Section 8 Energy Consumption: Cold Shower

What Do You See?

Learning Outcomes

In this section, you will

- **Calculate** the heat gained by a sample of water.
- **Calculate** the electrical energy converted into heat by a resistor.
- **Calculate** the efficiency of a transformation of electrical energy to heat.
- **Explore** the power ratings and energy consumption levels of a variety of electrical appliances.

TECH LAB

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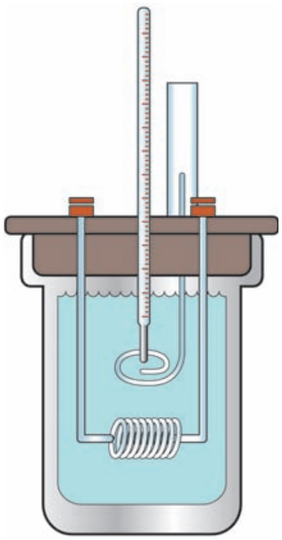
What Do You Think?

The entire daily energy output of a Homes For Everyone (HFE) generator would not be enough to heat water for an average American family for a day.

- **If an electrical heating coil (a type of resistor) were submerged in a container of water, and if a current were to flow through the coil to make it hot, what factors would affect the temperature increase of the water?**

Identify as many factors as you can, and predict the effect of each on the water temperature. 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

1. Assemble and use an electric calorimeter according to the directions given by your teacher.

   Alternatively, your teacher may provide you with a heating coil and two nested styrene-foam cups. If a cover could be created for the styrene-foam cups, it will improve the data you can collect.

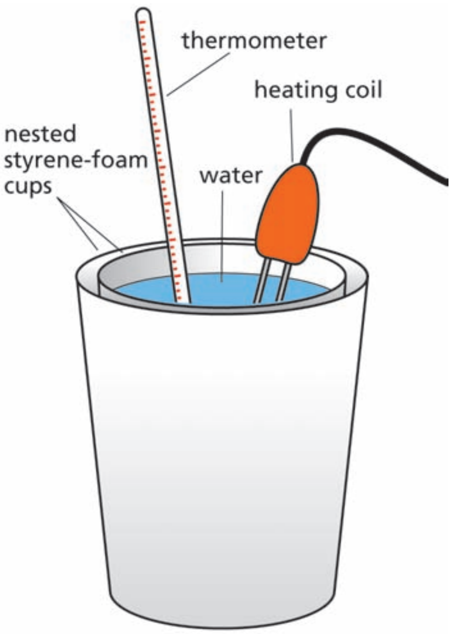
If a heating coil is used, you must be sure to never have the heating coil plugged in if the coil is out of the water. This requires you to place the coil in the water and then plug it in. You can then unplug the coil and remove it from the water. If the coil is plugged in while it is out of the water, it will be permanently broken in a very short time.

Add a measured amount of cold tap water to the calorimeter.

a) Record the mass of the water. (You will need to find the mass of an empty container, as well as the mass of the container plus the measured amount of water.)

b) Measure and record the beginning temperature of the water.

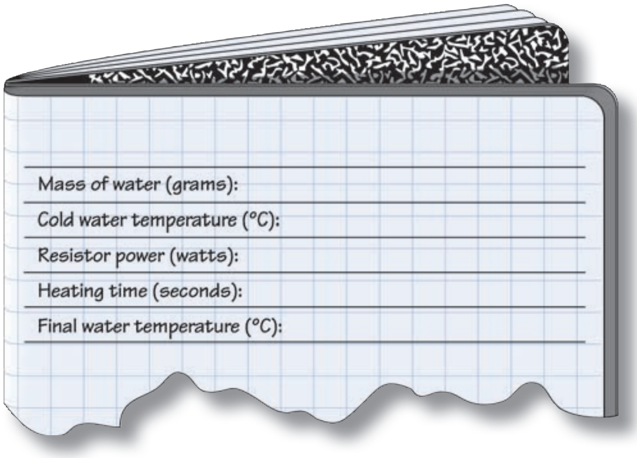
c) Record the watt rating of the resistor that will be used to heat the water. (The watt rating is often written on the appliance.)



