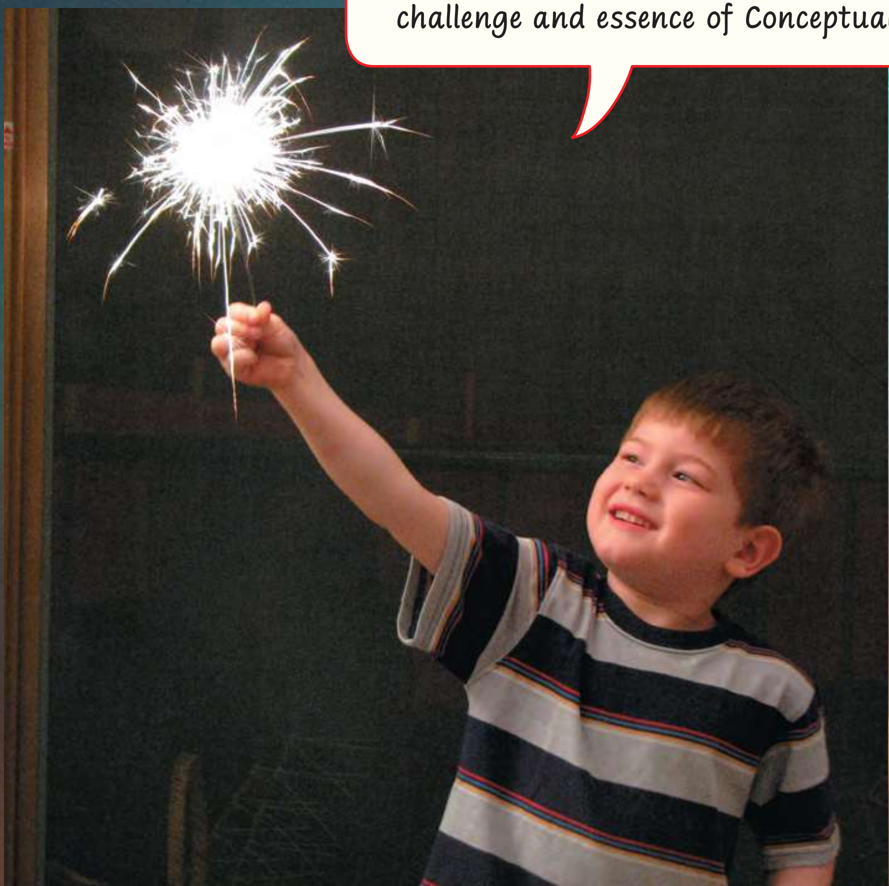
PART THREE

Heat



CHAPTER FIFTEEN

15 Temperature, Heat, and Expansion

1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1 The Hewitts next to slow-moving lava in Hawaii. **2** Anette Zetterberg asks her students to predict whether the ball can pass through the hole when the ring is heated. **3** Agricultural technologist Terrence Jones services a computerized field transmitter that monitors soil moisture, temperature, and humidity at six depths—information useful to ensuring grapes are at the ideal level of ripeness to begin the winemaking process. **4** Ole Anton Haugland holds an “empty” can upside down. Aage Mellem places a flame at its opening, heating and expanding the air inside that in turn inflates the red balloon—aha, just as occurs in the operation of a hot-air balloon.

I remember, as a child, that whenever my family drove past the Massachusetts Institute of Technology in Cambridge, a few miles from my home in Saugus, the name RUMFORD inscribed at the top of one of the prominent buildings was pointed out to me. I was told that our family is descended from this great scientist and diplomat.

Rumford was born Benjamin Thompson in Woburn, Massachusetts, in 1753. By age 13, he demonstrated unusual skill with mechanical devices and had an almost faultless command of language and grammar. Soon he was attending science lectures at Harvard University. At the age of 19, he became a schoolmaster in Concord (earlier called Rumford), New Hampshire. There he met and married a rich widow 14 years his senior. Then, during the outbreak of the American Revolution, he sided with those loyal to England, for a time spying on their behalf. Facing arrest in 1776, he abandoned his wife and daughter and fled just ahead of a mob armed with hot tar and bags of feathers. He made his way to Boston during the evacuation of British troops and caught a ship to England. Once there, his scientific career prospered. His experiments with gunpowder were so successful that at age 26 he was elected to the prestigious Royal Society. He eventually made his way to Bavaria, where he was made a count by the Bavarian prince for whom he was making cannons. He chose the name Count Rumford, after Rumford, New Hampshire.

A cannon is made by first casting a large metal cylinder in a foundry. The cylinder is then turned on a lathe, where the barrel is bored by advancing a stationary drill bit down the casting. Rumford's lathe was horse-driven, as was common at the time. Rumford was puzzled about the huge amounts of heat given off in the process. The notion of heat at the time, a hypothetical fluid called caloric, didn't fit the evidence. With a dull drill, the amount of heat was greater. As long as the horses kept at their work, more and more heat was produced. The source of heat was not something in the metal, but the motion of the horses. This discovery occurred long before friction was seen as a force, and before the concept of energy and its conservation were understood. Rumford's careful measurements convinced him of the falseness of the caloric theory of heat. Nevertheless, the caloric theory of heat as a fluid held sway for many years. Over time, Rumford's experiments were repeated and led to the connection between heat and work.

Rumford's achievements weren't limited to science. For example, while in Munich, he put unemployed beggars to work making uniforms for the Army. He also put them to work on public projects, one of which is now the famous English Gardens. A bronze statue of Count Rumford stands there as testimony of the gratitude of the citizens of Munich.

Rumford's many inventions made him a wealthy man. In 1796, he gave $5000 each to the Royal Society of Great Britain and to the American Academy of Arts and Sciences to fund medals to be awarded every two years for outstanding scientific research on heat or light. Over the years, a galaxy of scientific stars in Europe and America have received the medals, including Michael Faraday, James Maxwell, Louis Pasteur, and Thomas Edison. The residue of Rumford's estate was left to Harvard University, where it was used to establish the present Rumford Professorship.

Rumford was honored worldwide. In 1805 he wooed and married Madame Lavoisier, widow of Antoine Lavoisier. The marriage was brief, however, and they soon separated. Rumford settled in Paris and continued his scientific work, extending the long list of his many inventions, until his death in 1814.

What an incredible relative!

15.1 Temperature

ADDITIONAL RESOURCES
Videos
Screencasts

All matter—solid, liquid, gas, and plasma, is composed of continuously jiggling atoms or molecules. Because of this random motion, the atoms and molecules in matter have kinetic energy. The average kinetic energy of the individual particles produces an effect we can sense—warmth. The quantity that indicates warmth with respect to some standard is called **temperature.** The first "thermal meter" for measuring temperature, the *thermometer*, was invented by Galileo in 1602 (the word *therm* is from the Greek term for "heat"). The familiar thermometer, a glass rod with a liquid in the interior that rises and falls with temperature, was invented by Gabriel Fahrenheit in the early 1700s and quickly came into widespread use. Fahrenheit devised a numeric scale and marked them on his thermometers. For nearly 300 years the favored liquid to use in the interior of his thermometers was

FIGURE 15.1
Can we trust our sense of hot and cold? Will both fingers feel the same temperature when removed and placed in the warm water?

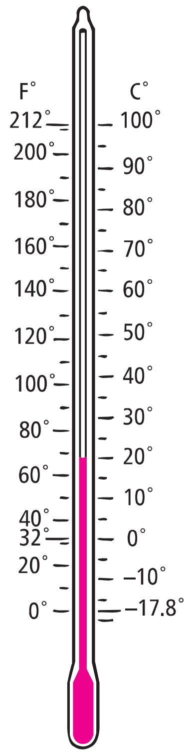


FIGURE 15.2
Fahrenheit and Celsius scales on a thermometer.

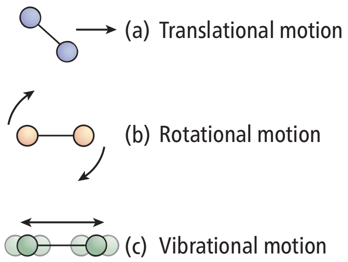


FIGURE 15.3
Particles in matter move in different ways. They move from one place to another, they rotate, and they vibrate to and fro. All these modes of motion, plus potential energy, contribute to the overall energy of a substance. Temperature, however, is defined by translational motion.

mercury, which is now phasing out because of the toxicity of mercury. We express the temperature of some quantity of matter by a number that corresponds to its degree of hotness or coldness on some chosen scale.

