SECTION 9

Comparing Energy Consumption: More for Your Money

Section Overview

Students investigate the efficiency of three different appliances used to heat equal amounts of water from the same initial temperature to a given final temperature. They calculate the energy consumed by each appliance, the efficiency of each appliance, and the cost. They are then introduced to heat transfer by conduction, convection, and radiation. Applying the concepts of power and energy consumption, students determine the cost and efficiency of various common household appliances. They then apply the information they gather to determine which type of water-heating appliance and other household appliances they will include in their appliance design package and what guidelines they will supply.

Background Information

Often, the words thermal energy and heat energy are interchanged; however, they mean different things. Thermal energy is the internal energy of a substance that is affected when heat energy is added to the substance. Thermal energy depends on the temperature of the substance and its mass.

When heat energy is added to a substance it may increase the average kinetic energy of the molecules making up the substance. The average kinetic energy of the atoms/molecules making up a substance is its temperature. If the substance is undergoing a phase change (e.g., solid to liquid, liquid to gas, etc.), then the temperature does not change. This is because the overall temperature or average kinetic energy of all the molecules does not change. What occurs is a transfer of kinetic energy from the more energetic molecules to the less energetic molecules until all the atoms or molecules in the solid state have become energetic enough to break the bonds that held them in place to reach a liquid state. After this occurs, the temperature begins to rise again if more heat is added.

As a liquid substance is heated, the liquid molecules gain kinetic energy. The average kinetic energy rises and so the temperature rises, until the liquid reaches its boiling point. At this point, the atoms/molecules have enough energy for their bonds to break, and they fly apart from each other forming a gas. The temperature doesn't rise because the liquid particles cannot move any faster without escaping the liquid state.

When substances condense or become solid, heat energy from the substance is transferred to its surroundings. Heat energy is the energy transferred from one object to another during an interaction that increases the average kinetic energy of the substance on the molecular level (the temperature), or changes the phase of the substance. The volume of the substance may also change when heat is transferred to it. Most solids will expand when heated since their molecules/atoms are more energetic and move back and forth with a greater amplitude even though they are still held in place. Water is an exception to this. At water's freezing point it expands – that is ice takes up more space than the same number of water molecules in the liquid state.

An important fact is that almost all interactions result in at least one of the interacting objects becoming warmer. No energy description of interactions is complete without accounting for the heat transfers that are byproducts of interactions. These heat transfers are often connected with energy loss in the system. Fundamentally, thermal energy is kinetic energy (energy of motion) at the atomic level.

Crucial Physics

- Heat energy is transferred when a warmer object interacts with a cooler object. Heat energy may be transferred by conduction, convection, or radiation.
- Although various devices may consume equal amounts of energy, they may not transfer their energy to another system equally well. The ability of one system to transfer its energy to another system is a measure of the system's efficiency.
- Heat transferred by conduction occurs when objects of different temperature are in contact with each other and heat energy is transferred from particle to particle. This occurs within a substance or between two substances.
- Heat energy transferred by convection occurs through the movement of a fluid (gas or liquid).
- Heat energy transferred by radiation occurs when the warmer object emits electromagnetic radiation in all directions and the cooler object absorbs some or all of it. The objects do not have to be in contact with each other.

Learning Outcomes	Location in the Section	Evidence of Understanding
Measure and compare the energy consumed by appliances.	***Investigate*** Steps 1-6	Students measure the initial and final temperatures and the time involved in heating a known amount of water using a microwave, a hot plate, and an immersion heating coil. They calculate the energy consumed to heat the water from the known power ratings and time.
Compare the costs of operating a variety of electrical appliances in terms of power ratings, amount of time each appliance is used, and billing rate.	***Investigate*** Steps 8 and 9	Students measure time and temperature change involved in heating a known amount of water. They calculate the energy transferred to the water using the mass, specific heat, and measured temperature change. They compare the energy consumed by each heating appliance to the amount of energy transferred to the water. Then they compare the cost effectiveness of each appliance for heating water. Students also compare the costs of using various appliances (selected in the previous section) for a month.
Distinguish among the three ways of heat transfer.	***Physics Talk***	Students are introduced to and should discuss how heat energy may be transferred by conduction, convection, and radiation and describe the method of heat energy transfer for each appliance they used to warm water. They distinguish between these types of heat energy transfer as they answer questions.

Section 9 Materials, Preparation, and Safety

Materials and Equipment

PLAN A

Materials and Equipment	Group (4 students)	Class
Beaker, glass, 1 L	3 per group	
Stirring rod, glass, 8 in.-12 in.	1 per group	
Thermometer	1 per group	
Heater, electric immersion	1 per group	
Stopwatch	1 per group	
Hot plate, student, electric		2 per class
Wire gauze, square, 4 in. x 4 in. (w/ ceramic center)		2 per class
Scale, electronic, 0.1-g readability, 0-1500 g		1 per class
Wire gauze, square, 4 in. x 4 in. (w/ ceramic center)		2 per class
Water, cold, 1 L*	1 per group	
Access to a microwave oven*		1 per class

*Additional items needed not supplied

Time Requirements

- Allow at least one class period or 45 minutes for this *Investigate*.
- Depending on the wattage of the appliances chosen, the *Investigate* may take a longer or shorter amount of time.

Teacher Preparation

- This *Investigate* requires a microwave oven. One may be available to be borrowed from the school's teacher's lounge, or you may choose to bring one from home. Inexpensive ovens may also be purchased for less than $50.
- The power output of the microwave oven is listed on the back or the inside of the oven. This is not the power the microwave uses.
- The student groups should rotate through use of the microwave oven. If the temperature of the water is only raised to 50°C for the three methods of heating, the time to heat one liter should not be more than about three minutes for even small ovens.

Safety Requirements

- Do not heat the water above 50°C to prevent any dangers of spilled hot water.
- Observe the safety precautions for thermometers in *Sections 7* and *8*.
- Goggles are required.
- Observe the safety rules for use of the hot plate in *Section 7*.
- Observe the safety rules for use of the heating coil in *Sections 7* and *8*.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Beaker, glass, 1 L		3 per class
Stirring rod, glass, 8 in.-12 in.		1 per class
Thermometer		1 per class
Heater, electric immersion		1 per class
Stopwatch		1 per class
Hot plate, student, electric		2 per class
Wire gauze, square, 4 in. x 4 in. (w/ ceramic center)		2 per class
Scale, electronic, 0.1-g readability, 0-1500 g		1 per class
Wire gauze, square, 4 in. x 4 in. (w/ ceramic center)		2 per class
Water, cold, 1 L*		1 per class
Access to a microwave oven*		1 per class

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Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Organizing data	***Investigate*** Step 9	**Augmentation** • Many students struggle to organize data in a way that can be easily shared with other people. If students did not create similar charts in *Section 8*, provide them with a blank data table that has labeled columns to transfer data from their logs onto the sheet. This will allow the data to be shared more easily with group members. **Accommodation** • To minimize copying errors and save time, provide copies of individual student's data.
Calculations with decimal numbers Comparing decimals	***Physics to Go*** Questions 4-6	**Augmentation** • Students who struggle with number sense and concepts often ignore or misplace decimal points. • Remind students of the importance of decimal points by providing them with some examples to compare. "Would you want your allowance to be $0.50 or $50?" • Remind students to copy all of the numbers exactly as they appear from their papers into the calculator and from the calculator to their logs, including the decimal points.

