Name____ Date_______________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

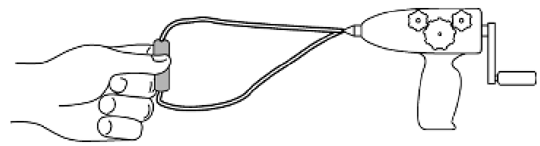
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water
Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid– vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups
Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

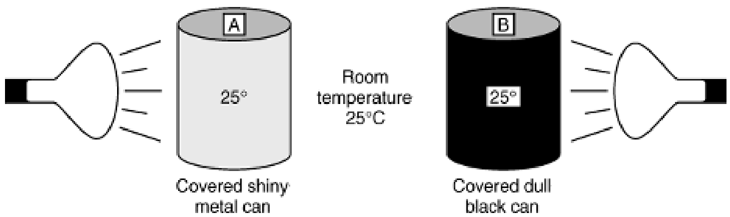
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

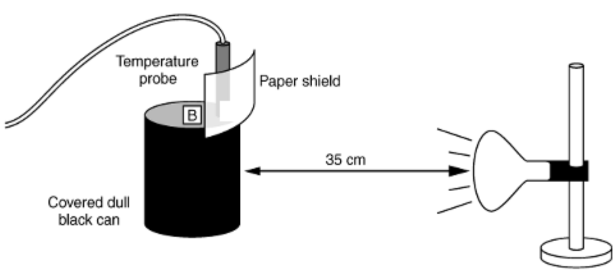


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date______________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

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INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

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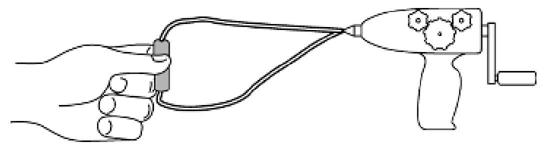
The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need
- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water

Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid–vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:
- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

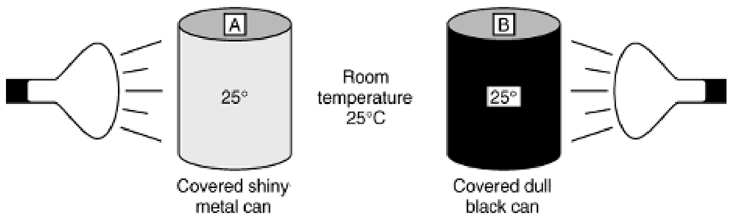
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

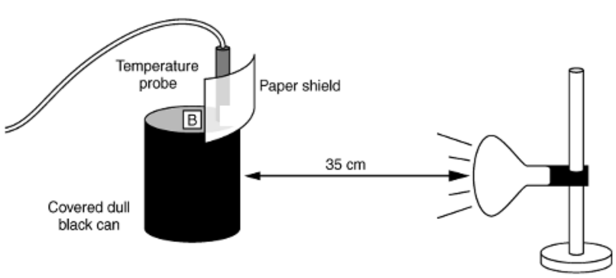


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_______________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

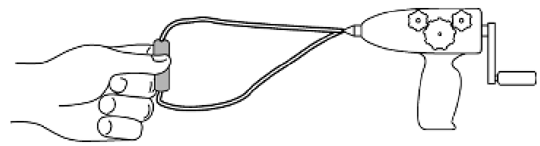
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water
Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

c_{water} =

dc_{water} =

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid– vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

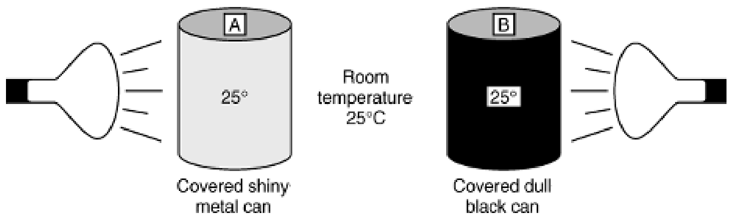
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

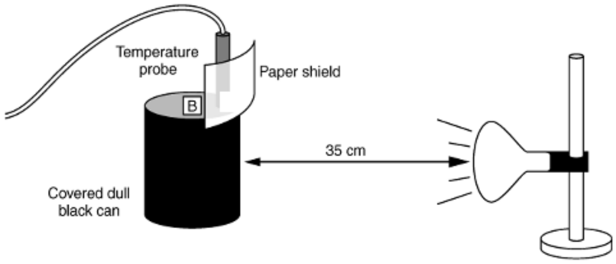


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_____________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

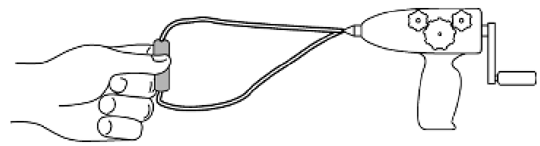
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water
Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value *c* in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid–vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