2. Note the time at which you begin sending electric current through the resistor. Keep the electric heater operating for the amount of time recommended by your teacher.

When you stop the current, note the time, stir the water, and measure the final, maximum temperature of the water.

a) In your log, record the final water temperature (°C) and the heating time (seconds).



Always make sure the coil (or heater) is completely submerged in the water.

Promptly dry up any spilled water.

Do not try to stir the water with the thermometer. If the thermometer should break, immediately notify your instructor.

3. Recall that the heat gained by an object can be found using the equation:

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

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, and

ΔT is the change in temperature in degrees Celsius.

Use the equation to calculate the heat gained by the water in the calorimeter. The specific heat of water is 4.18 J/g°C.

a) Show your calculation in your log.

4. Recall also that power rating, in watts, is expressed as the amount of energy, in joules, that something consumes per unit of time. Mathematically, power is expressed as

$$P = \frac{E}{t} \text{ so } E = Pt$$

where E is energy in joules (watt-seconds),
P is power in watts (joules/second),
t is time in seconds.

Energy can be expressed in watt-seconds (otherwise known as a joule).

The energy calculated from the temperature change of the water should be equal to the energy calculated from the power rating of the appliance and the time.

a) Compare these two values for the heat gained by the water. If the values are not the same, you cannot conclude that the conservation of energy principle is wrong. Rather, you have to assume that the electrical energy was not all used to heat the water.

b) Where could the "lost" energy have gone?

5. If all of the electrical energy used did not go into heat in the water, then you know your system for heating water is less than 100% efficient. Calculate the efficiency of your water-heating device.

If the appliance were 100% efficient, all of the electrical energy would have heated the water; if the appliance were 50% efficient, only half of the electrical energy would have heated the water.

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%$$

a) Record your calculations in your log.

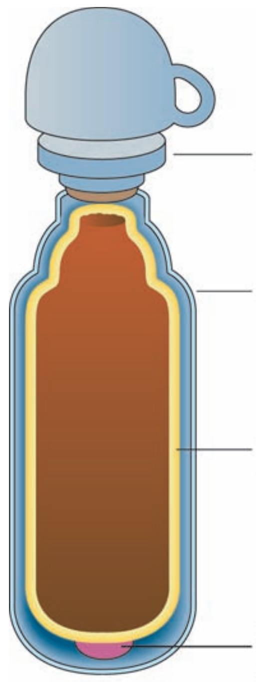
Physics Talk

ENERGY CONSUMPTION

Electric power companies usually charge for the energy used in units of "kilowatt-hours," where a kilowatt, or 1000 W (watts), is the power that would be used, for example, by placing ten 100-W light bulbs in parallel. If you left these ten light bulbs on for one hour, the amount of energy that would be used would be

$$\begin{aligned} \text{1 kilowatt-hour of energy} &= \text{power} \times \text{time} \\ &= 1000 \text{ W} \times 1 \text{ h} \\ &= 1000 \text{ W} \times 3600 \text{ s} \\ &= 3{,}600{,}000 \text{ J} \end{aligned}$$

A joule is a much smaller quantity of energy than a kilowatt-hour and would be the equivalent of having a 1-W bulb on for 1 s. That is, one joule equals one watt-second.



What is the world's greatest invention? A comedian once replied: "The thermos. When you put a cold drink in it, it stays cold. When you put a hot drink in it, it stays hot. How does the thermos know?"

A cup of hot water left on a table cools down. A cup of cold water left on the same table warms up. How can you change the temperature or keep the temperature constant?

Heat is a transfer of thermal energy. Energy in one form must come from energy in another form. Energy must be conserved. If you wish to heat up water, you must supply it with a source of energy like a flame, an electrical heater, or a hot metal.

If a system is isolated from outside sources of energy, one part of the system may warm up and another part may cool down, but the total energy must remain constant. In this *Investigate*, you calculated the electrical energy that was used to heat the water. Thermal energy, like all forms of energy, is measured in units of joules (J). You used the following equation.

