SECTION 7

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

Section Overview

Students investigate how mixing hot and cold water affects the water's temperature. Using their measurements and analysis, they make predictions on what the final temperature of a mixture of hot and cold water might be for given volumes of cold and hot water. They explore the differences in how the temperature changes when 60 g of cool water is mixed with 100 g of hot water and how a piece of hot metal of the same mass and initial temperature as the hot water added to 60 g of cool water affects its temperature. Their observations lead to an extension of the law of conservation of energy and provide evidence that supports the concept of specific heat. Students apply this principle to calculate the specific heat of the metal used in their experiment. They are then introduced to the three laws of thermodynamics and they apply them to solve problems involving heat transfer and entropy. They use this information to explain why it is important for the HFE design to only heat as much water as is needed. Students also consider how the energy required to heat food and water might need to be limited in their HFE design due to the energy constraints.

Background Information

An object's temperature is a measure of the average kinetic energy of its atoms. As the average kinetic energy of the atoms increases, the temperature of the object increases. Heat transfers occur by conduction, radioactive transfers, or convection.

Heat transferred by conduction requires two objects of different temperatures to touch each other. Heat energy from the warmer object is transferred to the cooler object. This occurs due to collisions between particles of the two objects in contact with each other at the surface, and between more energetic particles the objects are composed of. In this way, the average kinetic energy of the particles of both objects reaches equilibrium and the objects reach the same temperature.

Heat can also be transferred by electromagnetic radiation. In this case, the warmer object does not need to be in contact with the cooler object. The warmer object emits electromagnetic radiation that is absorbed by the cooler object. This absorbed electromagnetic radiation is transformed into the kinetic energy in the cooler object, increasing its temperature. A good example of this is the energy transferred to Earth from the Sun.

A third way that heat energy is transferred is through convection. In this process, a fluid substance (gas or liquid) is heated in a given location. The warmer fluid becomes less dense and rises, while the cooler more dense fluid sinks toward the warming source. This sets up what is known as convection currents in the fluid. Convection is a process that occurs due to buoyancy and does not occur in situations involving zero gravity. The heat energy transferred between particles on the atomic level still occurs due to either collisions or radioactive processes.

When an object is heated through a transition phase, its average temperature does not change until the entire substance has changed phase. The heat energy transferred to or from the object while it is changing phase is called latent heat and does not contribute to the overall average kinetic energy, rather, it contributes to the changing of bonds.

On a molecular level, solids have a lattice structure that allows them to vibrate in place but not move around each other. As a solid is heated its molecules vibrate with greater amplitude and frequency.

This weakens the bonds holding them in their lattice. If the heat energy continues to be transferred to the substance, its molecules will move fast enough to break the bonds that hold them in the lattice. This occurs at the melting temperature. As the solid melts, the temperature stays the same because the atoms in the solid are still bound to the lattice. Through collisions, energy is transferred to these atoms until the entire solid melts. At this point, the temperature will again begin to rise.

In a liquid, the molecules of the liquid adhere to each other. As the liquid is heated, this adhesion between molecules lessens until the boiling temperature is reached and the molecules break the bonds and fly apart, forming a gas. As this occurs, the temperature and average kinetic energy of the liquid remains the same. The added heat energy is used to break the adhesive bonds. These processes are reversed for condensation and freezing.

All interactions involve some sort of heat transfer. For electric circuits, the electrons flowing through the conducting material collide with other atoms within the material, transferring some of their kinetic energy. This increases the average kinetic energy of the atoms within the conductor and increases their thermal energy. The circuit becomes warmer than its environment and then transfers heat energy to the environment through collisions between the surfaces in contact and through radioactive transfers. This warms up the environment and is an example of entropy increasing. Entropy can be thought of as the amount of disorder or the amount of energy that can no longer be harnessed to do work.

NOTES

Crucial Physics

- Heat is a form of energy and can be transferred from a warmer object to a cooler object.
- The temperature of an object is a measure of the average kinetic energy of the particles that make up the object.
- The specific heat of a material is a measure of how much energy is required to heat up 1 g of the material by 1°C.
- Energy is conserved. When heat is transferred from a warmer object to a cooler object, the amount of energy transferred from the warmer object is equal to the amount of energy transferred to the cooler object if the system is closed. This can be expressed as:

  $$\Delta Q_1 + \Delta Q_2 = 0$$
  $$m_1 c_1 (T_{1f} - T_{1i}) + m_2 c_2 (T_{2f} - T_{2i}) = 0$$

- Two objects in thermal contact reach thermal equilibrium and have the same final temperature.
- The zeroth law of thermodynamics: 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.
- The first law of thermodynamics: the heat 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.
- The second law of thermodynamics: heat energy is transferred from warmer objects to cooler objects and never goes from cooler objects to warmer objects spontaneously.
- Entropy is a thermodynamic property of a substance associated with the degree of disorder in the substance. In irreversible processes such as the spontaneous transfer of heat energy from a warmer object in contact with a cooler object, entropy increases.

Learning Outcomes	Location in the Section	Evidence of Understanding
Assess experimentally the final temperature when two liquids of different temperatures are mixed.	***Investigate*** Steps 1-3	Students measure the temperatures of certain amounts of hot water and cold water, mix them together, and measure their temperature. Students do this for different volumes of cold water to determine the relationship between changing the volume of cold water and the final temperature of the warm/cold water mixture.
Assess experimentally the final temperatures when a hot metal is added to cold water.	***Investigate*** Step 5	Students plan and run an experiment to compare how temperature changes when hot and cool water are mixed compared to cool water with a piece of hot metal placed in it.
Calculate the heat lost and the heat gained of two objects after they are placed in thermal contact.	***Investigate*** Step 6 ***Physics Talk*** ***Physics to Go*** Questions 4-6, and 8	Students read about specific heat and then calculate the specific heat of the metal they used in their experiment. Students also calculate final temperatures and heat transfers between objects in contact using equations derived from the law of conservation of energy.
Discover if energy is conserved when two objects are placed in thermal contact and reach an equilibrium temperature.	***Physics Talk*** ***Physics Essential Questions*** ***Physics to Go*** Questions 6, 8	Students read about conservation of energy and how this is represented mathematically using the heat transfer equation.
Explain the concept of entropy as it relates to objects placed in thermal contact.	***Physics Talk***	Students read about and discuss the laws of thermodynamics, thermal energy, temperature, and entropy. Using the concept of entropy, students explain what happens when objects are in thermal contact, and when the number of particles increases.

NOTES

Section 7 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Graduated cylinder, plastic, 100 mL	1 per group	
Beaker, glass, 1 L	1 per group	
Stirring rod, glass, 8 in.-12 in.	1 per group	
Thermometer	1 per group	
Tongs, crucible, 18 in.	1 per group	
Specific heat specimen, set		2 per class
Hot plate, student, electric		2 per class
Wire gauze, square, 4 in. x 4 in. (w/ ceramic center)		2 per class
Cup, styrene foam, 12 oz	2 per group	
Paper, graph, pkg. of 50		1 per class
Water, cold, 1 L*	1 per group	

*Additional items needed not supplied

Time Requirements

- Allow one and one-half class periods or 65 minutes to complete the *Investigate* portion of this section.

Teacher Preparation

- A source of hot and cold water will be needed for this *Investigate*. If hot water is not available, use several hot plates to heat water before the start of the *Investigate*. If heating the water in a beaker, be certain to use borosilicate glass.
- Styrene-foam or similar cups should be used to prevent excess heat being transferred to the student's hands or to the environment.
- Specific heat samples may be used for different groups so that the specific heat of various metals may be obtained. If these samples are not available, brass hooked masses may be used.
- Tie a string to each of the specific heat samples to be used sufficiently long so that the students may gently lower them into the hot water. The samples should stay in the water for approximately three minutes to guarantee thermal equilibrium between the hot water and the metal.
- A container with a handle is best for dispensing the hot water to the students.
- Use a stirring rod to stir the water, not the thermometer.

Safety Requirements

- Caution the students to be very careful pouring the hot water. Hot water can cause severe burns. If hot water is accidentally spilled on someone, the immediate addition of cold water placed on the injured area will reduce the heat and the extent of the injury before seeking medical attention.
- Caution the students in the proper use of hot plates. Even though the water may not be dangerously hot, the hot plate will be hot enough to cause severe burns.
- The thermometers should only be used for measuring temperature, not to stir the water. If a thermometer breaks, abide by your schools' safety regulations for spilled mercury if a mercury thermometer is used. If an alcohol thermometer is used, carefully clean up all pieces immediately.
- Goggles are required for this *Investigate*.
- Use tongs or similar devices to remove heat samples from the hot water.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Graduated cylinder, plastic, 100 mL	1 per group	
Beaker, glass, 1 L	1 per group	
Stirring rod, glass, 8 in.-12 in.	1 per group	
Thermometer	1 per group	
Tongs, crucible, 18 in.	1 per group	
Specific heat specimen, set		2 per class
Hot plate, student, electric		2 per class
Wire gauze, square, 4 in. x 4 in. (w/ ceramic center)		2 per class
Cup, styrene foam, 12 oz	2 per group	
Paper, graph, pkg. of 50		1 per class
Water, cold, 1 L*	1 per group	

*Additional items needed not supplied

Time Requirements

- Allow one and one-half class periods or 65 minutes to complete the *Investigate* portion of this section.

Teacher Preparation

- A source of hot and cold water will be needed for this *Investigate*. If hot water is not available, use several hot plates to heat water before the start of the *Investigate*. If heating the water in a beaker, be certain to use borosilicate glass.
- Styrene-foam or similar cups should be used to prevent excess heat from being transferred to the student's hands or to the environment.
- Specific heat samples may be used for different groups so that the specific heat of various metals may be obtained. If these samples are not available, brass hooked masses may be used.
- Tie a string to each of the specific heat samples to be used sufficiently long so that the students may gently lower them into the hot water. The samples should stay in the water for approximately three minutes to guarantee thermal equilibrium between the hot water and the metal.
- A container with a handle is best for dispensing the hot water to the students.
- Use a stirring rod to stir the water, not the thermometer.