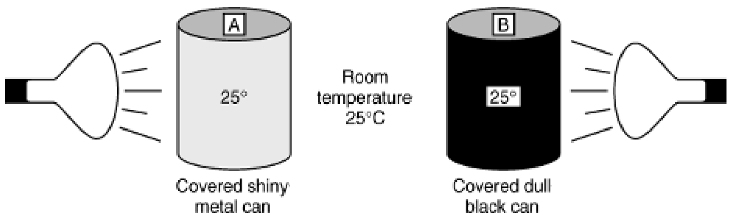
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

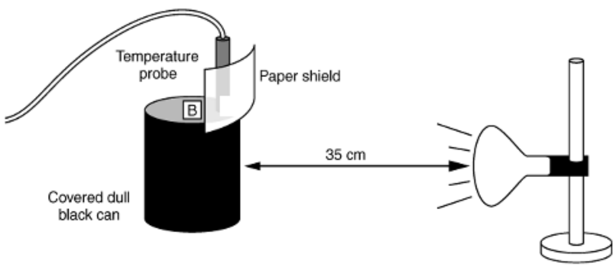


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_______________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

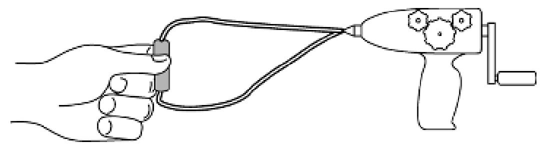
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water
Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A.   How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B.   What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid–vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:
- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

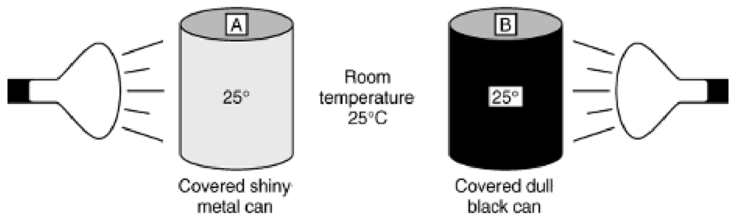
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

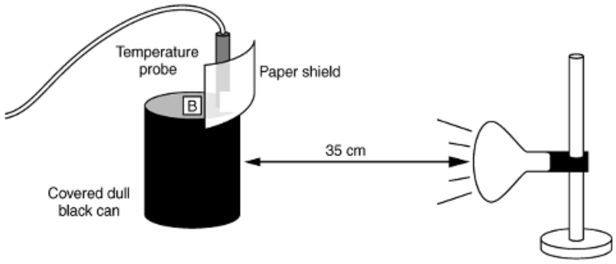


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_____________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

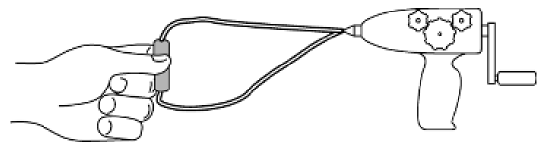
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water
Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A.   How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B.   What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

c_{water} =

dc_{water} =

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid– vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

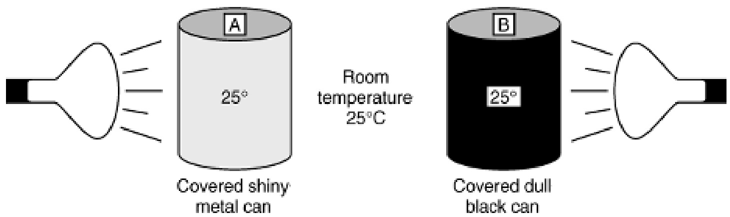
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

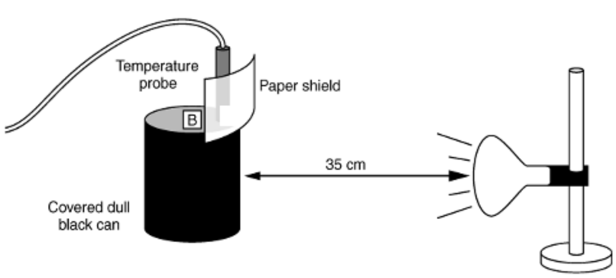


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_______________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

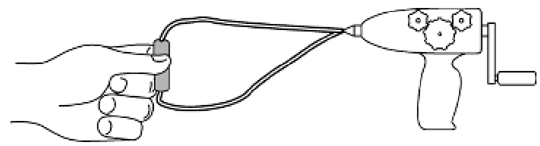
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:

1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.

