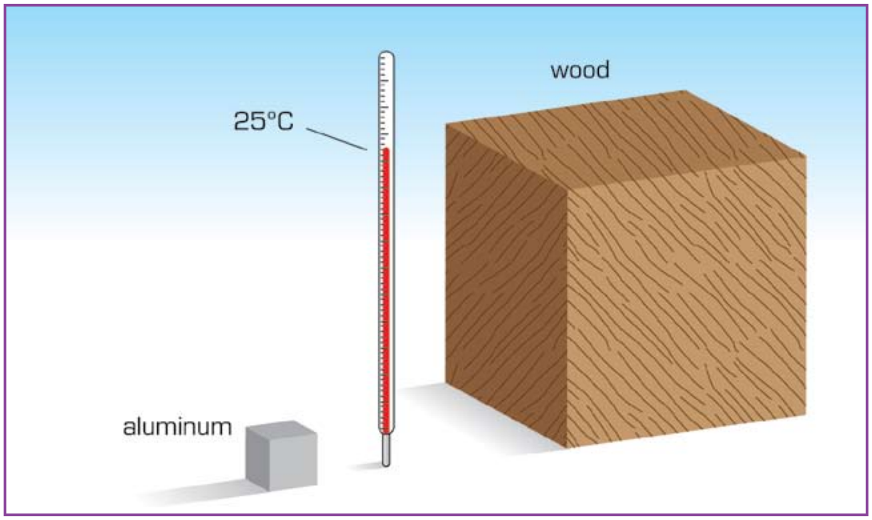
3.4 Read

How Can You Compare the Thermal Energy of Two Different Types of Matter?

If two objects made of the same substance have different masses or temperatures, you can determine which has more thermal energy. If the objects have different masses but are otherwise the same, the one with more mass has more thermal energy. If the objects have different temperatures but are otherwise the same, the warmer one has more thermal energy. However, if two objects are made of different substances, you need more information to determine which object has more thermal energy.

The picture below shows a block of wood and a block of aluminum metal. Both blocks have been sitting on the table for some time and are at the same temperature. Both blocks also have the same mass. Up until now, mass and temperature are the only factors you have investigated for thermal energy. How can you decide whether the wood block or the aluminum block has more thermal energy?



Identical masses of different materials can have different amounts of thermal energy, even at the same temperature. This means that *the material that makes up the substance* is a third factor that affects how much thermal energy a substance has. For example, 1 g of water at 25°C has about 10 times as much thermal energy as 1 g of iron at the same temperature.

Scientists use a measurement called **specific heat** to describe how much thermal energy is required to raise the temperature of different substances. The units for specific heat are joules per gram per degree Celsius (J/g•°C). The specific heat of water is 4.184 J/g•°C. This means it takes 4.184 J of thermal energy to raise the temperature of 1 g of water by 1°C.

Two important things to remember about specific heat are:

- The greater the specific heat of a material, the more thermal energy is required to raise its temperature.
- The greater the specific heat of a material, the more thermal energy it has compared to some other material with the same mass and temperature.

The specific heat of iron is 0.449 J/g•°C. This means that if you have some water and a piece of iron with the same mass and temperature as the water, the water has about 10 times as much thermal energy as the iron. Water also needs 10 times as much thermal energy as iron does to raise its temperature by 1°C. In fact, water's specific heat is greater than the specific heat of every type of metal.

specific heat: the heat required to raise the temperature of 1 g of a substance 1°C.

Because water has a high specific heat, it takes a lot of energy to heat water to boiling, but once water is hot, it will remain hot for a long time. The high specific heat of water makes it a good substance for storing thermal energy. This is one reason water is often used in cooking.

If you think about hard-boiling eggs, you may be able to better appreciate just how special water's specific heat is. Suppose you want to hard-boil an egg. All of the particles in the egg need to be heated completely to hard-boil it. You know from your experiment with the ice and water that thermal energy from warm water can transfer into a substance submerged in the water. The way people normally hard-boil eggs is to submerge the eggs in water, turn the heat up to boil the water, and then let the eggs boil in the water and absorb its thermal energy. People usually allow the water to boil for about 5 min to hard-boil the eggs. Then they remove the eggs from the water and cool them.

However, because water has such high specific heat, there is a way to hard-boil eggs using less energy. You can use the thermal energy from the burner to bring the water with the eggs to a boil, and then turn off the burner. The water will stay hot long enough to fully cook the eggs without extra energy from the burner.

