Physics 216 Lab 8, Spring 2018
Introduction to Temperature and Heat

OBJECTIVES

- To acquire an operational definition of temperature and to understand the connection between temperature and thermal equilibrium.
- To understand how the temperature of a body changes as it undergoes thermal interactions with its surroundings.
- To understand the difference between the quantity of heat energy transferred to or from an object and its temperature.

OVERVIEW

In this lab you will learn how physicists define and use familiar terms like "heat" and "temperature" in a way that helps them to understand thermal processes.

Temperature is one of the most familiar and fundamental *thermodynamic* quantities. In this lab, you will observe how the temperature of a system is affected when it interacts with its surroundings or another system at a different temperature. Since we cannot *see* what really goes on when something changes temperature, we have to develop some new concepts to try to explain what is happening. One of these new concepts is that of *heat transfer*. It is essential to understand the difference between the temperature of an object and the heat transferred to or from the object. This will be a major focus of this lab.

INVESTIGATION 1: TEMPERATURE MEASUREMENT

Thermometers register changes in temperature by using materials that change in some way as they are heated or cooled. For example, the column of liquid (alcohol or mercury) in a common thermometer expands when heated and contracts when cooled. Thus, the length of the column can be used to measure temperature, and we could crudely define temperature *as a quantity that is related to the height of a column of liquid inside a familiar glass bulb thermometer*. If the length of the column is associated with standard temperature units and scales such as Fahrenheit or Celsius, the thermometer is said to be *calibrated*.

Other properties, such as the electrical resistance of certain materials, depend on temperature. Thus, it is also possible to use electronic devices to measure temperature. Such systems have several advantages over glass bulb thermometers. The sensors can be much smaller and usually respond more quickly to changes in temperature.

In the first activity of this lab you will use both a familiar glass bulb thermometer and an electronic sensor to measure the temperatures of various objects. The purpose of this activity is to become familiar with the Celsius and Kelvin temperature scales. You will also gain some experience with electronic temperature measurement, some of the limitations of electronic sensing, and features of the temperature measuring software.

To conduct this investigation you will need

- glass thermometer, calibrated with Celsius scale (25 to 105°C)
- 2 temperature sensors
- hot water (about 80°C)
- crushed ice and cold water
- Styrofoam cup, 300 mL, (for crushed ice)
- vat (to prevent spills)

Activity 1-1: Glass Bulb and Electronic Thermometers

Be sure that two electronic temperature sensors are plugged into the appropriate ports on the LabPro interface. Open the LabPro software and load the experiment file called **L01A1-1(Dig. Readouts).cmbl**. When the file has loaded, you should see the digital readouts of the temperature sensors displayed in degrees Celsius.

Once you have the two temperature sensors connected, make sure that they are properly working by measuring the temperatures of the air, body temperature (inside elbow), ice water, room-temperature water, and hot water and compare the readings of the temperature sensors to the reading on a glass thermometer. Be sure that the three thermometer tips are sensing the same temperature by placing them right next to each other. Additionally, you should stir the water continuously and ice samples to be sure that the whole sample is at the same temperature. Record the temperatures in Table 1-1 and fill in the corresponding Fahrenheit and Kelvin temperatures.

Table 1-1

	Glass bulb thermometer temperature (°C)	Electronic temperature sensors (°C)		Calculated temperature (°F)	Calculated temperature (K)
		Sensor 1	Sensor 2		
Room Air					
Body (inside elbow)					
Ice Water (equal amts. of ice and water, stirred)					
Room temperature water					
Boiling water					

Question 1-1: Do the readings of the three thermometers agree? If not, why might they not agree?

An electronic temperature sensor must be calibrated against a glass bulb thermometer or some other known standard. A default calibration is stored in the Logger Pro software, but if you find that the readings of your electronic temperature sensors differ from each other or from the glass bulb thermometer by more than ±0.5°C, then you need to recalibrate the electronic sensors.

