 to –15
8	temperature of a candle flame	200
9	comfortable temperature for heat-loving bacteria	20 to 25
10	<i>normal human body temperature</i>	37
11	temperature of ice cream	40
12	oven temperature for baking bread	1
13	temperature of food in a freezer	100
14	temperature of the interior of the Sun	6000
15	temperature of hot tea or coffee	1150
16	<i>temperature of boiling water at sea level</i>	55
17	<i>temperature of a slush of pure water and ice</i>	800
18	temperature of the surface of the Sun	0

The descriptions in this table do not match the temperature in the column beside them. Your job is to work with a partner to unscramble them.

## The Right Device for the Job

Could you use the same device to measure the temperature of the surface of the Sun and the body temperature of a parrot? Probably not. Thermometers have been developed to suit almost every purpose, from measuring the extreme cold of outer space to estimating the temperatures of stars. Each of the thermometers described below contains a **sensor** — a material which is affected by changes in some feature of the environment, such as temperature. The sensor produces a **signal** — information about temperature, such as an electrical current. The signal affects a **responder** — a pointer, light, or other mechanism that uses the signal in some way.

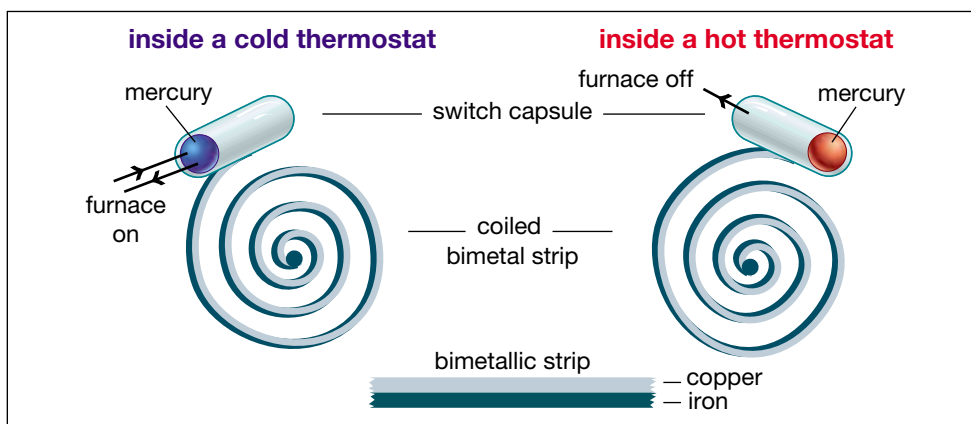
### The Thermocouple

In a thermocouple, wires made of two different metals are twisted together. When the twisted wire tips are heated, a small electrical current is generated. The amount of current depends on the temperature of the wires. The electrical current from the thermocouple can be used to turn a switch or a valve on or off if the temperature changes.

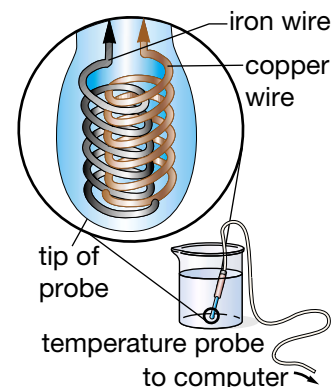
Thermocouples can measure temperatures so high that ordinary laboratory thermometers fail because the liquid in them would start to boil. They cannot be used to measure low temperatures accurately.

### The Bimetallic Strip

A bimetallic strip is made of two different metals joined firmly together. As the strip is heated, one metal expands more than the other. The strip is forced to coil more tightly. When the strip cools, the process is reversed. The same metal that expanded rapidly now contracts rapidly and the strip uncoils again. Movements of the strip can operate a type of electrical switch, which can be used to control furnaces, air conditioners, refrigerators, or other devices. Examine Figure 3.10 to find out how a bimetallic strip turns a furnace on and off.



**Figure 3.10** In a thermostat, the bimetallic strip is fastened to a glass capsule containing a drop of liquid mercury metal. When the bimetallic strip cools, the capsule tilts. The mercury rolls to one end, fills the gap between two wires, and completes an electrical circuit. The furnace or air conditioner is switched on. When the bimetallic strip bends the other way, the mercury rolls away from the wires, breaking the circuit. The furnace or air conditioner is switched off.