Nearly all materials expand when their temperature is raised and contract when their temperature is lowered. Most thermometers measure temperature by means of the expansion or contraction of a liquid, usually mercury or colored alcohol, in a glass tube with a scale.

On the most widely used temperature scale, the international scale, the number 0 is assigned to the temperature at which water freezes and the number 100 to the temperature at which water boils (at sea-level atmospheric pressure). The space between is divided into 100 equal parts called *degrees*; hence, a thermometer so calibrated has been called a *centigrade thermometer* (from *centi*, "hundredth," and *gradus*, "step"). However, it is now called a *Celsius thermometer* in honor of the man who first suggested the scale, the Swedish astronomer Anders Celsius (1701–1744).

Another temperature scale, the Fahrenheit scale, is popular in the United States. On this scale, the number 32 is assigned to the temperature at which water freezes, and the number 212 is assigned to the temperature at which water boils. Such a scale makes up a Fahrenheit thermometer, named after its illustrious originator, the German physicist Daniel Gabriel Fahrenheit (1686–1736). The Fahrenheit scale will become obsolete if and when the United States goes metric.[1]

The temperature scale favored by scientists is the Kelvin scale, named after the Scottish physicist William Thomson, 1st Baron Kelvin (1824–1907). This scale is calibrated not in terms of the freezing and boiling points of water but in terms of energy itself. The number 0 is assigned to the lowest possible temperature—**absolute zero,** at which a substance has absolutely no kinetic energy to give up.[2] Absolute zero corresponds to -273°C on the Celsius scale. Units on the Kelvin scale have the same size increments as degrees on the Celsius scale, so the temperature of melting ice is 273 K. There are no negative numbers on the Kelvin scale. We won't treat this scale further until we study thermodynamics in Chapter 18.

Arithmetic formulas used for converting from Fahrenheit to Celsius, and vice versa, are popular in classroom exams. Such arithmetic exercises are not really physics, and the probability that you'll have the occasion to do this task elsewhere is small, so we will not be concerned with them here. Besides, this conversion can be very closely approximated by simply reading the corresponding temperatures from the side-by-side scales in Figure 15.2.

Temperature is related to the random motion of atoms and molecules in a substance. (For brevity, in this chapter we'll simply say *molecules* to mean *atoms and molecules*.) More specifically, temperature is a measure of the average "translational" kinetic energy of random molecular motion (motion that carries the molecule from one place to another) in a substance as shown in Figure 15.3. Molecules may also rotate or vibrate, with associated rotational or vibrational kinetic energy—but these motions are not translational and don't define temperature.

[1]The conversion to Celsius would put the United States in step with the rest of the world, where the Celsius scale is the standard. But, Americans are slow to convert. Changing any long-established custom is difficult, and the Fahrenheit scale does have some advantages in everyday use. For example, its degrees are smaller ($1°F = 5/9°C$), which gives greater accuracy when reporting the weather in whole-number temperature readings. Then, too, people somehow attribute a special significance to numbers increasing by an extra digit. Thus, when the temperature of a hot day is reported to reach 100°F, the idea of heat is conveyed more dramatically than by stating that the temperature is 38°C. Like so much of the British system of measure, the Fahrenheit scale is geared to human beings.

[2]Even at absolute zero, a substance has what is called "zero-point energy," which is unavailable energy that cannot be transferred to a different substance. Helium, for example, has enough motion at absolute zero to avoid freezing. The explanation for this involves quantum theory.

CHECK POINT

True or false: Temperature is a measure of the total kinetic energy in a substance.

CHECK YOUR ANSWER

False. Temperature is a measure of the *average* (not *total*!) translational kinetic energy of molecules in a substance. For example, there is twice as much total molecular kinetic energy in 2 L of boiling water as in 1 L—but the temperatures of the two volumes of water are the same because the *average* translational kinetic energy per molecule is the same in each.

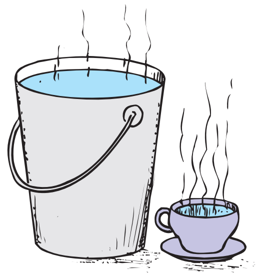


FIGURE 15.4
There is more molecular kinetic energy in the container filled with warm water than in the small cupful of higher-temperature water.

The effect of translational kinetic energy versus rotational and vibrational kinetic energy is dramatically demonstrated by a microwave oven. The microwaves that bombard your food cause certain molecules in the food, mainly water molecules, to flip to and fro and to oscillate with considerable rotational kinetic energy. But oscillating molecules don't cook food. What does raise the temperature and cook the food, and swiftly, is the translational kinetic energy imparted to neighboring molecules that are bounced off the oscillating water molecules. (To picture this, imagine a bunch of marbles set flying in all directions after encountering the spinning blades of a fan—also, see page 493.) If neighboring molecules didn't interact with the oscillating water molecules, the temperature of the food would be no different than before the microwave oven was turned on.

Interestingly, what a thermometer really displays is its *own* temperature. When a glass thermometer is in thermal contact with something whose temperature we wish to know, energy will flow between the two until their temperatures are equal and thermal equilibrium is established. If we know the temperature of the thermometer, we then know the temperature of what is being measured. A thermometer should be small enough that it doesn't appreciably alter the temperature of what is being measured. If you are measuring the air temperature of a room, then your thermometer is small enough. But, if you are measuring the temperature of a drop of water, contact between the drop and the thermometer may change the drop's temperature—a classic case of the measuring process changing the thing that is being measured. Modern thermometers bypass the expansion of liquid in a glass tube and measure temperature by the infrared radiation emitted by objects. These are the now popular IR thermometers (next chapter).

FIGURE 15.5
The temperature of the sparks is very high, about 2000°C. That's a lot of energy per molecule of spark. Because of the few molecules per spark, however, the internal energy is safely small. Temperature is one thing; transfer of energy is another.

15.2 Heat

If you touch a hot stove, energy enters your hand because the stove is warmer than your hand. When you touch a piece of ice, however, energy transfers from your hand into the colder ice. The direction of spontaneous energy transfer is always from a warmer object to a neighboring cooler object. The energy transferred from one object to another because of a temperature difference between them is called **heat.**

It is important to point out that matter does not *contain* heat. This was discovered by Rumford in his cannon-boring experiments, as mentioned earlier. Rumford, and other investigators that followed, realized that matter contains molecular kinetic energy and possibly potential energy, *not heat*. Heat is *energy in transit* from a body of higher temperature to one of lower temperature. Once transferred, the energy ceases to be heat. (As an analogy, work is also energy in transit. A body does not *contain* work. It *does* work or has work done on it.) In earlier chapters, we called the energy that results from heat flow *thermal energy* to make clear its link to heat and temperature. In this chapter, we will use the term that scientists prefer, *internal energy*.

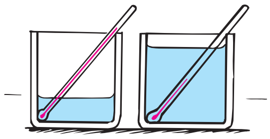


FIGURE 15.6
Although the same quantity of heat is added to both containers, the temperature increases more in the container with the smaller amount of water.

Temperature is measured in degrees; heat is measured in joules.

Internal energy is the grand total of all the energies inside a substance. In addition to the translational kinetic energy of jostling molecules in a substance, there is energy in other forms. There is rotational kinetic energy of molecules and kinetic energy due to internal movements of atoms within molecules. There is also potential energy due to the forces between molecules. So a substance does not contain heat—it contains internal energy.

When a substance absorbs or gives off heat, the internal energy of the substance increases or decreases. In some cases, as when ice is melting, the added heat does not increase the molecular kinetic energy but goes instead into other forms of energy. The substance undergoes a change of phase, which we will cover in detail in Chapter 17.

For two things in thermal contact, heat flow is from the higher-temperature substance to the lower-temperature substance. This is not necessarily a flow from a substance with more internal energy to a substance with less internal energy. There is more internal energy in a bowl of warm water than there is in a red-hot thumbtack; yet, if the tack is immersed in the water, heat flows from the hot tack to the warm water and not the other way around. Heat never flows of itself from a lower-temperature substance into a higher-temperature substance.

