Section 7 Laws of Thermodynamics: Too Hot, Too Cold, Just Right

What Do You See?

Learning Outcomes

In this section, you will

- **Assess** experimentally the final temperature when two liquids of different temperatures are mixed.
- **Assess** experimentally the final temperature when a hot metal is added to cold water.
- **Calculate** the heat lost and the heat gained of two objects after they are placed in thermal contact.
- **Discover** if energy is conserved when two objects are placed in thermal contact and reach an equilibrium temperature.
- **Explain** the concept of entropy as it relates to objects placed in thermal contact.

What Do You Think?

As you add cold milk to hot coffee, you expect that the milk will get a bit warmer and the coffee will get a bit colder.

- **What determines the final temperature of the coffee and milk?**

Record your ideas about this question in your *Active Physics* log. Be prepared to discuss your responses with your small group and the class.

Investigate

In this investigation, you will determine the final temperature of a cold water and hot water mixture. Styrene-foam cups work well as containers for this investigation. The insulation "protects" the experiment from the environment by reducing heat transfer with anything outside of the cup.

Use a heat-proof holder, such as a glove or tongs, while pouring.

1. Pour 100 mL of hot water into a styrene-foam cup and measure the temperature of the water. Pour 100-mL of cold water into a second styrene-foam cup and measure its temperature.

a) Record the temperature of the hot water.

b) Record the temperature of the cold water.

c) Predict the final temperature of the mixture of hot and cold water.

2. Add the cold water to the hot water. Measure the final temperature.

a) Record the temperature of the mixture.

b) Compare your predicted value with the recorded value.

3. Vary the experiment by changing the amount of cold water. Mix 100 mL of hot water with 50 mL of cold water; 75 mL of cold water; 125 mL of cold water; and 150 mL of cold water.

a) Make a data table. Record your observations.

b) Construct a graph of the results. Plot the final temperature on the *x*-axis and the amount of cold water added on the *y*-axis.

c) Use your graph to predict the final temperature when 108 mL of cold water is added to 100 mL of hot water.

4. Cool water can be heated with the addition of hot water. How well would a piece of hot metal heat the cool water? Plan an experiment to compare: (1) the effect of adding 100 g of hot water to a styrene-foam cup with 60 g of cool water, with (2) the effect of adding 100 g of metal heated to the same temperature as the hot water to a separate styrene-foam cup with 60 g of cool water.

Clean up any spilled water immediately, especially off the floor so that no one slips.

One way to heat the metal is to place it in a bath of hot water for three to five minutes. The length of time you need to keep the metal in the water bath depends upon the size of the metal. You can then use tongs to gently lift the metal from the hot water. As soon as the metal is out of the water, you will need to hold it over several pieces of paper towel folded to make a small mat and shake off drops of the hot water so that none of the hot water enters the beaker with the cold water. You want to try to place only the metal gently into the cold water.

a) Record your experiment design in your log.

b) Predict whether the individual cups of cool water will reach the same final temperature.

c) Do you think it matters what kind of metal you use? For example, will equal masses of copper or aluminum produce the same final temperature? Explain your answer.

Make sure that your design is approved before you continue with the experiment.

5. Conduct the experiment.

a) Record the final temperature of each trial:

- hot water mixed with cool water
- hot metal mixed with cool water

b) Did the hot metal warm the cool water as much as an equal mass of hot water?

6. Read the first part of the *Physics Talk*, Specific Heat.

a) Calculate the value of the specific heat, c, for the metal that you used to heat the water.

b) Your teacher will tell you the accepted value for the specific heat of the metal you used. How does the specific heat that you calculated compare with the accepted value of specific heat for that metal?

c) Explain any differences between the two values.

Physics Talk

LAW OF CONSERVATION OF ENERGY

Specific Heat

In the first part of the *Investigate*, you saw that adding equal amounts of hot water and cool water produced a final temperature halfway between the initial temperatures of both. When the proportions of the hot and cold water were varied, the temperature changed. The final temperature was somewhere between the two initial temperatures, and nearer to the temperature of the water with the larger mass.