**Figure 3.9** A thermocouple being used to measure the temperature of a liquid

## Pause & Reflect

Try to identify the parts of each thermometer described here. What is the function of each responder? Does it display information, make a permanent record, control some other device, or do some other useful task?

## Did You Know?

Your body has its own temperature sensor inside your brain. It monitors your internal temperature. If the temperature outside your body changes, the sensor signals the brain to release chemicals that will enable your body to adjust to its normal 37°C.

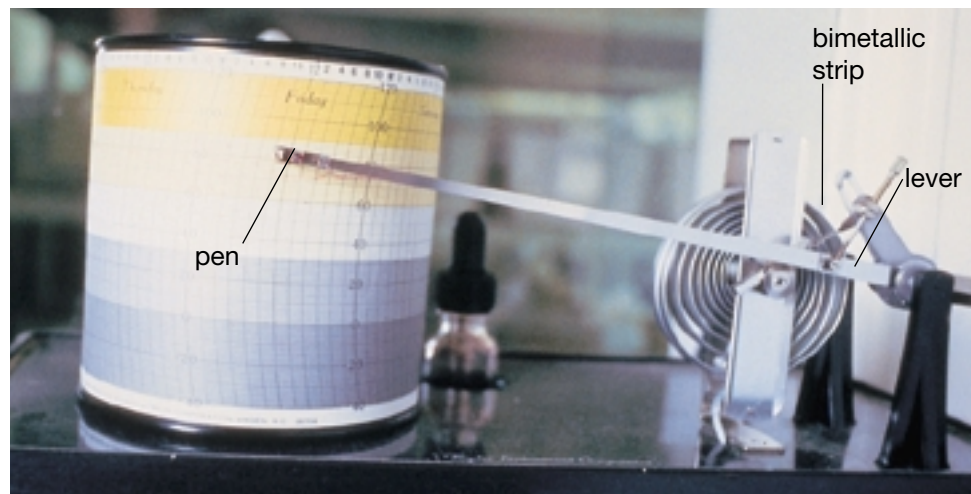


## Word **CONNECT**

Recording thermometers are sometimes called “thermographs.” The syllable “therm” comes from the Greek word for temperature or heat, and the syllable “graph” comes from the Greek word for writing. Thus a thermograph is a “temperature writer.” List as many other “therm” and “graph” words as you can, along with their meanings.

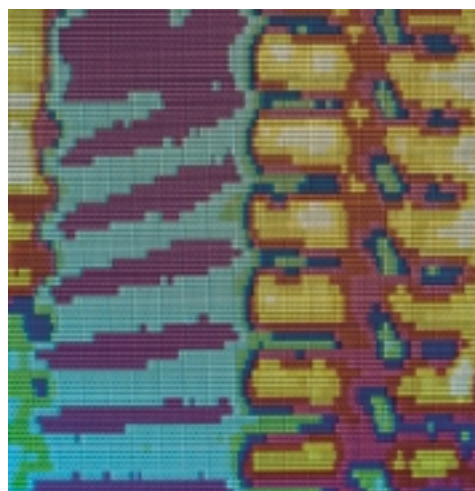
## The Recording Thermometer

In one type of recording thermometer, a bimetallic strip coils and uncoils as the temperature changes. One end of the strip is attached to a long, light metal lever that holds a special pen. Tiny movements of the bimetallic strip cause much larger movements of the free end of the lever and the pen. The pen traces a rising and falling line on a strip of paper attached to a slowly turning drum. The drum usually makes one turn every seven days, so each strip of paper contains a record of temperature changes for an entire week. (You will find out about another instrument that works in a similar way in Unit 5.)



**Figure 3.11** This recording thermometer uses a bimetallic strip to detect changes in temperature. The end of the coil is attached to the short end of a lever. The long end of the lever is attached to a pen that makes a permanent recording of the temperature on graph paper attached to a rotating drum.

## The Infrared Thermogram



The photograph on the left shows an infrared image; the one on the right is a normal photograph of the same image. What colours in the thermogram indicate the highest and lowest temperatures? In the winter, how could you identify air leaks around doors and windows from an infrared image? How could a building owner use this information to reduce heating costs and conserve fuel?

