2.3 THERMAL ENERGY TRANSFER AND TEMPERATURE CHANGES

Armed with our understanding of the concept of temperature, we will now turn our attention to trying to understand "heat." Clearly, we can increase the temperature of an object by heating it up, but what exactly does "heating it up," mean? One way of heating something up is to place it on a hot burner. But are there other ways? That is the topic of the next activity.

Heating Water with Mechanical Work

If temperature is a measure of how quickly molecules are moving, then perhaps we can increase an object's temperature by physically making the molecules move faster. In fact, pioneering experiments in heat and temperature tried to do just this. Scientists would spin paddle wheels in liquids and try to measure a change in temperature. You will do this in the next activity, albeit in a less controlled manner.

Activity 2.3.1 Shake it, Baby!

a) Your instructor will place a small amount of water (50-100 g) in a thermos, which is an insulated container designed to prevent heat from entering or leaving the container. Write down the initial temperature of the water that is placed in the thermos.

Figure C-9: A thermos is an insulating container designed to prevent heat from entering or leaving. (Corbis Images)

b) After the thermos is sealed, your instructor will begin shaking it vigorously. This is difficult work, so after about a minute or so, it will be passed to one of the students in class. This student should continue to shake the thermos vigorously for about a minute or so, then pass it on to someone else. When the thermos has gone around the whole room, pass it back to the instructor, who will open it and measure the temperature of the water inside. (Since this will take some time, your instructor might want you to work ahead on the next activity while all the shaking is going on.) Write down the final temperature of the water after having been shaken.

NAMES and PICTURE:

c) From a molecular perspective, what is different about the water after having been shaken and what caused the change? (You should think a bit more deeply than just replying, "the shaking caused the change.")

Heating Water with Electric Work

This following activity involves heating up some water while monitoring its temperature in a way that might be a bit more familiar. You will be using an immersion heater, which is similar to a stove's burner. When on, electricity causes the immersion heater to get hot and become a "source of heat." We use the immersion heater instead of a stove because it is easier to control. It is also a more delicate piece of equipment and you need to be careful with it.

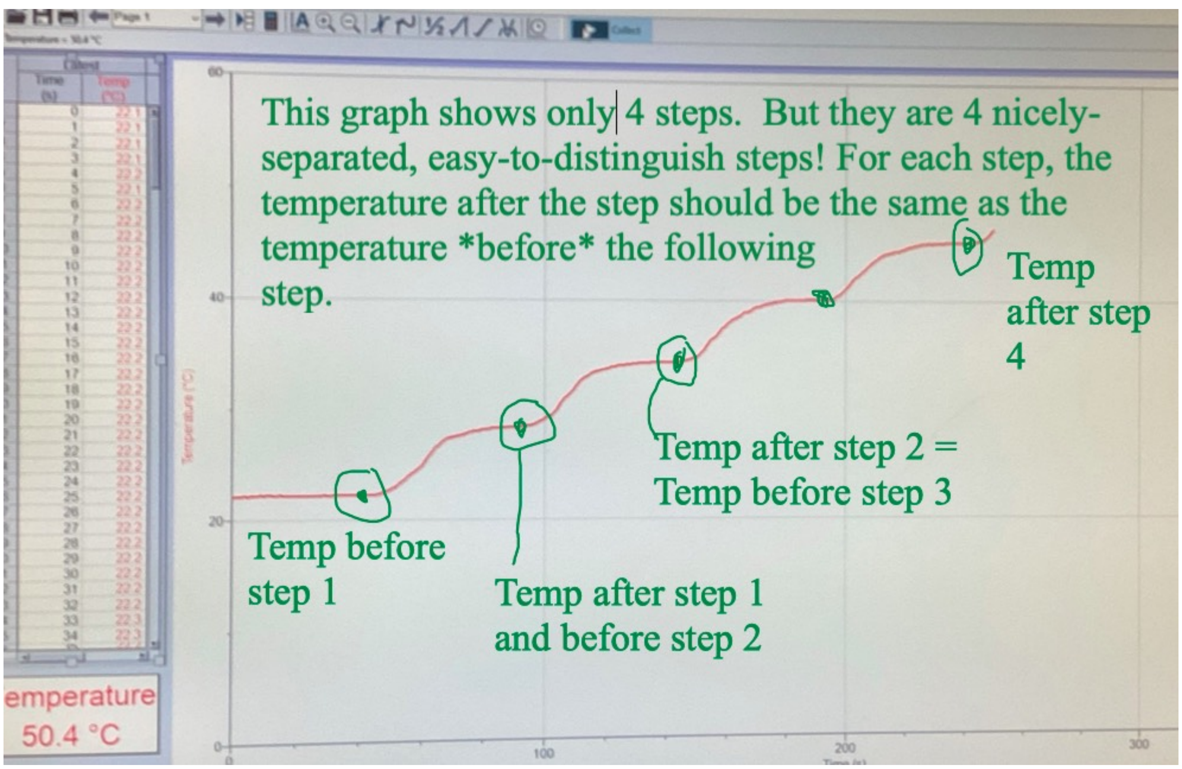
Caution: ***Never plug the heat pulser into the wall when it is not in the water.*** This will damage the heating unit. It is all right to plug the heat pulser into the computer, but make sure it is immersed in water before actually pulsing heat. Another thing to remember is that when the heater is on, ***the metal portion of the heating unit shouldn't touch anything except the water***. This includes the air in the room, you, and your partner!