If you need to calibrate your temperature sensor, find the **calibrate** feature in Logger Pro and follow the instructions given on the computer screen. Put both temperature sensors simultaneously into the same samples of water at known temperatures. For what you will be doing in this lab, ice water and hot tap water will work fine for the two different temperatures needed for calibration. Use your glass bulb thermometer as a standard. Once the sensors have been recalibrated, repeat the measurements above and correct the temperature readings in the table. You may want to **name and save your calibration file**.

Question 1-2: Any of the temperatures you have measured might be used as fixed points to define a temperature scale. Which of these might be reliable ones; that is, which ones are truly *repeatable temperatures*? Explain.

Question 1-3: What is the number of divisions (degrees) between the freezing point and boiling point of water on the Celsius, Kelvin, and Fahrenheit scales? Compare 1°C, 1 K, and 1°F: which represents the largest temperature difference? The smallest? Do any represent the same temperature difference?

=> Checkpoint 1

Activity 1-2: Reaching Thermal Equilibrium

Prediction 1-1: Suppose you want to measure room temperature with a thermometer that has been in ice water. If you want an accurate value, for which would you need to wait longer: measuring room temperature water or room temperature air? Explain the reason for your prediction and any assumptions you make.

To test your prediction using the electronic temperature sensors, open experiment file called **L01A1-2 (Reaching Equilibrium).cmbl** and set up the software to graph two temperature sensors vs. time over a range of 0 to 30°C for a time interval of 240 s. If you had to recalibrate the two temperature sensors in Activity 1-1, you should load the saved calibration file.

With a container of room-temperature water nearby, start with both sensors in ice water. **Begin graphing** and simultaneously move one sensor into air and the other into room-temperature water. Record the time for the temperature sensors to reach room temperature.

Ice water to room temperature air: $\Delta t =$ ______s

Ice water to room temperature water: $\Delta t =$ ______s

Question 1-4: Which reached room temperature faster? On the basis of these measurements, what should you watch out for in making temperature measurements?

Prediction 1-2: Suppose you take two thermometers out of hot water, dry one, and then wave both around in the air. Will there be any difference in the time it takes them to reach room temperature? Why or why not?

To test your prediction, adjust the temperature axis so that it includes the temperature of your hot water. **Begin graphing** with both temperature sensors in the hot water. At the same moment, dry just one of the probes, and begin **shaking both vigorously** in the air. Record the time intervals for the temperature sensors to reach room temperature.

Hot water to room air (dried): $\Delta t =$ ______s

Hot water to room air (wet): $\Delta t =$ ______s

Question 1-5: Which reached room temperature faster? Can you explain why? On the basis of these measurements, what should you watch out for in making temperature measurements?

=> Checkpoint 2

INVESTIGATION 2: THERMAL EQUILIBRIUM AND HEAT TRANSFER

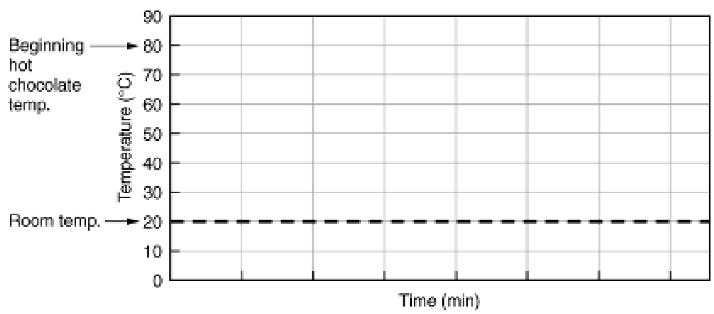
You have already seen that hot objects cool down until they reach the same temperature as objects around them. This process is also described as reaching *thermal equilibrium*. Observations such as these lead most people to the conclusion that objects at different temperatures interact with each other through the transfer of something from hotter objects to cooler ones.

Let's begin with some predictions. Suppose you have a cup of hot chocolate. You place it on the lab table and let it sit for a long while.

Prediction 2-1: How cool will the hot chocolate get?