How much heat flows depends not only on the temperature difference between substances but on the amount of material as well. For example, a barrelful of hot water will transfer more heat to a cooler substance than will a cupful of hot water. There is more internal energy in the larger volume of water.

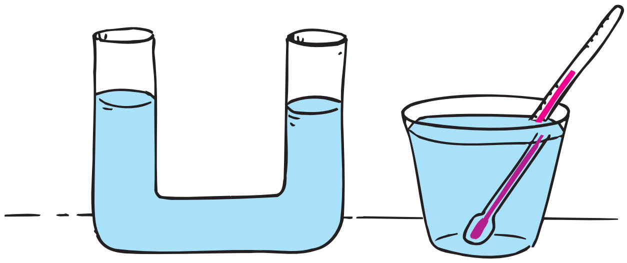


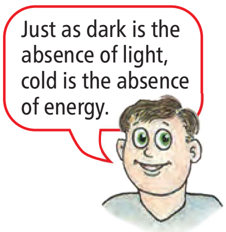
FIGURE 15.7
Just as water in the two arms of the U-tube seeks a common level (where the pressures at any given depth are the same), the thermometer and its immediate surroundings reach a common temperature (at which the average molecular KE is the same for both).

CHECK POINT

1. **Suppose you apply a flame to 1 L of water for a certain time and its temperature rises by 2°C. If you apply the same flame for the same time to 2 L of water, by how much will its temperature rise?**
2. **If a fast marble hits a random scatter of slow marbles, does the fast marble usually speed up or slow down? Of the initially fast-moving marble and the initially slow ones, which lose(s) kinetic energy and which gain(s) kinetic energy? How do these questions relate to the direction of heat flow?**

CHECK YOUR ANSWERS

1. Its temperature will rise by only 1°C because there are twice as many molecules in 2 L of water, and each molecule receives only half as much energy on average.
2. A fast-moving marble slows when it hits slower-moving marbles. It transfers some of its kinetic energy to the slower ones. Likewise with the flow of heat. Molecules with more kinetic energy that are in contact with molecules that have less kinetic energy transfer some of their excess energy to the less energetic ones. The direction of energy transfer is from hot to cold. For both the marbles and the molecules, however, the *total* energy before and after contact is the same.



Measuring Heat

So heat is the flow of energy from one thing to another due to a temperature difference. Since heat energy is in transit, it is measured in joules. In the United States, a more common unit of heat is the *calorie*. The calorie is defined as the amount of heat required to change the temperature of 1 gram of water by 1 Celsius degree.[3]

The energy ratings of foods and fuels are determined by burning them and measuring the energy released. (Your body "burns" food at a slow rate.) The heat unit used to label foods is actually the kilocalorie, which is 1000 calories (the heat required to raise the temperature of 1 kilogram of water by 1°C). To distinguish this unit from the smaller calorie, the food unit is sometimes called a *Calorie* (with a capital *C*). It is important to remember that the calorie and Calorie are units of energy. These names are historical carryovers from the early idea that heat is an invisible fluid called *caloric*. This view persisted, even after Rumford's experiments to the contrary, into the 19th century.

We now know that heat is a form of energy transfer, not a separate substance, so it doesn't need its own separate unit. Someday the calorie may give way to the joule, an SI unit, as the common unit for measuring heat. (The relationship between calories and joules is that 1 calorie = 4.19 joules.) In this text, we'll learn about heat with the conceptually simpler calorie—but, in the lab, you may use the joule equivalent, where an input of 4.19 joules raises the temperature of 1 gram of water by 1°C.

FIGURE 15.8
In science lab, 1 calorie = 4.19 joules. In the kitchen, 1 Calorie = 1000 calories = 4190 joules, as Chef Manuel Hewitt attests. A potato provides slightly more than twice as many Calories of energy per gram as a carrot.

CHECK POINT

1. **An iron tack and a big iron bolt, both red-hot at the same temperatures, are dropped into identical containers of same-temperature water. Which one raises water temperature more?**
2. **Which raises the water temperature more: the addition of 1 calorie or 4.19 J?**

CHECK YOUR ANSWERS

1. The iron bolt, having more internal energy at the same temperature of the smaller tack, raises the temperature of water more. This example underscores the difference between temperature and internal energy.
2. Neither. They expressed the same amount of energy in different units.

Both heat and work are "energy in motion"—energy being transferred from one substance to another. Both are measured in energy units, usually joules.

15.3 Specific Heat Capacity

You've likely noticed that some foods remain hotter much longer than others do. If you remove a piece of toast from a toaster and pour hot soup into a bowl at the same time, a few minutes later the soup is still pleasantly warm, while the toast has cooled off considerably. Similarly, if you wait a short while before eating a slice of hot roast beef and a scoop of mashed potatoes, both initially at the same temperature, you'll find that the meat has cooled off more than the potatoes.

Different substances have different capacities for storing internal energy. If we heat a pot of water on a stove, we might find that it requires 15 minutes to raise it from room temperature to its boiling temperature. But if we put an equal mass of iron on the same flame, we would find that the water would rise through

FIGURE 15.9
The filling of hot apple pie may be too hot to eat even though the crust is not.

[3]A less common unit of heat is the British thermal unit (BTU). The BTU is defined as the amount of heat required to change the temperature of 1 lb of water by 1 Fahrenheit degree. One BTU equals 1054 J.

the same temperature range in only about 2 minutes. For silver, the time would be less than a minute.

Different materials require different quantities of heat to raise the temperature of a given mass of the material by a specified number of degrees. This is partly due to different materials absorbing energy in different ways. The energy may be spread around among several kinds of energy, including molecular rotation and potential energy, which raises the temperature less. Except for special cases such as helium gas, the energy is always shared among different kinds of motion, but in varying degrees.

Whereas 1 gram of water requires 1 calorie of energy to raise its temperature 1 Celsius degree, it takes only about one-eighth as much energy to raise the temperature of a gram of iron by the same amount. Water absorbs more heat per gram than iron for the same change in temperature. We say water has a higher **specific heat capacity** (sometimes simply called *specific heat*).

The specific heat capacity of any substance is defined as the quantity of heat required to change the temperature of a unit mass of the substance by 1 Celsius degree.

If you add 1 calorie of heat to 1 gram of water, you'll raise its temperature by 1°C.

If we know the specific heat capacity c, then the quantity of heat Q transferred when a mass m of a substance undergoes a change in temperature ΔT is *specific heat capacity* $\times$ *mass* $\times$ *temperature change*. In equation form, $Q = cm\Delta T$.

We can think of specific heat capacity as thermal inertia. Recall that *inertia* is a term used in mechanics to mean the resistance of an object to a change in its state of motion. Specific heat capacity is a sort of thermal inertia because it signifies the resistance of a substance to a change in its temperature.

CHECK POINT

1. **Does a substance with a low specific heat capacity warm quickly or slowly when heat is applied?**
2. **Why does a piece of watermelon stay cool for a longer time than sandwiches when both are removed from a picnic cooler on a hot day?**

CHECK YOUR ANSWERS

1. It warms quickly. Low specific heat capacity means a quicker change in temperature.
2. Water in the watermelon has more "thermal inertia" than sandwich ingredients, and it resists changes in temperature much more. This thermal inertia is specific heat capacity.

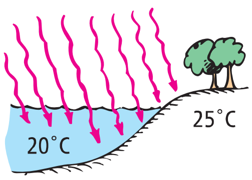


FIGURE 15.10
Because water has a high specific heat capacity and is transparent, it takes more energy to warm the water than to warm the land. Solar energy incident on the land is concentrated at the surface, which becomes hot much quicker.

15.4 The High Specific Heat Capacity of Water

Water has a much higher capacity for storing energy than all but a few uncommon materials. Due to water's strong hydrogen bonds, a relatively small amount of water absorbs a large quantity of heat for a correspondingly small temperature rise. Because of this, water is a very useful cooling agent in the cooling systems of automobiles and other engines. If a liquid of lower specific heat capacity were used in cooling systems, its temperature would rise higher for a comparable absorption of heat.