Change in heat
= mass of object × specific heat of material × temperature change

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

where ΔQ is a measure of change in heat in joules,
m is the mass of the substance in grams,
c is the specific heat of the substance, and
ΔT is the change in temperature in degrees Celsius.

Energy used to heat the object can also be calculated using the following equation:

Since energy = power × time
and power = voltage × current
then, energy = voltage × current × time

$$E = VIt$$

where E is the energy in joules (J),
V is the voltage in volts (V),
I is the current in amperes (A), and
t is the time in seconds (s).

Sample Problem

A 12-V starter battery in a car supplies 48 A of current to the starter. If the starter draws energy for 15 s, how much energy does the starter use?

Strategy: You can use the equation to calculate energy.

Given:

$V = 12\text{ V}$

$I = 48\text{ A}$

$t = 15\text{ s}$

Solution:

$$
\begin{aligned}
E &= VIt \\
&= (12\text{ V})(48\text{ A})(15\text{ s}) \\
&= \left(12\ \frac{\text{J}}{\cancel{\text{C}}}\right)\left(48\ \frac{\cancel{\text{C}}}{\cancel{\text{s}}}\right)(15\ \cancel{\text{s}}) \\
&= 8640\text{ J (or about 8600 J)}
\end{aligned}
$$

Recall that voltage was energy per unit of charge, and current is unit of charge per second. Multiplying these two will produce energy per second, the unit of power. Multiplying this by seconds gives you units of energy, in this case joules.

Efficiency

In the *Investigate*, you would expect that the heat energy you calculated from the temperature change of the water should be equal to the electrical energy you calculated from the power rating of the heater. The law of conservation of energy states that energy cannot be created or destroyed. However, when you compared the two values, you found that they were not equal. You calculated the efficiency of this transfer of energy using the following equation.

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%$$

The efficiency you calculated was probably less than 100%. Therefore, you realized that some energy must have been "lost." You should expect this loss because energy is lost from the system and is transferred to the surrounding environment. Thermal energy may have escaped as heat through the insulation of the cup or calorimeter or the top of the water surface of the cup. Some of the energy could have been transferred to the thermometer and the resistor may still have been warm when you removed it from the cup. This is the case any time energy is transferred. Some of the energy is transformed into forms of energy that are not useful at the moment.

Checking Up

1. How is the energy used by a light bulb related to the power of the light bulb? What equation would you use to determine the energy used?
2. What units do physicists use to measure heat energy and electrical energy?
3. What equation could you use to calculate energy used by an appliance if you knew the voltage, current, and time during which the current flows?
4. How is the percentage efficiency of an energy transformation calculated?

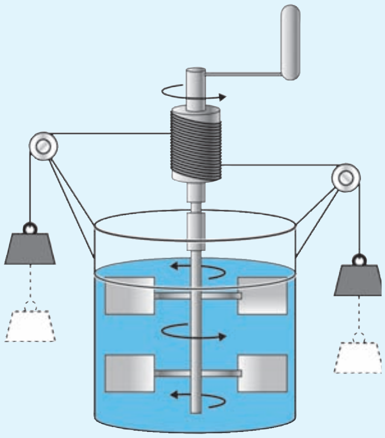
Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
◆◆	◆	◆◆	

Mechanical Equivalent of Heat

In this section, you were able to find the relationship between electrical energy and thermal energy. By stirring water, you can also increase its temperature. By measuring the amount of work that is done by stirring, you can find the mathematical relationship between mechanical work and heat.

The experiment was first performed by Sir James Joule. (Yes, the joule was named after him.) In his experiment, he had two weights fall to the ground. As they fell, they turned paddles that were immersed in water. He then measured the change in the temperature of the water. By calculating the change in energy of the falling weights and the increase in temperature of the water, Joule calculated the mechanical equivalent of heat.



The change in gravitational energy is equal to

$$m_f g \Delta h$$

where m_f is the mass of the falling object,

g is the acceleration of the object due to gravity in meters per second squared, and

Δh is the change in height in meters.

The change in thermal energy is equal to

$$m_w c \Delta T$$

where m_w is the mass of the water in grams,

c is the specific heat of the water,

ΔT is the change in temperature in degrees Celsius.