Prediction 2-2: Where does the heat go as the hot chocolate cools?

Prediction 2-3: Sketch on the axes below your prediction of how the temperature of the hot chocolate will change with time. (Assume that the beginning temperature is 80°C and that room temperature is 20°C.)



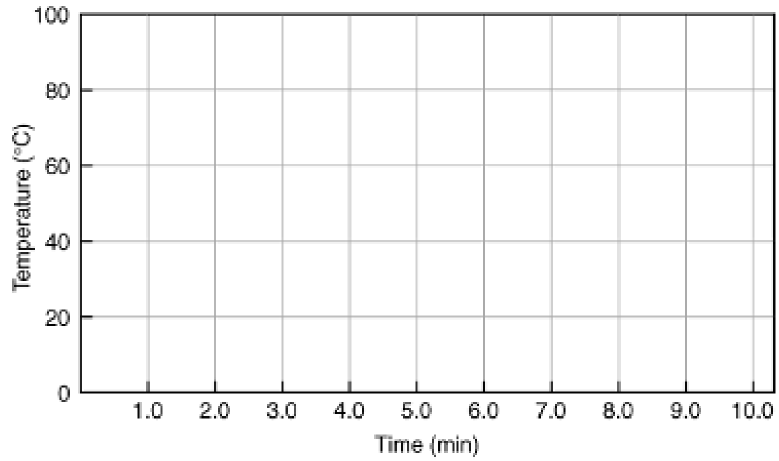
Prediction 2-4: Is the *rate* at which the temperature of the hot chocolate drops always the same, or does it change as the hot chocolate gets cooler? If it changes, is the rate faster when the hot chocolate is hotter or cooler?

Activity 2-1: Cooling Water–A Temperature History

While we do not have hot chocolate, you can still test your predication using hot water instead. To test your predictions, you will need

- computer-based laboratory system with 2 temperature sensors
- hot water (at least 80°C) or immersion heater to heat water
- container (>50 mL)
- *uninsulated* glass, plastic, metal, or paper cup
- vat (to prevent spills)

To test your prediction using the electronic temperature sensors, open experiment file called **L01A2-1 (Cooling Water).cmbl** and set up the software to graph temperature sensor 1 vs. time over the appropriate temperature range for a time interval of 10 min. If you had to recalibrate the two temperature sensors in Activity 1-1, you should load the saved calibration file.



Once you have measured room (air) temperature with sensor 1 and recorded it in column 1 of Table 2-1 on the top of the next page after its reading remains constant, put temperature sensor 1 in the *uninsulated* cup. Add a small amount of hot water (about 50 mL at 80°C or higher) and immediately **begin graphing** and, using temperature sensor 2, see if you can find where the heat is transferred as the hot water cools by seeing what is getting warmer. Sensor 1 will continue to measure the water temperature (you stir gently to keep the whole water sample at a uniform temperature).

Fill in the temperatures in Table 2-1 using sensor 2–once near the beginning of the experiment, then again after about 5 min. *For each temperature reading, be sure to wait long enough for the sensor to reach the temperature you are measuring*. Fill in all of column 1, then do column 2. Once ten minutes have passed, record the temperature of the water after 10 min and calculate the change in temperature of the water in the first and last five minutes.

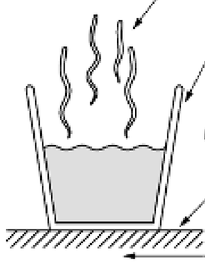
Δ temperature in first 5 min: ______°C

Δ temperature in last 5 min: ______°C

Leave the cup of water for the rest of the lab and measure its temperature and room (air) temperature again just before you leave. Record these in the table.

Table 2-1

	1 Temp. near beginning of expt.	Temp. after about 5 minutes	Temp. after 10 minutes	Temp. at end of lab
Sensor 1 Room air temp.				
Water temp				
Sensor 2 Air above hot water				
Side of cup				
Air temp. near side of cup				
Table nearby				
Table under cup				



Question 2-1: As the temperature of the hot water drops, does the temperature of anything else rise (relative to room temperature)? What things had the largest temperature rise according to your measurements?