Safety Requirements

- Caution the students to be very careful pouring the hot water. Hot water can cause severe burns. If hot water is accidentally spilled on someone, the immediate addition of cold water placed on the injured area will reduce the heat and the extent of the injury before seeking medical attention.
- Caution the students in the proper use of hot plates. Even though the water may not be dangerously hot, the hot plate will be hot enough to cause severe burns.
- The thermometers should only be used for measuring temperature, not to stir the water. If a thermometer breaks, abide by your schools' safety regulations for spilled mercury if a mercury thermometer is used. If an alcohol thermometer is used, carefully clean up all pieces immediately.
- Goggles are required for this *Investigate*.
- Use tongs or similar devices to remove heat samples from the hot water.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Reading a thermometer scale	***Investigate*** Steps 1-3, and 5	**Augmentation** • Students may struggle to read thermometers because they often cannot figure out the number scale that is used on the thermometer. Also, if students can figure out the scale, they often struggle with estimation. • Draw a large-scale model of the specific thermometer used in class and ask students to work in pairs to figure out the number scale. • There are many Web sites that provide opportunities for students to practice reading thermometers and provide feedback for correct and incorrect answers. • Provide direct instruction and guided practice for students to learn how to make accurate temperature measurements to the nearest degree, half of a degree, etc. • Pair students who are struggling to read the temperature on the thermometer with students who can easily make accurate readings and would take the time to show someone else how to read it.
Making a data table	***Investigate*** Step 3.a)	**Augmentation** • Some students may be able to create their own data table without teacher assistance, but other students may still have a difficult time making a table independently. Organizing information is especially difficult for students with learning disabilities or attention and focus difficulties. • Ask students to make a short list of what information must be recorded to create the graph in *Step 3.b*). Once their list is approved, students can create their table and begin the experiment. **Accommodation** • Give students a blank data table to tape into their logs. The table may or may not include the row and column headings, depending on the level of a student's need.
Constructing a graph	***Investigate*** Step 3.b)	**Augmentation** • For students who struggle with their visual spatial and/or visual motor skills, provide graph paper to help students locate the correct spot for plotting data points. • Students who struggle with number concepts may have a difficult time setting up the scales on the *x* and *y*-axes. Tell students to identify the highest value for each axis and decide on an appropriate scale to allow all of the points to be plotted on the graph. Provide opportunities to practice this skill. • Teach students to use rulers or index cards to plot data points in the correct position. **Accommodation** • Teach students how to use a computer spreadsheet-application program to create graphs. Computer programs are helpful accommodations for students with many different kinds of disabilities, as long as instruction is provided to help students learn how to use the programs.
Understanding essential concepts	***Physics Talk***	**Augmentation** • Students who struggle with reading comprehension will struggle to understand this material without some teacher guidance. • Ask students to make drawings to represent their understanding of temperature, heat, and the laws of thermodynamics. • Remind students to read the *Checking Up* questions before beginning their reading. **Accommodation** • Provide a guided reading sheet that includes page numbers and purposefully directs students to pull important points out of the reading. • Provide direct instruction to highlight the key points from this section.

Learning Issue	Reference	Augmentation and Accommodations
Understanding heat gain and heat loss	***Physics Talk*** ***Physics to Go*** Questions 4-9	**Augmentation** • Positive and negative number concepts provide a challenge for students who struggle with basic number concepts and number sense. • Teach students, in reference to thermal energy, that positive numbers represent the gain of energy and negative numbers represent the loss of energy. • Many students try to put the larger number first in all subtraction problems, especially when they are entering numbers into a calculator. Model the sample problem and point out that final temperature is always first when calculating the change in temperature.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Understanding concepts, higher order thinking	***Active Physics Plus***	Patterns are an important concept in science. Help students identify the pattern here, if necessary, and challenge them to come up with a way to represent the pattern mathematically.
Critical thinking Comprehension	***Physics Essential Questions*** Why do you believe?	Hold a class discussion about the question: "What do people mean when they ask us to conserve energy, when you know that energy is always conserved?" ELL students may be confused about the everyday phrase "conserve energy," now that they have learned the law of conservation of energy. They will benefit from discussion and explanation.
Critical thinking	***Physics to Go*** Questions 5.c), 6.c), and 8.c)	Give students the opportunity to discuss their thoughts on these questions with one another. Walk around the classroom, listening to their ideas. Clear up any misunderstandings with a brief class discussion.

Point out new vocabulary words in context and practice using the words as much as possible throughout the section. As you work through the section, have students write the following terms in their *Active Physics* log and add the definitions in their own words: bedrock principle, configurations, entropy, equilibrium temperature, first law of thermodynamics, heat, irreversible, law of conservation of energy, pendulum, second law of thermodynamics, specific heat, surroundings, temperature, thermodynamics, tongs, zeroth law of thermodynamics.

There is much new vocabulary in this section. One way to practice using the vocabulary is for students to work in teams to write meaningful sentences about the content in this section. Students should strive to write simple sentences using the vocabulary words. The goal is to use correctly as many words as possible.

The rubric for grading these sentences should include four elements: correct science, correct usage of vocabulary, correct sentence structure and grammar, and quantity of work.

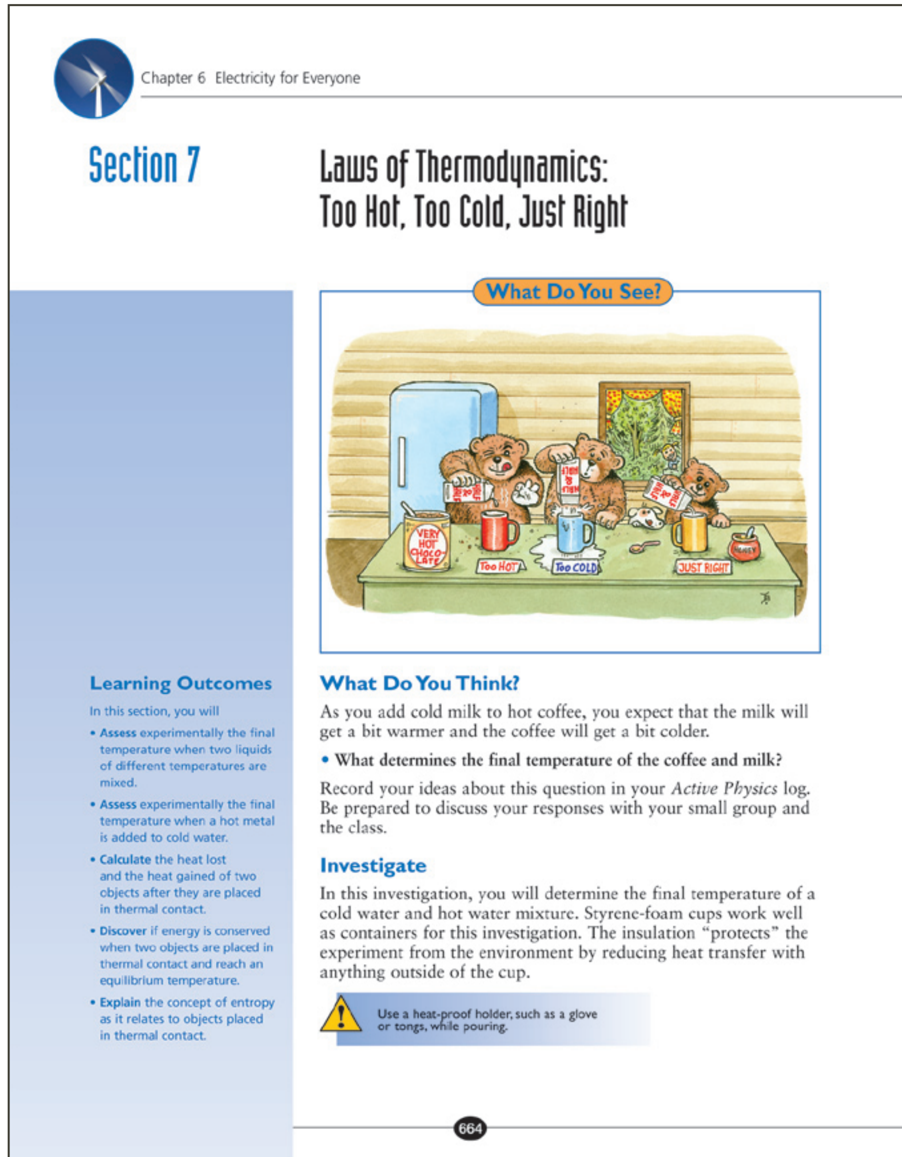
Rapid feedback about students' sentences is essential, because the sentences and errors will be fresh in the students' minds. A good method for providing this feedback is to prepare a list of examples of incorrect sentences from the work collected. Divide examples into the following categories: incorrect science, incorrect usage of vocabulary, incorrect sentence structure, and incorrect grammar. Choose several examples to use in each category and edit the sentences until they contain only one or two obvious errors, or limit the choices to these kinds of sentences. At the beginning of class, on the day following the sentence-writing activity, provide each student with a page containing a double-spaced, typed list of the incorrect sentences with headings for the categories. Allow students 10 minutes to silently make corrections to the sentences. Then, place a copy of the list on the overhead projector and collect students' ideas on how to repair the sentences, guiding them toward correct science and English usage.

SECTION 7

Teaching Suggestions and Sample Answers

What Do You See?

The title of this section gives a direct clue to what the artist is trying to illustrate through the *What Do You See*? section. You could ask your students what they think the relative temperatures of the cups of cocoa are or how the three bears might have made their cups of hot cocoa at different temperatures if they all started with cocoa at the same temperature. Consider using the overhead of this illustration to highlight its significant aspects. Urge students to look at the labels and facial expressions of the bears closely before they form any impression of what they think the artist is trying to convey.


Chapter 6 Electricity for Everyone

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.

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Students' Prior Conceptions

In 2008, Dr. Robert Tinker of the Concord Consortium stated that one of the most documented areas in science educational research is students' understanding and misconceptions about heat and temperature. Yet, nuances in teaching and learning about these topics persist. How do teachers lead students to understand subtle differences between heat and temperature? Leading students to make predictions, to measure and record specific data, to model these data, and to reason about their constructs in this *Investigate* is a positive approach.

1. **Heat and temperature are often confused and some of the confusion arises because of the terminology. Students believe temperature is a measure of heat and they are very resistant to changing this idea.** A simple correlation is to have students relate temperature to random thermal motion. As the temperature of molecules increases, the random kinetic energy of the molecules also increases. Atoms speed up when their temperature rises. In the investigation in which the hot metal interacts with the cooler water and the temperature of the liquid increases, students should be led to consider the kinetic energy of the metallic molecules and their heat content. The role of mass in determining the total energy available to be transferred should be emphasized and how a subsequent change in temperature of the energy receiving liquid depends upon both the kinetic energy of the metal molecules (the initial temperature) and how many molecules are present (the mass).

What Do You Think?

Consider asking students what they think this section is about and how it might connect with electric circuits and the *Housing for Everyone* appliance package they are designing.

Ask them what happens when a hot beverage is mixed with cold milk. Then have them record their ideas to this question in their *Active Physics* logs. Encourage them to discuss their ideas with their group members and write their initial responses on the board. At this stage, the class discussion should motivate students to think about the physics concepts that they will be investigating as they progress through the section.

What Do You Think?

A Physicist's Response

There are a few factors that determine the final temperature when two objects of different temperature are in contact with each other or are mixed together, such as hot cocoa and cold milk. These factors are the mass of each object, the initial temperature of each object, and the specific heat of each object. The specific heat of a substance is the amount of energy required to raise the temperature of 1 g of the substance by 1° Celsius.
The specific heat depends upon the atomic/molecular structure of the substance. In all cases, energy must be conserved. Heat energy is transferred from the warmer substance (the hot cocoa) to the cooler substance (the cold milk) and the cooler surroundings (the mug, and the air). If the system is isolated from the surroundings, then all the energy transferred from the warmer substance goes to the cooler substance. Energy is transferred from the warmer substance to the cooler substance until a thermal equilibrium is reached. When the substances have reached thermal equilibrium, they have the same temperature.