Water also takes a long time to cool, a fact that explains why, in earlier times, people used hot-water bottles on cold winter nights. Today, in many places, electric blankets have replaced them. This tendency of water to resist changes in temperature improves the climate in many locations. The next time you are looking at a world globe, notice the high latitude of Europe. If water did not have a high specific heat capacity, the countries of Europe would be as cold as the northeastern regions of Canada, because both Europe and Canada receive about the same amount of sunlight per square kilometer. The Atlantic current known as the Gulf Stream carries warm water northeast from the Caribbean. It retains much of its internal energy long enough to reach the North Atlantic off the coast of Europe, where it then cools. The energy released, about 1 calorie per degree for each gram of water that cools, transfers to the air, where it is carried by the westerly winds over the European continent.

A similar effect occurs in the United States. The winds in the latitudes of North America are westerly. On the West Coast, air moves from the Pacific Ocean to the land. Because of water's high specific heat capacity, an ocean does not vary much in temperature from summer to winter. The water is warmer than the air in the winter and cooler than the air in the summer. In winter, the water warms the air that moves over it, and the air warms the coastal regions of North America. In summer, the water cools the air, and the coastal regions are cooled. On the East Coast, air moves from the land to the Atlantic Ocean. Land, with a lower specific heat capacity, gets hot in the summer but cools rapidly in the winter. As a result of water's high specific heat capacity and the wind directions, the West Coast city of San Francisco is warmer in the winter and cooler in the summer than the East Coast city of Washington, DC, which is at about the same latitude.

Islands and peninsulas that are more or less surrounded by water do not have the same extremes of temperatures that are observed in the interior of a continent. When air is hot in summer months, water cools it. When air is cold in winter months, water warms it. Water moderates temperature extremes. The high summer and low winter temperatures common in Manitoba and the Dakotas, for example, are largely due to the absence of large bodies of water. Europeans, islanders, and people who live near ocean air currents should be glad that water has such a high specific heat capacity. San Franciscans are!

Climate is about average behavior, whereas weather is about the fluctuations. Climate refers to the type of clothes in your closet. Weather tells you which to wear each day.

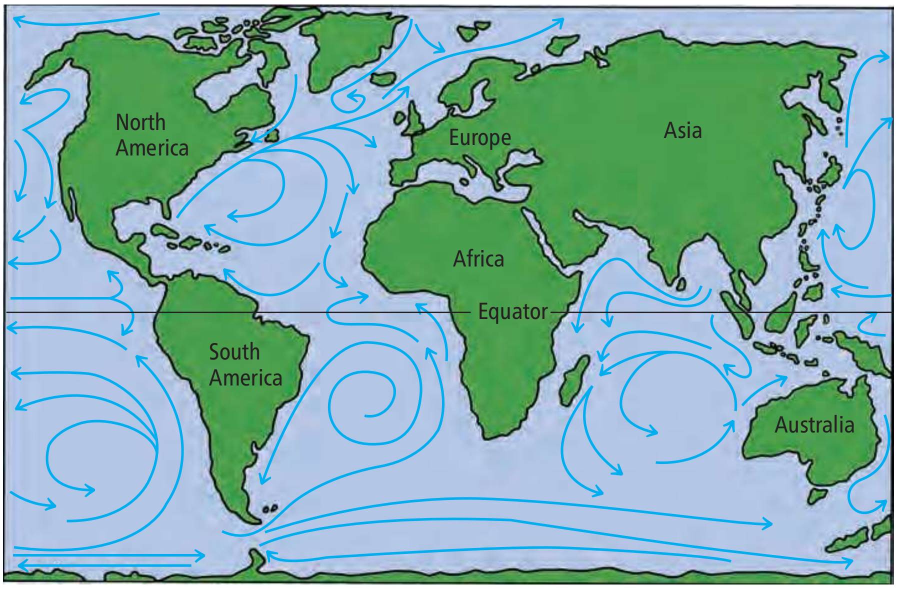


FIGURE 15.11
Many ocean currents, shown in blue, distribute heat from the warmer equatorial regions to the colder polar regions.

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- Just as the outer side of a carousel platform always provides the fastest ride, locations closer the Earth's equator travel fastest and farthest than locations farther from the equator. Things moving toward the equator that are not fixed to the ground, such as air, water, and airplanes, can't keep up with the faster-moving ground beneath them. They tend to swerve. This is the *Coriolis effect.* So ocean currents heading toward the equator tend to deviate to the west, while currents heading away from the equator deviate to the east. That's why ocean currents in the Northern Hemisphere tend to circulate clockwise, while currents in the Southern Hemisphere tend to circulate counterclockwise, as is evident in Figure 15.11.

CHECK POINT

Which has a higher specific heat capacity: water or sand?

CHECK YOUR ANSWER

Water has a higher specific heat capacity. Water has greater thermal inertia and takes a longer time to warm in the hot sunlight and a longer time to cool on a cold night. Sand has a low specific heat capacity, as evidenced by how quickly the surface warms in the morning sunlight and how quickly it cools at night. (Walking or running barefoot across scorching sand in the daytime is a much different experience than walking on cool sand in the evening.)

15.5 Thermal Expansion

When the temperature of a substance is increased, its molecules or atoms jiggle faster and move farther apart, on the average. The result is an expansion of the substance. With few exceptions, all forms of matter—solids, liquids, gases, and plasmas—generally expand when they are heated and contract when they are cooled.

In most cases involving solids, these changes in volume are not very noticeable, but careful observation usually detects them. Power lines become longer and sag more on a hot summer day than on a cold winter day. A metal lid on a glass jar can often be loosened by heating the lid under hot water. If one part of a piece of glass is heated or cooled more rapidly than adjacent parts, the resulting expansion or contraction may break the glass, especially if the glass is thick. Pyrex heat-resistant glassware is an exception because it's specially formulated to expand very little with increasing temperature (about a third as much as ordinary glass).

FIGURE 15.12
One end of the bridge is fixed, while the end shown rides on rockers to allow for thermal expansion.

The expansion of substances must be accommodated in structures and devices of all kinds. A dentist uses filling material that has the same rate of expansion as teeth. The aluminum pistons of some automobile engines are just a bit smaller in diameter than the steel cylinders to allow for the much greater expansion rate of aluminum. Civil engineers use reinforcing steel that has the same expansion rate as concrete. Long steel bridges commonly have one end fixed while the other end rests on rockers (Figure 15.12). The Golden Gate Bridge in San Francisco contracts more than a meter in cold weather. The roadway itself is segmented with tongue-and-groove–type gaps called *expansion joints* (Figure 15.13). Similarly, concrete roadways and sidewalks are intersected by gaps, sometimes filled with tar, so that the concrete can expand freely in summer and contract in winter.

FIGURE 15.13
This gap in the roadway of a bridge is called an expansion joint; it allows the bridge to expand and contract.

In times past, railroad tracks were laid in 12-meter segments connected by joint bars, with gaps for thermal expansion. In summer months, the tracks expanded and the gaps were narrow. In winter, the gaps widened, which was responsible for a more pronounced clickity-clack when the trains rolled along the tracks. We don't hear clickity-clacks these days because someone got the bright idea to eliminate the gaps by welding the tracks together. Doesn't expansion in the summer heat cause the welded tracks to buckle, as shown in Figure 15.14? Not if the tracks are laid and welded on the hottest summer days! Track shrinkage on cold winter days stretches the tracks, which doesn't cause buckling. Stretched tracks are okay.

FIGURE 15.14
Thermal expansion. The extreme heat on a hot summer day caused the buckling of these railroad tracks.

CHECK POINT

1. **Why do both a party balloon and a railroad track increase in size when their temperatures rise?**
2. **Why do they decrease in size when cooled?**

CHECK YOUR ANSWERS

1. Heated molecules in each jiggle faster and occupy more space, much more for the balloon because it is gaseous.
2. When each is cooled, molecules jiggle slower and settle into less space.

Different substances expand at different rates. When two strips of different metals—say, one of brass and the other of iron—are welded or riveted together, the greater expansion of one metal results in the bending of the strip, as shown in Figure 15.15. Such a compound thin bar is called a *bimetallic strip*. When the strip is heated, one side of the double strip becomes longer than the other, causing the strip to bend into a curve. In contrast, when the strip is cooled, it tends to bend in the opposite direction because the metal that expands more also shrinks more. The movement of the strip may be used to turn a pointer, regulate a valve, or close a switch. Bimetallic strips are used in oven thermometers, electric toasters, and a variety of devices.