Question 2-2: Did the temperature drop more in the first 5 min or in the last 5 min? Why do you think this happened? What do you conclude about the rate of cooling of water as the temperature of the water drops?

=> Checkpoint 3

Activity 2-2: Temperature Change and Heat Transfer

We know that when a hotter substance comes into thermal contact with a cooler one the temperatures of the two substances change. This temperature change is easy to observe in situations where substances (*e.g.*, liquids) can be mixed together or come into thermal contact with each other without mixing. Do the initial temperatures alone allow us to predict the final temperature of the system after the two substances have interacted with each other? In the next activity you will examine more carefully this interaction between hot and cold objects. First make a couple of predictions.

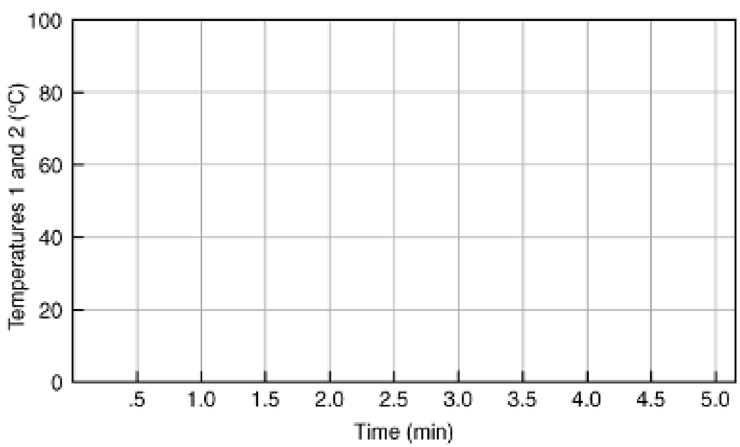
Suppose you have hot water at 80°C in a small, sealed, uninsulated container and a larger amount of water at room temperature (20°C) in an insulated cup. The container is submerged in the water in the cup and left there for a long time.

Prediction 2-5-A: What do you predict will be the final temperature of the water in the container? Will it be midway between 80 and 20°C; closer to 80°C; or closer to 20°C?

Prediction 2-5-B: What do you predict will be the final temperature of the water in the cup? Will it be midway between 80 and 20°C? Or will it be closer to 80°C or closer to 20°C?

Prediction 2-5-C: Is it possible knowing just the initial temperatures of the two water samples to predict *exactly* what the final temperature will be? Explain.

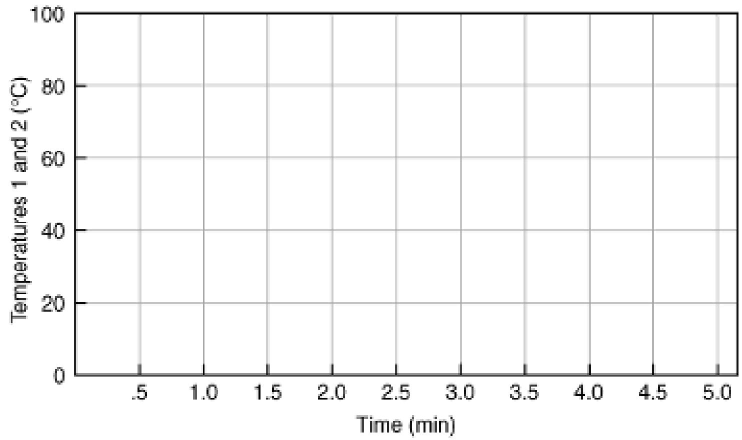
Prediction 2-5-D: How will the temperatures of the two water samples change with time? Sketch a prediction on the graph below for the temperatures of the two water samples as a function of time.