NOTES

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Comprehension Higher-order thinking	***Active Physics Plus***	Remind students of their experience in *Section 4* of this chapter where they used a scale of 1 to 10 to rate their confidence in knowing the contents of the black box. They can apply that experience when they design their cooking experiment. You may wish to have a brief discussion about subjectivity vs. objectivity. Science is primarily concerned with objectivity, but when factors outside of science come to play in decision-making (such as determining the "best" way to cook a hot dog), subjective concerns play a role as well. As young adults, students will encounter many situations in which they must weigh objective scientific data against subjective social concerns.
Answering higher order questions	***Physics to Go*** Question 7	When students evaluate cooking utensils, you may wish to have some pots, pans, and other implements, such as spatulas and spoons, on hand for reference and comparison.

ELL students benefit greatly from writing in English. Ask students to write definitions for heat transfer, conduction, convection, and radiation in their own words. Have them give examples of each of the three types of heat transfer, and include labeled illustrations as well. Encourage them to state how each type of heat transfer follows the second law of thermodynamics.

Students could also write about what it means for an appliance to be energy efficient. Students' ideas could differ somewhat because what constitutes efficiency is partly open to interpretation and depends on the needs and situation of the consumer.

ELL students also benefit greatly from speaking in English. When students have completed their writings, ask for ELL volunteers to explain each type of heat transfer to the class, and re-create their illustrations on the board. Open the class to discussion and comments. Challenge students to think of some situations in which different types of heat transfer are found in nature. Examples include weather patterns, convection in lake-water turnover and in the water of geysers, conduction between the feet of animals and Earth's surface, and radiation from the Sun. For extra credit, encourage ELL students to research one of these natural phenomena, tie it into what they are learning in class and what they need to do for the *Chapter Challenge*, and give a class presentation.

Research skills are tremendously important in science. To fully understand radiation, students may benefit from researching the behavior of electromagnetic energy. Connecting to what is already known is also vitally important in science, and is one of the ways in which scientists develop theories. To this end, encourage students to review their *Let Us Entertain You* notes about wave behavior to look for information that may help them understand radiation.

SECTION 9

Teaching Suggestions and Sample Answers

What Do You See?

Have a class discussion on the illustration. Consider using the overhead of the illustration as a focal point for the discussion. Ask students to describe what they see and what they think it means. Students will probably suggest that the person is trying to figure out which method of heating water will boil water first. Ask them how this might also connect with the title of the section. Record their initial impressions on the board. You can refer to them at a later point during students' investigation of physics concepts in this section.

What Do You Think?

Ask the class what they currently know about warming water. Students should realize that water requires more heat energy to warm it than many materials. Have students answer the question in their logs and discuss their ideas with their group members. Then have a class discussion on students' responses. Accept all answers and remind students that they will be returning to this question later. This is also an opportunity to identify any misconceptions that students might have.

What Do You Think?

A Physicist's Response

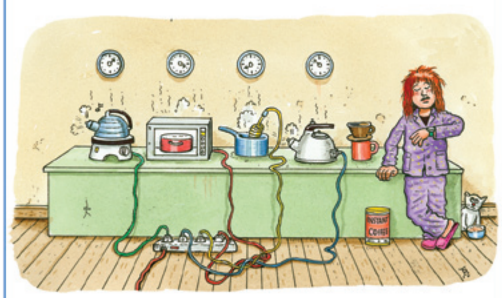
Most high-efficiency appliances are worth the added cost. Two important factors come into play: the priorities of the purchaser, and the overall cost based on those priorities.

The way to determine if the product is worth the cost is to determine the total cost over the lifetime of the appliance (or over a long time period) versus the amount of savings the appliance provides. For example, if one's top priority is monetary cost, then a water heater that saves a family on the average $100 a year but costs $500 more than the usual water heater will be less expensive only if it is used for more than five years. This assumes that the cost of maintenance is the same for both water heaters and that both water heaters will have a lifetime that exceeds five years.

As another example, imagine a refrigerator that saves on the average $50 a year, but is known to have problems that on the average cost $200 over five years. If this refrigerator costs $50 more than the less energy efficient refrigerator then it will not save the family that purchases it any money. However, it may still be more environmentally friendly causing less pollution and waste. In this case the monetary costs are not worth it, but the environmental costs may be worth it.

Section 9 Comparing Energy Consumption: More for Your Money

What Do You See?



Learning Outcomes

In this section, you will

- **Measure** and compare the energy consumed by appliances.
- **Compare** the costs of operating a variety of electrical appliances in terms of power ratings, amount of time each appliance is used, and billing rate.
- **Distinguish** among the three ways of heat transfer.

What Do You Think?

Some hot-water heaters and furnaces for homes are more than 90% efficient.

- **If high-efficiency appliances cost more, are they worth the added cost?**

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

You will be heating up water three different ways in this section and comparing the energy, time, and costs for each.

1. Place 250 mL of cold tap water in a beaker made of heat-resistant glass. Make sure the outside of the beaker is dry so it does not slip from your grasp. Measure the temperature of the water.

   a) Record the temperature of the water in your log.

   b) Record the quantity of water in milliliters and grams. (1 mL of water has a mass of 1 g.)

Students' Prior Conceptions

Teaching this section offers you the opportunity to use fundamental reasoning and math skills with the students. There are no identified science prior conceptions in the research data base.

Investigate

Teaching Tip

If a microwave oven is not available, one may be borrowed from the school, or a small counter-top model could be brought into school for this *Investigate.*

The amount of heat delivered to the water in 2 min will depend upon the power rating of the microwave oven. Test the oven first to ensure that the water does not get so hot as to be dangerous to handle. If it does, reduce the heating time accordingly to reach the desired temperature. Gloves are also a good precaution in case the beaker becomes too warm.

1.

This investigation may be done as a class demonstration, or the students may be rotated in groups as they use the microwave. The microwave is the limiting factor in this section, so some students should start with *Steps 3* or *5* first if it is not done as a class demonstration. Students that start with *Steps 3* or *5* should be provided a final temperature to attain.

1.a)

Students should record the initial temperature of the water. It is desirable to have the same initial temperature for all trials. Tap water should provide this.

1.b)

Students record the mass of the water in the beaker. Students should try to have the mass as close as possible for the three trials to make comparisons easier.

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2.

The power rating of the microwave may be found on the back, bottom, or on a label inside the microwave. This is not the actual power drawn by the microwave, but rather the power that the oven is able to deliver to the contents.

2.a)

Students record the power of the microwave, heating time (2 min), and final temperature of the hot water in their logs. Students should stir the water before taking the measurement but not with the thermometer.

2.b)