2. **Students often believe that cold is transferred; the colder object cools the warmer object.** They do not reason that heat is transferred. Encourage careful measurements and observations in the mixing of hot and cold liquids and what happens to the temperature of each substance as they reach the equilibrium temperature. Listen carefully to students as they use their data to reason about what happens. They should stipulate that heat flows from the warmer liquid; the warmer water loses heat as evidenced by its drop in temperature, and into the colder object, as evidenced by its rise in temperature.
3. **Because students have naïve constructs dealing with the transfer of heat energy within a closed system, it is natural to assume that they also reason incorrectly about the concept of entropy. Students may believe that you can never get a system less energetic than the way that it started.** This section may enable students to visualize what happens to the molecules of a system when heat energy is transferred; they may correctly reason that adding heat to a system causes molecules and atoms to speed up. In order for a system to become more arranged, for the entropy to decrease, energy must be transferred from within the system to outside the system. Emphasize this direction of heat-energy transfer in the experiment where energy is subtracted from the metal and added to the water. The entropy of the water is, therefore, increased while the entropy of the metal is decreased.

Investigate

Teaching Tip

If a source of hot water is not available, a coffee pot may be used to safely dispense hot water and keep it at the desired temperature.

Students should take the temperature of the hot water fairly quickly to prevent heat loss, and quickly complete *Step 1*. Consider having students measure the temperature of the cold water first.

1.

The "hot" water may either be hot water from the tap, or water heated by the teacher. Water above 60°C is not necessary and not recommended. The cold water from the tap works well (usually about 20°C).

1.a)

Students measure and record the initial hot water temperature.

1.b)

Students measure and record the initial cold water temperature. Cold water from the tap (usually about 20°C) works well.

1.c)

Many students may predict the temperature of the mixture correctly, which is halfway between the hot and cold value.

Teaching Tip

Students should take the temperature of the hot-cold water mixture fairly quickly to prevent heat loss. Stirring the hot-cold water mix for 5 s will help produce a more reliable temperature measurement.

2.a)

Students record the temperature of the hot and cold water mixture. If the measurements are correct, the temperature should ideally be halfway between the hot and cold temperature. Some heat may have been transferred to the environment due to the open top; however, this should be a minimal amount.

2.b)

Students compare their prediction to their measurements.

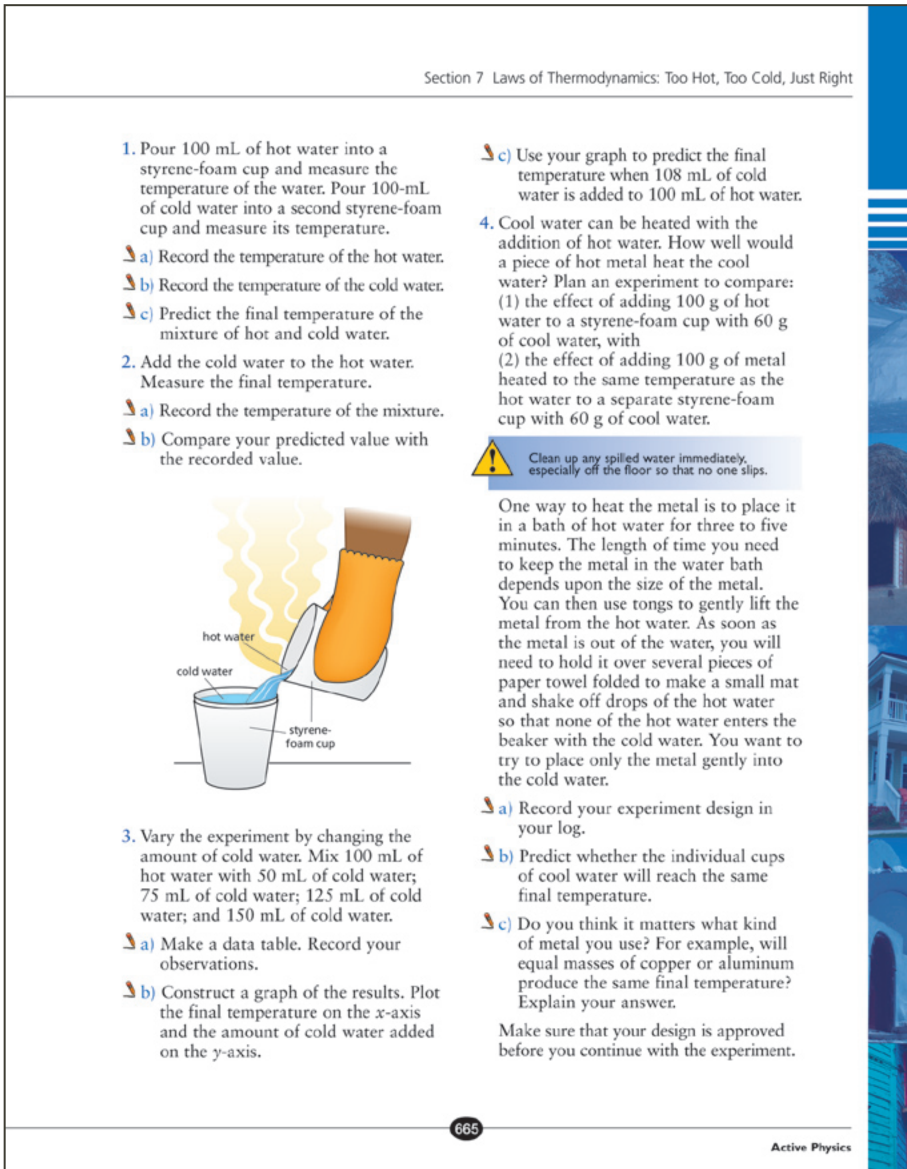
3.

The final temperatures of the mixtures will vary depending upon the initial temperature of the water being mixed. When the 100 mL of hot water is poured into the 50 mL of cold water, the increase in temperature should ideally be two-thirds of the original difference in temperatures. For the 75-mL cold, the temperature should ideally be four-sevenths of the temperature difference toward the hot temperature from the cold. For the 125-mL cold, the temperature should ideally be five-ninths of the temperature difference toward the cold, etc. (These values come from the fractional parts of the hot water divided by the total parts of water, e.g., 100-mL hot/(100-mL hot + 75-mL cold) = 4/7.)

3.a)

Students create a data table and record their measurements in it. Students' data tables should look similar to the following:

Amount of cold water (__°C) poured into 100 mL of hot water (___°C). (mL)	Final temperature of water mixture (°C)
50	
75	
100	
125	
150	



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

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.

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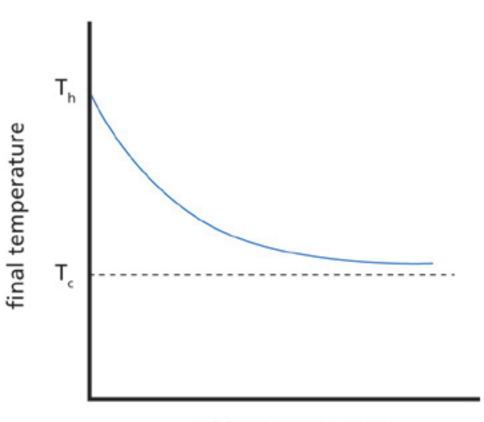
Active Physics

3.b)

Students' graphs should appear similar to the one below:



3.c)

Students interpolate the value for 108 mL of cold water from their graph.

Teaching Tip

If the students are heating the metal in a glass beaker on a hot plate, care should be taken that the metal is not dropped in the beaker, which may break. If the water is heated to boiling, the temperature will be most reliable, since additional heat will not affect the temperature

4.

Students design an experiment to compare how cool water warmed by hot water or a piece of hot metal compares. Their experiment should be similar to the experiment they performed with mixing different amounts of water in *Step 2*.

4.a)

Students may predict that the piece of metal will heat the water more than the warm water, since they are less used to hot metal than hot water. Typically metal holds about one-tenth the heat per gram as compared to water, so the effect of the water is expected to be far greater for equal masses.

4.c)

Students probably will suspect that the type of metal makes little or no difference.

5.

Students' experimental designs should be approved before they conduct the experiment. Pay particular attention to safety precautions with very hot water, which can cause burns.

5.a)

Students complete their experiments and record their data in a table. The final temperatures will depend upon the initial temperatures, and the type of metal used.

CHAPTER 6

5.b)

Students observe that an equal mass of hot metal does not warm the cool water as much as the hot water at the same initial temperature.

6.a)

Based on the information in the *Physics Talk*, students should be able to calculate the metal's specific heat. If they correctly understand specific heat, they should realize that if a piece of hot metal with a lower specific heat was added to cold water, it should result in less heat energy transferred to the cold water and a lower final temperature.

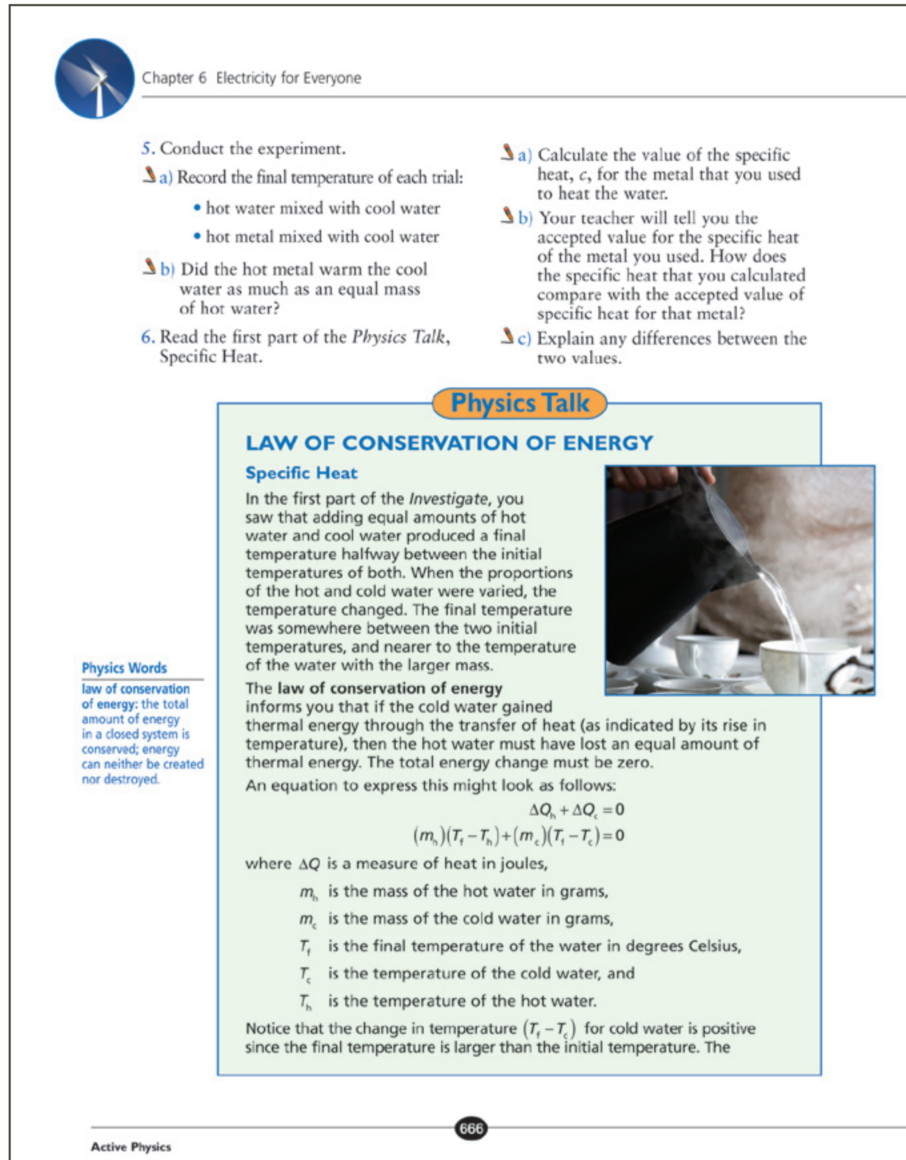
6.b)

Students compare their value of the specific heat for the metal to the accepted value provided by the teacher. Some values of specific heat are provided below:

Material	Specific heat (J/g°C)
copper	0.385
aluminum	0.897
silver	0.233
gold	0.129
iron	0.450

6.c)

Differences between the measured and accepted values may depend upon the students' accuracy in doing the measurements, excess water that was not removed, energy transferred to the environment, etc.