2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water

Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid– vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

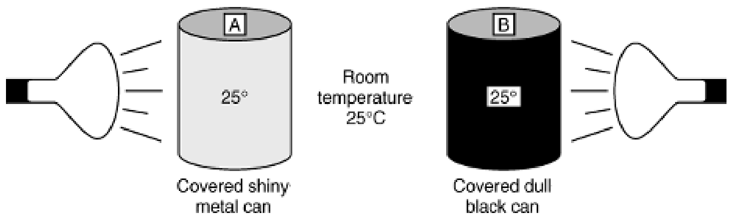
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

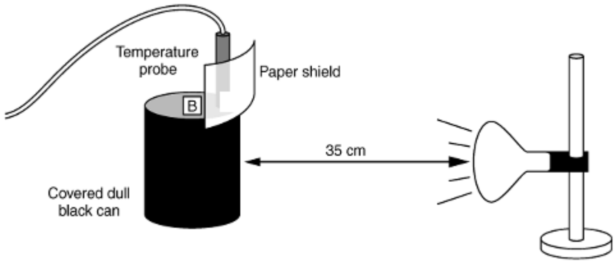


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_____________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

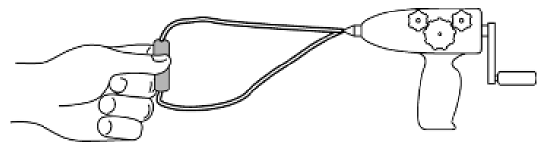
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water

Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid–vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION
In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

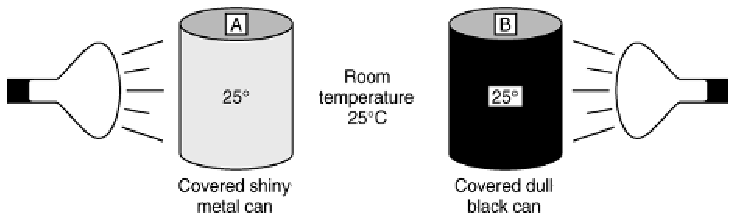
To test your prediction you will need
- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

Activity 5-1: Shiny Metal Can and Dull Black Can
Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

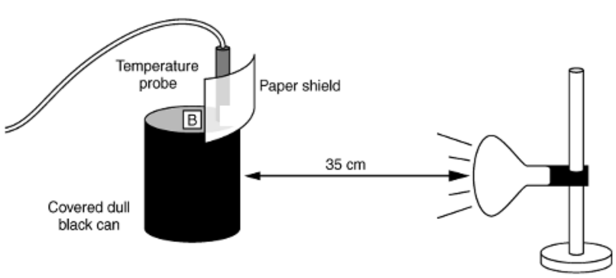


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_______________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

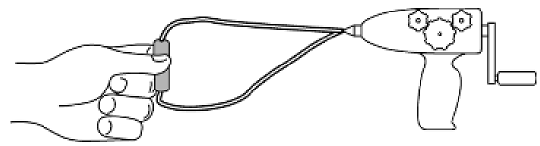
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:

1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.

2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water

Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.

A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{water} =$

$dc_{water} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil

You can use the same method to determine the specific heat of a different liquid–vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

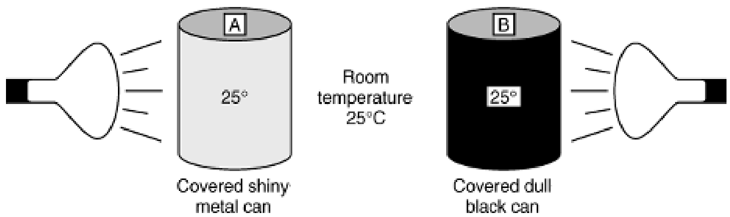
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

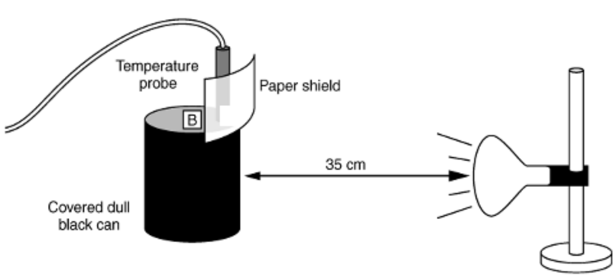


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_____________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

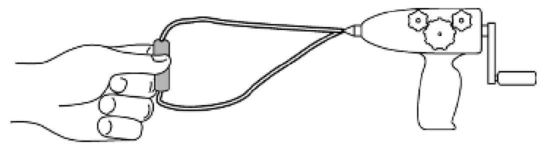
INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor



Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).

Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water

Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid– vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need
- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

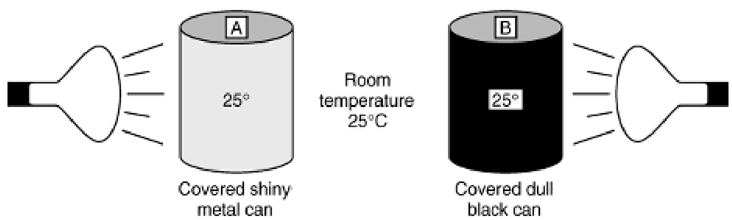
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

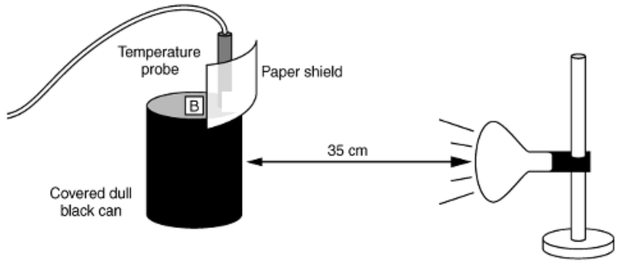


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date______________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

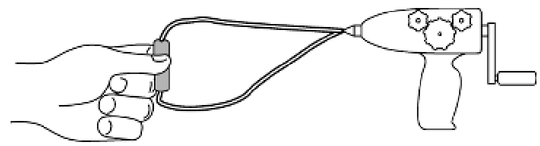
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water
Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil
You can use the same method to determine the specific heat of a different liquid–vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:
- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

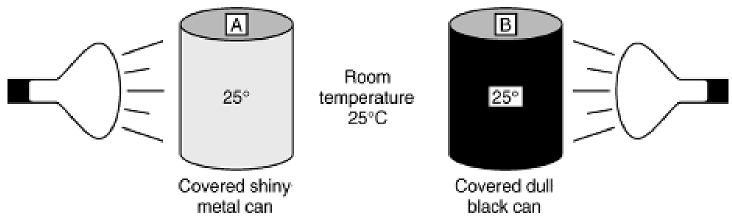
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

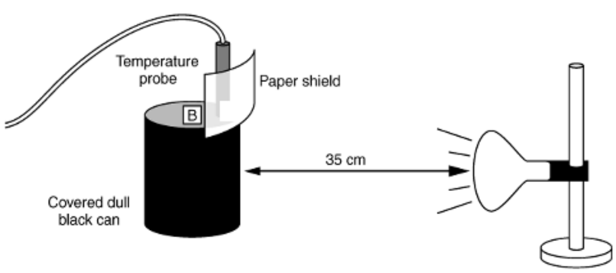


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_______________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

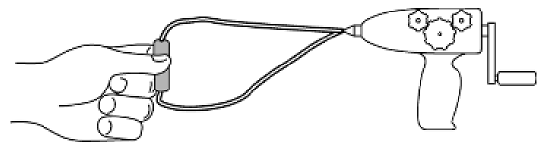
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:
1. Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.
2. Keep stirring the liquid at all times.

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water
Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don’t pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil

You can use the same method to determine the specific heat of a different liquid– vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:
- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

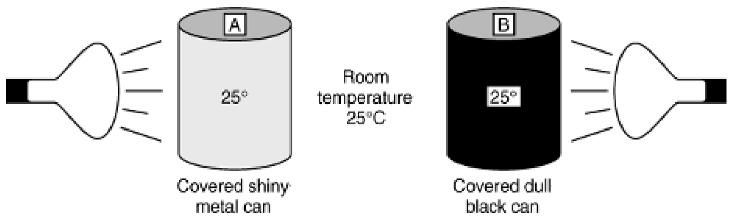
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

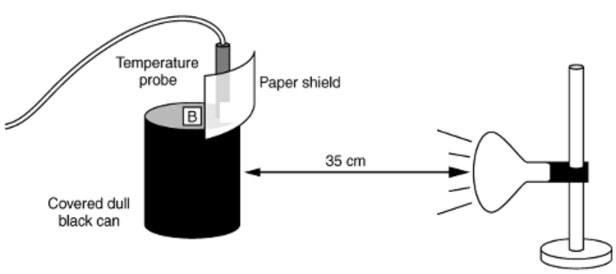


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6

Name____ Date_______________

Physics 216 Lab 9, Spring 2018
Energy Transfer and Temperature Change

Objectives

- To quantify the relationship between heat transfer to a system and the change in temperature of the system.
- To understand the meaning of *specific heat* and measure its value for several liquids.
- To examine the dependence of heat transfer between two objects on the difference in temperature between the objects.
- To explore heat transfer mechanisms.

Overview

So far you have made observations that indicate that energy transfer (via "heat") takes place when two substances in thermal contact are at different temperatures. While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in the first part of this lab you will examine the mathematical relationship between these quantities.

In the second part of the lab, we will look at questions like the following: What are the most effective ways of slowing the inevitable transfer of heat energy from inside to outside your home in the winter, or outside to inside in the summer? A hot cup of coffee on the table will eventually cool down to room temperature. How can you keep it hot longer? You might try a cover, or a Styrofoam cup, or even a Thermos bottle to slow down the inevitable. Which of these is more effective, and how does each work to slow cooling of the coffee?

INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

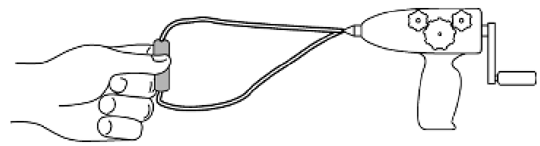
In this investigation you will explore other ways of raising the temperature of a system by observing what happens when you do mechanical work and electrical work on the system. Note: this activity can be done at any time during the lab while you're waiting for something to cool down.

Activity 1-1: Electrical Work and Temperature Change

The hand-operated Genecon generator produces an electric voltage when the crank is turned. The electrical power output of the Genecon when it is connected to an electrical device like a heater increases as the crank is turned faster. (Up to a limit!) That is, the Genecon changes mechanical energy into electrical energy. Therefore, rotating the crank at a uniform rate produces electrical energy at a uniform rate (constant *power*). To explore this, you will need

- Genecon or other hand-operated electrical generator
- 47-Ω resistor

Connect the wires from the Genecon to the wires from the resistor. Hold the resistor between your fingers while your partner rotates the crank as fast and steadily as s/he can (stop before you burn yourself!).



Question 1-1: Describe what you felt. Can electrical energy produce a change in temperature?

Question 1-2: Based on your observations and measurements in this investigation, is it plausible that heat and work are both ways of transferring energy into a system to raise its internal energy? Explain.

INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE CHANGE

If you transfer equal pulses of heat energy to a *perfectly insulated* cup of some liquid, what determines how much temperature change ΔT takes place?

Prediction 2-1: How does ΔT depend on

A. The number of pulses of heat energy you transfer (Q)?

B. The mass (m) of liquid in the cup?

C. The kind of liquid you have?

In this investigation you will conduct a series of observations in which you examine *quantitatively* the relationship between ΔT and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time.

To do the series of observations you should have the following equipment:

- computer-based laboratory system with one temperature sensor
- heat pulser with 200-W immersion heater
- Styrofoam cup
- beaker or can (to keep the Styrofoam cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:

1. **Do not plug in the immersion heater unless it is immersed in liquid. Use enough liquid in each case to make sure the electric coil is covered in every observation.**
2. **Keep stirring the liquid at all times.**

Activity 2-1: Transferring Different Amounts of Heat Energy to the Same Mass of Water

Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker or can to make it more stable.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.

Open the experiment file called **Heating Water (L01E3-2)** to display temperature vs time axes. Click the LabPro icon and **set up the Heat Pulser to transfer 2-s pulses** of heat energy.

Begin graphing. *Stir the water vigorously the entire time the computer is graphing the temperature*, now and during the rest of these activities. Record the initial temperature of the water in Table 2-1.

For the first 10 s, don't pulse the heater. Then pulse the heat pulser by pushing the **HEAT** button or key every 10 s for a total of 4 pulses. *Keep stirring*. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

Use Experiment | Store Latest so that the graph will **remain persistently displayed on the screen** for later comparison.

Calculate the temperature change and the temperature change per pulse and record these in the table.

Now replace the water in the cup with 75 g (mL) of room-temperature water and repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. *Remember to stir the water continuously while graphing, and wait 10 s before pulsing the heater*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in the table.

Table 2-1

Mass of water (g)	Initial temperature (°C)	Final temperature (°C)	Temperature change(°C)	Number of heat pulses transferred	Temperature change per pulse (°C/pulse)
75				4	
75				8	
150					

Question 2-1: How does the change in temperature (ΔT) appear to depend on the amount of heat energy transferred (Q) to a fixed mass of water? State a mathematical relationship in words and as an equation, based on your measurements in this activity.

Question 2-2: Does the temperature *change* produced by one pulse depend on how warm the water already is? Why or why not?

Prediction 2-2: You originally heated 75 g of water with 4 heat pulses. Suppose you transfer heat energy to a larger mass of water.
A. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water*?

B. What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water*?

Replace the water in the cup with twice the mass of room-temperature water as before. Record the beginning temperature of the water in Table 2-1 and repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change* as the 75 g of water had with 4 pulses. *Remember to stir the water continuously while graphing*. When the temperature stops changing, record the final temperature. Calculate the temperature change and change per pulse and record these in Table 2-1.

Question 2-3: Did the number of pulses required to heat twice as much water agree with your prediction? Explain.

Question 2-4: Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

Question 2-5: Based on your graphs and data, does the following mathematical relationship make sense? $Q = cm\,\Delta T$, where Q is the heat energy transferred to the water, m is the mass of the water, ΔT is the change in temperature, and c is a constant characteristic of the liquid. Explain how well your results are described by this relationship.

° Checkpoint 1

Activity 2-2: Specific Heat of Water

In the previous two activities, you have examined the relationship between the amount of heat energy transferred to a system and the system's change in temperature. To be more quantitative (e.g., to be able to predict numerical temperature changes), it is necessary to specify what amount of heat energy transfer will produce a one degree change in temperature in a unit mass of a material. This quantity is known as the *specific heat* of the material. It is the value c in the equation in Question 2-5.

$$\text{specific heat} = c = \frac{\Delta Q}{m\Delta T}$$

The standard units for heat energy (J), mass (kg), and temperature (°C), give us the unit for specific heat, J/kg·°C.