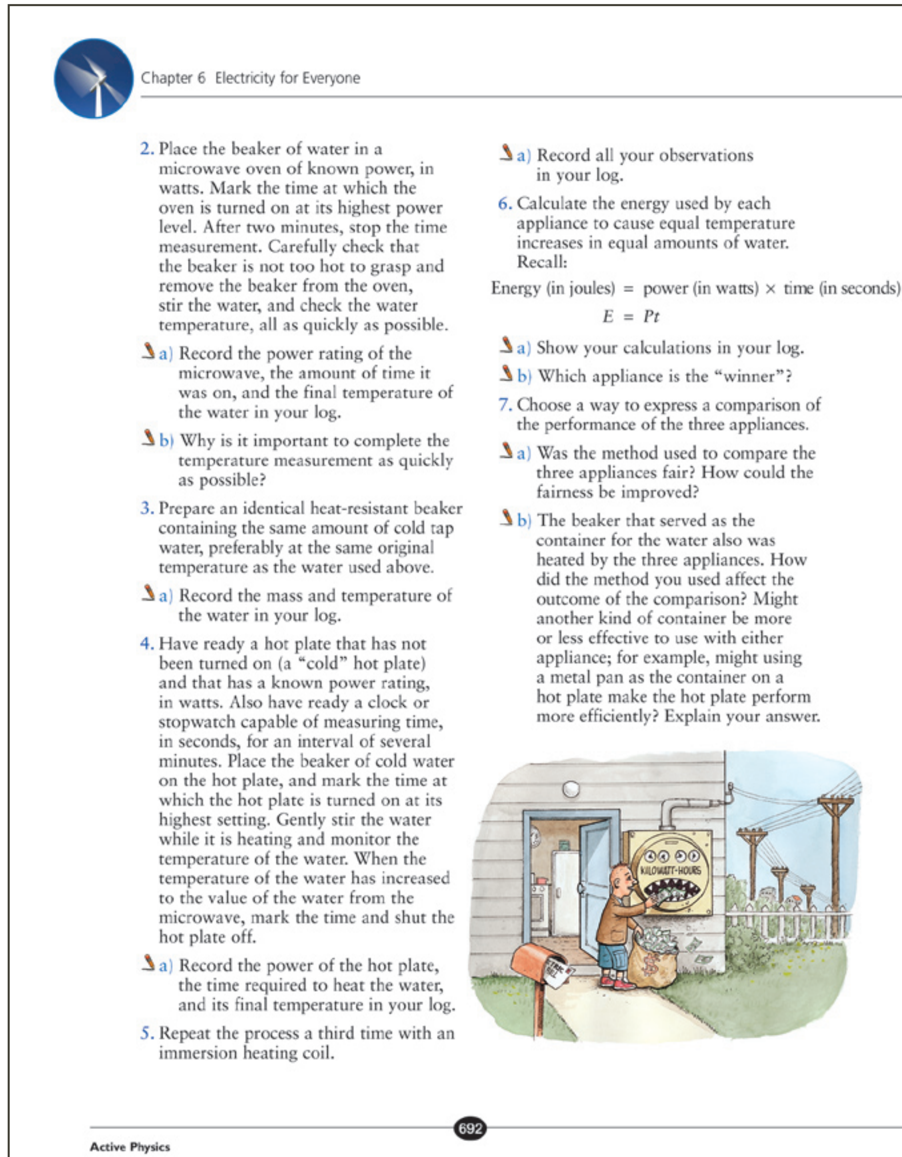
Temperature measurements should be completed as quickly as possible because heat energy will be transferred from the water to the surroundings (e.g., air in the room), reducing the water's temperature.

3.a)

Students record the mass and initial temperature for this new cold-water trial.

Teaching Tip

Dry the bottom of the glass beaker completely before placing on the hot plate.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2. Place the beaker of water in a microwave oven of known power, in watts. Mark the time at which the oven is turned on at its highest power level. After two minutes, stop the time measurement. Carefully check that the beaker is not too hot to grasp and remove the beaker from the oven, stir the water, and check the water temperature, all as quickly as possible.

a) Record the power rating of the microwave, the amount of time it was on, and the final temperature of the water in your log.

b) Why is it important to complete the temperature measurement as quickly as possible?

3. Prepare an identical heat-resistant beaker containing the same amount of cold tap water, preferably at the same original temperature as the water used above.

a) Record the mass and temperature of the water in your log.

4. Have ready a hot plate that has not been turned on (a "cold" hot plate) and that has a known power rating, in watts. Also have ready a clock or stopwatch capable of measuring time, in seconds, for an interval of several minutes. Place the beaker of cold water on the hot plate, and mark the time at which the hot plate is turned on at its highest setting. Gently stir the water while it is heating and monitor the temperature of the water. When the temperature of the water has increased to the value of the water from the microwave, mark the time and shut the hot plate off.

a) Record the power of the hot plate, the time required to heat the water, and its final temperature in your log.

5. Repeat the process a third time with an immersion heating coil.

a) Record all your observations in your log.

6. Calculate the energy used by each appliance to cause equal temperature increases in equal amounts of water. Recall:

$$\text{Energy (in joules)} = \text{power (in watts)} \times \text{time (in seconds)}$$

$$E = Pt$$

a) Show your calculations in your log.

b) Which appliance is the "winner"?

7. Choose a way to express a comparison of the performance of the three appliances.

a) Was the method used to compare the three appliances fair? How could the fairness be improved?

b) The beaker that served as the container for the water also was heated by the three appliances. How did the method you used affect the outcome of the comparison? Might another kind of container be more or less effective to use with either appliance; for example, might using a metal pan as the container on a hot plate make the hot plate perform more efficiently? Explain your answer.

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4.a)

Students record the power rating of the hot plate, the time it takes the cold water on the initially cold hot plate to warm up to the same final temperature of the water warmed in the microwave, and the final temperature of the water heated on the hot plate in their logs. The hot plate will have some energy still stored in the plate when the trial is finished. The power rating of the hot plate is normally found on a label on the side or back. Students should turn off the hot plate so that it may cool for the next group.

5.a)

Students repeat the procedures for heating water this time using an immersion coil. They should record their measurements of the water's mass and initial temperature, the time it took for the water to reach the same final temperature as in *Step 1*, the final temperature of the water after heating, and the power rating of the immersion coil.

6.a)

Students should calculate and record in their logs the energy each appliance provided to reach the same final temperature for equal masses of water. It is expected that each appliance will have delivered different amounts of energy.

8. You measured the time that each appliance was used and calculated the energy used. You can also calculate the expense of that energy. To calculate the expense of running an electrical appliance you can use the following equation.

Cost = energy × price per unit of energy

Energy can be expressed in joules, which are equivalent to watt-seconds. However, electricity is usually priced by the kilowatt-hour. Converting from watt-seconds to kilowatt-hours (kW•h) will require you to convert the time to hours and the watts to kilowatts.

$$\text{kW}\cdot\text{h} = 1000\ \text{W} \times 3600\ \text{s} = 3{,}600{,}000\ \text{W}\cdot\text{s}$$

a) Calculate the cost of using each appliance to heat the water. Assume that the cost of electricity is 10.40 cents per kilowatt-hour.

b) Does the cost difference seem significant? Explain your answer.

9. In a previous section, you estimated the time that an appliance is used, and the amount of energy required to use it for one month. Now you will calculate the expense of that energy. Combine the lists from the group members and calculate the expense of running the electrical appliances.

a) Record your calculations in your log.

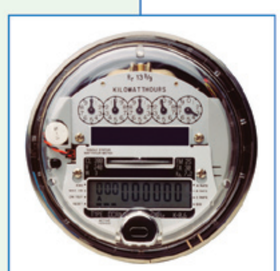
b) Does the cost of running the appliances seem significant? Explain your answer.

Physics Talk

DETERMINING ENERGY CONSUMPTION

The electrical energy consumed by appliances can be determined in different ways. If the power rating of an appliance is known, and if the power remains at a steady value while the appliance is in use (for example, a light bulb will use electricity at a constant rate), the energy, in kW • h, can be calculated by multiplying the power of the appliance, in kilowatts, by the time, in hours, for which the appliance is used.

Determining the energy consumed by some appliances, however, is tricky, because the appliances vary in power while they are in use. For example, a refrigerator may cycle on and off under the control of a thermostat. Therefore, it is not operating during all of the time it is "plugged in" and the calculation described above would lead to a misleadingly high value for the refrigerator's energy consumption. For such appliances whose power varies throughout time, a kilowatt-hour meter is used to measure the total energy consumed, with variations in power throughout time taken into account. The same kind of meter, a kilowatt-hour meter, is used by the power company to measure the total electrical energy used in your home. The meter is mounted somewhere at your home (usually on an outside wall) so that it can be read by the power company's "meter reader," or electronically.