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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.

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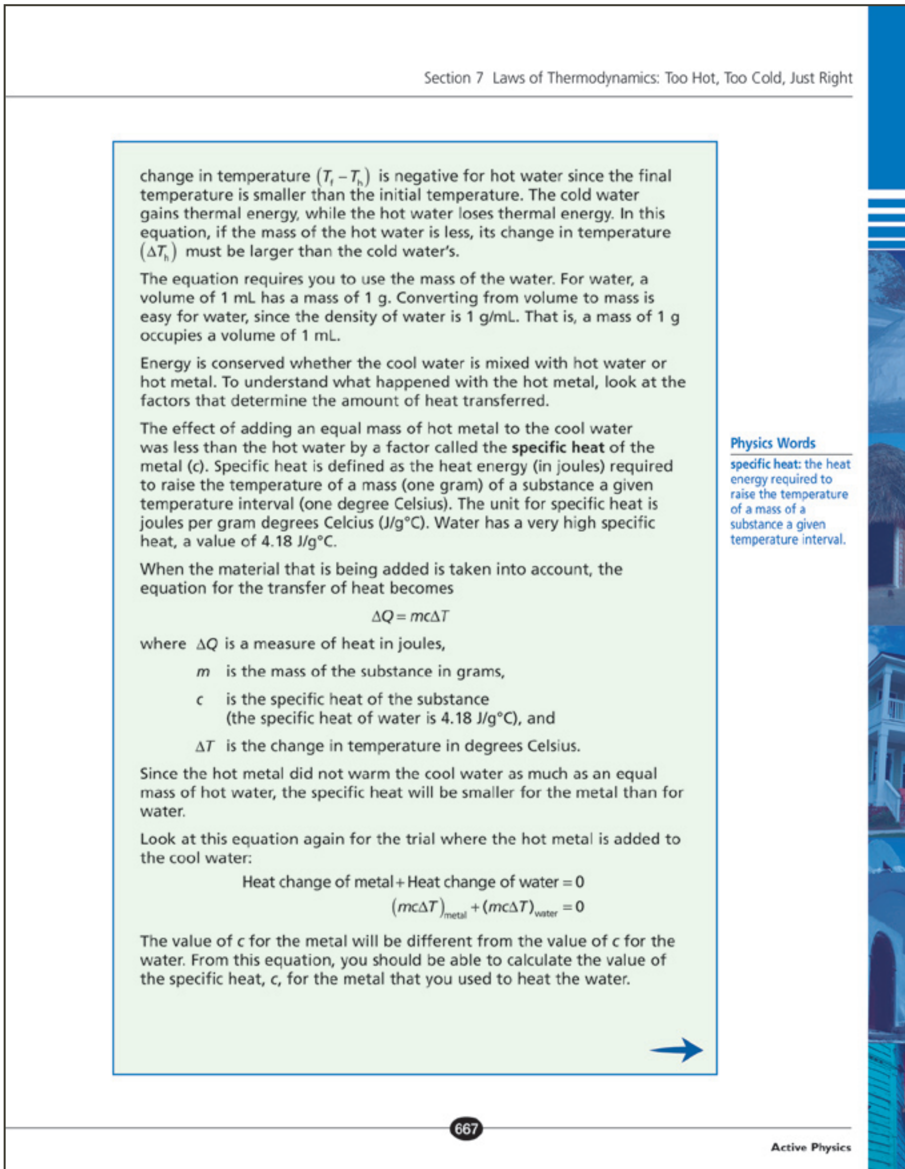
Active Physics

Physics Talk

In a discussion, emphasize to the class that energy is always conserved when considering the energy transferred from and to a system or within the system. For example, the heat energy from the hot water is transferred to the cold water and some of it is also transferred to the environment. The amount of energy the environment, cup, and cold water receive during the interaction with the hot water is equal to the amount of energy transferred from the hot water.

Point out that if no energy is transferred to the environment or the cup (the system is isolated), the cold water receives all the energy transferred away from the hot water. Then describe the factors that affect the heat energy transfer: the mass of the objects, the initial temperatures, and the specific heat.



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

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.

Physics Words

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

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:

$$\text{Heat change of metal} + \text{Heat change of water} = 0$$

$$(mc\Delta T)_{metal} + (mc\Delta T)_{water} = 0$$

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.

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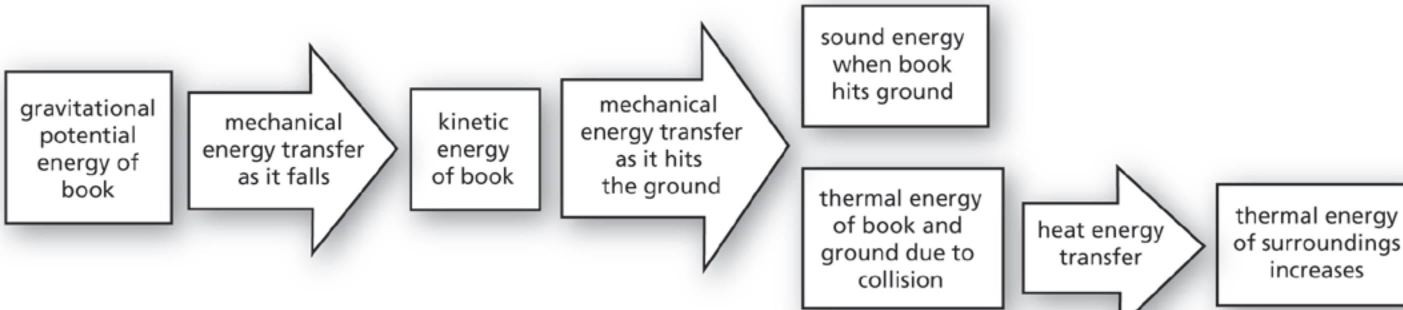
Active Physics

Ask students if the warm water or the metal increased the cool water's temperature more. Emphasize that water has a higher specific heat—that it requires more energy per gram to increase its temperature than the metal does and hence contains more energy per gram at equivalent temperatures. Ask students what values they calculated for the specific heat of the metal they used in the *Investigate*. Go through the description in the student text on how to calculate the specific heat, using student data as an example. Then discuss the sample problem.

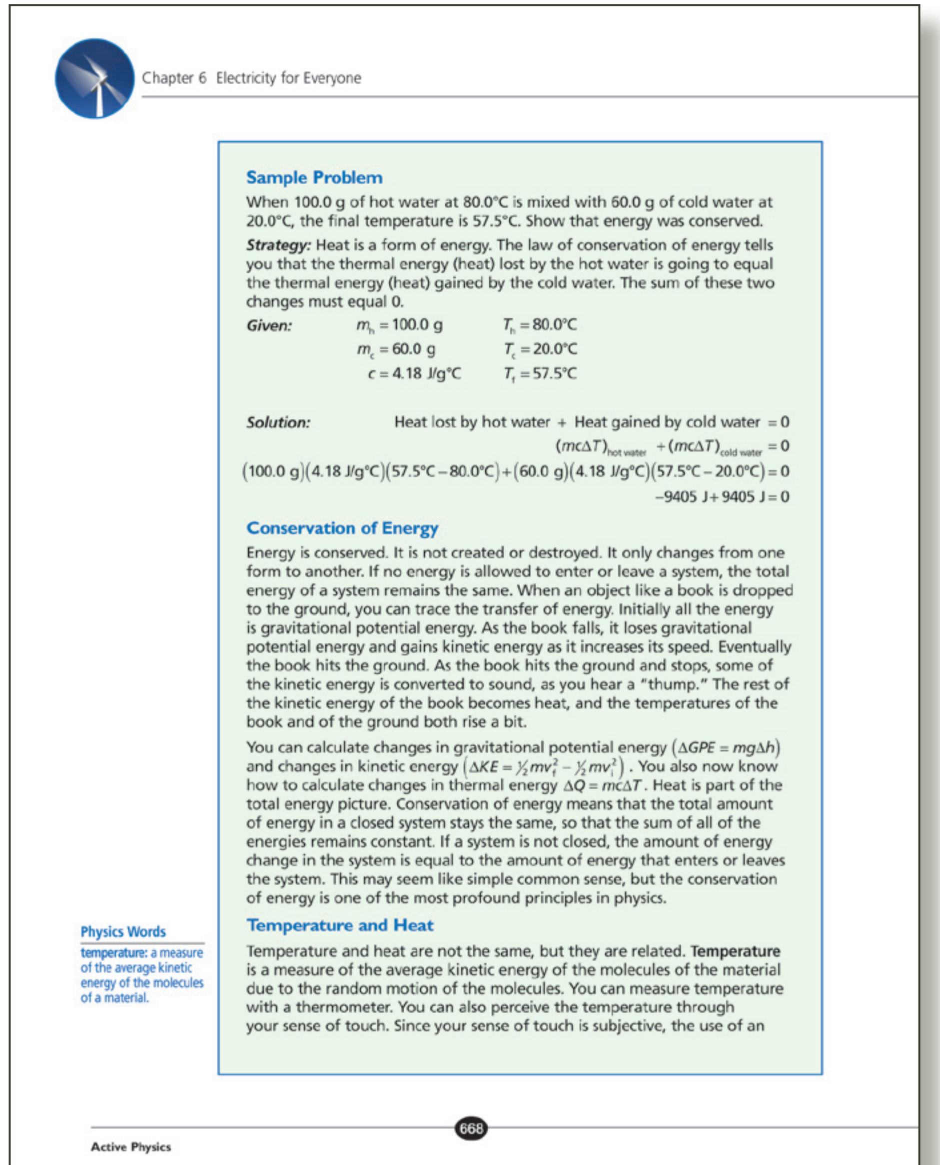
Have a class discussion on conservation of energy. Describe for students how energy is transformed from one type to another and transferred from one object to another, but is never created nor destroyed. Discuss the example of a book falling to the ground and the different types of energy transformations and transfers that occur. Consider constructing a diagram, similar to the one below, showing the flow of energy in open and closed systems. Emphasize that energy is always conserved.