Objects do not have to be glowing red hot to give off radiation. Anything that is warmer than absolute zero gives off infrared radiation (IR), a type of radiation similar to light, that your eyes cannot detect. Your skin can detect infrared radiation when you are near hot objects. Even if you are not actually touching the object, you can feel the warmth. Infrared radiation can be photographed with special films or detected by electronic sensors that display images on television screens. The colour or brightness of the infrared image shows the temperature of the object (see Figure 3.12). In Topic 8, you will learn more about a Cool Tool that uses IR.

## INTERNET CONNECT

[www.mcgrawhill.ca/links/sciencefocus7](http://www.mcgrawhill.ca/links/sciencefocus7)

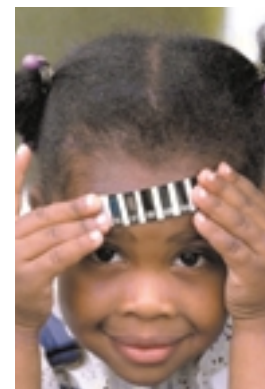
Warm objects, such as your body, give off more infrared radiation than cool objects. Thermograms of certain body parts can help physicians diagnose some medical problems. To explore more about this topic go to the web site above. Click on **Web Links** to find out where to go next.

## TOPIC 2 Review

1. Suppose that you were present on the hottest day ever reported in Canada.
  - (a) What would your body temperature have been?
  - (b) If the air temperature had dropped by  $5^{\circ}\text{C}$ , would you have felt warm or cold?
2. Describe how a thermostat controls the temperature in a building.
3. **Apply** What might be the advantages and disadvantages of using a thermocouple instead of a regular lab thermometer?
4. **Apply** Many household appliances, such as irons, are heated electrically. They usually contain a thermostat that switches electricity on and off to keep the appliance at a constant temperature. Think of at least three examples of other appliances that might use thermostats to switch electricity on and off.
5. **Thinking Critically** Choose the most appropriate temperature-measuring instrument to use in each situation below. In each case, explain your choice.
  - (a) controlling an electric frying pan
  - (b) making long-term temperature records at a weather office
  - (c) detecting small forest fires before they spread
  - (d) monitoring temperatures inside a furnace
  - (e) checking trains for overheating wheel bearings as they pass by a station
  - (f) studying temperature changes inside a building over a 24 h period

## DidYouKnow?

Some kinds of crystals turn certain colours at different temperatures. You may have seen these crystals in strips used to take your temperature. When you place the strip on your forehead, the crystals that change colour will show the temperature of your skin.



# 3 The Particle Model, Temperature, and Thermal Energy

## DidYouKnow?

The idea that all matter is made of particles was first proposed about 2400 years ago in ancient Greece. Modern scientists have been gathering evidence to test the theory for more than 200 years. They have used the theory to explain their observations and to predict results of their investigations. The particle theory of matter has been so useful that it is now universally accepted as a model.

Try waving your hand in the air. Now think about moving your hand through water. Is that easier or more difficult? What if you tried to move your hand through wood or steel? How difficult is that? Why? Moving your hand through air is easy because the particles that make up air are spaced far enough apart. Your hand can easily move them aside. Why might such movement be more difficult where the other substances are concerned?

First, you should know that the particles in all matter are extremely small. What do the words “extremely small” mean in relation to the particle model? Imagine a drop of water balanced on your fingertip. How many individual water particles are clinging together to create the drop? The answer is about 1 700 000 000 000 000 000 — one thousand seven hundred million million million! No wonder you cannot see the particles with your unaided eye.

## Pouring? Shaping? Filling?

Scientists use the idea of particles to explain the properties that are common to all solids, all liquids, and all gases. This diagram shows how the particle model explains a solid, liquid, and gas.



A solid

B liquid

C gas

### Procedure Analyzing and Interpreting

Examine the diagram to find the answers to the following questions.

## Find Out ACTIVITY



- Name the state(s) in which a material
  - has a fixed shape
  - takes the shape of its container
  - always fills whatever container it is in
- Name the state(s) in which the particles are
  - far apart from each other
  - relatively close together
  - free to move around
  - held in fixed positions

### What Did You Find Out? Analyzing and Interpreting

Use the particle model to explain your answers to questions 1 and 2.



