THERMAL ENERGY TRANSFER AS AN ENERGY EXCHANGE

16.8. IS THERMAL ENERGY TRANSFER REALLY AN ENERGY TRANSFER?

So far you have made observations that indicate that interactions take place when two substances in thermal contact are at different temperatures. We have dubbed these interactions "thermal energy transfer." In this Activity Guide and in most textbooks, you are told glibly that thermal energy (or heat) transfer is an energy transfer. What evidence do you have that this is so?

16.8.1. Activity: Speculations on Thermal Energy Transfer as Energy Exchange

Discuss any reasons that you and your classmates can think of for identifying thermal energy transfer with energy transfer (other than "the text says so"!). This is not an obvious identification because we have no way of seeing what is going on.

Let's try an observation that might help make the identification of thermal energy transfer with energy transfer plausible. This observation involves the use of a hand-operated device to warm your finger. For this observation you will need the following:

- 1 mini-generator (hand-operated)
- 2 alligator clip leads (for the generator)
- 1 miniature light bulb
- 1 light bulb socket
- 1 nichrome wire, approximately 18" long

Recommended Group Size:	2	Interactive Demo OK?:	N

You should wrap the wire loosely around your index finger, attach it to the generator, and have your partner turn the crank.

16.8.2. Activity: Doing Mechanical Work to Warm Your Finger

a. What happens to your wire-wrapped finger when the mini-generator crank is being turned?

Fig. 16.9.

b. Remember the definition of work? Are you exerting a force on the handle as you turn the crank? If so, is the handle moving in the direction of the force you are exerting? Are you doing mechanical work when you turn the crank? Why or why not?
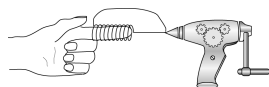
c. Is it less work to turn the crank when the wire is not attached to the generator? What happens when a light bulb is attached?

d. What is probably happening to the energy you expend doing the work to turn the crank? What types of energy transformations might be taking place when the finger is wrapped with wire?

Clearly, when the bulb lights as you crank the generator, mechanical energy is causing the generation of electrical energy. Although you might not have studied electrical energy yet in a formal way, from what you observed above you can see that the electrical energy produced by the mechanical work resulted in a thermal transfer that raises your finger's temperature. Thus, it seems appropriate to associate the <mark>warming</mark> of your finger with energy exchange. In the next set of activities you will be using electrical energy as a mechanism for the quantitative study of thermal energy transfer in relation to temperature change for different types of substances.

The idea of heating as an energy transfer process that results from temperature differences leads to more formal definitions of thermal energy exchange and of temperature as a measure of thermal equilibrium. These are summarized below. Although we ask you to memorize very few things in this course, these definitions should be memorized and their meanings understood. Retaining these two important thermodynamic concepts is critical to mastering the next unit on the First Law of Thermodynamics, the ideal gas law, and heat engines.

1. Thermal energy transfer or exchange is energy in transit between two systems in thermal contact due only to temperature difference with the hotter system losing energy as the cooler system gains it.
2. Two objects are in *thermal equilibrium*, and hence have the *same temperature*, if no net energy is exchanged between them when they are placed in thermal contact.

16.9. THE HEAT PULSER—A NEW RESEARCH INSTRUMENT

The computer-based temperature-sensing system can be outfitted with an electrical heat pulser. This pulser can be activated by <mark>pressing</mark> a key on the computer keyboard. Hitting the "pulse" button on the computer screen will turn on a pulse for a time period that you can set in the software. The power in watts (the rate at which the pulser delivers energy) is determined by the power rating of the pulser unit. Since the power, P, is energy per unit time, you can calculate the amount of thermal energy transfer, <mark>Q</mark>, in joules delivered to a substance each time you activate the heat pulser. Recall that 1 watt = 1 joule/second.

If Δt is the preset time for a heat pulse, then

$$P = \frac{Q}{\Delta t} \quad \text{or} \quad Q = P\Delta t$$

The heat pulser is extremely valuable in quantifying the relationship between thermal energy transfer and temperature change for different substances. Let's experiment with it a bit. To do this you will need:

- 1 computer data acquisition system
- 1 temperature sensor
- 1 heat pulser
- 1 immersion heater, 200 W
- 1 Styrofoam cup (and water)
- 1 vat (to perform activities in)

Recommended Group Size:	4	Interactive Demo OK?:	N

Warning: Never turn on a heat pulser unless the immersion heater coil is completely submerged in water. Otherwise it will burn out!