CHAPTER 6



Discuss the relationship between temperature and heat. Point out that the temperature of an object is equal to the average kinetic energy of the atoms that make up the object—the more kinetic energy the atoms have, the higher their temperature—while heat energy is the energy transferred between objects of different temperatures and depends not only on the kinetic energies of the substances (temperatures) but also their mass, atomic structure, and molecular bonds (internal potential energy). Describe what occurs when a warm and cold object are in contact with each other. Check students' understanding and consider asking questions such as: How does it feel when you touch a cup of hot cocoa? (*It feels warm*.) What is happening to make your hands feel warm? (The atoms/molecules in the hot cocoa have a lot of kinetic energy. When the hot cocoa atoms/molecules collide with the inside of the mug they transfer energy to the atoms/molecules of the mug, so the average kinetic energy of the mug atoms/molecules [its temperature] increases. The mug atoms/molecules then collide with the hand atoms/molecules increasing their kinetic energy and average temperature. This sends a signal to the brain that lets us know the mug feels warmer than our hands.)

Discuss the zeroth law of thermodynamics and how important it is for the study of thermal energy. If students ask about substances changing phase but not temperature, let them


Chapter 6 Electricity for Everyone

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:
$m_h = 100.0$ g $\quad T_h = 80.0°C$
$m_c = 60.0$ g $\quad T_c = 20.0°C$
$c = 4.18$ J/g°C $\quad T_f = 57.5°C$

Solution:

$$\text{Heat lost by hot water} + \text{Heat gained by cold water} = 0$$
$$(mc\Delta T)_{\text{hot water}} + (mc\Delta T)_{\text{cold water}} = 0$$
$$(100.0\text{ g})(4.18\text{ J/g°C})(57.5°C - 80.0°C) + (60.0\text{ g})(4.18\text{ J/g°C})(57.5°C - 20.0°C) = 0$$
$$-9405\text{ J} + 9405\text{ J} = 0$$

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.

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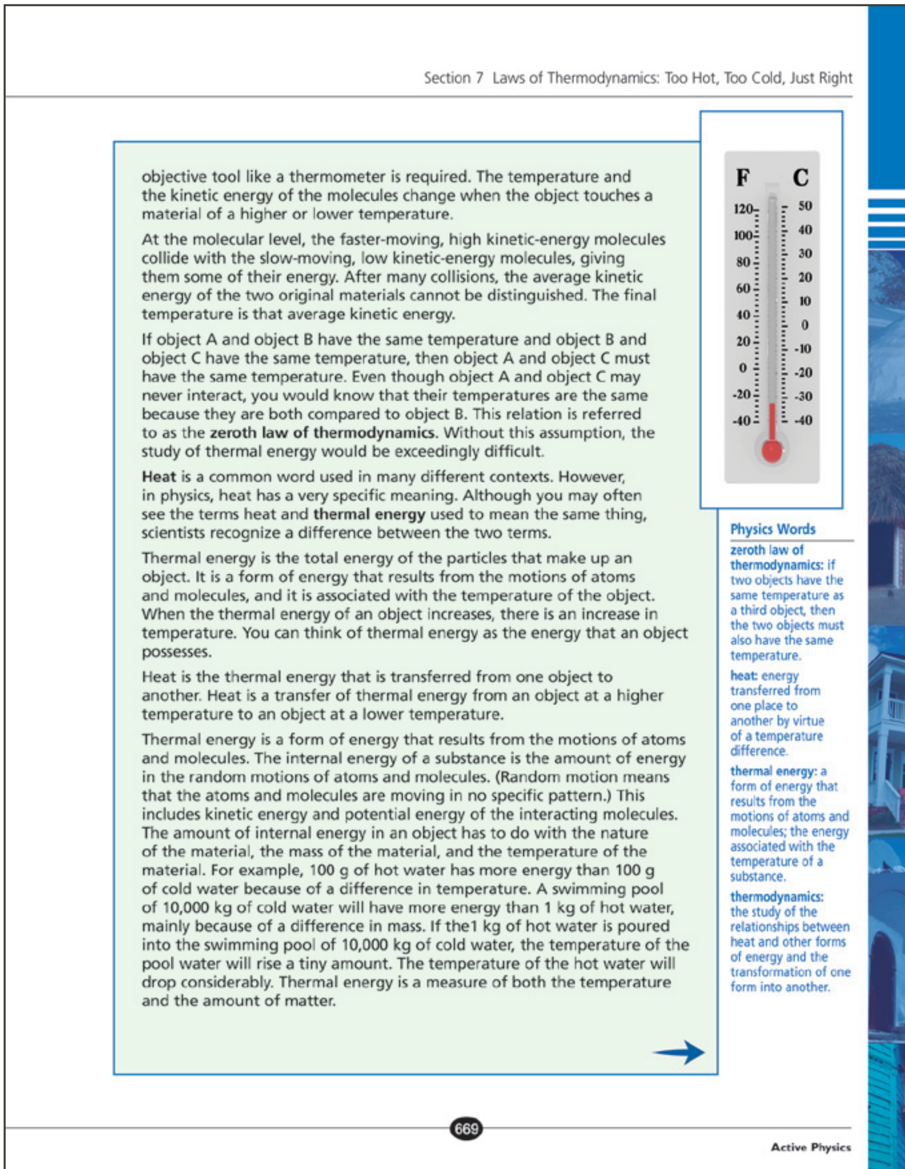
know that this is called latent heat. Latent heat is the amount of heat energy absorbed or released by a substance during a phase change in which intermolecular bonds are either formed or broken. The temperature of the substance does not change, but heat energy must be transferred to the substance from warmer surroundings or released from the substance to the surroundings for the phase change to occur.

The kinetic energy of the atoms remains the same during this process, but the atoms are now in a different position relative to the other atoms in the substance.

Have a class discussion on the first law of thermodynamics and point out that the first law of thermodynamics is just the conservation of energy. It states that the heat energy transferred to or from a system is equal to the change in the internal energy



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.

of the system plus the work done by or to the system. Discuss the example of a gas heated in a container with a moveable piston as the lid. Describe the first law of thermodynamics mathematically. The heat energy transferred in this system (ΔQ) is equal to the change in the internal energy of the system (ΔU) plus the work done by or to the system (W) in raising the piston. As the gas cools, the amount of heat lost by the gas ((ΔQ) is equal to the change in its internal energy (ΔU) and the work done on the gas by the descending piston (W).

Describe the second law of thermodynamics—When two objects of different temperatures are in contact, heat energy flows spontaneously from warmer objects to cooler objects. This is why when hot cocoa is poured into a cup the cup does not get cooler and the cocoa does not get warmer. Emphasize that our sense of touch is very subjective, for example in a 70˚F room a rug would not feel cold, but a 70˚F tile floor would. This has to do with the fact that heat energy is transferred from the warmer human feet faster to the tile floor than to the rug. This has to do with the heat capacity of the floor and the rug. The faster the rate at which heat energy can be transferred through a substance that is at a lower temperature, the cooler it feels to us.

Discuss entropy by stating that entropy is the amount of disorder or the amount of heat energy transferred that cannot be returned because the process is irreversible. Describe how entropy (disorder) increases when a solid turns into a liquid and a liquid into a gas. Discuss the example of the gas molecules in the student text. Emphasize that disorder or entropy of a system always increases for irreversible processes and thermal energy is transferred from hot objects to cold objects spontaneously. Entropy determines that thermal energy never spontaneously goes from cold to hot. Some reversible and irreversible processes are listed below in the following table:

Reversible	Irreversible
a pendulum	car crashes
something that oscillates	shattered glass
compressing a spring	tearing a piece of paper
stretching a spring	when something burns
dropping a perfectly elastic ball	chewing and digesting food

CHAPTER 6

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.

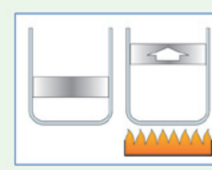
This situation is quite common. If you put a cup of hot coffee in a cold metal cup, there would be a similar effect. The coffee could cool from 90°C to 80°C and the metal could warm from 5°C to 80°C. If you knew the masses of the metal and the coffee and the specific heat of the metal, you could again 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.

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.

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.

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.



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

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.

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.

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.

CHAPTER 6

Checking Up

1.

The temperature of a substance is the average kinetic energy of the atoms and molecules that make up the substance.

2.

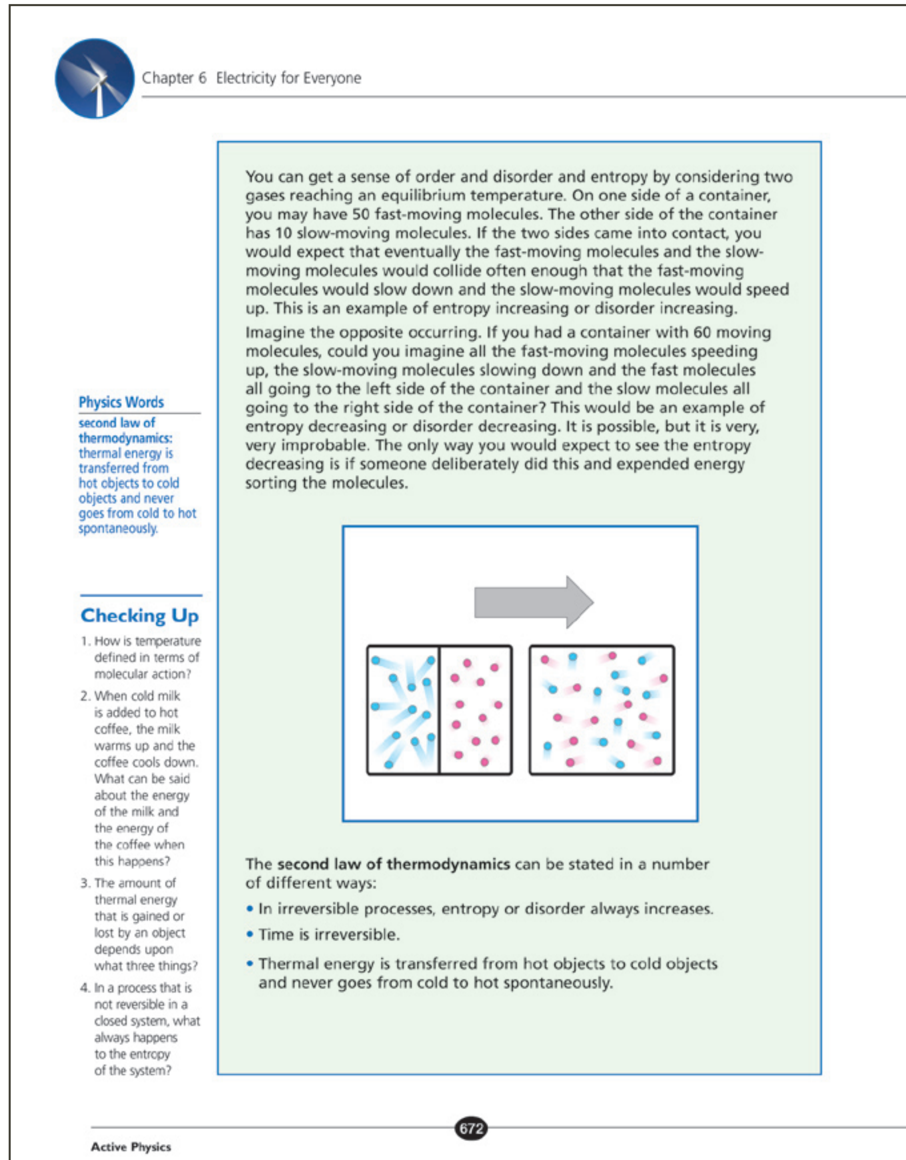
The hot coffee transfers some of its energy to the cool milk. This results in a decrease of thermal energy of the coffee and an increase of thermal energy of the milk. This means that the coffee molecules are less energetic (their average kinetic energy has decreased), and the milk molecules are more energetic (their average kinetic energy has increased).