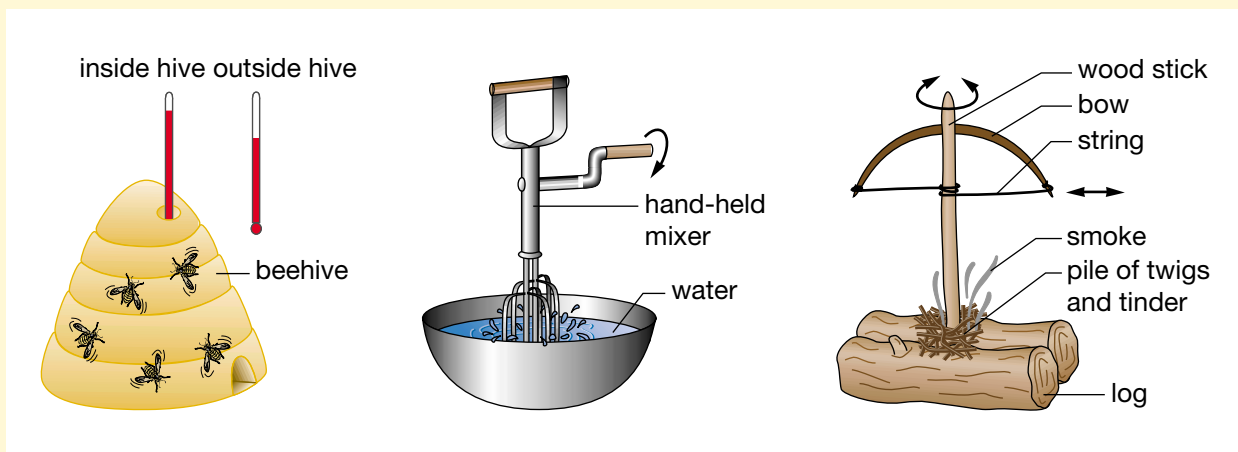
The **particle model of matter** is a scientific description of many different features of these tiny particles. Three of the most important ideas of the model are:

- All substances are made of tiny particles too small to be seen.
- The particles are always in motion — vibrating, rotating, and (in liquids and gases) moving from place to place.
- The particles have spaces between them.

## Find Out **ACTIVITY**

### Detect a Connection

How does a material change when it is warmed or cooled?  
How does warming or cooling affect the tiny particles of which everything is made?



#### Procedure Analyzing and Interpreting

Carefully examine each picture. Then answer the following questions.

- One way that bees control the temperature in their hive is by beating their wings vigorously. Explain what happens to
  - the motion of the air particles in the hive
  - the air temperature in the hive
- Water warms up slightly if it is stirred vigorously.
  - What happens to the motion of the water particles as they are stirred?
  - How is the behaviour of the water particles similar to the behaviour of the air particles in the beehive in question 1?
- To start a fire, early people used a fire drill to twirl a stick pressed against a piece of wood.
  - What happened to the temperature at the pointed end of the drill?
  - What do you think caused the particles of wood to change temperature?

#### What Did You Find Out? Analyzing and Interpreting

- What common feature caused the changes in temperature in each example you examined?
- Identify at least two other situations that are similar to the three examples in this activity.

## DidYouKnow?

Antoine Lavoisier (1743–1794) believed that an invisible substance called caloric fluid caused changes in temperature. Fires, for example, had a lot of caloric fluid, so they were hot. If caloric fluid moved from a fire to a cooking pot, the pot warmed up. For many years, scientists tried to detect and measure caloric fluid. No one could. Finally scientists stopped looking for it and abandoned Lavoisier's theory.

## Temperature and the Particle Model

As you probably noticed in the last activity, if the motion of the particles in a substance changes, the temperature of the substance changes, too. When a substance warms — when its temperature increases — its particles are moving faster. When a substance cools — when its temperature decreases — its particles are moving more slowly.

This idea forms the basis for a fourth point in the particle model:

- The motion of the particles increases when the temperature increases. The motion of the particles decreases when the temperature decreases.

It is not easy to test this idea directly. As you now know, the smallest particles of matter are too tiny to observe clearly. They can be observed only in large groups. In any substance, some particles always seem to be moving faster than average. Other particles seem to be moving unusually slowly. The *average* speed of many particles, however, is always indicated by their temperature.

Temperature indicates the average speed of particle motion in a substance.

## DidYouKnow?

Observations of many different phenomena suggest that particles of matter are attracted to each other. Scientists think that forces between particles are responsible for the characteristics of materials you use every day. You will be able to infer many features of these forces as you continue studying science.