The table below shows the specific heat of different materials with which you are familiar.

Specific Heat Table

Material	Specific heat (J/g·°C)
Air (nitrogen)	1.03
Aluminum	0.897
Diamond	0.510
Iron	0.449
Polyethylene (PET, a type of plastic)	1.79
Sand (quartz)	0.742
Water	4.186

Stop and Think

1. Which material listed in the table requires the greatest amount of energy for 1 g to be heated by 1°C?
2. You are choosing a material that can store a lot of thermal energy but not get very hot (not reach a high temperature). Would you choose a material with a low or high specific heat? Give reasons for your answer.
3. A container of water can be heated by adding hot water or a piece of hot metal. If the mass of the water is equal to the mass of the metal, which material will have the greater effect on the water's temperature? Justify your answer.
4. On a hot day, which would you expect to have a higher temperature, sand or water, if they have the same mass? Why?
5. Think back to the experiment you did with the water and ice. More of the ice submerged in cold water melted than the ice in the bag sitting on the table. The water was cooler than the air in the classroom. Why did the cold water melt more ice than the warm air?

How Specific Heat of Water Affects Climate

You may know that the climate near a large lake or near the ocean is milder than the climate farther inland. A milder climate means that it is less hot in the summer and less cold in the winter. Temperatures near a large lake or the ocean are milder because of the specific heat of the water compared to the specific heat of land. Water absorbs heat slowly and also releases heat slowly. Land absorbs heat more quickly, but it also releases its heat more quickly.

During the summer, when the weather is warmer, the land absorbs thermal energy from the air more quickly than the water does, so the temperature of the land rises faster than the temperature of the water. When the land temperature rises, air that is above land far from large bodies of water receives thermal energy from below and becomes warmer. Air that is above a large body of water receives less thermal energy from below. So air that is farther inland is generally warmer in the summer than air close to lakes or oceans.

In the fall when the air is cooler, less thermal energy is available. As the land and water cool in the fall, the water retains more of the thermal energy it absorbed during the summer. During cold weather, the land cools more quickly, so in winter it has less thermal energy to transfer to the air above it. Because its specific heat is lower than the water, the air above large bodies of water receives a larger transfer of thermal energy from below than air that is inland. So the air near lakes and oceans is generally warmer in the winter than inland air. The larger the lake, the more thermal energy it has stored up to heat the air around it. This keeps temperatures more moderate near large bodies of water.

Which will warm up faster, the water or the sand in this coastal area?

How Does Thermal Energy Raise the Temperature of a Substance?

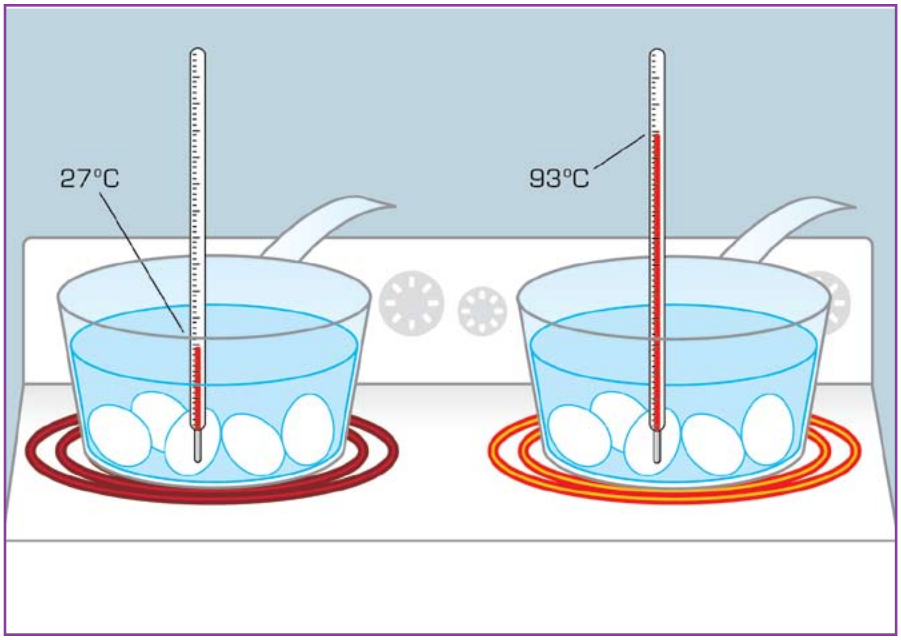
In the experiment in *Section 3.2,* when you put bags of ice into the beakers of water, the ice began to melt. Thermal energy was transferred from the warm water to the ice. The thermal energy heated the ice, so some of it melted and became water. At the same time, the loss of thermal energy cooled the water in the beaker. How did this happen?

conduction: the transfer of thermal energy by direct contact.