3.

The amount of heat that is transferred to or from an object interacting with another object of different temperature depends on the masses of the objects, the initial temperatures of the objects and the specific heats of the objects involved.

4.

In all irreversible processes of a system, the entropy of the system increases.


Chapter 6 Electricity for Everyone

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?

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Active Physics

Active Physics Plus

This *Active Physics Plus* provides an opportunity for students to deepen their understanding of entropy through examples and applying what they know to solve problems involving entropy. A discussion of heat engines and the second law of thermodynamics is also provided with sample problems for students to have a deeper insight into the laws of thermodynamics. While going through the sample problems, explain to students that work is equal to the amount of force applied to an object parallel to the direction of motion multiplied by the distance the object moves.

1.

The probability of all the particles being on one side of the box (either the right side or the left side) would be 2 in 16 possibilities for 4 particles; 2 in 32 possibilities for 5 particles; 2 in 1024 possibilities for 10 particles. For this situation, the number of possible configurations is 2 raised to the number of particles. The mathematical pattern found is that for each side there is 1 in 2^n possibilities, where n is the number of particles. Because there are two sides and

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

Active Physics **Plus**

+Math	+Depth	+Concepts	+Exploration
•••		•	

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.

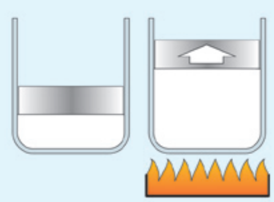
1. Repeat this example and find the probability for all the particles in the box to be on one side if there were four, five, or ten particles in the box. For ten particles in the box, you will probably want to find a mathematical pattern rather than writing out all possible configurations.

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.

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was removed. The gas molecules are moving in random directions and with random speeds and collide with each other randomly. When the wall is removed, the gas molecules will occupy the entire space of their container, still moving randomly. The probability of any single particle being on one side of the container is 1/2, the probability of 10 particles being on one side of the container at the same time is then $(1/2)^{10}$. The probability of a given number of particles being on one side at the same time decreases as the number of particles increases. The probability is $(1/2)^n$, where n is the number of particles.

For the one-liter bottle, the probability would be $(1/2)^{1,000,000,000,000,000,000,000}$, or one possibility in $2^{1,000,000,000,000,000,000,000}$.

you are looking for the likelihood of all the particles being found on either side, there are then 2 in 2^n possibilities, where n is the number of particles.

2.

The likelihood that some particles are on both sides increases as the number of particles increases. This decreases the possibility that all the particles will be found on just one side of the box. If, for example, these were marbles stacked on the right side of the box, and the box was then carried across the room, it is very unlikely that all the marbles would stay where they started, and it is also unlikely that their collisions and motions would cause them to stack up again. Consider if this were a gas in a container with a removable wall in the middle, and with all the gas molecules were on one side before the wall

CHAPTER 6

Chapter 6 Electricity for Everyone

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:

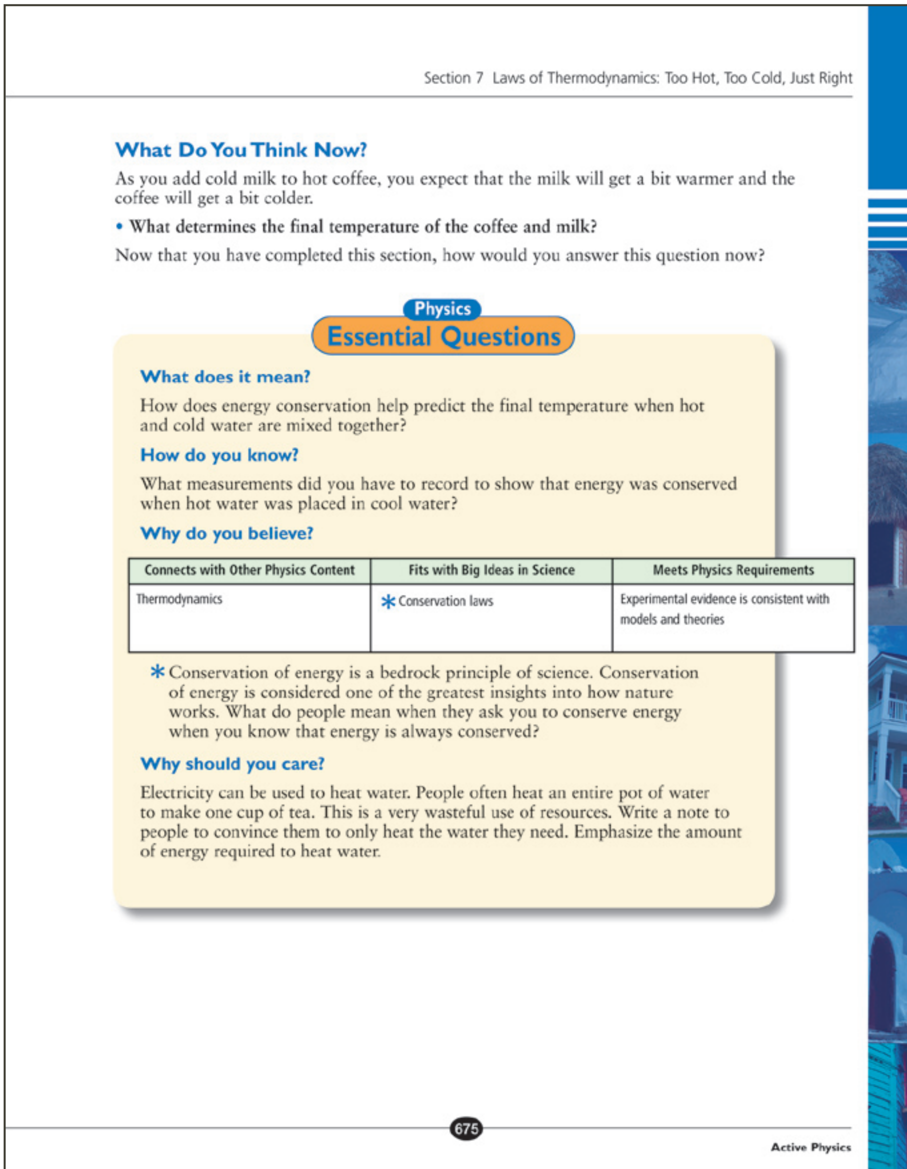
$W = F \times d$

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.


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

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.

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Active Physics

What Do You Think Now?

Ask students to review their previous answers to the question in the *What Do You Think?* section. Ask them how they would answer this question now and survey the class for how many students changed their ideas. Consider discussing the information in *A Physicist's Response*. Encourage them to reflect on their *Investigate* and *Physics Talk* and edit their original responses with examples and explanations. Their answers should show an understanding of thermal equilibrium and the laws of thermodynamics. Allow time for any questions that students might still have. Reiterate that you will be checking for the correctness of their responses, so they consult with their peers before they arrive at a final answer.

Physics Essential Questions

What does it mean?

When hot and cold water are mixed, the cold water will gain energy and become warmer. The hot water will lose an equal amount of energy and become cooler. Because the energy gained and the energy lost is equivalent, the total energy is conserved.

How do you know?

To calculate the gain and loss of energy of the water, measurements of the mass of the water and the change in temperature of the water were taken, and the specific heat of water also needed to be known.

Why do you believe?

Energy is always conserved. Some energy is in a more useful form than other energy. When people remind us to conserve energy, they mean that you should conserve (and not use) the energy that is in a useful form like fuel, and not convert it into heat if it is not necessary.

Why should you care?

It takes a great deal of energy to heat water. A metal pot placed on the stove gets hot very quickly. It does not require much energy to raise its temperature. Cold water takes substantially more time (and more energy) to get hot. Heating up more water than you need takes more time and more energy. The only convenience is foregoing the measurement of how much water you need. Is this worth the cost?

Reflecting on the Section and the Challenge

Using the information in the student text, discuss the importance of heating water for survival and that it takes considerable energy to heat water. Emphasize how crucial it will be for students to calculate the energy required to change the temperature of water or foods when they consider their appliance design package for the HFE.

Physics to Go

1.