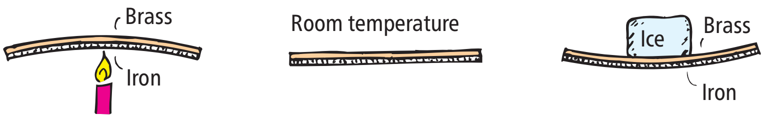

FIGURE 15.15
A bimetallic strip. Brass expands more when heated than iron does and contracts more when cooled. Because of this behavior, the strip bends as shown.

A practical application of different rates of expansion is the thermostat (Figure 15.16). The back-and-forth bending of the bimetallic coil opens and closes an electric circuit. When the room becomes too cold, the coil bends toward the brass side, which activates an electrical switch that turns on the heat. When the room becomes too warm, the coil bends toward the iron side, which activates an electrical switch that turns off the heating unit. Refrigerators are equipped with thermostats to prevent them from becoming either too warm or too cold.

Liquids expand appreciably with increases in temperature. In most cases, the expansion of liquids is greater than the expansion of solids. The gasoline overflowing a car's tank on a hot day is evidence for this. If the tank and its contents expanded at the same rate, they would expand together and no overflow would occur. Similarly, if the expansion of the glass of a thermometer were as great as the expansion of the mercury, the mercury would not rise with increasing temperature. The reason the mercury in a thermometer rises with increasing temperature is that the expansion of liquid mercury is greater than the expansion of glass.

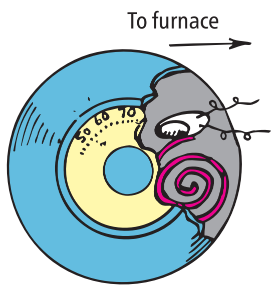

FIGURE 15.16
A pre-electronic thermostat. When the bimetallic coil expands, the drop of liquid mercury rolls away from the electrical contacts and breaks the electric circuit. When the coil contracts, the mercury rolls against the contacts and completes the circuit.

FIGURE 15.17
Place a dented ping-pong ball in boiling water, and you'll remove the dent. Why?

CHECK POINT

To repair a dented ping-pong ball, why is it a good idea to place it in boiling water?

CHECK YOUR ANSWER

Expansion of air inside the ping-pong ball will likely pop it back to its original shape.

Expansion of Water

Water, like most other substances, expands when heated. But, interestingly, it *doesn't* expand in the temperature range between 0°C and 4°C. Something quite fascinating happens in this range. Ice has a crystalline structure, with open-structured crystals. Water molecules in this open structure occupy a greater volume than in the liquid phase (Figure 15.18). This means that ice is less dense than water.

fyi

- Snowflakes form mainly from water vapor rather than liquid water. Truly symmetrical snowflakes are the exception rather than the rule. Many mechanisms interrupt perfect snowflake growth. Like everything else, no two are identical. In 1611, the astronomer Kepler wrote a paper on six-cornered snowflakes. Fifty-four years later, physicist Robert Hooke used his early microscope to sketch the forms of snowflakes.

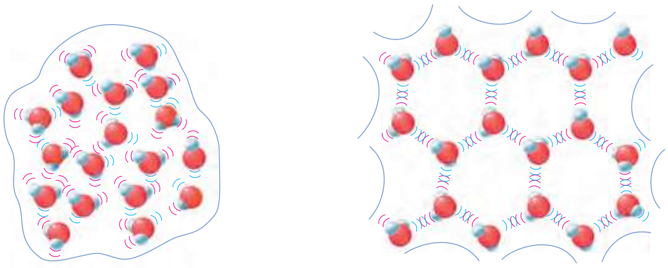

FIGURE 15.18
Liquid water is more dense than ice because water molecules in a liquid are closer together than water molecules frozen in ice, where they have an open crystalline structure.

CHECK POINT

What's inside the open spaces of the water crystals shown in Figures 15.18 and 15.19? Is it air, water vapor, or nothing?

CHECK YOUR ANSWERS

There's nothing at all in the open spaces. It's empty space—a void. If there were air or vapor in the open spaces, the illustration should show molecules there—oxygen and nitrogen for air and H_2O for water vapor.

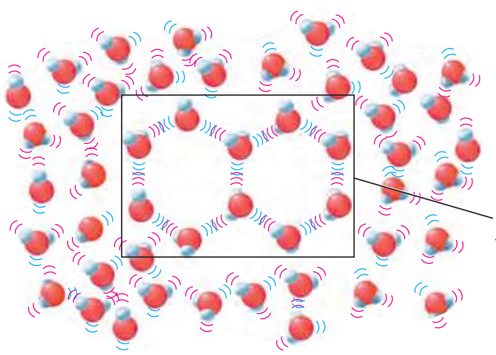

FIGURE 15.19
The open structure of the 3-dimensional ice crystals that form as water freezes creates a microscopic slush that slightly increases the volume of the water.

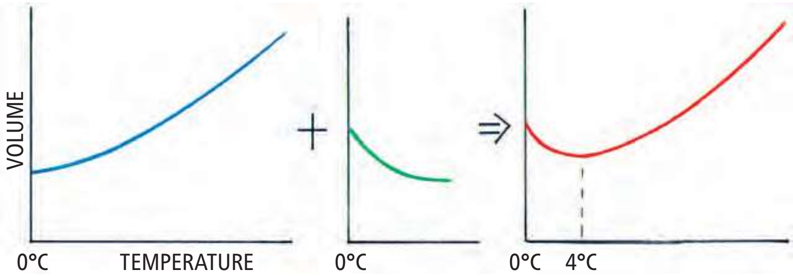

FIGURE 15.20
The blue curve indicates the normal expansion of water with increasing temperature. The green curve indicates the contraction of ice crystals in ice water as they melt with increasing temperature. The red curve shows the result of both processes.

When ice melts, not all the open-structured crystals collapse. Some microscopic crystals remain in the ice-water mixture, making up a microscopic slush that slightly "bloats" the water, increasing its volume slightly (Figure 15.19). This results in ice water being less dense than slightly warmer water. As the temperature of water at 0°C is increased, more of the remaining ice crystals collapse. The melting of these crystals further decreases the volume of the water. The water undergoes two processes at the same time—expansion and contraction (Figure 15.20). Volume tends to increase due to greater molecular motion with increased temperature, while volume at and near 0°C decreases as ice crystals collapse upon melting. The collapsing effect dominates until the temperature reaches 4°C. After that, expansion overrides contraction because most of the microscopic ice crystals have melted by then (Figure 15.21).

When ice water freezes to become solid ice, its volume increases by nearly 10% and its density is lowered. That's why ice floats on water. Like most other substances, solid ice contracts with further cooling. This behavior of water is

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- How does rock salt spread on icy roads in winter help to melt ice? It so happens that salt in water separates into sodium and chlorine ions, which when they join water molecules, give off energy that melts microscopic parts of an icy surface. The pressure of automobiles rolling along the salt-covered icy surface forces the salt into the ice, enhancing the melting process. The only difference between the rock salt and the salt you sprinkle on popcorn is the size of the crystals.

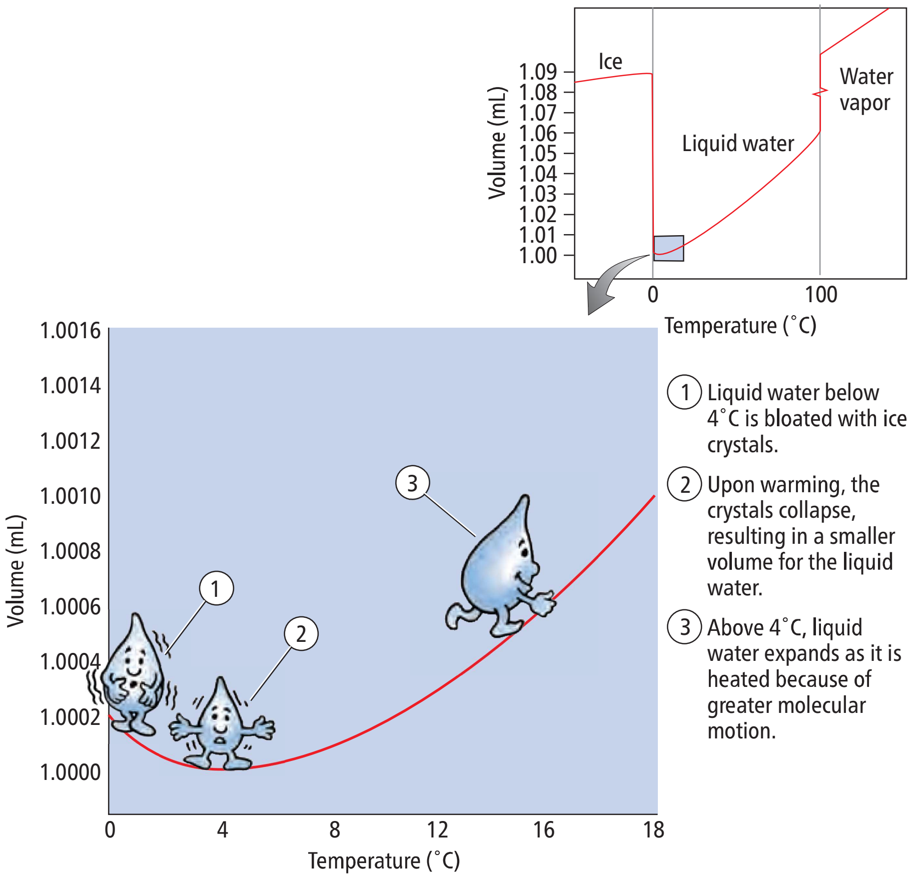
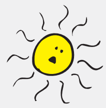