To test your predictions using the electronic temperature sensors, you will need the following materials in addition to those you used in Activity 2-1:

- more hot water (about 80°C)
- 35-mm-film container with a hole in the cover just large enough for a temperature sensor
- Styrofoam or other *insulated* cup

Open the experiment file called **L01A2-1 (Temp. Change and Heat Transfer).cmbl** and set up the software to display and graph both temperature sensors vs. time as seen on the axes below. If you had to recalibrate the two temperature sensors in Activity 1-1, you should load the saved calibration file.



Use the film container to pour enough full containers of room-temperature water into the cup so that the film container can be submerged in the water,

Number of containers full of water put in the cup: ______

Carefully push temperature sensor 2 through the hole in the film container cover (it should be a tight fit) and put temperature sensor 1 in the cup. Fill the film container with water near 80°C and seal it with the cover and sensor.

Quickly record the initial temperatures below, and **begin graphing**. Once you have started graphing, submerge the film container in the cup. Gently move the container up and down to mix the water in the cup for the rest of this activity.

Hot container: ______ Cool cup: ______

When you are done with this activity, remove the probe from the cover very gently by pushing (not pulling) it through the hole.

Question 2-3: Did the final temperatures of the hot water and cool water agree with your prediction? Does the final temperature seem to depend on anything besides the initial temperatures of the water in the container and in the cup? Explain.

What would happen to the final temperature if you changed the relative amounts of water so that there was more hot water in the container and less cool water in the cup?

Question 2-4: As the hot water cooled down, what happened to the room-temperature water? What is the mechanism by which the two temperatures changed even though no hot water mixed with the room-temperature water?

Question 2-5: How can you tell when thermal equilibrium has been reached? Is there any evidence that whatever "flowed" from one container of water to the other has stopped flowing? What is this evidence?

Comment: As you have observed in this investigation, inevitably, parts of any thermally isolated (i.e., insulated) system having different temperatures will interact until the entire system is at the same temperature. This may seem like a mysterious process, because the interaction that causes temperature changes *can occur without an exchange of matter*.

You should have noticed from your experiments that the relative masses of the parts of your thermally isolated system affect the value of the final equilibrium temperature. Thus, the interaction between two parts of a system cannot be explained as a simple *temperature* exchange. We need to create a new concept to help us understand heating and cooling processes. Scientists have invented the term *heat transfer* to explain this phenomenon.

The use of the noun "heat" is misleading, since using this term implies the exchange of a substance between two parts of a system. The word "heat" is actually a sloppy shorthand for an interaction process that leads to temperature changes. As a reminder that we are dealing with a process rather than a substance, we will use the term *heat transfer* and not simply *heat*. In future labs we will develop the idea that "heating" is actually a form of energy transfer. In the next investigation, you will explore the relationship between heat transfer and temperature.

=> Checkpoint 4

INVESTIGATION 3: TEMPERATURE IS NOT THE WHOLE STORY

You know that one way to raise the temperature of a substance like water is to "heat" it, say on a stove or with a small immersion heating coil. Your computer-based temperature system can be outfitted with a heat pulser consisting of an immersion heater connected to the computer interface. Each time you push the **HEAT** button or key, a pulse of the same amount of energy is transferred to the system you are examining.

You will first explore a situation where heat is transferred to water and yet *the temperature of the water does not change*. Then you will examine the amounts of heat transfer needed to bring about the same temperature change in different masses of water. First a prediction:

Prediction 3-1: If you transfer heat to water in a cup at the same rate as it is leaving, what will happen to the temperature of the water? What will happen if you transfer in more heat than is transferred out? Less than is transferred out? Explain.

