Name____________________ Date______________

# Pre-Lab Preparation Sheet for Lab 2: Energy Transfer and Temperature Change

*(Due at the beginning of Lab 2)*

**Directions:**
Read over Lab 2 and then answer the following questions about the procedures.

1. What is your Prediction 1-1?

2. What is your Prediction 2-1?

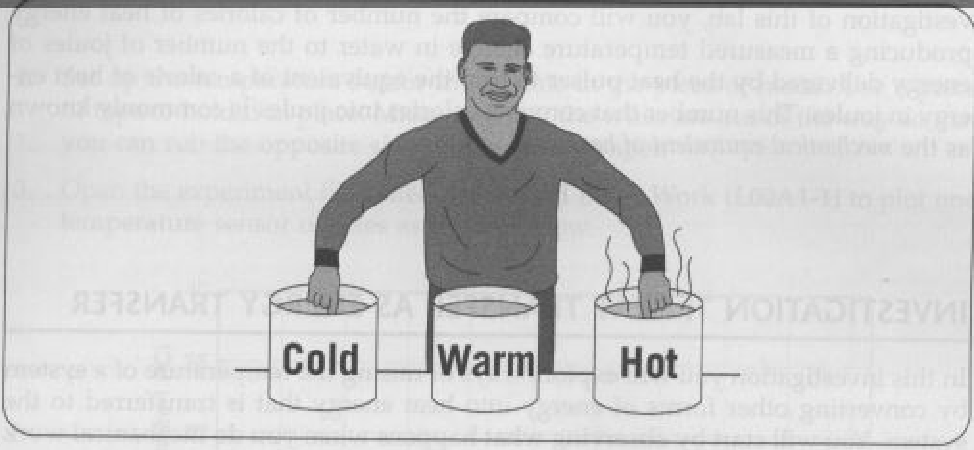
3. Why are first 4 and then 8 pulses of heat transferred to the same mass of water in Activity 2-1?

4. How is specific heat capacity defined? How will you find the specific heat capacity of water in Activity 2-2?

5. What is the meaning of *mechanical equivalent of heat?*

Name________________ Date__________ Partners________________

# LAB 2: ENERGY TRANSFER AND TEMPERATURE CHANGE




*. . . the quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of energy expended.*

—James Joule

## OBJECTIVES

- To establish the concept of *heat* as *heat energy transfer* from a substance at a higher temperature to one at a lower temperature.
- To quantify the relationship between the heat energy transferred 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 determine the equivalence between the common unit of heat energy, the *calorie*, and the unit of energy, the *joule*.

## OVERVIEW

So far you have made observations that indicate that interactions take place when two substances in thermal contact are at different temperatures. We have called these interactions "heat energy transfer." There are other ways to raise the temperature of an object. For example, you could rub a piece of metal on emery paper or sandpaper and measure its temperature increase with a thermometer. Also, as you have observed in Lab 1, it is possible to produce a temperature increase using an electric heater by supplying electrical energy to it. Observations like these caused physicists and engineers in the middle of the nineteenth century to conclude that heat is just a form of energy, the form that flows when there is a temperature difference between two objects. Today a physicist or engineer would say that *heat is actually heat (or thermal) energy transfer.*

While you have already observed a relationship between the heat energy transferred to a system and the temperature change of the system, in this lab you will examine the mathematical relationship between these quantities. In doing so, you will look at the amount of heat energy transfer needed to raise the temperature of one unit of mass of a substance by one degree, which is called the *specific heat* of the substance. You will find the specific heat of water and another liquid.

The common unit of heat energy is the calorie. Mechanical energy is measured in joules, a familiar unit used in your study of mechanics. In the final investigation of this lab, you will compare the number of calories of heat energy producing a measured temperature change in water to the number of joules of energy delivered by the heat pulser to find the equivalent of a calorie of heat energy in joules. This number that converts calories into joules is commonly known as the *mechanical equivalent of heat*.

## INVESTIGATION 1: HEAT TRANSFER AS ENERGY TRANSFER

In this investigation you will explore ways of raising the temperature of a system by converting other forms of energy into heat energy that is transferred to the system. You will start by observing what happens when you do mechanical work on the system and then when you do electrical work on the system.

**Prediction 1-1:** If you hold a piece of metal in your hand and rub it back and forth on emery paper or sandpaper, do you expect the temperature of the metal to change? How will it change?

Suppose that you rub the metal back and forth for twice as long a time. Will the temperature change be different from before? If so, how will the temperature change differ?