Joule found that 4.18 J of work were required to raise the temperature of 1 g of water 1°C.

1. In a fitness center, an athlete may be able to lift 20 kg from the floor to her waist (a distance of 1 m) over and over again every second.
   a) Calculate the change in gravitational potential energy ($mg\Delta h$) every time she lifts the 20 kg. (Assume that $g = 10 \text{ m/s}^2$.)
   b) Someone has a clever idea. Why not have the energy that the athlete is expending be used for heating up water for coffee? How much energy is required to heat 1 cup of water (250 g) from 20°C to 100°C?
   c) How many seconds would the athlete have to lift weights to produce the energy required to heat up the water for a cup of coffee?
2. Chemical energy in your food can be measured in joules. In the United States, people are accustomed to the energy in food being measured in calories. One food calorie is written as 1 C and is equivalent to 4185 J. Since many humans eat 2000 C a day, this is a staggering amount of energy. Where does it all go?
   a) Using the fitness center example, calculate the total energy expended if the athlete were to lift the weights for a one-hour workout without any rest whatsoever.
   b) What percentage of her 2000 C of food was used in lifting the weights.
   c) Where do you think the rest of the consumed energy goes?
3. A cup of hot coffee will eventually cool off until it reaches room temperature. If you wanted to keep the coffee warm, you would have to keep providing some energy transfer to the coffee. This is often done with heat from a hot plate or an electrical heating coil that you used in the investigation. The human body must stay at approximately 98.6°F. A change in body temperature of just 10°F will kill a person. A 110-lb person has a mass of approximately 50 kg.
   a) Devise a way to find out how much energy is required to keep this 50-kg person at 98.6°F (37°C), when they are in a room that is 20°C.
   b) What percentage of that person's 2000 C of food would be used to maintain body temperature?

What Do You Think Now?

At the beginning of this section, you were asked:

- **If an electrical heating coil (a type of resistor) were submerged in a container of water, and if a current were to flow through the coil to make it hot, what factors would affect the temperature increase of the water?**

Having completed this section and the previous section, identify as many factors as you can, and predict the effect of each on the water temperature.

Physics

Essential Questions

What does it mean?

Electrical appliances are rated in watts and energy is measured in joules. Utility companies calculate total energy use in kilowatt-hours. How can a utility company calculate the energy use in joules or kilowatt-hours if they know the power in watts of an appliance and the time that the appliance is used?

How do you know?

Electrical energy can be used to increase the temperature of a clothing iron and a cup of water, or decrease the temperature of items in a refrigerator or a room with an air conditioner. How can you measure the electrical energy used to heat water?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Electricity and magnetism	* Conservation laws	Good, clear, explanation, no more complex than necessary.

* Energy conservation is a guiding organizing principle of all science. Describe and give a specific example of energy transfer that includes electrical energy, thermal energy and mechanical energy.

Why should you care?

Each appliance in your Homes For Everyone (HFE) package is going to require a certain amount of energy. The wind generator has an upper energy limit. How can this limited energy be used to maximum advantage to enhance the well being of the people?

Reflecting on the Section and the Challenge

In this section, your knowledge of how to calculate electric power consumption was extended to include how to calculate electric energy consumption. You also learned that heating water electrically requires a lot of energy and can be quite inefficient. All of this knowledge applies directly to the selections you will make for your HFE appliance package.

Physics to Go

1. The calorimeter did not allow the water to trap 100% of the energy delivered to it by the resistor. Some of the heat probably escaped from the water. Identify and explain ways in which you think heat may have escaped from the water, reducing the efficiency of the calorimeter.