Use the data from the previous activity to determine the specific heat of water. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-2. Calculate the total heat energy transferred by the heater using the power rating of the heater in watts (W) and the total time of heat pulses transferred to the water in each run of the experiment. Then calculate the specific heat for each run.

Table 2-2

Mass of water (kg)	Number of heat pulses	Total time of heat pulses (s)	Total energy transferred by heater(J)	Change in temperature (°C)	Specific heat (J/kg·°C)
0.075	4				
0.075	8				
0.150					

Calculate the average value of the specific heat of water from the three values in your table, and then calculate the uncertainty using the standard deviation of the mean of the three values in the table:

$c_{\text{water}} =$

$dc_{\text{water}} =$

Question 2-6: How closely do the three values of the specific heat agree with each other?

Question 2-7: How well does the average value with its uncertainty agree with the accepted value, c_{water} = 4186 J/kg·°C? If your measured value is not in good agreement with the accepted value, is your measured value too small or too large?

Question 2-8: Can you think of any reasons why you would expect your measured value to differ from the accepted value? Do your reasons explain why the value came out the way it did?

° Checkpoint 2

Extension 2-3: Specific Heat of Vegetable Oil

You can use the same method to determine the specific heat of a different liquid– vegetable oil. In addition to the materials used before, you will need

- room-temperature vegetable oil
- clean, dry Styrofoam cup

Warning: Do not heat the oil over 70°C at any time during the experiment!!!!

Based on Activities 2-1 and 2-2, devise a procedure to find the specific heat of vegetable oil with an estimate of the uncertainty. (*Note that vegetable oil has a different density than water*.) Describe the steps below and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

Results (with uncertainty):

Question 2-9: Which substance changes temperature the most for a given amount of heat energy transfer, the water or the oil? Which has the larger specific heat?

° Checkpoint 3

INVESTIGATION 3: HEAT ENERGY TRANSFER AND TEMPERATURE DIFFERENCE

Without perfect insulation, a house will transfer heat energy to its surroundings when it is colder outside than inside. How much energy is needed to replace this heat energy, and how might we reduce the rate of energy loss? In the following activities you will look more quantitatively at the factors that affect the rate at which heat energy is transferred from one object to another.

In the next investigation, you will explore how the rate of heat energy transfer depends on the difference in temperature. This should shed some light on your winter heating bill. In the remaining investigations you will look at the ways that heat energy is transferred–*conduction, convection, and radiation*–and the most effective ways of reducing each of them.

Activity 3-1: Hot water becomes cool water

Prediction 3-1: How does the rate of heat energy transfer from hot water to the cooler room depend on the temperature of the water? Suppose that room temperature is 20°C and you have two cups of water, one at 30°C and one at 60°C. Will you need to transfer heat energy at a different rate to keep these cups at 30 and 60°C? If so, which one will have a higher rate of heat energy transfer, and how much higher (twice as large? three times as large? some other ratio)?

To test your predictions you will need

- computer-based laboratory system with one temperature sensor
- hot water (about 70°C)
- container marked in mL
- *uninsulated* glass beaker
- vat (to prevent spills)

Open the experiment file called **Cooling Down (L03A2-1)**. Record room (air) temperature in Table 3-1. Pour about 100 mL of hot water about 45°C warmer than room temperature into the *uninsulated*, uncovered cup. Put the sensor into the water.

Table 3-1

Initial temperature of water	Room (air) temperature	Temperature difference (°C)	Time for temperature to drop 1 °C (s)	Rate of cooling (°C/s)

Begin graphing, and *while stirring continuously* wait till the temperature drops 1.0 °C from the initial value. Record in Table 3-1 the initial temperature and the time for the temperature to drop by 1.0°C.

Repeat this process, recording the time it takes for water that is about 35°C above room temperature to drop by 1.0°C, and the time it takes for water that is about 25°C above room temperature to drop by 1.0°C. You may need to change the temperature axis on your graph. Be sure to stir continuously.

Prediction 3-2: How much time do you think it will take to keep the same amount of water 15°C warmer than room temperature to drop 1.0 °C? Explain your answer.

Test your prediction by repeating the procedure above for water that is about 15°C above room temperature. Be sure to stir continuously. Record your data in Table 3-1.

Question 3-1: How did your results compare with your prediction?

Question 3-2: Describe the relationship between rate of heat energy transfer and difference in temperature based on your data in Table 3-1.

Carry out Extension 3-2 in which you try to find a mathematical relationship between rate of heat transfer and temperature difference.