To test your predictions you will need

- computer-based laboratory system
- temperature sensor
- *RealTime Physics Heat and Thermodynamics* experiment configuration files
- fine emery paper or sandpaper
- iron nail
- piece of metal with embedded electrical heater, hole for temperature sensor, and foam insulation with which to hold it



### Activity 1-1: Mechanical Work and Temperature Change

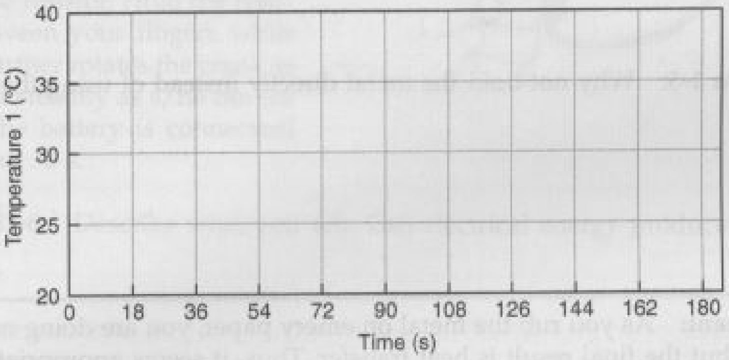
1. Grasp the nail near its head with your fingers, with the head facing down, and rub it vigorously back and forth on the emery paper.

**Question 1-1:** Describe what you felt. Was there a temperature change?

**Question 1-2:** Was there any transfer of matter to the nail as the rubbing took place? Was there any evidence of mechanical work being done while the rubbing took place? Explain.

2. Set up the temperature sensor in the hole in the piece of metal. Use a piece of tape to hold it in place. Make sure that the wires are out of the way so that you can rub the opposite side on the emery paper.

3. Open the experiment file called **Mech. and Elect. Work (L02A1-1)** to plot one temperature sensor on axes as shown below.




4. If necessary, **load the calibration file** for your temperature sensor.

5. **Begin graphing,** and then after 10 s, hold the metal using the foam insulation and begin rubbing the bottom of the metal on the emery paper. Rub for 20 s, applying a uniform force and moving the metal back and forth over a distance of about 10 cm (3 inches) on the emery paper.

6. After the 20 s of rubbing, hold the metal above the emery paper (grasping it with the foam) until the temperature stops changing. Then wait about 5 s more, *note the time,* and rub for 40 s more. Try to rub with the same force and over the same distance as before.

   Again hold the metal with the foam, this time until the end of the 180 s.

7. If you are going to do Extension 1-2, then transfer your data so that the graph will **remain persistently displayed on the screen** for later comparison.

8. **Print your graph** and affix it over the previous axes. Indicate with double arrows on the graph the time periods when the metal was being rubbed.

9. Use the **analysis feature** of the software to read the data from your graph and fill in Table 2-1.

> **Comment:** By rubbing with the same force over the same length, the rate of doing work (the *power*) should be constant. If this is so then the total work done in rubbing the metal on the emery paper should be proportional to the time interval of rubbing. That is, if you rub for twice as long, you will do twice as much work.

**Table 2-1**

| Time interval of rubbing (s) | Final temp. (°C) | Initial temp. (°C) | Temp. change (°C) |
|---|---|---|---|
| 20 | | | |
| 40 | | | |

**Question 1-3:** Based on your data, does there appear to be a relationship between the temperature change and the work done by rubbing? Explain.

**Question 1-4:** What does the shape of your graph imply about the relationship between the work done and the temperature change?

**Question 1-5:** Why not hold the metal directly instead of using the foam insulation?

**Comment:** As you rub the metal on emery paper, you are doing mechanical work, but the final result is heat transfer. Thus, it seems appropriate to associate heat transfer as *heat energy transfer.*

It is important to carefully distinguish between the concepts of temperature and heat energy transfer as we have refined them in this activity. They are summarized below.

1. *Heat energy* is energy in transit between two systems in thermal contact due to temperature difference only, with the hotter system losing heat energy as the cooler system gains it. To remind ourselves of this, we will often use the phrase *heat energy transfer.*
2. Two objects are in *thermal equilibrium*, and hence have the *same temperature,* if no energy on average is exchanged between them when they are placed in thermal contact.

If you have additional time, carry out Extension 1-2, in which you will examine temperature changes as a result of conversion of electrical energy to heat energy.