6.b)

The winning appliance is the one that used the least amount of energy to reach the same final temperature. Typically this is the immersion coil.

7.

A method of comparing the three appliances could be by measuring their efficiency. The efficiency is the heat gained (the same for all three water trials) divided by the energy provided. This will be a number less than one. Multiplying by 100% will provide a percent efficiency.

7.a)

The "fairness" of the test might be improved by finding the energy that is still in the hot plate or the microwave oven at the trial's end. The actual energy the microwave uses rather than its nominal power rating would also provide a more accurate measure of its efficiency.

7.b)

The beaker will absorb heat from hot plate more than it will from the microwave and immersion coil, since the hot plate must first warm the beaker before the heat energy from the beaker is transferred to the water. The immersion coil and the microwave oven heat the water directly so less heat is transferred to the beaker in the process. Using a metal pan for the hot plate would allow for a quicker and more efficient transfer of heat to the water by the hot plate because metal has a lower specific heat than glass.

8.a)

Students should calculate the cost of running the three appliances at 10.40 cents per kWh.

8.b)

Students may think that the cost difference is insignificant, and opt for the speed of the microwave.

9.a)

Students should calculate the energy expense for their list of appliances.

9.b)

Students should realize that as the time for which the appliance is run increases, and as the power it consumes increases, any difference in energy efficiency becomes more significant.

Physics Talk

Have a class discussion on how energy consumption is calculated and how some appliances might cycle on and off at irregular time intervals.

CHAPTER 6

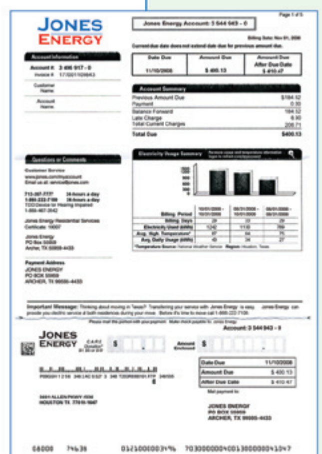
Describe the electric meter used by power companies to determine electrical energy used in buildings. Go through the sample problem with the class and discuss how over long periods of use the three methods used to warm the water could have significantly different costs.

Emphasize that heat energy is always transferred from the warmer to the cooler object. Consider having students determine the cost over a month's time using the data they collected in the *Investigate* and describe how heat energy is transferred through conduction, convection, and radiation. Point out that heat energy by conduction requires physical contact between the two interacting objects.

Check to see if students understand that convection occurs in fluids (gases and liquids). Describe how the molecules of the fluid become less dense and get pushed upward, away from the heat source by the cooler more dense molecules, and the movement of the molecules in the fluid plays a major part in the transfer of heat energy. Consider mentioning that convection is related to buoyancy and gravity and does not occur in zero-gravity situations.

Students should also understand that heat energy is transferred by radiation and that the two interacting objects do not have to be in contact with each other. Describe how the radiation (electromagnetic waves) is absorbed by the atoms/molecules of the cooler substance and causes them to move faster. Then ask students to discuss the types of heat transfer that occurred in the *Investigate* they performed.

Chapter 6 Electricity for Everyone



Another way to determine the energy used by electrical appliances is to use the experience of power companies or corporations that sell electrical supplies. Extensive lists of appliances, their power ratings, and each appliance's average energy use per month by a typical family are available free from such sources.

The cost of operating an electrical appliance can be calculated using the following equation:

$$\text{Cost} = \text{energy} \times \text{price per unit of energy}$$

where energy is in kilowatt-hours (1000 W • h = 1 kW • h).

Sample Problem

An electric coffee maker uses an average of 22.5 kW • h of energy each month. If the family is charged \$0.12/kW • h for electricity, what is the average monthly cost of operating the coffee maker?

Strategy: Use the equation for cost.

Given:

Energy = 22.5 kW • h

Price = \$0.12 / kW • h

Solution:

$$\begin{aligned}\text{Cost} &= \text{energy} \times \text{price per unit of energy}\\ &= 22.5\ \text{kW}\cdot\text{h} \times \$0.12/\text{kW}\cdot\text{h}\\ &= \$2.70\end{aligned}$$

In this *Investigate*, you heated the same amount of water using an immersion heating coil, a microwave oven, and a hot plate. Although the water gained the same amount of energy in all three methods, the amount of electrical energy was different, as was the time required and the cost. The cost difference for the time you heated the water in the *Investigate* may have appeared insignificant. However, over long periods of time the differences in the energy used and the cost becomes evident.

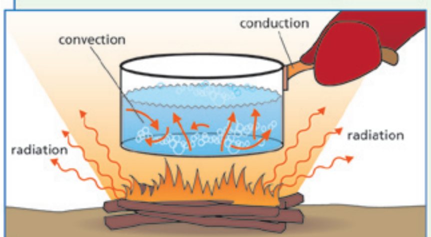
Heat Transfer

In this chapter, you have been looking at **heat transfer**. You saw that when there is a difference in temperature between two substances that are in contact, heat is always transferred between them. You also read that the second law of thermodynamics states that the transfer will always take place from the warmer body to the cooler one.

Physics Words

heat transfer: the transmission of heat energy from a warmer substance to a cooler substance.

Section 9 Comparing Energy Consumption: More for Your Money



You may have studied in previous science classes the three ways that heat can be transferred: **conduction, convection,** and **radiation.**

In the case of conduction, the thermal energy of a material is transferred to another material by direct contact of the materials with one another. In your investigation, the rapidly moving (and hence high energy) atoms in the heating coil came in direct contact with the cold water. The thermal energy of the coil's atoms was conducted by physical contact directly to the water molecules. In turn, energy from these molecules was transferred to adjacent molecules, and so on. In this way, the heat was dissipated throughout the water, warming it in the process. Conduction always requires direct contact.

Once the water near the coil became hotter than the other water, the water began circulating. The hot water moved up and away from the coil and cold water came in contact with the coil. These are convection currents in the water. Convection is another means of transmitting thermal energy. In convection, the molecules or atoms of a fluid (a liquid or a gas) that have more thermal energy will move faster than the surrounding molecules of that material. As a result, they will move farther apart and, therefore, become pushed by the colder, more closely packed molecules or atoms. As the hotter molecules spread out through the colder surrounding material, they carry their thermal energy (motion) with them, losing it along their path to other colder molecules by conduction. Convection then, is the transmission of heat from one place to another due to physical movement of a warmer fluid through a colder fluid.

When heating the water in the microwave oven, microwaves moved through the oven and were absorbed by the water molecules. This increase in kinetic energy of the water molecules resulted in an increased temperature of the water. Some people make sun-tea by placing cold water in a glass jar with tea bags. Placing the jar in direct sunlight for a few hours will make the tea. The radiation from the Sun is used to heat the water. Radiation is the third form of energy transmission. In radiation, the electromagnetic radiation given off by high-energy (hot) materials can be transmitted through objects, or even a vacuum, at the speed of light. When this energy strikes a material that can absorb it, the radiant energy causes the atoms or molecules of the material it strikes to move faster and the molecules now have more heat.

Physics Words

conduction: the transfer of heat energy from particle to particle between substances through contact or within a substance.

convection: the transfer of heat energy through the movement of air or liquid currents.

radiation: the transfer of heat energy by emission of electromagnetic radiation in all directions.