FIGURE 15.21
Between 0°C and 4°C, the volume of liquid water decreases as the temperature increases. Above 4°C, water behaves the way other substances do: Its volume increases as its temperature increases. The volumes shown are for a 1-gram sample.

LIFE AT THE EXTREMES

Some deserts, such as those on the plains of Spain, the Sahara in Africa, and the Gobi in central Asia, reach surface temperatures of 60°C (140°F). Too hot for life? Not for certain species of ants of the genus *Cataglyphis*, which thrive at this searing temperature. At this extremely high temperature, the desert ants can forage for food without danger from the presence of lizards, which would otherwise prey upon them. Resistant to heat, these ants can withstand higher temperatures than any other creatures in the desert (except microbes). Unique triangular hairs over a silvery coat on the topsides of their bodies both reflects visible and near-infrared light, in addition to radiating heat away. They scavenge the desert surface for the corpses of those creatures that did not find cover in time, touching the hot sand as little as possible while often sprinting on four legs with two held high in the air. Although their foraging paths zigzag over the desert floor, their return paths are almost straight lines to their nest holes. They attain speeds of 100 body lengths per second. During an average six-day life, most of these ants retrieve 15 to 20 times their weight in food.

From deserts to glaciers, a variety of creatures have invented ways to survive the harshest regions of the world. A species of worm thrives in the glacial ice in the Arctic. There are insects in the Antarctic ice that pump their bodies full of antifreeze to ward off becoming frozen solid. Some fish that live beneath the ice are able to do the same. Then there are bacteria that thrive in boiling hot springs as a result of having heat-resistant proteins.



An understanding of how creatures survive at the extremes of temperature can provide clues for practical solutions to the physical challenges that humans face. Astronauts who venture from Earth, for example, will need all the techniques available for coping with unfamiliar environments.

very important in nature. If water were most dense at 0°C, it would settle to the bottom of a pond or lake. Water at 0°C, however, is less dense and “floats” at the surface. So again we see why ice forms at the surface.

So a pond freezes from the surface downward. In a cold winter, the ice will be thicker than in a milder winter. The water temperature at the bottom of an ice-covered pond is 4°C, which is relatively warm for the organisms that live there. Interestingly, very deep ponds and lakes are normally not ice covered even in the coldest of winters. This is because all the water must be cooled to 4°C before lower temperatures can be reached. For deep water, the winter is not long enough to reduce an entire pond to 4°C. Any 4°C water lies at the bottom. Because of water’s high specific heat capacity and poor ability to conduct heat, the bottom of a deep body of water in a cold region remains at a constant 4°C year-round. Fish should be glad that this is so. We should *all* be glad that ice is less dense than liquid water, otherwise all winter lakes and ponds would freeze solid!

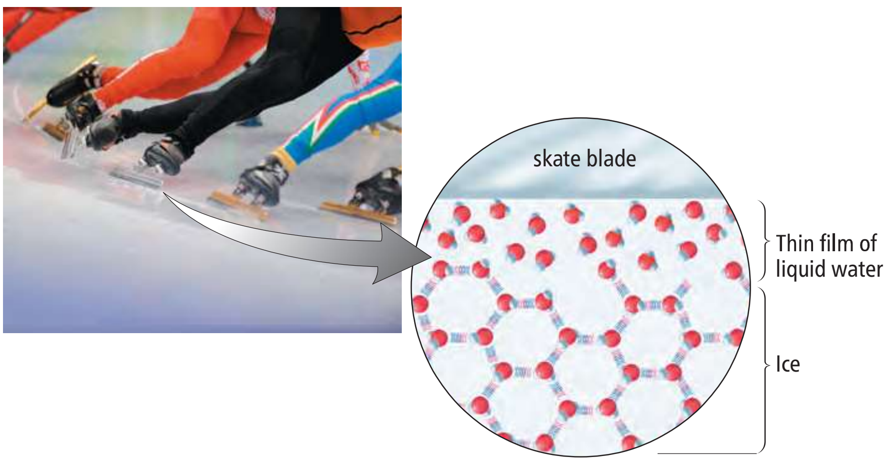


FIGURE 15.22
Ice is slippery because its crystalline structure is not easily maintained at the surface.

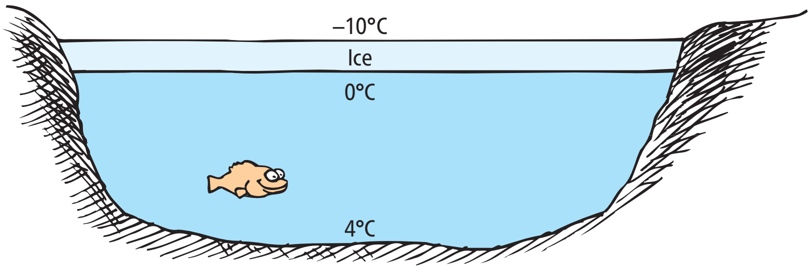


FIGURE 15.23
As water is cooled at the surface, it sinks until the temperature of the entire lake is 4°C. Only then can the surface water cool to 0°C without sinking. Once ice has formed, temperatures lower than 4°C can extend down into the lake.

CHECK POINT

1. **What was the precise temperature at the bottom of Lake Michigan, where the water is deep and the winters long, on New Year's Eve in 1901?**
2. **Why do fish benefit from water being most dense at 4°C?**

CHECK YOUR ANSWERS

1. 4°C because the temperature at the bottom of any body of water containing any 4°C water has a bottom temperature of 4°C, for the same reason that rocks are at the bottom. Rocks are more dense than water, and 4°C water is more dense than water at any other temperature. So both rocks and 4°C water sink to the bottom. Water is also a poor heat conductor, so if the body of water is deep and in a region of long winters and short summers, the water at the bottom likely remains a constant 4°C year-round.
2. Since water is most dense at 4°C, colder water rises and freezes on the surface, which means that fish remain in relative warmth!

Chapter 15 Review

For instructor-assigned homework, go to: www.masteringphysics.com

SUMMARY OF TERMS (KNOWLEDGE)

Temperature A measure of the average translational kinetic energy per molecule in a substance, measured in degrees Celsius or Fahrenheit or in kelvins (K).

Absolute zero The lowest possible temperature that a substance may have—the temperature at which molecules of the substance have their minimum kinetic energy.

Heat The energy that flows from a substance of higher temperature to a substance of lower temperature, commonly measured in calories or joules.

Internal energy The total of all molecular energies, kinetic plus potential, that are internal to a substance.

Specific heat capacity The quantity of heat per unit mass required to change the temperature of a substance by 1 Celsius degree.

READING CHECK QUESTIONS (COMPREHENSION)

15.1 Temperature

1. What is meant by temperature? What is the underlying cause of warmth produced by matter?
2. What happens to kinetic energy at absolute zero?
3. Which form of energy determines temperature: translational kinetic energy, rotational kinetic energy, vibrational kinetic energy, or all of these?
4. Why should a thermometer be smaller than the object of which the temperature is being measured?