## Extension 1-2: Electrical Work and Temperature Change

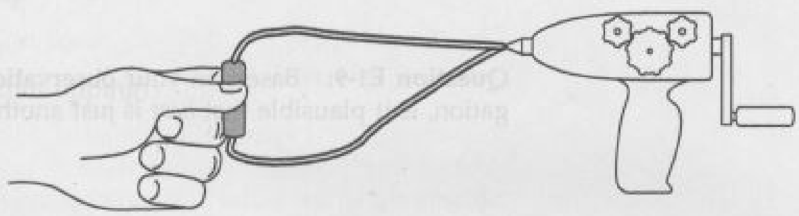
The hand-operated generator produces an electric voltage when the crank is turned. The electrical power output of the generator (when it is connected to an electrical device like a heater, for example) increases as the crank is turned faster. (Up to a limit!) That is, the generator changes mechanical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

[If a generator is not available, you may use a 6-V lantern battery instead. In this case the electric voltage is produced by chemical reactions inside the battery— Chemical energy is changed into electrical energy. As long as the battery is connected to an electrical device like a heater, it produces electrical energy at a uniform rate (constant *power*).]

In addition to the materials above, you will need

- Hand-operated electrical generator [or a 6-V lantern battery]
- 47-Ω resistor
- ½-inch-thick slab of foam insulation

1. Explore the effect of the generator [or battery] on the resistor. Connect the wires from the generator [or battery] 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 [or while the battery is connected] for about 30 s.



**Question E1-6:** Describe what you felt. Can electrical energy produce heating effects?

2. The software should be set up as in the previous activity—experiment file called **Mech. and Elect. Work (L02A1-1).**
3. Connect the generator to the resistor embedded in the metal used in Activity 1-1. [If you are using a battery, don't connect it until you have been graphing for 10 s.] Insert the temperature sensor into the piece of metal as in Activity 1-1. Keep the metal isolated from the table with the piece of foam insulation.
4. **Begin graphing,** and then after 10 s, begin turning the crank as fast as you can while maintaining a steady rate [or connect the battery]. Crank for 20 s. [Disconnect the battery after 20 s.]
5. After the 20 s, wait until the temperature stops changing. Then wait about 5 s more, *note the time,* and crank for 40 s more. [Connect the battery for 40 s more.] Try to crank at the same steady rate as before.

   Stop cranking [disconnect the battery] for the rest of the 180 s.
6. **Print your graph** and affix it over the previous axes. Indicate with double arrows on the graphs the time periods when the generator was being cranked [or the battery connected].
7. Use the **analysis feature** in the software to read the data from your graph and fill in Table E2-2.

**Question E1-7:** Compare your graphs for mechanical and electrical heating. In what ways are they similar and different?

**Table E2-2**

| Time interval of cranking (s) | Final temperature (°C) | Initial temperature (°C) | Temperature change (°C) |
|---|---|---|---|
| 20 | | | |
| 40 | | | |

**Question E1-8:** Does there appear to be a relationship between the temperature change and the electrical energy generated by cranking the generator [or by the battery]? Explain.

**Question E1-9:** Based on your observations and measurements in this investigation, is it plausible that *heat* is just another form of *energy?* Explain.

> **Comment:** As you crank the generator, mechanical work is causing the generation of electrical energy. Again, as in Activity 1-1, the final result is heat transfer.

In the next investigation you will again use a heat pulser as in Lab 1. Now you can understand the mechanism of the heating effect as the conversion of electrical energy to heat energy.

## INVESTIGATION 2: RELATIONSHIP BETWEEN HEAT ENERGY AND TEMPERATURE

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

**Prediction 2-1:** How does $\Delta T$ 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 $\Delta T$ and these other variables. To do this you will need to investigate all three factors by changing only one variable at a time. For example, you can use the same mass of room-temperature water for a series of experiments and vary only the amount of heat energy you transfer. Then you can use the same amount of heat energy and vary the mass of the water. Finally, you can use the same mass of liquid and the same amount of heat energy and vary the type of liquid (e.g., use oil instead of water).