The **law of conservation of energy** informs you that if the cold water gained thermal energy through the transfer of heat (as indicated by its rise in temperature), then the hot water must have lost an equal amount of thermal energy. The total energy change must be zero.

An equation to express this might look as follows:

$$\Delta Q_h + \Delta Q_c = 0$$

$$(m_h)(T_f - T_h) + (m_c)(T_f - T_c) = 0$$

where ΔQ is a measure of heat in joules,

m_h is the mass of the hot water in grams,

m_c is the mass of the cold water in grams,

T_f is the final temperature of the water in degrees Celsius,

T_c is the temperature of the cold water, and

T_h is the temperature of the hot water.

Notice that the change in temperature $(T_f - T_c)$ for cold water is positive since the final temperature is larger than the initial temperature. The

Physics Words

law of conservation of energy: the total amount of energy in a closed system is conserved; energy can neither be created nor destroyed.

change in temperature $(T_f - T_h)$ is negative for hot water since the final temperature is smaller than the initial temperature. The cold water gains thermal energy, while the hot water loses thermal energy. In this equation, if the mass of the hot water is less, its change in temperature (ΔT_h) must be larger than the cold water's.

The equation requires you to use the mass of the water. For water, a volume of 1 mL has a mass of 1 g. Converting from volume to mass is easy for water, since the density of water is 1 g/mL. That is, a mass of 1 g occupies a volume of 1 mL.

Energy is conserved whether the cool water is mixed with hot water or hot metal. To understand what happened with the hot metal, look at the factors that determine the amount of heat transferred.

The effect of adding an equal mass of hot metal to the cool water was less than the hot water by a factor called the **specific heat** of the metal (c). Specific heat is defined as the heat energy (in joules) required to raise the temperature of a mass (one gram) of a substance a given temperature interval (one degree Celsius). The unit for specific heat is joules per gram degrees Celcius (J/g°C). Water has a very high specific heat, a value of 4.18 J/g°C.

When the material that is being added is taken into account, the equation for the transfer of heat becomes

$$\Delta Q = mc\Delta T$$

where ΔQ is a measure of heat in joules,

m is the mass of the substance in grams,

c is the specific heat of the substance (the specific heat of water is 4.18 J/g°C), and

ΔT is the change in temperature in degrees Celsius.

Since the hot metal did not warm the cool water as much as an equal mass of hot water, the specific heat will be smaller for the metal than for water.

Look at this equation again for the trial where the hot metal is added to the cool water:

$$\text{Heat change of metal} + \text{Heat change of water} = 0$$
$$(mc\Delta T)_{\text{metal}} + (mc\Delta T)_{\text{water}} = 0$$

The value of c for the metal will be different from the value of c for the water. From this equation, you should be able to calculate the value of the specific heat, c, for the metal that you used to heat the water.

Physics Words

specific heat: the heat energy required to raise the temperature of a mass of a substance a given temperature interval.

Sample Problem

When 100.0 g of hot water at 80.0°C is mixed with 60.0 g of cold water at 20.0°C, the final temperature is 57.5°C. Show that energy was conserved.

Strategy: Heat is a form of energy. The law of conservation of energy tells you that the thermal energy (heat) lost by the hot water is going to equal the thermal energy (heat) gained by the cold water. The sum of these two changes must equal 0.

Given:

$m_h = 100.0\text{ g}$ $\quad T_h = 80.0°\text{C}$

$m_c = 60.0\text{ g}$ $\quad T_c = 20.0°\text{C}$

$c = 4.18\text{ J/g°C}$ $\quad T_f = 57.5°\text{C}$

Solution:

$$\text{Heat lost by hot water} + \text{Heat gained by cold water} = 0$$

$$(mc\Delta T)_{\text{hot water}} + (mc\Delta T)_{\text{cold water}} = 0$$

$$(100.0\text{ g})(4.18\text{ J/g°C})(57.5°\text{C} - 80.0°\text{C}) + (60.0\text{ g})(4.18\text{ J/g°C})(57.5°\text{C} - 20.0°\text{C}) = 0$$

$$-9405\text{ J} + 9405\text{ J} = 0$$

Conservation of Energy

Energy is conserved. It is not created or destroyed. It only changes from one form to another. If no energy is allowed to enter or leave a system, the total energy of a system remains the same. When an object like a book is dropped to the ground, you can trace the transfer of energy. Initially all the energy is gravitational potential energy. As the book falls, it loses gravitational potential energy and gains kinetic energy as it increases its speed. Eventually the book hits the ground. As the book hits the ground and stops, some of the kinetic energy is converted to sound, as you hear a "thump." The rest of the kinetic energy of the book becomes heat, and the temperatures of the book and of the ground both rise a bit.