Using conservation of energy and assuming no energy is transferred from the system to the surroundings (the system is isolated) you have

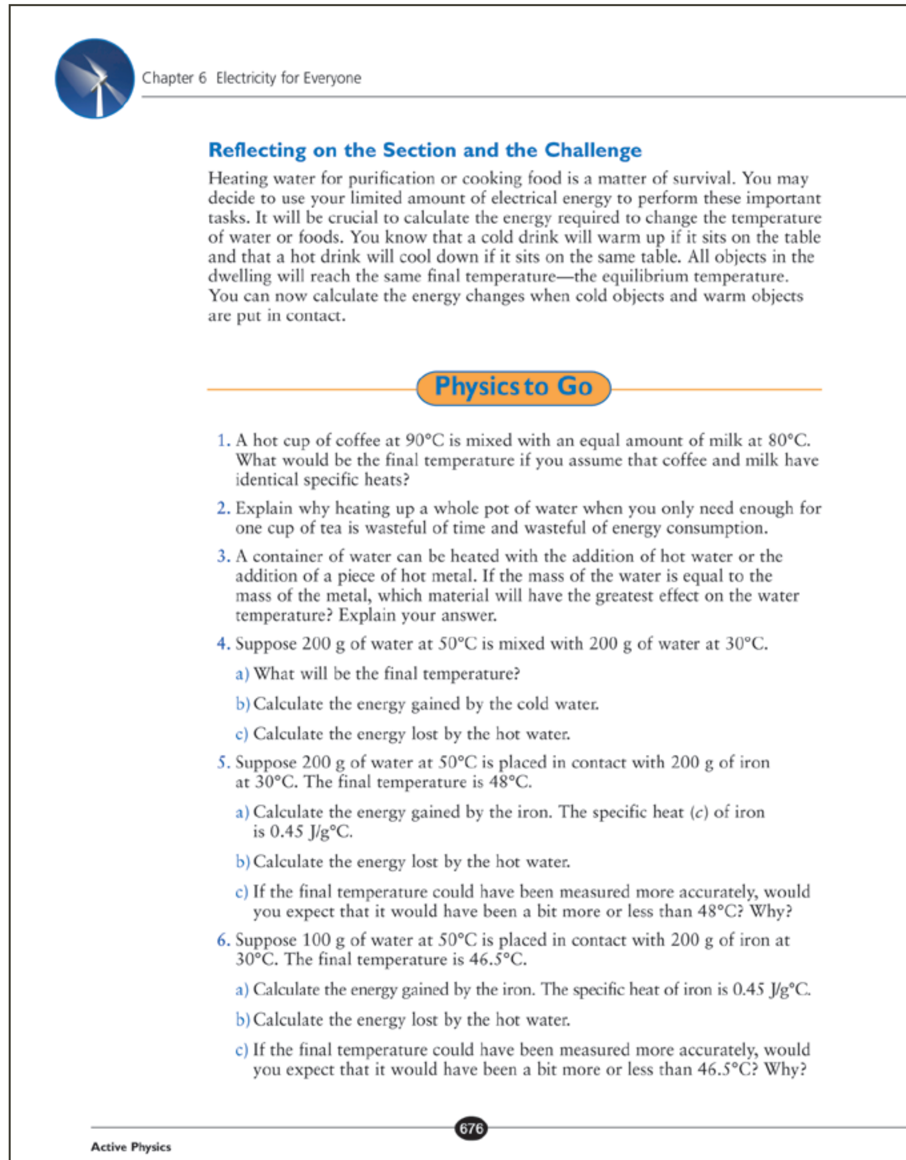
$$m_{\text{milk}} = m_{\text{coffee}} = m$$
$$c_{\text{milk}} = c_{\text{coffee}}$$
$$T_{\text{coffee}} = 90°\text{C}$$
$$T_{\text{milk}} = 80°\text{C}$$
$$T_{\text{final}} = ?$$

$$\Delta Q_{\text{coffee}} + \Delta Q_{\text{milk}} = 0$$
$$m_{\text{coffee}} c_{\text{coffee}} \left(T_{\text{final}} - T_{\text{coffee}}\right) + m_{\text{milk}} c_{\text{milk}} \left(T_{\text{final}} - T_{\text{milk}}\right) = 0$$
$$mc\left(T_{\text{final}} - 90°\text{C}\right) + mc\left(T_{\text{final}} - 80°\text{C}\right) = 0$$
$$2T_{\text{final}} = 80°\text{C} + 90°\text{C}$$
$$T_{\text{final}} = \frac{170°\text{C}}{2} = 85°\text{C}$$

2.

Explanation should have reasoning to support claims. Following is an example of an explanation:

Heating up a whole pot of water when you only need a cup is



Chapter 6 Electricity for Everyone

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?

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wasteful of time and energy because water has a high specific heat. It takes 4.18 J of energy to heat up 1 g of water by 1°C. A cup of water (8 oz) has about 227 g. To bring room temperature water (about 20°C) to boil (32°C) takes (4.18 J/g°C)(227 g)(12°C) = 11,386 J of energy or about 3.2 watt hours of energy. (The wind generator will deliver about 3 kWh per day to each home. As the mass of the water increases, the amount of energy needed increases. Since the rate at which the energy supplied is the same, it will take more time to boil more water.

3.

More heat energy is transferred to cool water when it is heated by adding water rather than metal of the same mass and temperatures because water has a higher specific heat than metal. This is because it takes more energy to warm 1 g of water than it does to warm 1 g of metal, so more heat energy can be transferred from the water than the metal to warm the cool water.

4.a)

Students may recognize that this is similar to *Question 1* because the mass of each substance is the same, and the specific heats are equal.

Given:

$m_{\text{warm}} = 200\text{ g};\ T_{\text{warm}} = 50°\text{C}$

$m_{\text{cool}} = 200\text{ g};\ T_{\text{cool}} = 30°\text{C}$

$$\Delta Q_{\text{warm}} + \Delta Q_{\text{cool}} = 0$$

$$m_{\text{warm}}c_{\text{warm}}\left(T_{\text{final}} - T_{\text{warm}}\right) + m_{\text{cool}}c_{\text{cool}}\left(T_{\text{final}} - T_{\text{cool}}\right) = 0$$

$$(200\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)\left(T_{\text{final}} - 50°\text{C}\right) + (200\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)\times\left(T_{\text{final}} - 30°\text{C}\right) = 0$$

$$2T_{\text{final}} = 50°\text{C} + 30°\text{C}$$

$$T_{\text{final}} = \frac{80°\text{C}}{2} = 40°\text{C}$$

4.b)

The heat energy transferred to the cold water is

$$\Delta Q_{\text{cool}} = m_{\text{cool}}c_{\text{cool}}\left(T_{\text{final}} - T_{\text{cool}}\right)$$

$$\Delta Q_{\text{cool}} = (200\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)(40°\text{C} - 30°\text{C})$$

$$\Delta Q_{\text{cool}} = (200\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)(10°\text{C}) = 8360\text{ J}$$

4.c)

The heat energy transferred from the warm water is equal to the heat energy transferred to the cool water. The negative sign indicates it is transferred from the warmer water.

$$\Delta Q_{\text{warm}} + \Delta Q_{\text{cool}} = 0$$

$$\Delta Q_{\text{warm}} = -\Delta Q_{\text{cool}}$$

$$\Delta Q_{\text{warm}} = -8360\text{ J}$$

5.a)

Given:

$m_{\text{iron}} = m_{\text{water}} = 200\text{ g};\ T_{\text{iron}} = 30°\text{C}$

$T_{\text{water}} = 50°\text{C};\ T_{\text{final}} = 48°\text{C}$

$c_{\text{iron}} = 0.45\,\frac{\text{J}}{\text{g°C}}$

$$\Delta Q_{\text{iron}} = m_{\text{iron}}c_{\text{iron}}\left(T_{\text{final}} - T_{\text{iron}}\right)$$

$$\Delta Q_{\text{iron}} = (200\text{ g})\left(0.45\,\frac{\text{J}}{\text{g°C}}\right)(48°\text{C} - 30°\text{C})$$

$$\Delta Q_{\text{iron}} = 1620\text{ J}$$

5.b)

$$\Delta Q_{\text{water}} = m_{\text{water}}c_{\text{water}}\left(T_{\text{final}} - T_{\text{water}}\right)$$

$$\Delta Q_{\text{water}} = (200\text{ g})\left(4.18\,\frac{\text{J}}{\text{g°C}}\right)(48°\text{C} - 50°\text{C})$$

$$\Delta Q_{\text{water}} = -1672\text{ J}$$

The negative sign indicates the energy of the water decreased.

5.c)

The energy decrease of the hot water should be equal to the energy increase of the iron, or the energy transferred from the hot water to the iron if no energy was transferred to the surroundings. Some energy must have been transferred to the surroundings since the hot water transferred two more joules of energy than that gained by the metal. If the final temperature could have been measured more accurately, it would have been a bit more because the decrease in the water's energy at the final temperature of 48°C is slightly higher than the increase in energy of the iron.

6.a)

Given:

$m_{\text{water}} = 100\text{ g};\ T_{\text{water}} = 50°\text{C}$

$m_{\text{iron}} = 200\text{ g};\ T_{\text{iron}} = 30°\text{C}$

$T_{\text{final}} = 46.5°\text{C};\ c_{\text{iron}} = 0.45\frac{\text{J}}{\text{g°C}}$

$$\Delta Q_{\text{iron}} = m_{\text{iron}}c_{\text{iron}}\left(T_{\text{final}} - T_{\text{iron}}\right)$$

$$\Delta Q_{\text{iron}} = (200\text{ g})\left(0.45\frac{\text{J}}{\text{g°C}}\right)\times(46.5°\text{C} - 30°\text{C})$$

$$\Delta Q_{\text{iron}} = 1485\text{ J}$$

6.b)

$$\Delta Q_{\text{water}} = m_{\text{water}}c_{\text{water}}\left(T_{\text{final}} - T_{\text{water}}\right)$$

$$\Delta Q_{\text{water}} = (100\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)\times(46.5°\text{C} - 50°\text{C})$$

$$\Delta Q_{\text{water}} = -1463\text{ J}$$

6.c)

If the final temperature could have been measured more accurately it would be higher because there was a greater decrease in energy of the water than there was an increase in energy of the iron. This would not account for all the big difference between energies. Probably some heat energy was transferred to the surroundings.

7.

Using conservation of energy

Given:

$m_{warm} = 300\text{ g};\ T_{warm} = 50°C$
$T_{final} = 40°C;\ T_{cool} = 10°C$

$$\Delta Q_{warm} + \Delta Q_{cool} = 0$$
$$m_{warm}c_{warm}\left(T_{final} - T_{warm}\right) +$$
$$m_{cool}c_{cool}\left(T_{final} - T_{cool}\right) = 0$$
$$(300\text{ g})\left(4.18\ \frac{\text{J}}{\text{g°C}}\right)\times$$
$$(40°C - 50°C) +$$
$$m_{cool}\left(4.18\ \frac{\text{J}}{\text{g°C}}\right)(40°C - 10°C) = 0$$
$$-12{,}540\text{ J} + m_{cool}(125.4\text{ J/g}) = 0$$
$$m_{cool} = \frac{12{,}450\text{ J}}{125.4\text{ J/g}} = 100\text{ g}$$

8.a)

Given:

$m_{warm} = m_{cool} = 100\text{ g}$
$T_{warm} = 80°C;\ T_{cool} = 40°C$

$$\Delta Q_{warm} + \Delta Q_{cool} = 0$$
$$m_{warm}c_{warm}\left(T_{final} - T_{warm}\right) +$$
$$m_{cool}c_{cool}\left(T_{final} - T_{cool}\right) = 0$$
$$(100\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)(T_{final} - 80°C) +$$
$$(100\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)\times$$
$$(T_{final} - 40°C) = 0$$
$$2T_{final} = 80°C + 40°C$$
$$T_{final} = \frac{120\ °C}{2} = 60°C$$

8.b) and c)

Students should use conservation of energy to show that this result would obey energy conservation rules; however, it does not obey the laws of thermodynamics. Heat energy always flows spontaneously from the warmer object to the cooler object if they are interacting. Heat energy never flows from the cooler object to the warmer object spontaneously. Therefore, this situation is physically impossible.