## What Is Energy?

**Energy** is a measure of something's ability to do work — in other words, to cause changes. Whenever something happens, scientists are sure that energy is being transferred from one thing to another. Figure 3.13 shows some everyday examples. As you study the illustrations, try to describe three features of each situation:

- What has high energy? What has low energy?
- What change is being caused as energy is transferred?
- What source provides energy for the change? To what is the energy transferred?



**Figure 3.13A** Fully charged batteries can power a stereo; dead batteries cannot. A charged battery stores more energy than a dead battery.



**Figure 3.13B** A hot drink warms you more than a cold drink. Hot substances have higher thermal energy than cold materials.



**Figure 3.13C** Catching a heavy, fast-moving baseball stings more than catching a light, slow-moving Ping-Pong™ ball. The baseball has much more energy of motion than the Ping-Pong™ ball.



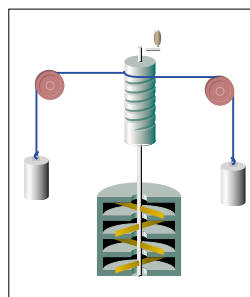
Hot-air balloons, ovens, a hot tub — these and many other devices are designed to release and transfer **thermal energy** (energy associated with hot objects). The fuel in a hot-air balloon burns, transferring thermal energy to air, which warms, expands, and lifts the balloon. Hot metal elements in an oven transfer thermal energy to food, warming and cooking it. Hot water in a hot tub transfers thermal energy to people in the tub.

Have you noticed the same two features of each energy example in this section? You can identify them in any situation where change is occurring.

- (a) Changes happen when there is a *difference* of energy. Every useful energy system has a high-energy source that powers the changes.
- (b) Energy is always transferred in the same direction: *from* a high-energy source *to* something with lower energy.



Energy is measured in joules (J), in honour of James Joule (1818–1889), an amateur scientist who devoted his life to studying energy. To investigate the connection between energy and temperature changes, Joule built many ingenious devices. One was a set of paddle wheels that stirred water as they were turned by falling weights. The temperature of the water increased a small, but measurable, amount. If you have a sensitive computerized temperature probe, you could repeat Joule’s experiment using an electric mixer or a blender to stir the water.



### Word **CONNECT**

The term “thermal energy” has a precise scientific meaning, but it is not used very much in everyday language. Scientists sometimes use the word “heat,” but they give it a specific meaning: thermal energy being transferred because of temperature differences. To avoid confusion, this textbook uses the scientific terms “thermal energy” and “energy transfer” whenever possible. Can you think of other words that have slightly different meanings in science and everyday life?



## Word **CONNECT**

How would you use the words “energy” and “temperature” in an everyday sense? How is this different from their scientific meanings? For each word, think of and write down a sentence which uses the word in an everyday sense. Now try to “translate” your sentences into scientific descriptions.

## Pause & Reflect

Compare the everyday definition of temperature as given on page 192 with the definitions given on page 204 and on this page. In your Science Log describe how the definition of temperature and your understanding of it have changed.



Potters need to check the very high temperatures inside the kilns that bake and harden their pottery. To do this, they use small ceramic pyramids called “pyrometric cones” like the ones shown in the photograph. Sets of four cones are placed in the kiln along with the pottery being fired. Two of the cones soften and bend over as the kiln heats up. The third cone bends at the desired temperature. If the fourth cone bends, the kiln has overheated and the pottery may be damaged. Potters refer to cones by code numbers. For example, a number 022 cone bends at 585°C, a number 1 cone bends at 1125°C, and a number 26 cone bends at 1595°C.



## Thermal Energy and Temperature Changes

Does your bedroom get chilly on cold winter nights? In just a few minutes, a small electric heater can warm the room up. The heater transfers thermal energy to the air. The air particles move faster as their average energy increases. You notice the temperature rising.

Now imagine trying to warm a very large building — maybe your school gymnasium — using the same heater running for the same amount of time. What a hopeless task! The same amount of thermal energy would be transferred to the air. But in the larger room there are many more air particles. Each particle gets only a tiny share of the extra energy. The average energy of the particles increases, but only a tiny bit. The air temperature rises, but not very much.