You can calculate changes in gravitational potential energy $(\Delta GPE = mg\Delta h)$ and changes in kinetic energy $\left(\Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2\right)$. You also now know how to calculate changes in thermal energy $\Delta Q = mc\Delta T$. Heat is part of the total energy picture. Conservation of energy means that the total amount of energy in a closed system stays the same, so that the sum of all of the energies remains constant. If a system is not closed, the amount of energy change in the system is equal to the amount of energy that enters or leaves the system. This may seem like simple common sense, but the conservation of energy is one of the most profound principles in physics.

Temperature and Heat

Temperature and heat are not the same, but they are related. **Temperature** is a measure of the average kinetic energy of the molecules of the material due to the random motion of the molecules. You can measure temperature with a thermometer. You can also perceive the temperature through your sense of touch. Since your sense of touch is subjective, the use of an

Physics Words

temperature: a measure of the average kinetic energy of the molecules of a material.

objective tool like a thermometer is required. The temperature and the kinetic energy of the molecules change when the object touches a material of a higher or lower temperature.

At the molecular level, the faster-moving, high kinetic-energy molecules collide with the slow-moving, low kinetic-energy molecules, giving them some of their energy. After many collisions, the average kinetic energy of the two original materials cannot be distinguished. The final temperature is that average kinetic energy.

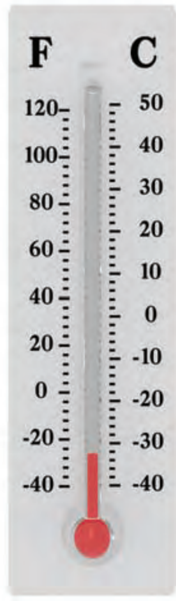
If object A and object B have the same temperature and object B and object C have the same temperature, then object A and object C must have the same temperature. Even though object A and object C may never interact, you would know that their temperatures are the same because they are both compared to object B. This relation is referred to as the **zeroth law of thermodynamics.** Without this assumption, the study of thermal energy would be exceedingly difficult.

Heat is a common word used in many different contexts. However, in physics, heat has a very specific meaning. Although you may often see the terms heat and **thermal energy** used to mean the same thing, scientists recognize a difference between the two terms.

Thermal energy is the total energy of the particles that make up an object. It is a form of energy that results from the motions of atoms and molecules, and it is associated with the temperature of the object. When the thermal energy of an object increases, there is an increase in temperature. You can think of thermal energy as the energy that an object possesses.

Heat is the thermal energy that is transferred from one object to another. Heat is a transfer of thermal energy from an object at a higher temperature to an object at a lower temperature.

Thermal energy is a form of energy that results from the motions of atoms and molecules. The internal energy of a substance is the amount of energy in the random motions of atoms and molecules. (Random motion means that the atoms and molecules are moving in no specific pattern.) This includes kinetic energy and potential energy of the interacting molecules. The amount of internal energy in an object has to do with the nature of the material, the mass of the material, and the temperature of the material. For example, 100 g of hot water has more energy than 100 g of cold water because of a difference in temperature. A swimming pool of 10,000 kg of cold water will have more energy than 1 kg of hot water, mainly because of a difference in mass. If the1 kg of hot water is poured into the swimming pool of 10,000 kg of cold water, the temperature of the pool water will rise a tiny amount. The temperature of the hot water will drop considerably. Thermal energy is a measure of both the temperature and the amount of matter.