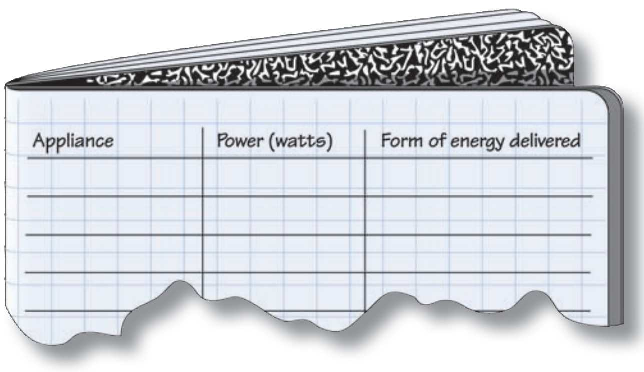
2. The calorimeter used in this investigation can be thought of as a scaled-down, crude version of a household hot-water heater. The efficiencies of hot-water heaters used in homes range from about 80% for older models to as much as 92% for new, energy-efficient models. Identify and explain ways in which you think heat escapes from household hot-water heaters, and how you could improve the efficiency of the heater.

3. From what you have learned so far, discuss the possibilities for providing electrically heated water for Homes For Everyone (HFE). Is a standard water heater of the kind used in American homes desirable, or possible, for HFE? What other electrical options exist for accomplishing part or all of the task of heating water for HFE?

4. For most Americans, the second biggest energy user in the home, next to the heating/air-conditioning system, is the water heater. A family of four that heats water electrically (some use gas or oil to heat water) typically spends about $35 per month using a 4500-W heater to keep a 160-L (40 gallon) tank of water hot at all times. The water is raised from an average inlet temperature of 10°C (50°F) to a temperature of 60°C (140°F), and the average family uses about 250 L (60 gallons) of hot water per day for bathing and washing clothes and dishes.

   In the above description, explain what each of the following numbers represents: 35, 4500, 160, 40, 10, 50, 60, 140, 250, 60.

5. Electrical appliances are designed to convert electrical energy into some other form of energy. Choose five appliances from the list of Home Electrical Appliances beginning on the next page that have a wide range of power. In your log, make a list like the one shown.



Home Electrical Appliances

Average Power and Average Monthly Energy Use for a Family of Four

Family Data

	Power (watts)	Energy/month (kWh/month)
Big Appliances		
Air Conditioner		
(Room)	1360	
(Central)	3540	
Clothes Washer	512	
Clothes Dryer	5000	
Dehumidifier	645	
Dishwasher	1200	
Freezer	400	
Humidifier	177	
Pool Filter	1000	
Kitchen Range	12,400	
Refrigerator	795	
Space Heater	1500	
Waterbed	350	
Water Heater	4500	
Small Refrigerator	300	
Lights & Minor Appliances (combined)		
Kitchen		
Baby Food Warmer	165	
Blender	300	
Broiler (portable)	1200	
Can Opener	100	
Coffee Maker		
Drip	1100	
Percolator	600	
Corn Popper		
Oil-type	575	
Hot Air-type	1400	
Deep Fryer	1500	
Food Processor	370	
Frying Pan	1200	
Garbage Disposal	445	
Sandwich Grill	1200	
Hot Plate	1200	
Microwave Oven	750	
Mixer	150	

Home Electrical Appliances

	Power (watts)	Energy/month (kWh/month)
Roaster	1400	
Rotisserie	1400	
Slow Cooker	200	
Toaster	1100	
Toaster Oven	1500	
Trash Compactor	400	
Waffle Iron	1200	
Entertainment		
Computer	60	
Radio	70	
Television	90	
Stereo	125	
VCR	50	
Personal Care		
Air Cleaner	50	
Curling Iron	40	
Hair Dryer	1200	
Hair Rollers	350	
Heat Blanket	170	
Heat Lamp	250	
Heat Pad	60	
Iron	1100	
Lighted Mirror	20	
Shaver	15	
Sun Lamp	300	
Toothbrush	1	
Miscellaneous		
Auto Engine Heater	850	
Clock	3	
Drill (1/4")	250	
Fan (attic)	375	
Fan (window)	200	
Heat Tape	240	
Sewing Machine	75	
Skill Saw	1000	
Vacuum Cleaner	650	
Water Pump (well)	335	