Heat is thermal energy that is transferred from one object or substance into another object or substance. You have read that heat naturally flows from hotter objects to colder objects. This transfer of thermal energy can happen in three different ways—through *conduction, convection,* and *radiation.*

Recall that when two substances at different temperatures are in contact with each other, the faster-moving particles of the warmer object collide with slower-moving particles in the cooler object. After many collisions, the particles in the cooler object have speeded up, and the particles in the warmer object have slowed down. Eventually, the two objects end up at the same temperature. This process is called **conduction**. Conduction occurs when two objects are in direct contact with each other. In conduction, the colder object gains thermal energy. The hotter object loses the same amount of thermal energy.

When you hard-boil eggs, heat moves by conduction from the burner to the pot, then from the pot to the water, then from the water to the eggs.



In the experiment in *Section 3.2,* the water in the beakers was not in direct contact with the ice. Thermal energy from the water was first transferred to the plastic bag. It was then transferred from the plastic bag to the ice, which was in direct contact with the bag. There are other familiar examples of conduction. When you hard-boil eggs on an electric stove, heat from the burner transfers by conduction to the pot, warming it up. The pot then transfers heat to water inside the pot. The water then transfers heat to the shells of the eggs, and the shells transfer heat to the insides of the eggs.

Another way to transfer thermal energy is through **convection**. You may know that warm air rises and cool air sinks. This is an example of convection. An electric space heater that is near the floor warms the air near it by conduction. This warm air rises, and cooler air rushes in to take its place. The cooler air is heated by the space heater, so it rises, and again cooler air takes its place. Eventually, the thermal energy released by the space heater is able to spread throughout a room by the rising and falling of air in the room. This movement of warmer air to cooler air is convection.

convection: the transfer of thermal energy by the movement of a fluid, such as water or air.

Convection will also occur in a beaker of water when an ice bag is placed in the water. The water near the ice becomes cooler by the transfer of thermal energy into the ice bag. This cooler water sinks toward the bottom of the beaker. It is replaced by warmer water rising from the bottom of the beaker. The entire beaker of water then cools off as it loses thermal energy to the bag of ice.

Baking is usually done in a convection oven. In a convection oven, the heating element or flame warms the air near it. As that air warms, it rises, and cooler air takes its place. A fan speeds up the movement of the air.

The oven in your kitchen is another example of convection. The food sits on racks near the center of the oven, while the heating elements are near the sides, top, or bottom. Thermal energy from the heating elements reaches the food by the convection of the air inside the oven.

Another way to transfer thermal energy is by radiation. Radiation occurs when some of the thermal energy in an object is converted into *electromagnetic waves* that spread outward from the object. You will learn more about electromagnetic waves in *Learning Set 4.*

Convection and conduction can transfer thermal energy only through matter, but radiation can transfer energy through matter or through empty space. This is why the Sun is able to transfer thermal energy to Earth. The Sun emits radiation in the form of electromagnetic waves. This radiation can travel through the empty space between the Sun and Earth. When matter absorbs radiation from the Sun, the particles of the matter move faster. When this happens, the thermal energy of the matter increases. Similarly, when matter emits radiation, the matter can lose thermal energy.

Another example of radiation is when you heat hot chocolate or popcorn in a microwave oven. Microwaves are a type of electromagnetic wave. The microwaves are generated in the oven and then absorbed by the food inside the oven. The thermal energy of the food increases when the absorbed radiation increases the speed of the particles that make up the food.

Microwave ovens use electromagnetic waves.

Your body warms up when the matter in your body absorbs radiation from the Sun.

Often, all three processes—conduction, convection, and radiation—occur at the same time. Remember the example of the oven in your kitchen. Thermal energy is transferred to air particles in contact with the heating elements by conduction. The movement of warmer air rising and cooler air sinking spreads thermal energy throughout the oven by convection. You can see the heating elements glowing because they are so hot. This glowing is an indicator of radiation. The heating elements are emitting electromagnetic waves, some of which are visible light that you can see. These electromagnetic waves also warm the air in the oven.