Physics Words

zeroth law of thermodynamics: if two objects have the same temperature as a third object, then the two objects must also have the same temperature.

heat: energy transferred from one place to another by virtue of a temperature difference.

thermal energy: a form of energy that results from the motions of atoms and molecules; the energy associated with the temperature of a substance.

thermodynamics: the study of the relationships between heat and other forms of energy and the transformation of one form into another.

The First Law of Thermodynamics

Thermodynamics is the study of the relationships between thermal energy and other forms of energy and the transformation of one form into another. In this *Investigate*, you mixed hot and cold water and observed how the final temperature of the mixture was related to the initial temperatures of the hot and cold water. The change in thermal energy of the hot and cold water were equal. The sum of the changes in the thermal energy was equal to zero.

The change in thermal energy of the water was dependent on the mass, the specific heat of water, and the change in temperature.

$$\Delta Q = mc\Delta T$$

When you mix cold milk with hot coffee, you expect the cold milk to warm a bit and the coffee to cool a bit. They will soon arrive at the same temperature. This can be explained using the conservation of energy. The milk gained some energy and the hot coffee lost some energy. It might be clearer if you look at some numbers. If the cold milk is at 5°C and the hot coffee is at 90°C, the final temperature of the milk-coffee mixture could be 80°C. In this case, the temperature of the milk rose 75°C and the temperature of the coffee fell 10°C. Energy was conserved. If you knew the mass of the coffee and the milk, you could compute the gain and loss of the energy by each substance using the relation $Q = mc\Delta T$. The change in energy of both the milk and the coffee would be the same.

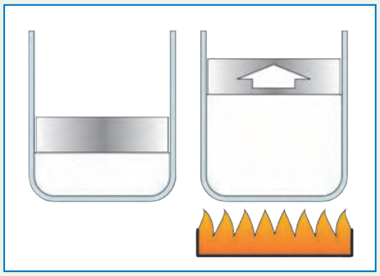
This situation is quite common. If you put a cup of hot coffee in a cold metal cup, there would be a similar effect. The coffee could cool from 90°C to 80°C and the metal could warm from 5°C to 80°C. If you knew the masses of the metal and the coffee and the specific heat of the metal, you could again compute the gain and loss of the energy with the relation $Q = mc\Delta T$. Again, the change in energy would be the same for the metal and for the coffee.

The conservation of energy with respect to hot and cold objects is referred to as the **first law of thermodynamics**. In the situations you have studied, the hot and cold materials did not interact with other materials. The hot and cold materials did not get heated from the outside nor did they use any of their thermal energy to do work by moving something. The first law of thermodynamics can also explain what happens if one of these two situations did occur.

Physics Words

first law of thermodynamics: the thermal energy added to a system is equal to the change in internal energy of the system plus the work done by the system on its surroundings.

Imagine a gas that is enclosed in a container with a movable top (a piston). Initially, the gas has a certain amount of thermal energy. The kinetic energy of the molecules that keep colliding with the piston keep it up. If an external flame were to heat the gas, the piston would move up. The gas did work on the piston by lifting it.



The conservation of energy would state that $\Delta Q = \Delta U + W$

The thermal energy (ΔQ) added is equal to the change in internal energy (ΔU) of the gas plus work (W) done lifting the piston. This is another way of stating the first law of thermodynamics.

The Second Law of Thermodynamics

When hot coffee is poured in a cold metal cup, it never happens that the metal gets even colder and the coffee gets even hotter. It never happens that the coffee heats up from 90°C to 92°C and the metal cools from 5°C to 1°C. In principle, the conservation of energy would be satisfied if the cold metal lost thermal energy and the coffee gained an equal amount of thermal energy so that no energy was created or destroyed. However, this never happens. It also never happens that if you leave a can of warm cola on the kitchen table that the cola gets colder and the room gets warmer.

If something never happens, you must assume that nature has placed a restriction on it. In this case, the restriction is called **entropy**. It informs you that the two materials in contact will reach a common equilibrium temperature. The transfer of heat can only take place in one direction — from hot to cold. Temperature tells you which way the thermal energy is transferred. A cooler metal will heat up (gain heat) when placed in contact with the hot coffee, but the cooler metal will never become cooler (lose heat) when placed in contact with the hot coffee.