Checking Up

1. What unit does the power company use to charge consumers for energy?
2. If a student leaves a 100-W light bulb on in his room for 1 h, how many kilowatt-hours of electricity does the bulb use? If the power company charges $0.18 per kilowatt-hour, how much will it cost to leave the light bulb on for this amount of time?
3. List two places where you could look to see how much electrical energy your family has used in the previous month.
4. What is the name given to heat transfer when objects are heated by direct contact? By currents flowing through a fluid? By electromagnetic waves?
5. When objects are heated by contact, what happens to the kinetic energy of the cold molecules in contact with the hot heating coil?
6. What happens to the distance between molecules in a fluid as their temperature increases?

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Active Physics

6-9a **Blackline Master**

Checking Up

1.

The power company charges energy consumption by the kilowatt hour (kW·h).

2.

If a 100-W bulb is used for 1 h, then

$E = Pt = (100\ \text{W})(1\ \text{h}) =$

$100\ \text{W} \cdot \text{h} = 0.1\ \text{kW} \cdot \text{h}$

If the power company charges $0.18 per kilowatt-hour, then the cost for using the light bulb for an hour is

$$\text{Cost} = (0.1\ \text{kW} \cdot \text{h})\left(\frac{\$0.18}{\text{kW} \cdot \text{h}}\right) =$$

$\$0.018 \approx \$0.02$

3.

Two places students could mention are the electrical meter and the electric bill.

4.

Heat energy transfers that require direct contact are heat energy transfers by conduction. Heat-energy transfers that occur by flowing fluids (liquids or gases) are heat-energy transfers by convection. Heat-energy transfers that occur by electromagnetic waves are heat-energy transfers by radiation.

5.

When objects are heated by contact, the warmer molecules collide with the cooler molecules, increase their kinetic energy, and therefore their temperature.

6.

Molecules in a fluid being warmed tend to move further apart as they are warmed, decreasing their density. This makes it easier for the more closely packed, cooler molecules to push them up and out of the way.

CHAPTER 6

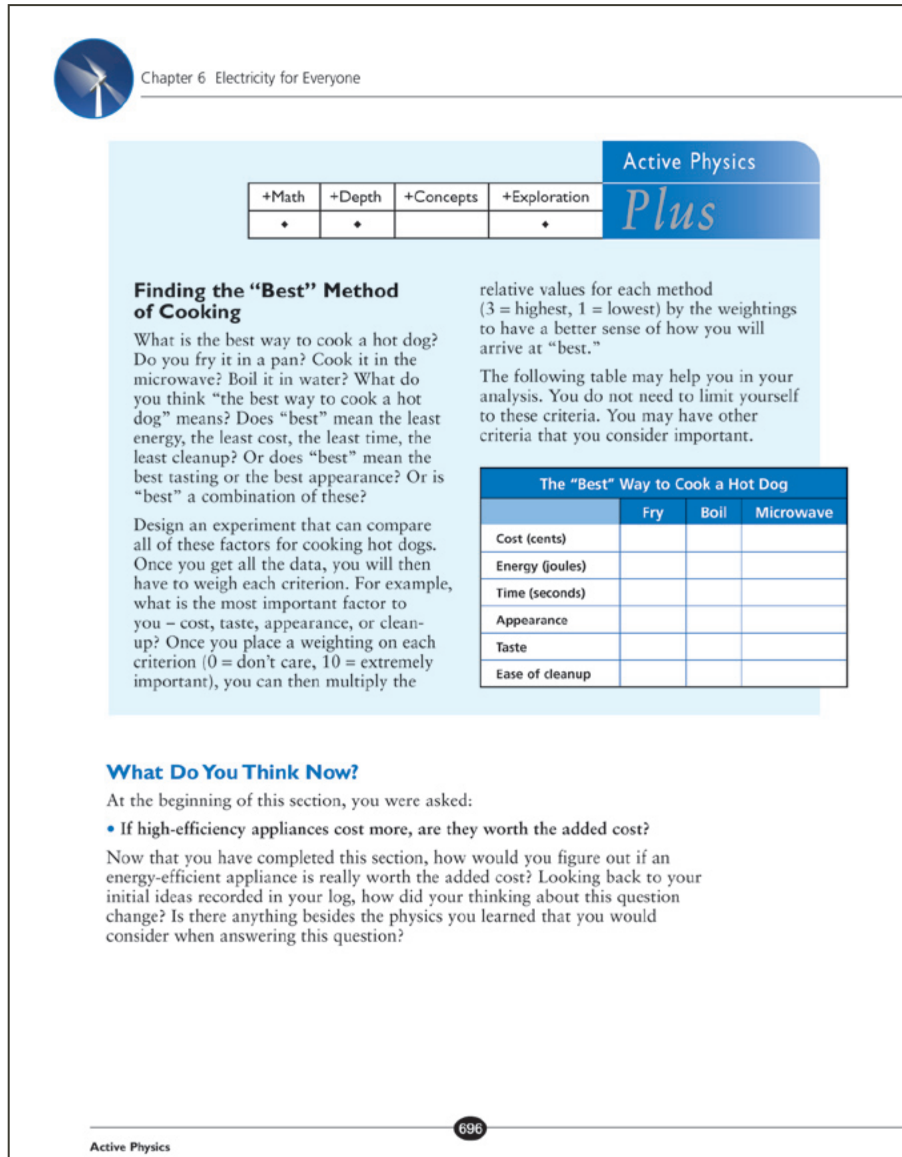
Active Physics Plus

This *Active Physics Plus* provides an opportunity for students to deepen their understanding of the concept of energy consumption and efficient appliances as they consider what makes the appliance efficient (just energy usage, cost, or some other factor).

Students should design an experiment to compare what they consider important factors in how to best cook a hot dog. They should compare frying, boiling, and microwaving the hot dog based on the factors they deem important to come up with the best method.

What Do You Think Now?

Remind students that it is important to be both energy-efficient and cost-efficient when designing their HFE appliance design and warm water might be part of that design. Then describe how consumers currently can purchase hot-water heaters and furnaces for homes that are more than 90% efficient. Ask students to review their previous answers to the question and what they would consider besides the physics presented in this section when answering this question. Consider discussing the information in *A Physicist's Response*.



Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
•	•		•

Finding the "Best" Method of Cooking

What is the best way to cook a hot dog? Do you fry it in a pan? Cook it in the microwave? Boil it in water? What do you think "the best way to cook a hot dog" means? Does "best" mean the least energy, the least cost, the least time, the least cleanup? Or does "best" mean the best tasting or the best appearance? Or is "best" a combination of these?

Design an experiment that can compare all of these factors for cooking hot dogs. Once you get all the data, you will then have to weigh each criterion. For example, what is the most important factor to you – cost, taste, appearance, or clean-up? Once you place a weighting on each criterion (0 = don't care, 10 = extremely important), you can then multiply the relative values for each method (3 = highest, 1 = lowest) by the weightings to have a better sense of how you will arrive at "best."

The following table may help you in your analysis. You do not need to limit yourself to these criteria. You may have other criteria that you consider important.