15.2 Heat

5. Is there a distinction between thermal energy and internal energy? Which term do physicists prefer?
6. What is internal energy? What are the different constituents of internal energy?
7. Does a hot object contain internal energy or heat? Or do the two terms mean the same thing?
8. What is the role of temperature with regard to the direction of internal energy flow?
9. How is the energy value of foods determined?
10. How is the unit of heat known as a 'calorie' defined?
11. How many joules are needed to change the temperature of 1 gram of water by 1°C?

15.3 Specific Heat Capacity

12. Why does iron warm faster than water upon the application of heat?
13. Does a substance that heats up quickly have a high or a low specific heat capacity?

15.4 The High Specific Heat Capacity of Water

14. Northeastern Canada and much of Europe receive about the same amount of sunlight per unit area. Why, then, is Europe generally warmer in the winter?
15. According to the law of conservation of energy, if ocean water cools, something else should warm. What is it that warms?
16. Why do islands and peninsulas surrounded by water not experience extreme temperatures?

15.5 Thermal Expansion

17. Why is it important that the material used in dental fillings has a rate of thermal expansion that matches the tooth material itself?
18. Why does a bimetallic strip bend with changes in temperature?
19. What would have happened if the glass of a thermometer expanded as much as mercury?
20. When the temperature of ice-cold water is increased slightly, does it undergo a net expansion or a net contraction?
21. Mention the temperature range where water doesn't expand upon heating.
22. Does "microscopic slush" in water tend to make it denser or less dense?
23. What happens to the amount of "microscopic slush" in cold water when its temperature is increased?
24. At what temperature do the combined effects of contraction and expansion produce the smallest volume for water?
25. Why does all the water in a lake have to be cooled to 4°C before surface water can be cooled below 4°C?

THINK AND DO (HANDS-ON APPLICATIONS)

26. Blow up a balloon to its maximum capacity, tie it shut (make sure it is tight), and place it into the refrigerator overnight. How does it appear in the morning? How does it appear on the kitchen table an hour or so later? What is happening?
27. When taking a brisk walk use your smartphone to measure the Calories you burn. Then go to your cupboard and find an equivalent amount of Calories of food. Does this make you want to reevaluate what you eat each day?
28. How much energy is in a nut? Burn it and find out. The heat from the flame is energy released when carbon and hydrogen in the nut combine with oxygen in the air (oxidation reactions) to produce CO_2 and H_2O. Pierce a nut (pecan or walnut halves work best) with a bent paper clip that holds the nut above the table surface. (Be sure to put something fireproof underneath.) Above this, secure a can of water so that you can measure its temperature change when the nut burns. Use about 10^3 cm (10 mL) of water and a Celsius thermometer. As soon as you ignite the nut with a match, place the can of water above it and record the increase in water temperature once the flame burns out. The number of calories released by the burning nut can be calculated by the formula $Q = cm\Delta T$, where c is its specific heat (1.0 cal/g·°C), m is the mass of water, and ΔT is the change in temperature. The energy in food is expressed in terms of the Calorie, which is 1000 of the calories you'll measure. So to find the number of Calories, divide your result by 1000. (See Think and Solve 33.)
29. Connect with your grandparents or other people older than you and describe how you're learning to see connections in nature that have been elusive to you until now and how you're learning to distinguish between related ideas. Use temperature and heat as examples.

PLUG AND CHUG (EQUATION FAMILIARIZATION)

The quantity of heat Q released or absorbed from a substance of specific heat c (which can be expressed in units cal/g·°C *or* J/kg·°C*) and mass m (in* g *or* kg*), undergoing a change in temperature* ΔT *is* $Q = cm\Delta T$

30. How much energy in calories is required to raise the temperature of 200 g of water from 20°C to 30°C? For the specific heat capacity *c*, use 1 cal/g·°C.
31. Use the same formula to calculate the heat required in joules to raise the temperature of the same mass (0.2 kg) of water through double the temperature interval. For the specific heat capacity *c*, use 4190 J/kg·°C.
32. Use the same formula to show that 4,190 joules are required to raise the temperature of a kilogram of water by 1 °C, which is the definition of specific heat capacity.

THINK AND SOLVE (MATHEMATICAL APPLICATION)

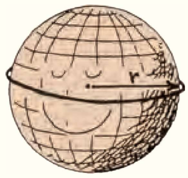
33. Will Maynez burns a 0.6-g peanut beneath 50 g of water, which increases in temperature from 22°C to 50°C. (The specific heat capacity of water is 1.0 cal/g·°C.)
    (a) Assuming that 40% of the heat released by the burning peanut makes its way to the water (40% efficiency), show that the peanut's food value is 3500 calories (equivalently, 3.5 Calories).
    (b) Then show how the food value in calories per gram is 5.8 kcal/g (or 5.8 Cal/g).

34. If you wish to warm 150 kg of water by 20°C for your bath, show that the amount of heat needed is 3000 kcal (3000 Cal, more than the amount of food energy the average human needs per day!). Then show that this is equivalent to about 12,600 kJ.
35. Calculate the amount of heat needed to raise the temperature of a 300-g aluminum cube from 30°C to 50°C. The specific heat of aluminum is 910 J/kg·°C.

To solve the problems below, you will need knowledge of the average coefficient of linear expansion, α*, which differs for different materials. We define* α *to be the change in length (L) per unit length—or the fractional change in length—for a temperature change of °C. That is,* $\Delta L/L$ *per °C. For aluminum,* $\alpha = 24 \times 10^{-6}/°C$*, and for steel,* $\alpha = 11 \times 10^{-6}/°C$*.*

The change in length ΔL *of a material is given by* $\Delta L = L\alpha\Delta T$*.*

36. A 1-meter-long bar expands by 0.3 cm when heated. If a 200-m bar of the same material is heated to the same temperature, calculate its final length.
37. Suppose that the 1.3-km main span of steel for the Golden Gate Bridge had no expansion joints. Show that for an increase in temperature of 20°C the bridge would be nearly 0.3 m longer.
38. Imagine a 40,000-km steel pipe that forms a ring to fit snugly entirely around the circumference of Earth. Suppose that people along its length breathe on it so as to raise its temperature by 1°C. The pipe gets longer—and is also no longer snug. How high does it stand above ground level? Show that the answer is an astounding 70 m higher! (To simplify, consider only the expansion of its radial distance from the center of Earth, and apply the geometry formula that relates circumference *C* and radius *r*, $C = 2\pi r$.)



THINK AND RANK (ANALYSIS)

39. The same heat Q is absorbed by different substances with the same mass, which results in the following: (a) the temperature of substance A increases by 10°C, (b) the temperature of substance B increases by 6°C, (c) the temperature of substance C increases by 24°C, and (d) the temperature of substance D increases 15°C. Rank the specific heat of the substances from least to greatest.
40. Four blocks of metals of different sizes at the same temperature are placed on a hot stove. Their specific heat capacities are listed below. If all were able to increase their temperature by 5°C, rank their mass from greatest to least: (a) Steel, 450 J/kg·°C; (b) Aluminum, 910 J/kg·°C; (c) Iron, 470 J/kg·°C; and (d) Copper, 390 J/kg·°C.

41. Three kinds of thin metal rods of the same length and initial temperature are placed on a tray and heated. Rank the expansion of these metal wires from least to greatest: (a) Brass, $\alpha = 2.0 \times 10^{-5}/°C$, (b) Aluminum, $\alpha = 2.4 \times 10^{-5}/°C$, and (c) Steel, $\alpha = 1.2 \times 10^{-5}/°C$.

42. The same temperature change ΔT is experienced by different wires with the same initial lengths, which results in the following observations: (a) the length of wire A increases by 1.0 mm, (b) the length of wire B increases by 1.6 mm, (c) the length of wire C increases by 0.7 mm, and (d) the length of wire D increases by 1.2 mm. Rank the coefficient of linear expansion of the wires in decreasing order.