You can see that there is a connection between thermal energy and temperature. Heating anything increases the *total* energy of all its particles. The *average* energy of the particles — the temperature of the substance — may increase a little or a lot. The temperature change depends on the number of particles; that is, the amount of material you are heating.

What about cooling? Imagine putting an ice cube in a glass of warm lemonade. The ice *absorbs* thermal energy as it melts. With less energy, the average motion of the particles in the lemonade slows down. The temperature of the lemonade drops.

Could the same ice cube cool off a bath or hot tub filled with steaming water? Hardly! The ice would absorb the same total amount of thermal energy as it melted. The average energy of the particles would drop only a tiny bit, because there are so many of them. Again, the temperature change depends on the amount of material, as well as on the change in thermal energy.

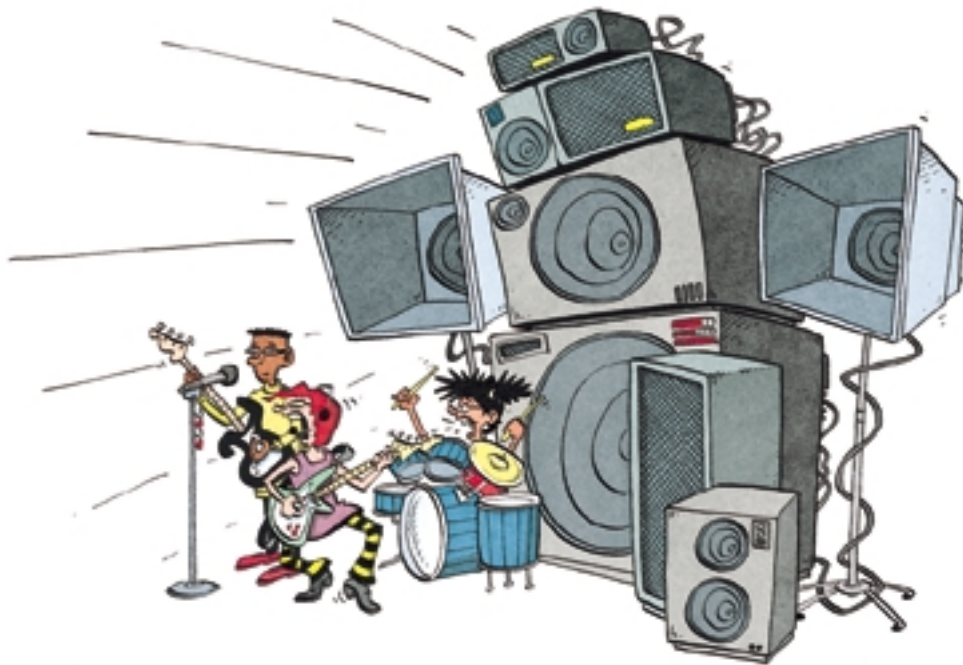
## What Energy Is ... and Is Not

*“I just don’t have enough energy to do my homework.”*

*“I’m so hungry! I need a big meal to get enough energy for the soccer game.”*

*“You look exhausted! Did cleaning your room use up all your energy?”*

Energy is *not* a substance. It cannot be weighed. It does not take up space. Energy describes a quality or condition. Think about words that describe other qualities or conditions. You might describe the drums in a band as “loud,” but that does not mean they are filled with extra “loudness.” If the guitar is played softly, that does not mean its “loudness” is almost used up.



What is energy? Energy is a property or quality of an object or substance that gives it the ability to move, do work, or cause changes. Energy is the topic of one of the most important laws of nature. The Law of Conservation of Energy states that: *Energy cannot be created or destroyed. It can only be transformed from one type to another or passed from one object to another.*

Is it still okay to say, “Wow, I’m feeling full of energy today”? Of course! Everyday language is fine for everyday life. Just remember to be more precise when you are giving a scientific description.

## Across Canada

Imagine trying to keep a toboggan hill covered in ice in the blazing sun, with the temperature well above freezing. That is the challenge that Bruce Welsh often faces between September and March each year. Bruce is supervisor of the refrigeration plant at Canada Olympic Park in Calgary, Alberta. As part of his job, he looks after the 2 km winding track that is used for bobsled and luge races. No matter what the weather, the ice on the track must be kept at 0 or  $-1^{\circ}\text{C}$ . That's the ideal temperature for the high-level competitions and training that take place there.