This irreversibility of heat flow helps to distinguish the past from the future. If you watch a movie of a pendulum moving back and forth, you may not be able to tell whether the film is being played forward or backward. If you watch someone break an egg and fry it, the film would look quite silly when played backward. It doesn't make sense that the egg could get un-fried and then return to its shell. Similarly, water in a glass in a warm room will never suddenly freeze into ice cubes and make the room warmer.

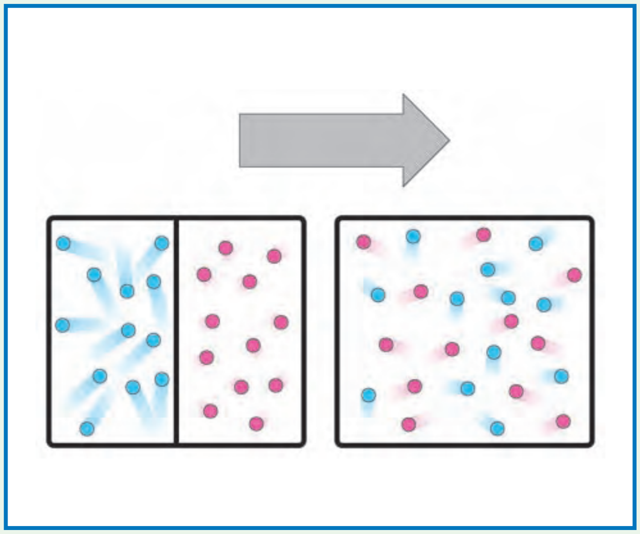
The irreversibility of heat flow is related to the entropy of the substances and is related to the order and disorder of the system. When hot and cold water are mixed, entropy (disorder) increases. When a solid turns to liquid or a liquid turns to gas, entropy (disorder) increases as well. A mathematical understanding of entropy requires a careful look at the possible distributions of energies of the molecules and can be described using statistical physics.

Physics Words

entropy: a thermodynamic property of a substance associated with the degree of disorder in the substance; a substance is more ordered as a solid than a liquid, and a liquid is more ordered than a gas.

You can get a sense of order and disorder and entropy by considering two gases reaching an equilibrium temperature. On one side of a container, you may have 50 fast-moving molecules. The other side of the container has 10 slow-moving molecules. If the two sides came into contact, you would expect that eventually the fast-moving molecules and the slow-moving molecules would collide often enough that the fast-moving molecules would slow down and the slow-moving molecules would speed up. This is an example of entropy increasing or disorder increasing.

Imagine the opposite occurring. If you had a container with 60 moving molecules, could you imagine all the fast-moving molecules speeding up, the slow-moving molecules slowing down and the fast molecules all going to the left side of the container and the slow molecules all going to the right side of the container? This would be an example of entropy decreasing or disorder decreasing. It is possible, but it is very, very improbable. The only way you would expect to see the entropy decreasing is if someone deliberately did this and expended energy sorting the molecules.



The **second law of thermodynamics** can be stated in a number of different ways:

- In irreversible processes, entropy or disorder always increases.
- Time is irreversible.
- Thermal energy is transferred from hot objects to cold objects and never goes from cold to hot spontaneously.

Physics Words

second law of thermodynamics: thermal energy is transferred from hot objects to cold objects and never goes from cold to hot spontaneously.

Checking Up

1. How is temperature defined in terms of molecular action?
2. When cold milk is added to hot coffee, the milk warms up and the coffee cools down. What can be said about the energy of the milk and the energy of the coffee when this happens?
3. The amount of thermal energy that is gained or lost by an object depends upon what three things?
4. In a process that is not reversible in a closed system, what always happens to the entropy of the system?

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
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Entropy

Imagine that there are three spheres in a box that has two sides. Each sphere is a different color—red, blue, purple. The possible configurations of the box are as follows:

Left side of the box	Right side of the box
R, B, P	
R, B	P
R, P	B
B, P	R
R	B, P
B	R, P
P	R, B
	R, B, P

Of the eight possible configurations, only one has all the particles on the left side of the box. That makes this configuration less likely than others where the particles are on both sides of the box. The configuration where all particles are on the left side of the box can be said to have low entropy and low disorder. If all the particles were to start on the left side of the box and were free to move about, you would expect at some later time to observe the particles more evenly distributed. There are six configurations where the particles are on both sides of the box. These represent higher entropy or higher disorder.