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

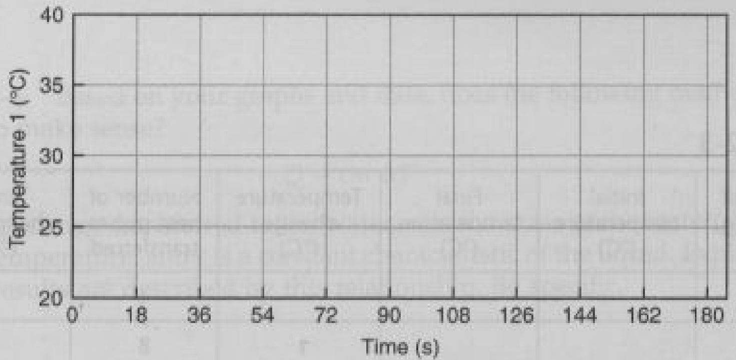
- computer-based laboratory system
- temperature sensor
- *RealTime Physics Heat and Thermodynamics* experiment configuration files
- heat pulser with 200-W immersion heater
- Styrofoam or other insulated cup
- stirring rod
- glass beaker (to keep the cup from tipping)
- room-temperature water
- electronic balance
- vat (to prevent spills)

Warnings:

1. **Do not plug in the immersion heater unless it is immersed in water.**
2. **Use enough liquid in each case to make sure the electric coil is just covered in every observation. Be careful not to use large amounts of liquid, because the heating process will take too long! Keep stirring the liquid at all times.**

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

1. Put a temperature sensor and the heater into the foam cup. (Put the foam cup in the beaker to avoid spillage.) Add 75 g (mL) of room-temperature water to the cup. Be sure that the water covers the coils of the heater.
2. Open the experiment file called **Heating Water (L02A2-1)** to display the axes that follow. This will also set up the heat pulser to transfer 5-s pulses of heat energy.




3. If necessary, **load the calibration** for the temperature sensor.

4. **Begin graphing.** *Stir the water vigorously the entire time the computer is graphing the temperature,* now and during the rest of these activities.

5. Measure the initial temperature of the water and record it in Table 2-3. (The temperature can be read more accurately from the digital display than from the graph.)

6. For the first 10 s, don't pulse the heat pulser. Then pulse it by pushing the Pulse button every 10 s for a total of 4 pulses. *Keep stirring.*

7. After the temperature stops changing, record the highest temperature reached as the final temperature in the table.

8. Transfer the data so that the graph will **remain persistently displayed on the screen** for later comparison.

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

**Question 2-1:** Describe the shape of your graph. What does this say about the relationship between the temperature change and the quantity of heat energy transferred to the water? (Remember that heat pulses were transferred at a constant rate.)

10. Replace the water in the cup with 75 g (mL) of room-temperature water. Record the beginning temperature of the water in Table 2-3.

11. Repeat this activity, transferring twice as many heat pulses (8) at a relatively constant rate to the same amount of water. Use the same setup as before.

    *Remember to stir the water continuously while graphing.* (Don't pulse the heater during the first 10 s, and then pulse the heater every 10 s for a total of 8 pulses.) When the temperature stops changing, record the final temperature.

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

13. **Print your graphs** and affix them over the previous axes.

**Question 2-2:** How does the change in temperature ($\Delta T$) 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.

**Table 2-3**

| 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 2-3:** Does the temperature *change* produced by one pulse depend on how warm the water is? Give evidence from your observations.

**Prediction 2-2:** Suppose you transfer heat energy to a larger mass of water. How will the temperature change?

**A.** You heated 75 g of water with 4 heat pulses. How many pulses do you think it will take to produce the same temperature increase if you heat *twice as much water* (150 g)? ______

**B.** What will be the temperature increase per pulse if you produce the same temperature increase for *twice as much water* (150 g)? ______

**14.** Replace the water in the cup with 150 g (mL) of room-temperature water. Record the beginning temperature of the water in Table 2-3.

**15.** Use the same setup as before. Repeat this activity, transferring enough heat pulses at a relatively constant rate to produce the *same temperature change as produced by 4 pulses for 75 g of water.*

*Remember to stir the water continuously while graphing.* (Don't pulse the heat pulser during the first 10 s, and then pulse it every 10 s.) When the temperature stops changing, record the final temperature.

**16.** Calculate the temperature change and change per pulse and record these in Table 2-3.

**17.** **Print the graph** and affix it below the previous graphs.

**Question 2-4:** Did the number of pulses required to heat 150 g of water agree with your prediction? Explain.

**Question 2-5:** Did the rise in temperature per pulse you calculated agree with your prediction? Explain.

**Question 2-6:** Based on your graphs and data, does the following mathematical relationship make sense?

$$Q = cm\,\Delta T$$

$Q$ is the heat energy transferred to the water, $m$ is the mass of the water, $\Delta T$ is the change in temperature, and $c$ is a constant characteristic of the liquid. Explain how well your results are described by this relationship. Be specific.