Extension 3-2: The Mathematical Relationship Between Heat Energy Transfer and Temperature Difference

Open a new (blank) LoggerPro file. In the table that appears, enter in adjacent columns the temperature difference and the rate of cooling from your data in Table 3-1, and produce a graph of rate of cooling vs. temperature difference.

Determine a mathematical relationship between the rate of heat energy transfer and the temperature difference using the Analyze/Curve Fit feature of LoggerPro. Is it appropriate to force the fit to pass through the origin? Why?

Print and/or save the graph (you'll need it for the postlab exercises).

Question E3-4: What does the mathematical relationship appear to be between the rate of heat energy transfer from a sample of hot water and the difference between the temperature of the water and room temperature?

° Checkpoint 4

INVESTIGATION 4: CONTROLLING THE TRANSFER OF HEAT ENERGY

In the previous investigation you observed that the rate at which heat energy is transferred from a warmer object to a cooler one depends on the *difference* in temperature. Consider a cup of hot coffee on the table in the lab. You might put it in a Styrofoam cup with or without a lid, a ceramic cup, a metal cup, etc. In each case, the initial temperature difference is the same, and in each case we know that the coffee will eventually cool down to room temperature. What else does the rate at which the temperature of an object changes depend on?

The transfer of heat energy from the hot coffee to its surroundings takes place through several different mechanisms. There is *conduction* through the cup into the table and surrounding air. There is *convection* from the air flow that results when the air is heated by the cup and coffee. Convection can also include some evaporation from the surface of the coffee. Finally, there is *radiation*, the electromagnetic waves (mostly infrared) emitted from the hot surfaces of the cup. In this investigation you will do

several experiments to see whether conduction or convection is a more important mechanism of heat energy transfer. In the next investigation, you will look at radiation.

Prediction 4-1: Which cup do you think will cool faster, a covered cup or an uncovered cup, both containing water at the same initial temperature? Do you think that covering a cup will make much difference in the rate of cooling?

You will need the following to test your prediction:
- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- 2 Styrofoam or other insulated cups with 75-mL marks
- Styrofoam covers with small hole for temperature sensor and Styrofoam pads to set cups on
- vat (to prevent spills)

Activity 4-1: To Cover or Not to Cover?
Open the experiment file called **Cooling Down (L03A2-1)** to set up temperature-time axes.

Place the two foam cups on Styrofoam pads on the table and be ready to cover one. Push the temperature sensor through the hole in the cover so that it fits tightly.

Record room (air) temperature: ______

Pour the same amount of water (about 75 mL) at about 70°C into each cup. This can most easily be done quickly by making a 75-mL mark on both cups beforehand and then filling to this mark.

Now, put the cover (with sensor) on one cup. Put a sensor in the other cup. *Both cups should be within about a degree of the same temperature–about 70°C–when you begin graphing*. If they are not, start over or use the immersion heater to heat the water.

Begin graphing and continue for 4 min. When the 4 minutes are up, use the analysis features in the LoggerPro software to record the initial and final temperatures of each cup in Table 4-1.

Question 4-1: From which cup was the most heat energy transferred during the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

Question 4-2: Did the cover slow down the rate of heat energy transfer very effectively? Explain your answer, using your experimental results.

Table 4-1

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Covered foam cup			
Uncovered foam cup			
Covered foam cup			
Covered metal cup			
Covered foam cup			
Covered double foam cup			
Rows below for Activity 5-1			
Covered shiny metal can			
Covered black painted can			

Activity 4-2: Covered Double-Foam and Covered Single-Foam Cups

Prediction 4-2: You found that a cover slowed down the rate of heat energy transfer. Which cup do you think will cool faster, a *covered* double-foam cup or a *covered* single-foam cup? Do you think that one will be very different from the other in its rate of cooling?

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* double-foam cup and through a *covered* single-foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 4-3: Which cup had the smaller change in temperature? Did it differ a lot or a little from the other in its rate of cooling?

Activity 4-3: Metal or Foam Cup

Prediction 4-3: Which cup do you think will cool faster, a covered metal cup or a covered foam cup? Do you think that one will be very different in its rate of cooling?

Compare the rate of temperature decrease (and heat energy transfer) through *a covered* metal cup and through a *covered* foam cup. Use 70°C water and the method of the previous activity. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Hint: to get the starting temperatures to be similar, you may need to add a little room-temperature water to the foam cup while stirring. Record your data in Table 4-1.

Question 4-4: Which cup had the smaller change in temperature?

Question 4-5: Why does the temperature drop so quickly when the hot water is first placed in the metal cup?

Use your data in Table 4-1 to answer the following questions.