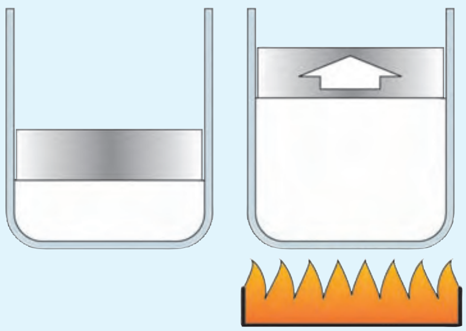
1. Repeat this example and find the probability for all the particles in the box to be on one side if there were four, five, or ten particles in the box. For ten particles in the box, you will probably want to find a mathematical pattern rather than writing out all possible configurations.

2. Using your calculations, explain why it appears that entropy or disorder will increase as the number of particles increases. In other words, if you were to start with all the particles in a box on one side, explain why you would expect to never see them on one side again.

In a one-liter bottle, there are over 10^{20} molecules of air. Can you imagine the probability that all the molecules would be in the bottom half of the bottle?

The Heat Engine and the Second Law of Thermodynamics

Once again, imagine a gas that is enclosed in a container with a movable top (a piston). Initially, the gas has a certain amount of thermal energy. The kinetic energy of the molecules keep colliding with the piston and keep it up. If an external flame were to heat the gas, the piston would move up. The gas did work on the piston by lifting it.



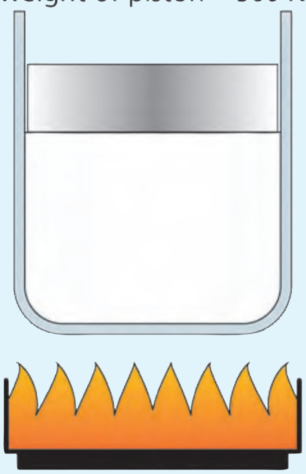
If the gas were then cooled by placing it in touch with a cold object, the gas molecules would lose kinetic energy and the piston would move down.

This is the basis of a simple heat engine: Heat the gas and move the piston up; cool the gas and move the piston down. If you keep repeating this, the piston moves up and down over and over and can turn the wheels of a car.

It would be great if this engine could be 100% efficient. That would mean that all the heat would get converted to mechanical energy. The laws of nature do not allow this 100% efficiency. This is another statement of the second law of thermodynamics.

Sample Problem

A heat engine consists of a quantity of gas in an enclosed cylinder with a mass located on top as shown in the diagram below. The mass can move freely up and down as the gas expands.



a) If 2000 J of heat are added to the cylinder and the internal energy of the gas increases by 1900 J, causing the gas to expand, how much work is done by the gas as it expands and moves the piston?

b) How high will the piston rise?

a) ***Strategy:***

Since the gas and the flame represent a closed system, the energy added by the flame must go to either increasing the internal energy of the gas, or toward work done by the gas.

Given:

$\Delta Q = 2000 \text{ J}$

$\Delta U = 1900 \text{ J}$

Solution:

Using the first law of thermodynamics:

$\Delta Q = \Delta U + W$

Solving for W

$$W = \Delta Q - \Delta U$$
$$= 2000 \text{ J} - 1900 \text{ J}$$
$$= 100 \text{ J}$$

b) ***Strategy:***

Work done equals force × distance, where the force the gas expands against is the weight of the piston that holds it in the cylinder.

Given:

$W = 100 \text{ J}$

$F = 500 \text{ N}$

Solution:

Using the equation for work:

$W = F \times d$

Solving for d

$$d = \frac{W}{F}$$
$$= \frac{100 \text{ J}}{500 \text{ N}} = 0.2 \text{ m}$$

If heat were now extracted from the cylinder, the gas would typically cool and the piston would fall as the gas contracts.

What Do You Think Now?

As you add cold milk to hot coffee, you expect that the milk will get a bit warmer and the coffee will get a bit colder.