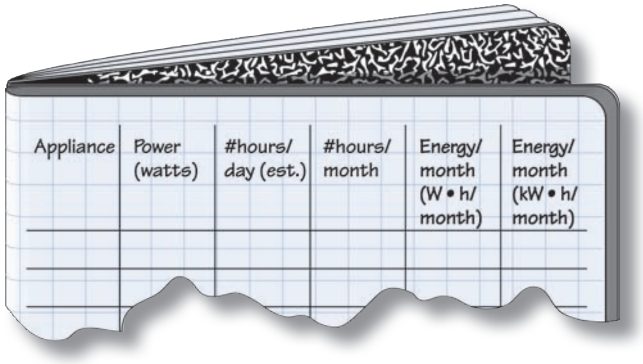
Please note: Average values of power are shown. The power of a particular appliance may vary considerably from the value in the table. Energy use will vary with family size (a four-member family is assumed for the tabled values), personal preferences and habits, climate, and season. Similar information in greater detail is available free upon request from most electric utilities.

Use information from the list of appliances to fill in the first two columns. In the third column, write the form of energy (heat, light, motion, sound, etc.) that you think each appliance is designed to deliver.

What pattern, if any, do you think exists between the power rating of an appliance and the form of energy it is designed to provide? Explain your answer.

6. Make a new list with six columns similar to the one shown. Choose five to ten appliances from the list. Record the name and power rating of that appliance. Record the approximate time that this appliance is used in one day. Calculate the time that this appliance is used in one month (assuming that a month has 30 days). Calculate the electrical energy that the appliance consumes.

   The energy used by an appliance in watt-hours (W • h) is found by multiplying the power of the appliance times the time it is used in hours in one month. Calculate the energy in kilowatt-hours (kW • h) by dividing the watt-hours by 1000 since there are 1000 W in 1 kW.



7. You use a 1500-W hair dryer for 5 min every morning to dry your hair.

   a) How much electrical energy are you changing to heat every day?

   b) If you could transfer all of that energy to heating up water for a shower, how much water could you heat from 20°C to 45°C?

   c) If one kilogram of water is about 0.26 gal (gallons), how many gallons of water does that represent? Is that enough water to take a shower? How much water do you think you use in a typical shower in your own home?

   d) Make a statement in your log about which use of this amount of energy would make most sense in your appliance package—using the hairdryer to dry your hair for 5 min, or taking a shower with that amount of energy?

8. Electric companies charge by the kilowatt-hour. Which of the following is the most expensive use of electricity over the course of a week? Show your calculations for each in your log.

   a) a 100-W light that is left on for 6 h per day

   b) a 1500-W hair dryer for 10 min every morning

   c) a 5000-W clothes dryer used for 70 min a week

   d) a 1200-W dishwasher that is run for 45 min, four times a week

   e) a 900-W water pump that is run for 50 min each day

Inquiring Further

1. EnergyGuide® labels

Find out about EnergyGuide® labels. The United States government established a federal law that requires EnergyGuide labels to be displayed on major appliances such as water heaters, refrigerators, freezers, dishwashers, clothes washers, air conditioners, furnaces, and heat pumps. The bright yellow EnergyGuide label allows consumers to compare the energy costs and efficiencies of appliances. Visit a store where appliances are sold and record the information given on the EnergyGuide labels of competing brands of one kind of appliance, such as water heaters. Prepare a short report on which appliance you would purchase, and why.

2. Reducing electric energy to heat water

Research ways to reduce the amount of electrical energy needed to provide hot water for your own home or an HFE dwelling. Some possibilities may include using solar energy and/or a "tempering tank" to heat the water partially, followed by "finishing off" the heating electrically, and tankless "instant" water heaters which use electricity to heat water, but only when hot water is needed. Prepare a report on your findings.

3. An average shower

Measure the amount of water the average member of your family uses when they take a shower. First, you have to locate your water meter. It is probably in your basement, although sometimes it is somewhere outside your house where the meter person can read it. It will probably measure in units of cubic feet of water. Note the meter reading before and after you take a shower. Make sure there is no other water running in the house (washing machine, sinks, etc.). To convert cubic feet to gallons, use the conversion factor

$$1 \text{ cubic ft water} = 7.5 \text{ gallons}$$

Compare the value of the energy used by the hair dryer with the energy used in heating of water for a shower in *Question 7* of the *Physics to Go*. Can you suggest a reasonable trade-off between taking a shower and using a hair dryer?