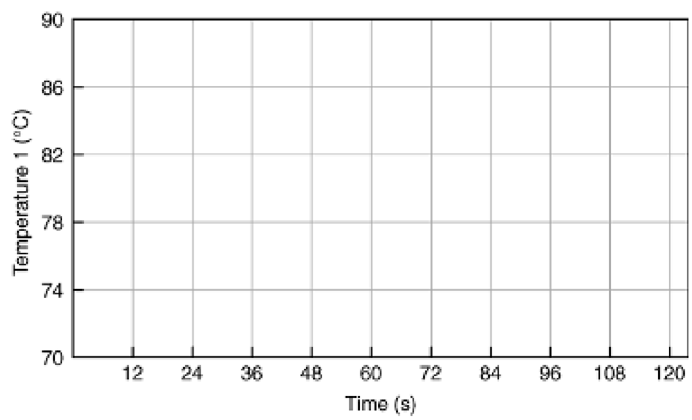
Activity 3-1: Keeping Hot Water Hot

In the first activity, you are going to try to keep hot water at a constant temperature by transferring heat with the heat pulser to replace the heat that is transferred out to the surroundings. You will need the following:

- computer-based laboratory system with one temperature sensor
- heat pulser (relay box and immersion heater)
- hot water (near 80°C)
- stirring rod
- container marked in mL
- *uninsulated* glass, plastic, metal, or paper cup
- vat (to prevent spills)

To test your prediction using an electronic temperature sensor and a heat pulser, open experiment file called **L01A3-1 (Keeping Hot).cmbl** and set up axes as seen below. This will also set up the heat pulser to transfer 2-s pulses of heat each time the **HEAT** button or key is pressed. If you had to recalibrate the two temperature sensors in Activity 1-1, you should load the saved calibration file.

Warning!! Do not plug the immersion heater into the pulser or press the HEAT button or key unless the heater is in the water. The heater will burn out if it is turned on even for a short time while not immersed in water.



Pour about 150 mL of hot water (near 80°C) into the uncovered metal can. Put the sensor and heater into the water, and plug the heater into the relay box just before starting. (Use the heat pulser to warm the water to 80°C before you start, if necessary.)

Water temperature at the start: ______°C

Begin graphing, and *while stirring continuously* try to keep the water temperature constant (within a degree). Press the **HEAT** button or key when you need to transfer more heat to the water. The computer will make marks on the graph each time you pulse the heater and will keep track of the number of pulses you use. *Keep stirring*!

When you are done, record the number of heat pulses transferred.

Number of heat pulses transferred: ______

Question 3-1: When you heat water (below the boiling point) in a tea kettle on the stove, the temperature of the water rises. How is it possible that in this activity heat was transferred to the water in the cup and yet the temperature remained the same?

Question 3-2: In this experiment there was no temperature change. What factor besides temperature change might determine the amount of heat transfer that was needed?

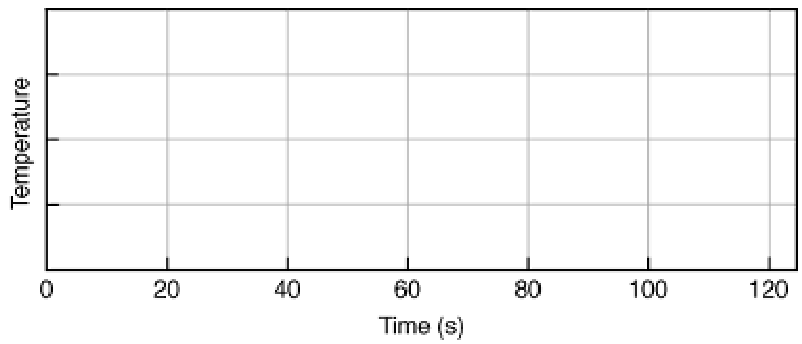
Question 3-3: In this experiment you are working as part of a *feedback loop* to determine when more heat is needed to keep the temperature of the water constant. Can you think of a device in your home that operates in a similar way?

=> Checkpoint 5

Extension 3-2: Heating Up Water

If you have additional time, try to raise the temperature of different masses of water in an insulated cup *by the same amount* by transferring heat from the heat pulser to the water.

Prediction E3-2: Heat is transferred to water in a perfectly insulated cup at a steady rate for 80 s, and then no more heat is transferred. No heat can leak in or out. Sketch on the graph on the next page your prediction for the temperature of the water as a function of time.