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. You have seen that the change in temperature is proportional to the amount of heat energy transferred and inversely proportional to the mass of the system. 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 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 2-6.

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

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

In the next activity you will calculate the specific heat of water from your data.

## Activity 2-2: Specific Heat of Water

1. Enter the number of pulses and temperature change data from Activity 2-1 in Table 2-4. Carry out the calculations in steps 2–3 to fill in the rest of the table.
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. (Recall that 1 W = 1 J/s.)
3. Calculate the specific heat for each run.
4. Calculate the average value of the specific heat of water from the three values in your table:

$$c_{water} =$$

**Question 2-7:** How closely did the three values of the specific heat agree with each other? How did the average value agree with the accepted value, e.g., in your textbook? What are the possible sources of experimental error that might explain any disagreement?

**Table 2-4**

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

**Question 2-8:** If the heater were plugged directly into a wall outlet so that it was transferring heat to the water continuously, how many seconds would it take to raise the temperature of 300 g of water by 25°C? Show your calculation and explain your reasoning. (Use $c_{water}$ = 4190 J/kg-°C.)

If you have enough time, carry out Extension 2-3 to find the specific heat of another liquid, vegetable oil.

## Extension 2-3: Specific Heat of Vegetable Oil

You can use the same method as in Activities 2-1 and 2-2 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 or other insulated cup

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

1. Follow the same procedure as in Activities 2-1 and 2-2 to find the specific heat of vegetable oil. Use just one run with a sample of about 75 g. (*Note that vegetable oil has a different density than water.*)
2. Describe the steps below *in words* and record all data, calculations, and the measured specific heat below.

Description of the procedure:

Data:

Calculations:

$c_{oil}$ = ______

**Question E2-9:** 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?

**Question E2-10:** Back in the good old days when a kid was given a hot baked potato to carry to school on a cold winter day, the potato kept her warm and served as lunch! Why might a hot potato be a better kid warmer than a bag of hot popcorn?

## INVESTIGATION 3: THE MECHANICAL EQUIVALENT OF HEAT

Before the mid-nineteenth century, *heat* was regarded as a substance rather than as a form of energy exchange between two substances. Heat was measured in its own special units called *calories*. By definition,

1 calorie = the quantity of heat that raises the temperature of 1 gram of water by 1 degree Celsius

(Note that the food calorie (also called a kilogram calorie or kilocalorie) is 1000 times larger than this.)

According to the definition of the calorie, the specific heat of water is

$$c_{\text{water}} = 1.0 \text{ cal/g-°C}.$$

In the mid-nineteenth century, James Joule carried out a series of experiments converting mechanical and electrical energy to heat, demonstrating that heat is a form of energy and not a substance, as you have seen in Investigation 1.

The immersion heater that you used in Investigation 2 works in the same way as the resistor connected to the generator (or battery) used in Investigation 1. The electrical energy transferred to the heater (supplied through the electrical outlet) is produced by a generator located at a power plant. The equivalent of your hand turning the crank of the generator is the transformation of either chemical potential energy (stored in fossil fuels), nuclear potential energy (stored in nuclear fuels), or gravitational potential energy (stored in water above a dam) into mechanical energy of the generator.

In the next activity you will find the quantitative *mechanical equivalent of heat*. Thus you will determine the number of joules that are equivalent to a calorie of heat energy.

### Activity 3-1: The Energy Equivalent of the Calorie

1. Choose the run in Table 2-4 that gave the specific heat value closest to 4190 J/kg-°C and enter the data in Table 2-5.
2. Calculate the total heat energy transferred to the water *in calories* using the relationship $Q = cm\,\Delta T$, using the specific heat of water in cal/g-°C, and enter in the fifth column of the table.
3. Calculate the mechanical equivalent of heat in J/cal (the ratio of the heat transferred by the heater in joules to the calculated heat in calories).

Table 2-5

| Mass of water (kg) | Total time of heat pulses (s) | Total energy transferred by heater (J) | Change in temperature (°C) | Calculated total heat energy transferred to water (cal) | Mechanical equivalent of heat (J/cal) |
|---|---|---|---|---|---|
| | | | | | |

**Question 3-1:** How does your measured value of the "mechanical equivalent of heat" agree with the accepted value of 4.19 J/cal? By what percentage do the values differ?

**Question 3-2:** Can you think of any reasons why you would expect your value to differ from the accepted value? Was your measured value too small or too large? Do your reasons explain why the value came out this way?

## CONCLUSIONS FROM LAB 2

*Please write your conclusions drawn from today's experiment(s) below.*