Reflect

List five different objects or machines that are used to transfer thermal energy from one place to another. Describe briefly the method by which each transfers thermal energy, and then classify each as using conduction, convection, radiation, or some combination of these. Be sure to cover each of these three processes at least once in your examples.

Thermal Energy from the Sun and Earth

You might appreciate the sunshine peeking through the clouds on a chilly day. But you might not appreciate how important that sunshine is. The Sun is the source of most of the energy used on Earth. The movement of air and water, the kinetic energy of living things and objects, light, and sound—all of these can be traced back to energy that originated in the Sun. This energy is transferred from the Sun to Earth by electromagnetic waves.

At the end of *Learning Set 1,* you read about chemical energy that is stored in fossil fuels. Remember that fossil fuels are the remains of plants that lived millions of years ago. Plants obtain the energy they need by transforming light energy from the Sun into chemical energy stored in starches. So even the chemical energy stored in fossil fuels can be traced back to the Sun.

geothermal energy: energy that comes from the natural internal heat of Earth.

While fossil fuels will run out someday, the Sun will fortunately shine in the sky for another five billion years. So not only is the Sun the ultimate source of all of Earth's energy, it is also the best source of renewable energy, energy that is continually resupplied. Many devices today, from calculators to electronic street signs, run on solar energy. Scientists are working on ways to make the transformation of radiation from the Sun into electrical energy more efficient so that more and more devices can rely on energy from the Sun alone.

Hot springs are a source of geothermal energy.

The Sun is a source of renewable energy that is far from Earth. However, radiation from the Sun can be kept from reaching Earth's surface by clouds. And in the middle of winter, Earth receives less energy from the Sun than in the summer. However, there is a source of renewable energy that is much closer and is not dependent on the weather or climate. This is **geothermal energy** from Earth. The root word "geo" means Earth, and "thermos" means heat, so geothermal energy is literally "heat from Earth."

Geothermal energy is thermal energy that comes from Earth's interior. This thermal energy is constantly being released at the surface, but it is released in greater amounts in certain locations. Volcanoes and hot springs are two examples of places that receive a large amount of geothermal energy.

In Iceland, where there are numerous cracks in Earth's crust, scientists have found ways to use the large amounts of available geothermal energy that is released through these cracks. Iceland is cold, but almost 90 percent of the energy needed to heat buildings and generate electricity in Iceland comes from geothermal energy. The geothermal energy is absorbed by water or steam in pipes far underground. The water or steam is then pumped to the locations that need to be heated.

In the United States, California uses the most of this clean, renewable energy source. Even so, geothermal energy today provides less than 1 percent of the world's population's energy needs.

This geothermal power plant in Iceland provides electricity to thousands of people.

Reflect

1. What are examples of the use of thermal energy in your home? What processes do these examples use to transfer thermal energy from one location to another?
2. What are the advantages of geothermal energy? Why is it not used everywhere to heat homes and generate electricity?
3. Do you think thermal energy is a kind of kinetic energy or a kind of potential energy?

Update the *Project Board*

It is time now to revisit the *Project Board*. Perhaps some of the questions you had about energy have been answered. Examine the questions in the *What do we need to investigate?* column. For which ones do you now know the answers? Record what you know now about thermal energy in the *What are we learning?* column.

You have a lot of evidence for what you know about thermal energy. Make sure you record evidence that supports what you have learned in the *What is our evidence?* column. If you have more questions, record them in the *What do we need to investigate?* column.

What's the Point?

Temperature, mass, and the type of material are factors that affect the thermal energy of an object. When two materials being compared are different, the temperature and the mass can be the same, but one material may contain more thermal energy than the other. Specific heat is a measure of the heat required to raise the temperature of one gram of a substance 1°C. Material with the higher specific heat will have more thermal energy than material with lower specific heat if they both have the same mass and temperature.

Thermal energy can be transferred from one place to another through conduction, convection, or radiation. Conduction is the transfer of thermal energy by objects or substances that are touching. Convection is the transfer of thermal energy by a moving fluid (liquid or gas). Radiation is the transfer of thermal energy by electromagnetic waves.

Two renewable sources of thermal energy are solar energy and geothermal energy. Solar energy is thermal energy transferred from the Sun through radiation. Geothermal energy is thermal energy that comes from Earth's interior.