The track is made of concrete. Inside it, just below the surface, is a system of pipes. Equipment in the refrigeration plant cools a liquid called a refrigerant and pumps it through these pipes to chill the track. This helps build up the layer of ice each September and keeps it from melting throughout the season. Bruce and his staff monitor the weather, and adjust the equipment to chill the refrigerant



**Bruce Welsh**

to a temperature that will keep the ice at the freezing point. Some days that's not easy.

"One year," Bruce recalls, "the air temperature reached  $18^{\circ}\text{C}$  in December. We had to run virtually every piece of equipment in our plant to successfully hold the ice."

Very cold days can be a problem too. Frost forms on the ice making it "sticky" and slowing down the sleds. Bruce can raise the ice temperature only by having crew members carefully spray it with water between races.

Dealing with whatever nature throws his way doesn't faze Bruce. "It's challenging, but the variety is what makes my job really interesting."

### TOPIC 3 Review

1. List the main points of the particle model of matter that were presented in this section. (Hint: Look back to pages 203 and 204.)
2. Why is it so hard to test the particle model to see if it is correct? (Hint: see page 204.)
3. Describe two situations in your life in which caused changes in something.
4. Name an important discovery or idea contributed by each of these scientists.
  - (a) James Joule
  - (b) Anders Celsius
  - (c) Lord Kelvin
5. How is thermal energy different from temperature? (Hint: You have studied three answers to this question so far).
6. **Thinking Critically** Modern scientists do not use Lavoisier's "caloric fluid" theory (see the Did You Know? on page 204). If this theory is wrong, why do you suppose it is discussed in many science textbooks?
7. **Thinking Critically** Think of a form of energy that you knew by name before you studied Topic 3.

### Pause & Reflect

The ideas in this Topic are tricky! Use them to write a short explanation in your Science Log that demonstrates your understanding of temperature, particle motion, and energy (especially thermal energy). Use your own words, and include examples or diagrams. With a partner, take turns reading your explanations. How are your ideas similar? How are they different?



If you need to check an item, Topic numbers are provided in brackets below.

## Key Terms

thermometers	energy	responder
scales	Celsius scale	thermal energy
particle model of matter	sensor	temperature
	signal	Kelvin scale

## Reviewing Key Terms

1. In your notebook, copy and complete the word game to find the name of a form of energy that you have studied in this unit.

- (a)    --- ■ -----
- (b)    - ■ ----- ■ ■
- (c)    -- ■ -----
- (d)    ----- ■ -----
- (e)    -- ■ -----
- (f)    -- ■ -----
- (g)    -- ■ -----

- (a) The ■■■■■ model of matter (3)
- (b) temperature-measuring device (2)
- (c) a measurement of something's ability to do work (3)
- (d) correctly position the number lines on a thermometer (2)
- (e) measure of the average speed of a substance's particles (2)
- (f) number markings that indicate a precise temperature (2)
- (g) temperature scale commonly used in Canada (2)

## Understanding Key Concepts

- 2. Give a reasonable temperature (in degrees Celsius) for each of the following situations: freezing water, room temperature, normal human body temperature, boiling water. (2)
- 3. Describe three steps in calibrating a thermometer. (2)
- 4. (a) What do thermometers measure? (2)  
 (b) What do thermometers actually detect about the moving particles that make up a sample of matter? (3)

- 5. What points in the particle model did you use in Topics 1-3? List them in point form. (2-3)
- 6. In your notebook, copy and complete the following table to explain the meaning of thermal energy. Give your table a title. (3)

	Substance with a large amount of thermal energy	Substance with a small amount of thermal energy
Average speed of particle motion		
Temperature		

- 7. In your notebook, copy and complete the following table to compare thermal energy and temperature. Give your table a title. (2)

	Thermal energy	Temperature
SI units of measurement		
What it tells about particles of matter		
Measuring device or method		

- 8. Explain how to make a rechargeable battery have each of these forms of energy: electrical energy, thermal energy. (3)
- 9. Copy and complete each of the following sentence starters.
  - (a) As particle motion increases, the temperature ... (3)
  - (b) As thermal energy increases, particles in a substance move ... (3)
  - (c) As thermal energy increases, particles' average speed ... (3)
- 10. With a partner, create a short skit to show the behaviour of particles of matter in each of these situations: low temperature, warming up, small amount of thermal energy, a large amount of thermal energy. (2, 3)