Question 4-6: Overall, which cup seemed most effective in decreasing the rate of heat energy transfer to the surroundings? Least effective? If you wanted to keep a cup of coffee hot, which of the things in the following list is most important? Second most important?

cover the container

substitute foam for metal

double the thickness of the foam

Question 4-7: Which mode of heat energy transfer–*conduction* or *convection*–is most affected by each of the methods explored in this investigation?

covering the container

substituting foam for metal

doubling the thickness of the foam

° Checkpoint 5

INVESTIGATION 5: HEAT ENERGY TRANSFER BY RADIATION

In the previous investigation, you examined the transfer of heat energy by conduction and convection. You looked at several ways that this transfer can be controlled by changing the construction of the container and the materials from which it is made. In this investigation, you will examine how the properties of the surface of the container affect radiation, the third important means of heat energy transfer.

Prediction 5-1: Two covered cans are filled with hot water. One is a shiny metal can, while the other is a dull black metal can. Which water do you think will cool at a faster rate? Do you think that one will be very different from the other in its rate of cooling? Why?

To test your prediction you will need

- computer-based laboratory system with two temperature sensors
- hot water (about 70°C)
- container marked in mL
- two similar cans, one unpainted (shiny) and one painted flat black on the outside
- covers with holes for temperature sensor

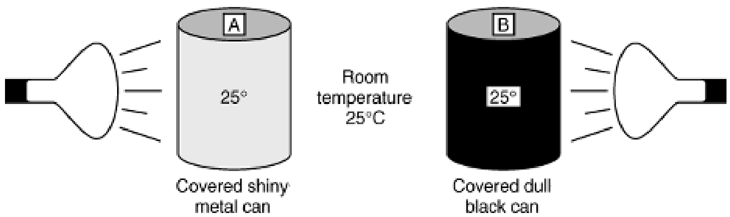
Activity 5-1: Shiny Metal Can and Dull Black Can

Compare the rate of temperature decrease (and the rate of heat energy transfer) through a *covered* shiny metal can and through a *covered* dull black painted can. Place the cans on top of the foam slabs. (You should be able to explain why the covers and foam slabs are important.) Use 70°C water and the method of Activities 4-1 to 4-3. *Be sure that both starting temperatures are the same and that the covers fit tightly*. Record your data in Table 4-1.

Question 5-1: Which cup had the smaller change in temperature in the 4 min? If you had to keep these cups at the same constant temperature using a heater, to which cup would you need to transfer heat energy at a faster rate?

You observed that a covered shiny can cools down differently than an identical can painted on the outside with flat black paint. What is going on here? It can't have to do with convection or conduction, since these have been reduced by the cover and the foam pad, and, in any case, should be the same for both cans. In the next activity, you will further examine the transfer of energy by radiation and how it is affected by the surfaces of objects.

Activity 5-2: Heating With Radiation

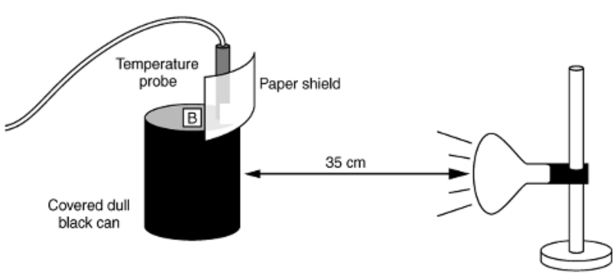


Prediction 5-2: Two cups of water absorb radiation from identical heat lamps. Both cups are covered and are identical except that one is shiny and the other is painted with flat black paint on the outside. Both cans contain 100 g of water at room temperature. Will the temperature of the water rise faster in the shiny or black can? Explain.

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

- heat lamp and socket
- meter stick
- piece of white paper to shield the temperature sensor

Open the experiment file called **Radiation (L03A3-2)**. Set up the heat lamp and black can as shown below, with the can on top of the foam pad. The face of the lamp and the can should be directly across from each other at the same height and about 35 cm apart. The paper shield should be taped so that it prevents radiation from the lamp from reaching the temperature sensor or wire directly.



Pour 75 mL of room-temperature water into the can, insert the temperature probe in the cover, and place the cover tightly on the can. Record the initial temperature of the water in Table 5-2. **Begin graphing** and turn on the heat lamp. At the end of 4 min, record the final temperature of the water in the table. Store the data so that the graph is **persistently displayed on the screen**.

Table 5-2

Experimental conditions	Initial temperature (°C)	Final temperature (°C)	Temperature change in 4 min (°C)
Black covered metal can			
Shiny covered can			

Repeat the procedure with the shiny metal can at exactly the same distance from the heat lamp. Record the initial and final temperatures in the table.

Calculate the temperature changes for 4 min for the two cans from your data.

Question 5-2: How did your prediction agree with your observations?

Question 5-3: Based on your observations, to which surface does the radiation from the heat lamp seem to be transferred at a faster rate–the black one or the shiny one?

Question 5-4: Based on your observations in Activity 5-1 and your answer to Question 5-1, what is the relationship between effectiveness at emitting radiation and effectiveness at absorbing radiation? If a surface is effective at absorbing radiation, will it be effective at emitting the same radiation?

° Checkpoint 6