16.9.1. Activity: The Pulser, Heating, and Energy Output

a. Open up the data acquisition software and use the experiment file L160901—or set up your software for temperature measurements. If necessary, calibrate your temperature sensor. Next, submerse the temperature sensor and immersion coil in water in an insulated Styrofoam cup. What happens to the temperature of the water when you press the on-screen pulse button to get a 30 s pulse from the immersion heater?

b. Earlier you observed the cooling rates of the hot water in an aluminum can. How might the heat pulser be used to keep the temperature of the hot water from decreasing?

c. What is the time that electricity flows in the immersion heater for each pulse of "heat"?

$$\Delta t = \qquad \text{s}$$

d. What is the power rating in watts listed on the heat pulser unit?

$$P = \qquad \text{watts}$$

e. Assuming that all the electrical energy contributed by the heat pulser results in thermal energy transfer to the liquid it is immersed in, calculate the thermal energy in joules transferred by one pulse. **Note:** Some of the electrical energy is transferred to the immersion coil also.

f. How much thermal energy will be transferred if the pulse time is doubled each time a pulse is activated?

16.10. THERMAL ENERGY TRANSFER, TEMPERATURE, AND SPECIFIC HEAT

If you transfer pulses of energy thermally to a perfectly insulated cup of some liquid, what determines how much temperature change, ΔT, takes place? How does ΔT depend on:

1. The amount of thermal energy you transfer? $[Q^{total}]$
2. The mass of liquid in the cup? $[m]$
3. The kind of liquid you have?

You should conduct a series of observations in which you demonstrate *quantitatively* that if the cup is *well insulated:*

$$\Delta T = \frac{Q^{total}}{c\,m} \qquad\qquad (16.2)$$

where c is a constant that depends on the kind of liquid you have. To do this project you will need to investigate the three factors by changing only one variable at a time. For example, you can use the same mass of room temperature water for a series of experiments and vary only the amount of thermal energy you add. Then you can use the same amount of thermal energy and vary the mass of the water. Finally, you can use the same mass of liquid and the same amount of thermal energy and vary the type of liquid (that is, use antifreeze as one liquid and water as the other). You should determine the values of c for both water (c_w) and antifreeze (c_a).

To do the series of observations you will have the following equipment available to you:

- 1 computer data acquisition system
- 1 temperature sensor
- 1 heat pulser
- 1 immersion heater, 200 W
- 2 Styrofoam cups
- 2 plastic cup lids
- 2 ceramic coffee mugs or 2 calorimetry cups
  (to keep the Styrofoam cups from tipping)
- 2 containers, 0.5 liter (for water at room temperature)
- antifreeze, 250 ml
- 1 electronic balance
- 1 vat (to prevent spilling)

Recommended Group Size:	4	Interactive Demo OK?:	N

By using the real time graphical display of temperature changes in L161001 or setting up your own experiment file, you can study the relationship between Q and ΔT in one run as long as the temperature pulses are added far enough apart to allow each resulting temperature change to be recorded before the next pulse is added.

Warnings: Use enough liquid in each case to make sure the electric coil is covered in every observation. Be careful not to use large amounts of liquid since the heating process will take too long! Keep stirring the liquid at all times. *Do not warm the antifreeze over 70°C at any time during the experiment!*

16.10.1. Activity: The Relationship of Thermal Energy Transfer and Temperature

a. List data and affix any relevant graphs in the space that follows. Describe your observations and findings. Please be as quantitative as possible.

b. What substance changes temperature the most for a given amount of thermal energy transfer—the water or the antifreeze? Which one has the higher value of c? Be sure to list appropriate units for c_a and c_w.

Back in the good old days when a kid was given a hot baked potato to carry to school on a cold winter day, the potato kept her warm and served as lunch! Why is a hot potato a better kid warmer that a small bag of popcorn? If a body made of a given substance has a certain thermal energy transfer, how much will its temperature increase? The answers to these questions involve a property of a substance called the *specific heat*. The constant c that you determined for water and antifreeze is known as the specific heat of a substance. *Specific heat is defined in J/kg · °C units as the amount of thermal energy transfer in joules needed to raise a kilogram of a substance by one degree Celsius.*

The mathematical definition of specific heat is constructed, in fact, by turning Equation 16.2 around to get

$$c \equiv \frac{Q}{m\Delta T} \tag{16.3}$$

Fig. 16.10.

A material with a high specific heat can have a large quantity of thermal energy transferred to it without changing its temperature very much. A material of the same mass with a small heat capacity will undergo the same temperature change when a smaller amount of thermal energy is transferred to it.