THINK AND EXPLAIN (SYNTHESIS)

43. Why can't you establish whether you have a high temperature by touching your own forehead?
44. In a conference room are chairs, a table, and people. Compared to the temperature of air in the room, which of these has a temperature (a) lower than, (b) greater than, or (c) equal to the air temperature?
45. Is it possible for the Kelvin and Fahrenheit scales to agree numerically at a specific reading?
46. Which is larger: a Celsius degree or a kelvin?
47. Which is the largest unit of heat transfer: Calorie, calorie, or joule?
48. Are the oscillating molecules of water responsible for food getting cooked in a microwave oven?
49. On average, which has more kinetic energy: a molecule in a gram of ice water or a molecule in a gram of steam? Defend your answer.
50. For the same mass, which will heat up faster when placed in an oven: iron or lead? Justify your answer.
51. Would using a mercury thermometer be effective enough if you wanted to measure the temperature of a drop of hot water? Why or why not?
52. Consider two glasses of same-temperature water, one filled and the other half-full. In which glass are the water molecules moving faster on average? In which is there greater internal energy? In which will more heat be required to increase the temperature by 1°C?
53. Why does the pressure of gas enclosed in a rigid container increase as the temperature increases?
54. Equally increasing the temperature of two different objects of the same length does not necessarily produce the same increase in length. Why not?
55. Which likely has the greater specific heat capacity: an object that cools quickly or an object of the same mass that cools more slowly?
56. Why do we often refer to specific heat capacity as *thermal inertia*?
57. If the specific heat capacity of water were less, would a nice hot bath be a longer or a shorter experience? Why?
58. Which would warm up faster in a hot oven, a slice of watermelon or a cheese sandwich of the same mass? Defend your answer.
59. A certain quantity of heat is applied to 1 kg and 2 kg samples of silver. Which sample undergoes the greater change in temperature? Defend your answer.
60. Ethyl alcohol has about one-half the specific heat capacity of water. If equal masses of each at the same temperature are supplied with equal quantities of heat, which will undergo the greater change in temperature? Why?
61. When a 1-kg metal pan containing 1 kg of cold water is removed from the refrigerator and set on a table, which absorbs more heat from the room: the pan or the water? Why?
62. In a laboratory experiment, you are tasked with cooling down the temperature of a pot of hot water. You have two available objects that can be used as a coolant: a cube of aluminum and a cube of copper of the same mass and at room temperature. Which of the two is more effective at decreasing the temperature of hot water? Defend your answer.
63. Two thin metallic strips riveted together (some thermostats are made this way) form a bimetallic strip that bends when heated. Why does the bimetallic strip bend instead of expanding linearly?
64. Iceland, so named to discourage conquest by expanding empires, is not at all ice covered like Greenland and parts of Siberia, even though it is not far from the Arctic Circle. The average winter temperature of Iceland is considerably higher than it is in regions at the same latitude in eastern Greenland and central Siberia. Why is this so?
65. Why does the presence of large bodies of water tend to moderate the climate of nearby land—to make it warmer in cold weather and cooler in hot weather?
66. If the winds at the latitude of San Francisco and Washington, D.C., were from the east rather than from the west, why might San Francisco be able to grow only cherry trees and Washington, D.C., both cherry trees and palm trees?
67. Why do you feel more uncomfortable during a hot and humid day as compared to a hot, dry day of the same temperature?

68. How does buoyancy play a role in the rising of warm air?
69. Cite an exception to the claim that all substances expand when heated.
70. Would a bimetallic strip function if the two different metals have the same rates of expansion? Is it important that they expand at different rates? Explain.
71. An old method for breaking boulders was to put them in a hot fire and then douse them with cold water. Why would this fracture the boulders?
72. Structural groaning noises are sometimes heard in the attic of old buildings on cold nights. Give an explanation in terms of thermal expansion.
73. Why is it important that glass mirrors used in astronomical observatories be composed of glass with a low "coefficient of expansion"?
74. In terms of thermal expansion, why is it important that a key and its lock be made of the same or similar materials?
75. Any architect will tell you that chimneys are never used as a weight-bearing part of a wall. Why?
76. Why do long steam pipes often have one or more relatively large U-shaped sections of pipe?
77. Why are light bulbs typically made of very thin glass?
78. One of the reasons the first light bulbs were expensive was due to the platinum electrical lead wires into the bulb, which were necessary because they expanded at about the same rate as glass when heated. Why is it important that the metal leads and the glass have the same coefficient of expansion?
79. Which of the following would do more damage to your hands if you were exposed to it: 100°C steam or 100°C hot air?
80. Suppose that water is used in a thermometer instead of mercury. If the temperature is at 4°C and then changes, why can't the thermometer indicate whether the temperature is rising or falling?
81. A piece of solid iron sinks in a container of molten iron. A piece of solid aluminum sinks in a container of molten aluminum. Why does a piece of solid water (ice) not sink in a container of "molten" (liquid) water? Explain, using molecular terms.
82. What happens to the volume of water as it is cooled from 3°C to 1°C?
83. State whether water at the following temperatures will expand or contract when warmed a little: 0°C, 4°C, 6°C.
84. Water pipes usually burst in the winter. What could be the reason behind this?
85. If water had a lower specific heat capacity, would ponds be more likely to freeze or less likely to freeze?
86. If cooling occurred at the bottom of a pond instead of at the surface, would the pond freeze from the bottom up? Explain.

Think and Explains are ***NOT Search*** **and Explain**. Exercise your brain by thinking, ***not*** by searching the Internet!

THINK AND DISCUSS (EVALUATION)

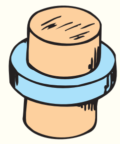
87. A canister contains a mixture of hydrogen and oxygen gases at the same temperature. Which molecules move faster, and, why?
88. One canister is filled with argon gas and second canister filled with krypton gas. If both gases have the same temperature, in which container are the atoms moving faster? Why?
89. Water expands when it turns to ice. Discuss how this relates to cracks and potholes that appear in cold places during the winter.
90. When constructing railways, engineers intentionally leave a small gap between the metal tracks. Why is this so?
91. An old remedy for a pair of nested drinking glasses that stick together is to run water at different temperatures into the inner glass and over the surface of the outer glass. In which glass should the cold water be placed?
92. Gas is sold by volume. Would you or the gas company gain by having gas warmed before it passed through your gas meter?
93. After filling your gas tank to the top and parking your car in direct hot sunlight, why does the gasoline overflow?
94. If you suddenly place just the bulb of a mercury thermometer into hot water, the reading on the thermometer initially goes down before beginning to rise. Explain what is happening.
95. If you drop a hot rock into a pail of water, the temperatures of the rock and the water will change until both are equal. The rock will cool and the water will warm. Does this hold true if the hot rock is dropped into the Atlantic Ocean? Discuss.
96. Heat added to some substances goes primarily into the translational kinetic energy of its molecules, which directly elevates temperature. For other substances, large proportions of the added heat energy also goes into vibrations and rotations of the molecules. Discuss whether you'd expect materials in which a lot of energy goes into non-translational molecular motions to have a high or a low specific heat capacity.

97. To the weight watcher, the peanut being eaten contains 10 Calories. His physics friend says that 41,900 joules will be released by the peanut when consumed. Is the friend is correct? Explain.

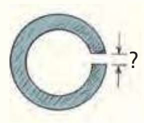
98. A metal ball is just able to pass through a metal ring. When Anette increases the temperature of the ball, however, it will not pass through the ring. What would happen if she instead increased the temperature of the ring, rather than the ball? Discuss whether or not the size of the hole increases, stays the same, or decreases.

99. Consider a pair of brass balls of the same diameter, one hollow and the other solid. Both are heated with equal increases in temperature. Discuss and compare the diameters of the heated balls.

100. After a machinist very quickly slips a hot, snugly fitting iron ring over a very cold brass cylinder, the two cannot be separated intact. Discuss why this is so.



101. Suppose that you cut a small gap in a metal ring. If you were to heat the ring, discuss whether the gap would become wider or narrower.



102. After you measure the dimensions of a plot of land with a steel tape on a hot day, you return and re-measure the same plot on a cold day. On which day do you determine the larger area for the land?

103. How would the shape of the volume versus temperature graph in Figure 15.21 differ if density rather than volume were plotted against temperature? Make a rough sketch.

104. Discuss how the combined volume of the billions and billions of hexagonal open spaces in the structures of ice crystals in a piece of ice compares with the portion of ice that floats above the waterline.

105. Does it make sense to say that heat is like love—that we cannot *be* either, for we can only give and receive it. Discuss your thoughts on this statement with a friend.

Think and Discuss is ***NOT Search*** **and Discuss**. Exercise your brain by thinking, ***not*** by searching the Internet!