The "Best" Way to Cook a Hot Dog

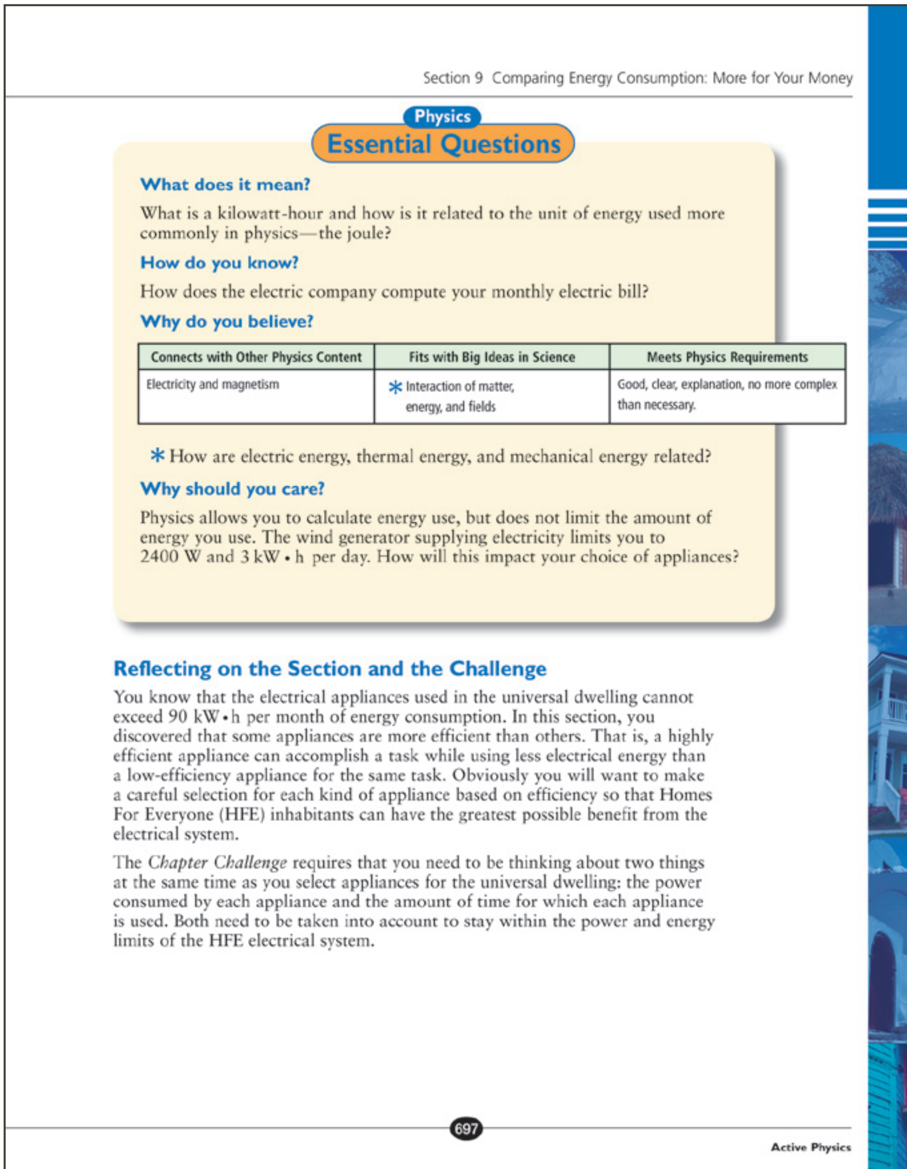
	Fry	Boil	Microwave
Cost (cents)			
Energy (joules)			
Time (seconds)			
Appearance			
Taste			
Ease of cleanup			

What Do You Think Now?

At the beginning of this section, you were asked:

- **If high-efficiency appliances cost more, are they worth the added cost?**

Now that you have completed this section, how would you figure out if an energy-efficient appliance is really worth the added cost? Looking back to your initial ideas recorded in your log, how did your thinking about this question change? Is there anything besides the physics you learned that you would consider when answering this question?



Physics
Essential Questions

What does it mean?

What is a kilowatt-hour and how is it related to the unit of energy used more commonly in physics—the joule?

How do you know?

How does the electric company compute your monthly electric bill?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Electricity and magnetism	* Interaction of matter, energy, and fields	Good, clear, explanation, no more complex than necessary.

* How are electric energy, thermal energy, and mechanical energy related?

Why should you care?

Physics allows you to calculate energy use, but does not limit the amount of energy you use. The wind generator supplying electricity limits you to 2400 W and 3 kW • h per day. How will this impact your choice of appliances?

Reflecting on the Section and the Challenge

You know that the electrical appliances used in the universal dwelling cannot exceed 90 kW • h per month of energy consumption. In this section, you discovered that some appliances are more efficient than others. That is, a highly efficient appliance can accomplish a task while using less electrical energy than a low-efficiency appliance for the same task. Obviously you will want to make a careful selection for each kind of appliance based on efficiency so that Homes For Everyone (HFE) inhabitants can have the greatest possible benefit from the electrical system.

The *Chapter Challenge* requires that you need to be thinking about two things at the same time as you select appliances for the universal dwelling: the power consumed by each appliance and the amount of time for which each appliance is used. Both need to be taken into account to stay within the power and energy limits of the HFE electrical system.

Reflecting on the Section and the Challenge

Using the information in the student text, discuss how the criteria that the energy consumed by each HFE dwelling cannot exceed 90 kW·h per month and 3 kW·h per day. Then emphasize that students will need to think about the following two things when deciding on their appliance package:

- the power consumed by each appliance, and
- the time the appliance is used.

Physics Essential Questions

What does it mean?

A kilowatt-hour is a unit of energy. Because power is measured in watts and one watt is equal to one joule/second, it can be seen that multiplying the power (in watts) by the time will yield energy. Because you use so much electricity, rather than measuring the power in watts and the time in seconds, you measure the power in kilowatts and the time in hours. One kilowatt-hour is equivalent to 3,600,000 J.

How do you know?

The electrical company installs a meter for each dwelling that measures the energy used in kilowatt-hours.

Why do you believe?

Electrical energy is related to voltage and current. Thermal energy is related to changes in temperature. Mechanical energy is related to the movement of objects. These energies can be transformed from one type to another and transferred between objects, for example the use of a hand generator in lighting a bulb. The total energy is always conserved.

Why should you care?

The total energy generated by the wind generator limits the total energy that is available for appliances. In viewing the energy needs of appliances, you quickly recognize how limited 3 kilowatt-hours is in comparison to how much energy you use every day.

Physics to Go

1.a)

The energy used can be calculated as follows:

$$E = Pt$$

$$(1500\ \text{W})(3\ \text{min})\left(\frac{60\ \text{s}}{1\ \text{min}}\right) =$$

$$270{,}000\ \text{J} = 270\ \text{kJ}$$

1.b)

$$E = Pt =$$

$$(1200\ \text{W})(4\ \text{min})\left(\frac{60\ \text{s}}{1\ \text{min}}\right) =$$

$$288{,}000\ \text{J} = 288\ \text{kJ}$$

2.

If both hair dryers in *Question 1* result in the same dryness of hair, then the hair dryer using less energy is more efficient. The hair dryer using less energy is the 1500-W hair dryer. Although its power rating is higher, it does not need to be used for as long a time, resulting in lower energy consumption.