Activity 2.3.2 Pulsing Heat in a Cup of Water

a) Begin by putting 100 grams of water into a Styrofoam cup and placing a heat pulser in the water with a stand. Set the total experiment time to 250 seconds and set the heat pulse length to 10 seconds. When you think you are ready, have your instructor check your set-up ***before*** starting the experiment! You will need to stir the water with the temperature sensor throughout this experiment, being careful not to touch the heat pulser with the temperature sensor. Begin the experiment and after about 40 seconds (don't forget to stir the water continually), click on the heat button. This will add a 10-second pulse of heat, which should increase the temperature of the water a little bit. After the temperature of the water has stabilized (which should take about 40 seconds) hit the heat button again. Repeat this process until the experiment ends. When you are done, you should have hit the heat button five times, once at 40, 80, 120, 160, and 200 seconds. Briefly describe the graph you obtained, and print out a copy for your activity guide.

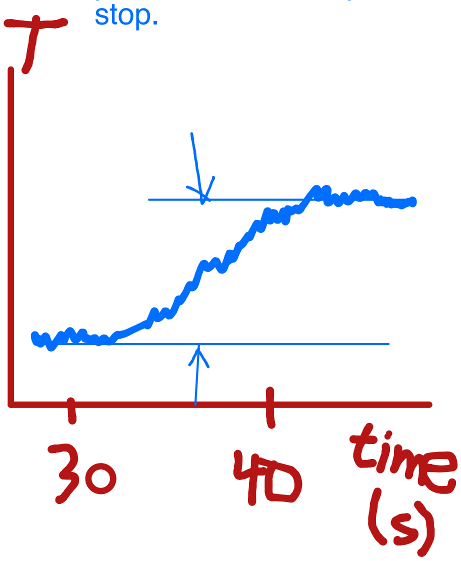
That is, watch Logger Pro as the seconds tick over in the data columns: Turn on the power strip connected to the heater coil, and then after 10 seconds, turn it off.

That is, take a picture and include it here, on an empty page that you added, in your lab report.



The Temperature after step 1 that you report should be the *same* as the Temperature before step 2. And so on for the other steps

If I start heating at 30 seconds and stop at 40 (see below), it might be that the heater is still hotter than the water after I've shut off the electricity and the water temp keeps rising. To catch the effect of *all* the electricity you put into the heater, use as your "Temp after pulse" the temperature **once it levels off**, after your pulse. Not the temperature right when you stop.



b) Fill in the following table by finding the temperature change for each pulse of heat that was added.

Heat Pulse	Temp. before pulse (ºC)	Temp. after pulse (ºC)	Temp. Change (ºC)
#1			
#2			
#3			
#4			
#5			

c) Explain what a 10-second pulse of heat does to your 100 grams of water. **Hint:** Is the temperature change for each pulse approximately the same?

Calculate the *average* of your 5 temperature changes. Make this a part of what you report as the effect of one 10-second pulse on your water. "On average…"

d) How much would you expect the temperature of 50 grams of water to rise when subjected to one 10-second heat pulse? What about 10 grams of water?

Be quantitative about this. *How many degrees* would you expect the temperature to rise in each of these two cases.

e) From a molecular perspective, what is different about the water before and after receiving a pulse of "heat?"

Heat as an Energy Transfer Process

As these last two activities showed, you can increase the temperature of water by placing a "heat source" in the water (the heat pulser), but you can also increase the temperature of water just by shaking it (with no heat source at all). This surprises many people. Remember, an increase in temperature just means that the molecules are moving more vigorously, so anyway that you can get the molecules moving more vigorously will result in an increase in temperature. By shaking the water, you are adding energy to the water which speeds up the motion of the molecules. In scientific terms, *work* is being done on the water.

Notice that whether we used an electrical source to "heat up" the water or we did work to "heat up" the water, the underlying result is the same in both cases; there is an increase in the motion of the water molecules. Viewed from this perspective, it may be clearer to think in terms of the "energy transferred" to the water. This *thermal energy* either comes from collisions with the molecules that make up the heating unit or from the energy that you used to shake up the thermos.

Quantifying Heat

Now, since the result is the same in both cases (i.e., the temperature of the water increased), we might choose to define "heat" (or *thermal energy*) in terms of the temperature change of water. In fact, this is precisely how scientists first defined heat: One *calorie* is the amount of thermal energy needed to raise the temperature of *one gram* of water by *one degree Celsius*. **Note:** The term *calorie* (with a small c) as defined here is not the same as the term *Calorie* (with a capital C) in regards to food consumption. One "food" *Calorie* is actually equal to one thousand *calories* as defined here. In this activity guide, unless specifically stated, we will always be referring to "non-food" *calories*. The following activity should help you get familiar with this unit of thermal energy.