$$\Delta Q_{warm} + \Delta Q_{cool} = 0$$
$$m_{warm}c_{warm}\left(T_{final} - T_{warm}\right) +$$
$$m_{cool}c_{cool}\left(T_{final} - T_{cool}\right) = 0$$
$$(100\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)\times$$
$$(100°C - 80°C) + (100\text{ g})\times$$
$$\left(4.18\frac{\text{J}}{\text{g°C}}\right)(20°C - 40°C) = 0\ \ ?$$
$$(8360\text{ J}) - (8360\text{ J}) = 0\ \ ?$$

9.a)

Given:

$m_{warm} = 100\text{ g};\ T_{warm} = 80°C$
$m_{cool} = 100\text{ g};\ T_{cool} = 20°C$

$$\Delta Q_{warm} + \Delta Q_{cool} = 0$$
$$m_{warm}c_{warm}\left(T_{final} - T_{warm}\right) +$$
$$m_{cool}c_{cool}\left(T_{final} - T_{cool}\right) = 0$$
$$(100\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)(T_{final} - 80°C) +$$
$$(100\text{ g})\left(4.18\frac{\text{J}}{\text{g°C}}\right)\times$$
$$(T_{final} - 20°C) = 0$$
$$2T_{final} = 80°C + 20°C$$
$$T_{final} = \frac{100°C}{2} = 50°C$$

9.b)

Given:

$m_{warm} = 100\text{ g};\ T_{warm} = 80°C$
$m_{cool} = 1\text{ g};\ T_{cool} = 20°C$

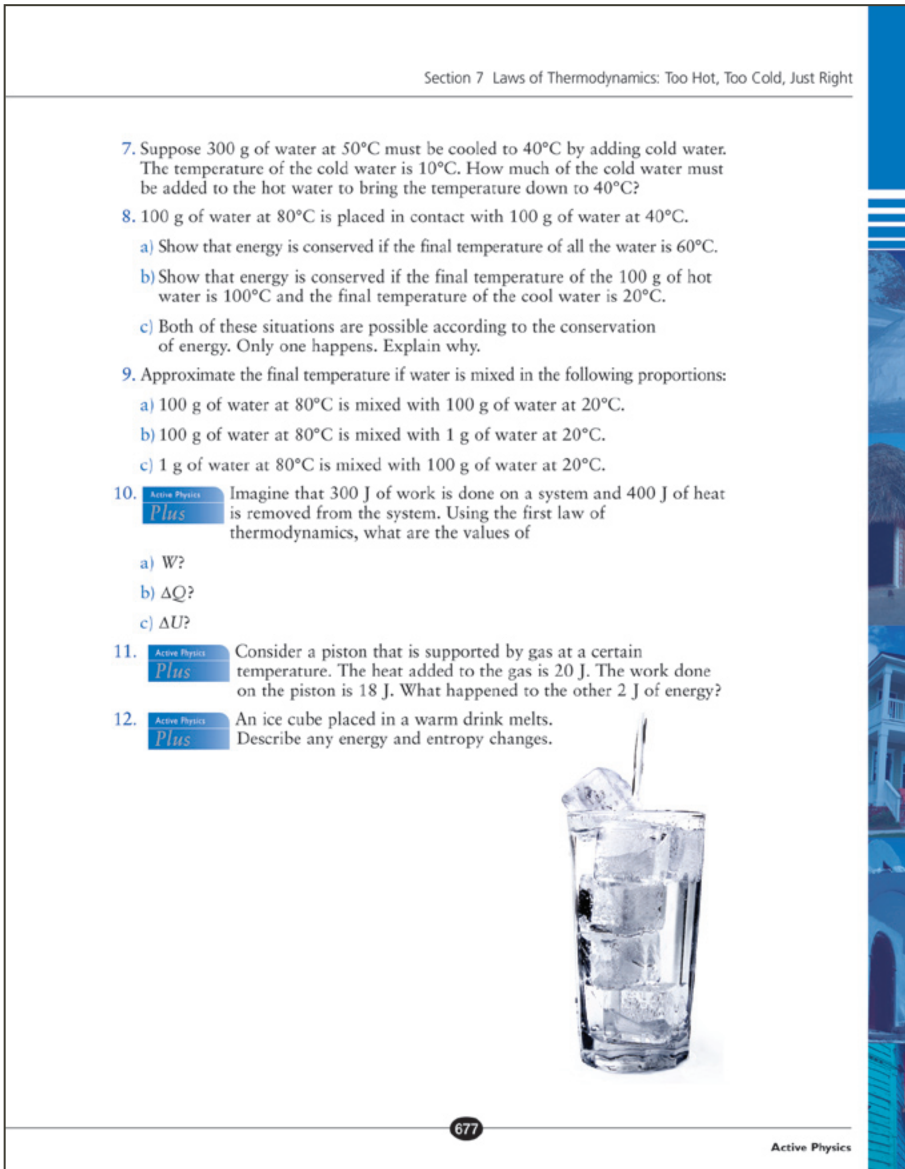
$$\Delta Q_{warm} + \Delta Q_{cool} = 0$$
$$m_{warm}c_{warm}\left(T_{final} - T_{warm}\right) +$$
$$m_{cool}c_{cool}\left(T_{final} - T_{cool}\right) = 0$$
$$(100\text{ g})\left(4.18\ \frac{\text{J}}{\text{g°C}}\right)\times$$
$$(T_{final} - 80°C) + (1\text{ g})\times$$
$$\left(4.18\ \frac{\text{J}}{\text{g°C}}\right)(T_{final} - 20°C) = 0$$
$$(101\text{ g})T_{final} = 8000\text{ g°C} + 20\text{ g°C}$$
$$T_{final} = \frac{8020\text{ g°C}}{101\text{ g}} = 79°C$$

9.c)

Given:

$m_{warm} = 1\text{ g};\ T_{warm} = 80°C$
$m_{cool} = 100\text{ g};\ T_{cool} = 20°C$

$$\Delta Q_{warm} + \Delta Q_{cool} = 0$$
$$m_{warm}c_{warm}\left(T_{final} - T_{warm}\right) +$$
$$m_{cool}c_{cool}\left(T_{final} - T_{cool}\right) = 0$$
$$(1\text{ g})\left(4.18\ \frac{\text{J}}{\text{g°C}}\right)\times$$
$$(T_{final} - 80°C) + (100\text{ g})\times$$
$$\left(4.18\ \frac{\text{J}}{\text{g°C}}\right)(T_{final} - 20°C) = 0$$
$$(101\text{ g})T_{final} = 80\text{ g°C} + 2000\text{ g°C}$$
$$T_{final} = \frac{2080\text{ g°C}}{101\text{ g}} = 21°C$$


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

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.

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Active Physics

10.a) Active Physics *Plus*

$W = -300$ J, work done on the system.

10.b) Active Physics *Plus*

$\Delta Q = -400$ J, heat removed from the system.

10.c) Active Physics *Plus*

$\Delta U = \Delta Q - W = -100$ J

11. Active Physics *Plus*

Energy must be conserved. If 20 J of heat was added to the gas, and 18 J of work was done by the gas, then 2 J of energy went to increasing the internal energy of the gas.

12. Active Physics *Plus*

Energy is transferred from the warm water to the ice cube raising the temperature of the ice until it reaches its melting point of 0°C, and then the ice continues to absorb heat energy from the water until it melts. The ice will absorb heat from the water until the ice molecules have enough energy to break them free of the solid lattice in which they are bound. (Latent heat, the amount of heat needed to change the phase of a substance.) When the ice melts, the molecules are no longer bound within the solid and move randomly in the water, increasing the entropy of the system. The latent heat of water or the amount of heat energy needed is much greater than the specific heat of water. For example, 1 g of ice at 0°C requires 334 J of heat energy to melt. This is much more than the 4.18 J of heat needed to raise 1 g of water by 1°C. It takes almost 80 times more energy to melt 1 g of ice than to raise 1 g of water by 1°C. Consider discussing the relevance of this with global warming and the melting of the polar caps.

CHAPTER 6

SECTION 7 QUIZ

6-7a **Blackline Master**

1. One hundred grams of water at 60°C is added to 400 g of water at 20°C in an insulated cup. If no heat is lost, what is the final temperature of the mixture?

   a) 28°C
   b) 30°C
   c) 32°C
   d) 40°C

2. Equal amounts of heat are added to pieces of metal of equal mass. The metal that will have the greater temperature rise is the metal with

   a) the large volume.
   b) the higher specific heat.
   c) the lower specific heat.
   d) the lower density.

3. If only the temperature of two objects is known, it is always possible to determine

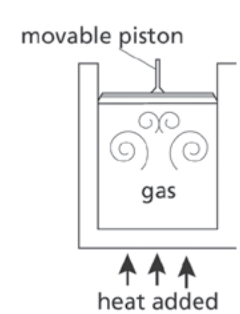
   a) the object's total internal energy.
   b) the direction of heat flow between the objects.
   c) which object has the greater specific heat.
   d) which object would heat water more when immersed.

4. Two objects have the same temperature. As a result, the molecules of the objects must have the same

   a) specific heat.
   b) internal energy.
   c) speed.
   d) average kinetic energy.

5. A gas is heated in a closed cylinder fitted with a movable piston as shown in the diagram to the right. When 375 J of heat are added to the gas and the internal energy of the gas increases by 125 J, how much work does the gas do moving the piston upward?

   a) 500 J
   b) 250 J
   c) 3 J
   d) 125 J



SECTION 7 QUIZ ANSWERS

1 a) 28°C.

$$\Delta Q_1 = \Delta Q_2$$

$$m_1 c_1 \left(T_{\text{final}} - T_{1\text{initial}}\right) + m_2 c_2 \left(T_{\text{final}} - T_{2\text{initial}}\right) = 0$$

$$(100 \text{ g})\left(4.18 \frac{\text{J}}{\text{g C}}\right)\left(T_{\text{final}} - 60 \text{ C}\right) + (400 \text{ g})\left(4.18 \frac{\text{J}}{\text{g C}}\right)\left(T_{\text{final}} - 20 \text{ C}\right) = 0$$

$$T_{\text{final}} = \frac{14{,}000 \text{ g C}}{500 \text{ g}} = 28 \text{ C}$$

2 c) The specific heat is the amount of energy needed to raise one gram of the substance by one degree Celsius. The lower the specific heat, the less energy is needed to increase its temperature.

3 b) This is because heat energy spontaneously flows from the warmer object to the cooler object if they are interacting. For the other options, another physical quantity would need to be known, such as the mass for the total internal energy, the type of substance or the mass and final temperatures for the specific heat, and the specific heat and mass for which object would heat water more.

4 d) The temperature of an object is equal to the average kinetic energy of the particles making up the object. Objects of different specific heat may still have the same temperature. Objects with the same internal energy may have different temperatures because this also depends on other physical characteristics, such as mass. Objects may be at rest or moving regardless of their temperature, and the particles that make up the object have various speeds.

5 b) Because the total energy is conserved, the energy received by the gas must go into increasing its total energy and doing work on its surroundings. Because 125 J of energy went to increasing its internal energy, the remaining 250 J of energy received by the gas must have gone into doing work on its surroundings.