3.a) and b)

$$E = Pt = (1200\ \text{W})\times$$

$$\left(\frac{1\ \text{hour}}{60\ \text{min}}\right)\left(\frac{30\ \text{min}}{1\ \text{day}}\right)\left(\frac{30\ \text{day}}{1\ \text{month}}\right) =$$

$$18{,}000\ \frac{\text{W}\cdot\text{h}}{\text{month}} = 18\ \frac{\text{kW}\cdot\text{h}}{\text{month}}$$

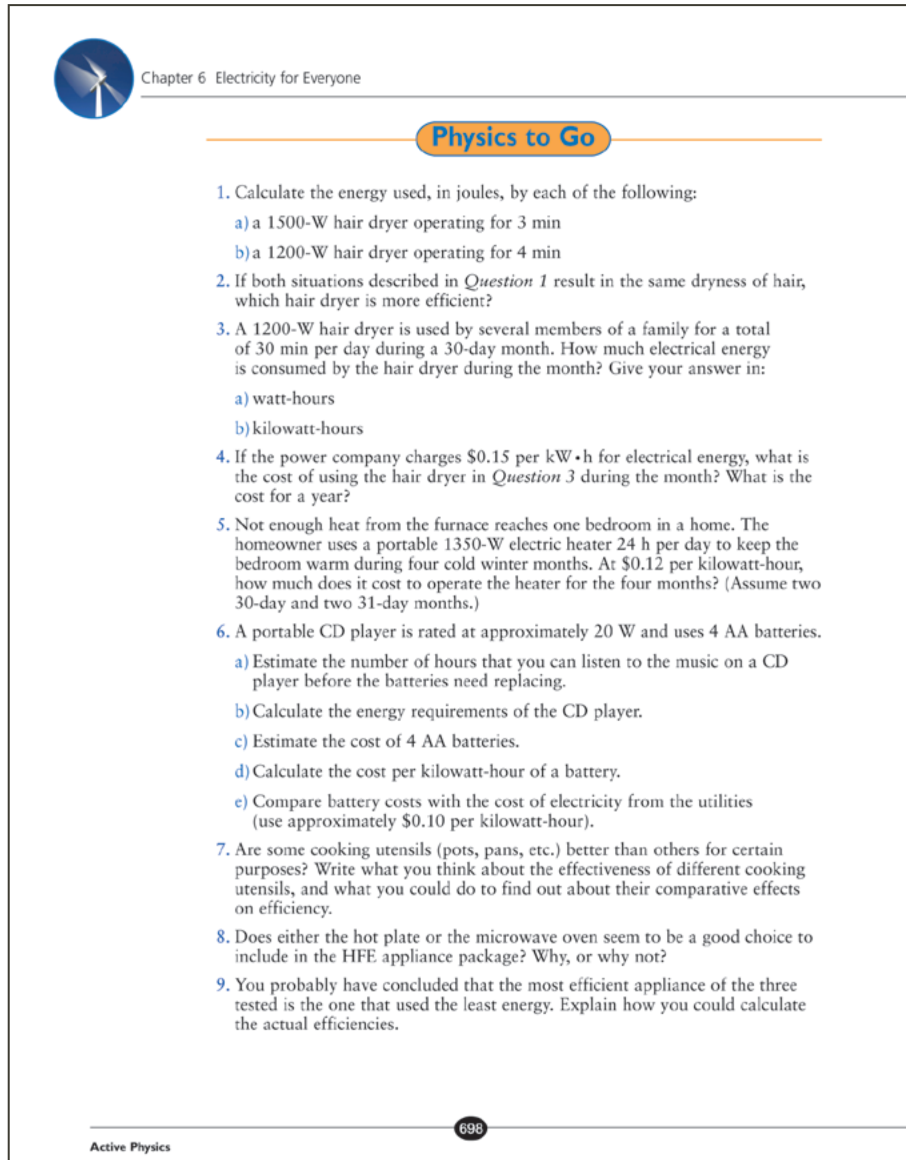
4.

Using the result of *Question 3*, the cost of the hair dryer is

$$\text{Cost}_{\text{per month}} =$$

$$\left(18\ \frac{\text{kW}\cdot\text{h}}{\text{month}}\right)\left(\frac{\$0.15}{\text{kW}\cdot\text{h}}\right) =$$

$$\frac{\$2.7}{\text{month}} \approx \frac{\$3}{\text{month}}$$


Chapter 6 Electricity for Everyone

Physics to Go

1. Calculate the energy used, in joules, by each of the following:
   a) a 1500-W hair dryer operating for 3 min
   b) a 1200-W hair dryer operating for 4 min
2. If both situations described in *Question 1* result in the same dryness of hair, which hair dryer is more efficient?
3. A 1200-W hair dryer is used by several members of a family for a total of 30 min per day during a 30-day month. How much electrical energy is consumed by the hair dryer during the month? Give your answer in:
   a) watt-hours
   b) kilowatt-hours
4. If the power company charges $0.15 per kW • h for electrical energy, what is the cost of using the hair dryer in *Question 3* during the month? What is the cost for a year?
5. Not enough heat from the furnace reaches one bedroom in a home. The homeowner uses a portable 1350-W electric heater 24 h per day to keep the bedroom warm during four cold winter months. At $0.12 per kilowatt-hour, how much does it cost to operate the heater for the four months? (Assume two 30-day and two 31-day months.)
6. A portable CD player is rated at approximately 20 W and uses 4 AA batteries.
   a) Estimate the number of hours that you can listen to the music on a CD player before the batteries need replacing.
   b) Calculate the energy requirements of the CD player.
   c) Estimate the cost of 4 AA batteries.
   d) Calculate the cost per kilowatt-hour of a battery.
   e) Compare battery costs with the cost of electricity from the utilities (use approximately $0.10 per kilowatt-hour).
7. Are some cooking utensils (pots, pans, etc.) better than others for certain purposes? Write what you think about the effectiveness of different cooking utensils, and what you could do to find out about their comparative effects on efficiency.
8. Does either the hot plate or the microwave oven seem to be a good choice to include in the HFE appliance package? Why, or why not?
9. You probably have concluded that the most efficient appliance of the three tested is the one that used the least energy. Explain how you could calculate the actual efficiencies.

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Active Physics

5.

Students should first calculate the energy consumed over the four-month period and then the cost.

Given:
$P = 1350$ W; $t = 24$ h/day
cost = \$0.12/kW · h

$E_{\text{per day}} = Pt =$
$(1350 \text{ W})(24 \text{ h/day}) =$
$32{,}400 \dfrac{\text{W}\cdot\text{h}}{\text{day}} = 32.4 \dfrac{\text{kW}\cdot\text{h}}{\text{day}}$
$E_{\text{4 months}} =$
$32.4 \dfrac{\text{kW}\cdot\text{h}}{\text{day}} \times 122 \text{ days} =$
$3952.8 \text{ kW}\cdot\text{h}$
$\text{Cost}_{\text{4 months}} =$
$(3952.8 \text{ kW}\cdot\text{h})(\$0.12 \text{ /kW}\cdot\text{h}) =$
\$474.3

6.a)

Students should estimate the number of hours by determining how much energy is available using the batteries. Students do not have enough information to determine the time. They will need to estimate it based on their experiences. Theoretically, an AA battery has about 15,390 J of energy stored in it. Because four of these batteries are being used, the amount of energy available is approximately 61,560 J. Using this information one can estimate the time. Students should have time estimates between 50 and 60 minutes.

6.b)

Students should use the relationship between energy consumption and power. They should note that the power is the energy supplied per second or 20 J/s.

From their time estimate they should be able to calculate an estimated energy consumption of the CD player using the equation $E = Pt$.

6.c)

Students should estimate the current cost for the batteries. They may include the extra costs involved such as fuel cost to travel to and from the store, or shipping costs.

6.d)

Students should calculate the cost of one battery by using the following relationship:

$$\text{cost}_{\text{per kW}\cdot\text{h}} = \frac{(\text{Cost of one battery})}{\begin{pmatrix}\text{Energy consumed by}\\ \text{CD player in kW}\cdot\text{h}\end{pmatrix}}$$

6.e)

Students should calculate how much the energy consumption would cost if the CD player used the energy provided by the power company versus the cost of using four AA batteries.

7.

Cooking pots and pans are designed to evenly spread heat; however, they may spread this heat differently. In a wok the heat is very high at the bottom of the pan, and sides near the bottom. Woks are designed to cook at very high temperatures for short amounts of time. This design helps the cook to move the food away from the high heat quickly. Griddles are designed to keep an even heat over a large, flat surface, perfect for making pancakes. No heat is needed through the sides.