Activity 2.3.3 Counting Calories

a) If it takes one calorie to raise the temperature of one gram of water by one degree Celsius, how many calories does it take to raise the temperature of 100 grams of water by one degree Celsius?

b) How many calories would it take to raise the temperature of 100 grams of water by 5 degrees Celsius?

c) How much thermal energy (in calories) is required to change 50 grams of water from 30 degrees Celsius up to 50 degrees Celsius?

d) How much thermal energy did each pulse of your heat pulser produce in the Activity 2.3.2? Show the details of your calculation.

2.4 SPECIFIC HEAT

Because we have defined a calorie in terms of its effect on one gram of water, it is particularly easy to determine how much thermal energy has been transferred to a specific amount of water if we know its temperature change. However, there are many situations when one might be interested in heating up a substance besides water. So the question naturally arises, if we transfer one calorie of thermal energy to one gram of a substance that is not water, will its temperature also increase by one degree Celsius? That is the topic of the following activity.

Activity 2.4.1 Activity: Pulsing Heat Again

a) Begin by placing 100 grams of anti-freeze into a Styrofoam cup and placing an immersion heater in it. Set the total experiment time to 250 seconds and prepare to deliver 10-second heat pulses to the water. **Note:** When you think you are ready, have your instructor check your set-up ***before*** starting the experiment! You will need to continually stir the anti-freeze with the temperature sensor throughout this experiment, being careful not to touch the heat pulser with the temperature sensor. Begin the experiment and after about 40 seconds, click on the heat button. After the temperature of the anti-freeze has stabilized (which should take about 40 seconds) hit the heat button again. Repeat this process until the experiment ends. When you are done, you will have clicked on the heat button five times, beginning at 40, 80, 120, 160, and 200 seconds. Briefly describe the graph you obtained, and print out a copy for your activity guide. Is there any difference between this graph and the graph you made in Activity 2.3.2?

In yellow container at the front of the classroom.

b) Fill in the following table by finding the temperature change for each pulse of heat that was added.

Heat Pulse	Temp. before pulse (ºC)	Temp. after pulse (ºC)	Temp. Change (ºC)
#1			
#2			
#3			
#4			
#5			

c) Knowing how much thermal energy is transferred to the anti-freeze in one 10-second pulse (see Activity 2.3.2), determine how much thermal energy it takes to increase the temperature of one gram of anti-freeze by one degree Celsius. Show your work.

The quantity just calculated—how much thermal energy it takes to change the temperature of one gram of anti-freeze by one degree Celsius—is an important and useful quantity. It is a property of the material that does not change as you add more material. Scientists call this quantity the *specific heat* of a substance and denote it with the symbol c. We already know that it takes one calorie to raise the temperature of one gram of water by one degree Celsius. This means that water has a specific heat of $c = 1\ \text{cal}/\text{g}^\circ\text{C}$. Since the specific heat tells us how much energy it takes to increase the temperature of *one* gram of a substance by one degree Celsius, the quantity mc (where m is the mass in grams) is the amount of energy it takes to increase the temperature of m grams by one degree Celsius.

Stated another way, $mc\Delta T$ is the amount of thermal energy gained by an object of mass m when its temperature changes from T_i to T_f. If $T_f > T_i$, then $\Delta T > 0$ and the energy *gained* by the object is positive. But if $T_f < T_i$, then $\Delta T < 0$ and the energy gained by the object is negative. This indicates that the object actually *lost* energy. Now, when two objects are placed in thermal contact with each other, the energy *gained* by one object will be exactly equal to the energy *lost* by the other object. We can use this fact to determine the final temperature of two cups of water when they are mixed together.

Activity 2.4.2 Thermal Energy Transfer

a) Suppose we have m_h grams of hot water, initially at a temperature of T_h and m_c grams of cold water initially at temperature T_c. After mixing, the final temperature is given by T_f. Write down an expression in terms of m_c, c, T_c and T_f for the heat *gained* by the cold water during the mixing process?

b) Write down an expression in terms of m_h, c, T_h and T_f for the heat *lost* by the warmer water during the mixing process. **Hint:** The quantity will be positive.

c) Now, equate the heat *gained* by the cooler water to the heat *lost* by the warmer water and solve for the final temperature T_f.

d) Compare your equation to the equation you deduced in Activity 1.2.2 and show that these two equations are identical.

Checkpoint Discussion: Before proceeding, discuss your ideas with your instructor.

The equation you derived here should be the same as the equation you deduced in Activity 1.2.2 from your experimental observations. Hopefully, you can appreciate this result even more now, knowing that it comes from equating the energy *lost* by the hot water to the energy *gained* by the cold water. In fact, this is actually one of the most important principles in all of the sciences. It is better known as the principle of energy conservation. Although we have not discussed it in detail, energy comes in many different forms, motion, thermal (heat), sound, chemical, solar, electrical, nuclear, etc. The conservation of energy principle states that energy can never be created or destroyed, it can only be changed from one form to another, or transferred from one object to another. We will not try to confirm this statement, but it is worth mentioning that it has been well verified experimentally and is one of the most fundamental ideas in the all the sciences.