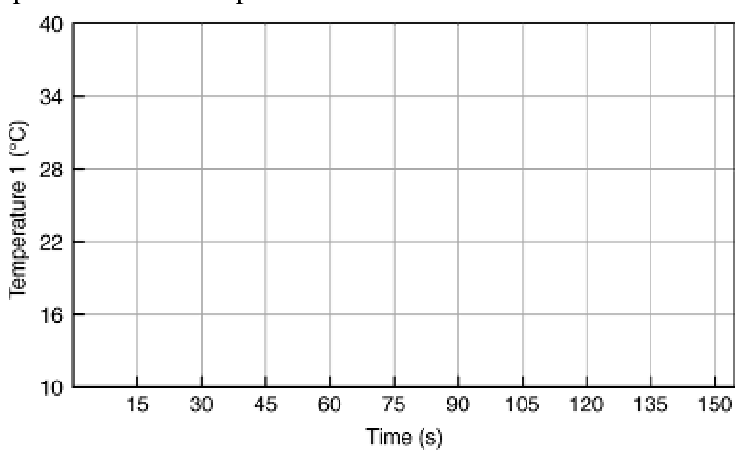


To test your prediction you will need the following materials in addition to those from the last activity:

- Styrofoam or other *insulated* cup
- room-temperature water

Open the experiment file called **Heating Water (L1E3-2)** to display the axes below. This will also set up the heat pulser to transfer 5-s pulses of heat.

Place the temperature sensor and the heater into the *foam (insulated) cup* and add 75 g (mL) of water near room temperature to the cup. Be sure that the water covers the coils of the heater.



Record the initial temperature of the water in Table E3-2 and b**egin graphing**. Stir the water vigorously during the entire time the computer is graphing the temperature.

For the first 10 s don't pulse the heater. Just watch the temperature when no heat is transferred. Then pulse the heater every 10 s for a total of 4 heat pulses. *Keep stirring*!

When the temperature stops increasing, record the final temperature in Table E3-2 and calculate the temperature change of the 75 g (mL) of water and the temperature change per heat pulse, and record these in the table on the next page.

Table E3-2

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change (°C)	Number of heat pulses	Temperature change per pulse (°C/pulse)
75				4	
150					

Use the features of your software to transfer your data so that the graph will remain **persistently displayed on the screen** for comparison during the next activity. (Experiment/Store Latest Run)

Question E3-4: Why did the temperature of the water rise during this activity, while it remained constant as heat was transferred in the previous activity?

Question E3-5: Did the shape of the graph agree with your prediction? Describe any differences.

Prediction E3-3: Suppose you started with twice as much water (150 g) at room temperature and wanted to heat the water to the *same final temperature* as you did the 75 g. How many heat pulses would you need to transfer? Explain how you arrived at your prediction.

Test your prediction by repeating the procedure above, this time using 150 g of room temperature water, and transferring as many heat pulses as you need to bring about the *same temperature change*. *Remember to stir vigorously throughout the experiment*.

Question E3-6: Did your results agree with your prediction? Describe any differences.

Question E3-7: Assume that very little heat is exchanged between the insulated cup and its surroundings while you transfer heat pulses to the water in it. How do you explain your observation that different numbers of heat pulses were needed to cause the **same temperature change** in these two experiments?

Question E3-8: Since heat was transferred by the heat pulser at a fairly steady rate, the time and the amount of heat transfer are proportional; that is, the horizontal axis could be re-labeled as "amount of heat transferred." From your graphs, what type of relationship appears to exist between the temperature of the water and heat transferred?

Question E3-9: How would the temperature changes for equal heat transfer to different amounts of water depend on the mass of the water? Describe the relationship between the temperature change (ΔT) and the mass (m) for a fixed amount of heat transferred in words and mathematically. (**Hint:** Look at your data for temperature change per pulse and at the slopes of your graphs.)

If you doubled the mass of the water and transferred the same amount of heat, what would happen to the temperature change?

=> Checkpoint 6