Pots and pans are designed to transfer heat quickly, that is why most are metal. Some dishes use stone, clay, or glass to cook in. These materials have a higher specific heat than the metal pots and pans and cook more evenly. They also keep food warmer longer because they absorb much more heat energy that transfers slowly after the food is taken out of the oven or off the cooking range.

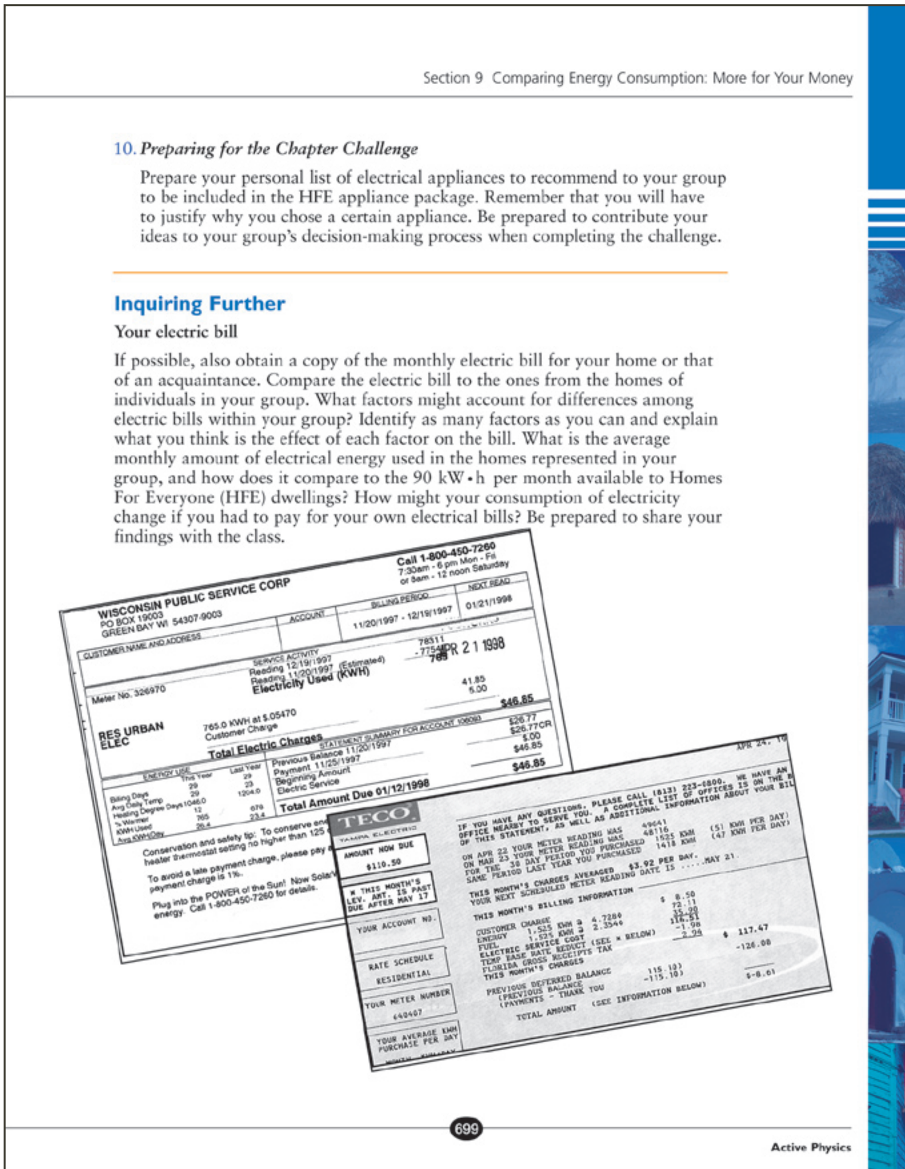
8.

Students should state whether or not the hot plate or microwave are good choices for the HFE appliance package, along with their reasoning.

9.

Students should describe that testing the actual efficiencies of the appliances requires not just measuring their energy efficiency, but their efficiency for cost, time, appearance, ease of use, maintenance, and the end results (e.g., how the food is). Students should describe how the efficiency could be calculated. An example is provided in the *Active Physics Plus*.

NOTES



10. *Preparing for the Chapter Challenge*

Prepare your personal list of electrical appliances to recommend to your group to be included in the HFE appliance package. Remember that you will have to justify why you chose a certain appliance. Be prepared to contribute your ideas to your group's decision-making process when completing the challenge.

Inquiring Further

Your electric bill

If possible, also obtain a copy of the monthly electric bill for your home or that of an acquaintance. Compare the electric bill to the ones from the homes of individuals in your group. What factors might account for differences among electric bills within your group? Identify as many factors as you can and explain what you think is the effect of each factor on the bill. What is the average monthly amount of electrical energy used in the homes represented in your group, and how does it compare to the 90 kW•h per month available to Homes For Everyone (HFE) dwellings? How might your consumption of electricity change if you had to pay for your own electrical bills? Be prepared to share your findings with the class.

10.

Preparing for the Chapter Challenge

Students should record a list of electrical appliances they will recommend to their group members for the HFE appliance package. Students should also record their reasoning for selecting each appliance.

Inquiring Further

Students should obtain an electric bill and compare it with electric bills brought in by group members. They should describe the factors that might affect the differences in the bills and how these might affect the bill. They should calculate the average monthly amount of electrical energy used in the homes represented in the group and compare this to the 90 kW·h per month available to the HFE dwellings. Students should also describe how their energy consumption might change if they had to pay their own electric bills.

SECTION 9 QUIZ

6-9b **Blackline Master**

1. A student forgets to turn off the 100-W light bulb in her room when she leaves for school in the morning. She returns 10 hours later (36,000 seconds) and turns off the light. If electricity costs 15 cents per kW·h, how much did it cost to leave on the 100-W light bulb for this amount of time?

   a) 15 cents
   b) 85 cents
   c) $1.50
   d) $5.00

2. A microwave oven that is rated at 960 W runs on 120 V. How much current does the oven use?

   a) 6 A
   b) 8 A
   c) 9.6 A
   d) 15 A

3. When heat energy is transferred by contact between two objects it is referred to as

   a) conduction.
   b) convection.
   c) radiation.
   d) transmission.

4. On a summer day, birds can often be seen soaring over an automobile parking lot riding the warm air currents that are rising from the heated surface. This process transfers heat from the surface to the clouds by a process called

   a) conduction.
   b) convection.
   c) radiation.
   d) transmission.

5. How much energy does a TV that operates on 120 V and draws 0.6 A of current use if it is on for 2 hours?

   a) 144 J
   b) 144,000 J
   c) 72,000 J
   d) 518,400 J

SECTION 9 QUIZ ANSWERS

1. a) $E = Pt = (100\text{ W})(10\text{ h}) = 1000\text{ W}\cdot\text{h} = 1\text{ kW}\cdot\text{h}$
   $\text{Cost} = 1\text{ kW}\cdot\text{h}(15\text{ cents/kW}\cdot\text{h}) = 15\text{ cents}$

2. b) $I = P/V = (960\text{ W})/(120\text{ V}) = 8\text{ A}$

3. a) Convection requires a fluid (gas or liquid), and radiation does not require contact. Heat transferred by conduction occurs when objects of different temperature are in contact with each other and heat energy is transferred from particle to particle. This occurs within a substance or between two substances.

4. b) Heat energy transferred by convection occurs through the movement of a fluid (gas or liquid).

5. d) $E = Pt = VIt = (120\text{ V})(0.6\text{ A})(2\text{ h})(3600\text{ s/h}) = 518,400\text{ J}$