- **What determines the final temperature of the coffee and milk?**

Now that you have completed this section, how would you answer this question now?

Physics
Essential Questions

What does it mean?

How does energy conservation help predict the final temperature when hot and cold water are mixed together?

How do you know?

What measurements did you have to record to show that energy was conserved when hot water was placed in cool water?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Thermodynamics	* Conservation laws	Experimental evidence is consistent with models and theories

* Conservation of energy is a bedrock principle of science. Conservation of energy is considered one of the greatest insights into how nature works. What do people mean when they ask you to conserve energy when you know that energy is always conserved?

Why should you care?

Electricity can be used to heat water. People often heat an entire pot of water to make one cup of tea. This is a very wasteful use of resources. Write a note to people to convince them to only heat the water they need. Emphasize the amount of energy required to heat water.

Reflecting on the Section and the Challenge

Heating water for purification or cooking food is a matter of survival. You may decide to use your limited amount of electrical energy to perform these important tasks. It will be crucial to calculate the energy required to change the temperature of water or foods. You know that a cold drink will warm up if it sits on the table and that a hot drink will cool down if it sits on the same table. All objects in the dwelling will reach the same final temperature—the equilibrium temperature. You can now calculate the energy changes when cold objects and warm objects are put in contact.

Physics to Go

1. A hot cup of coffee at 90°C is mixed with an equal amount of milk at 80°C. What would be the final temperature if you assume that coffee and milk have identical specific heats?
2. Explain why heating up a whole pot of water when you only need enough for one cup of tea is wasteful of time and wasteful of energy consumption.
3. A container of water can be heated with the addition of hot water or the addition of a piece of hot metal. If the mass of the water is equal to the mass of the metal, which material will have the greatest effect on the water temperature? Explain your answer.
4. Suppose 200 g of water at 50°C is mixed with 200 g of water at 30°C.
   a) What will be the final temperature?
   b) Calculate the energy gained by the cold water.
   c) Calculate the energy lost by the hot water.
5. Suppose 200 g of water at 50°C is placed in contact with 200 g of iron at 30°C. The final temperature is 48°C.
   a) Calculate the energy gained by the iron. The specific heat (c) of iron is 0.45 J/g°C.
   b) Calculate the energy lost by the hot water.
   c) If the final temperature could have been measured more accurately, would you expect that it would have been a bit more or less than 48°C? Why?
6. Suppose 100 g of water at 50°C is placed in contact with 200 g of iron at 30°C. The final temperature is 46.5°C.
   a) Calculate the energy gained by the iron. The specific heat of iron is 0.45 J/g°C.
   b) Calculate the energy lost by the hot water.
   c) If the final temperature could have been measured more accurately, would you expect that it would have been a bit more or less than 46.5°C? Why?

7. Suppose 300 g of water at 50°C must be cooled to 40°C by adding cold water. The temperature of the cold water is 10°C. How much of the cold water must be added to the hot water to bring the temperature down to 40°C?

8. 100 g of water at 80°C is placed in contact with 100 g of water at 40°C.

   a) Show that energy is conserved if the final temperature of all the water is 60°C.

   b) Show that energy is conserved if the final temperature of the 100 g of hot water is 100°C and the final temperature of the cool water is 20°C.

   c) Both of these situations are possible according to the conservation of energy. Only one happens. Explain why.

9. Approximate the final temperature if water is mixed in the following proportions:

   a) 100 g of water at 80°C is mixed with 100 g of water at 20°C.

   b) 100 g of water at 80°C is mixed with 1 g of water at 20°C.

   c) 1 g of water at 80°C is mixed with 100 g of water at 20°C.

10. Active Physics *Plus* Imagine that 300 J of work is done on a system and 400 J of heat is removed from the system. Using the first law of thermodynamics, what are the values of

   a) W?

   b) ΔQ?

   c) ΔU?

11. Active Physics *Plus* Consider a piston that is supported by gas at a certain temperature. The heat added to the gas is 20 J. The work done on the piston is 18 J. What happened to the other 2 J of energy?

12. Active Physics *Plus* An ice cube placed in a warm drink melts. Describe any energy and entropy changes.