Electrical Equivalent of Heat

Equipment Needed

<table>
<thead>
<tr>
<th>Equipment Needed</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Sensor</td>
<td>15 Ω, 5 w Resistor</td>
</tr>
<tr>
<td>Current Sensor</td>
<td>India Ink</td>
</tr>
<tr>
<td>Voltage Sensor</td>
<td>Water</td>
</tr>
<tr>
<td>Electrical Equivalent of Heat Apparatus</td>
<td>Protective gear</td>
</tr>
<tr>
<td>Balance</td>
<td></td>
</tr>
<tr>
<td>Digital Multimeter</td>
<td></td>
</tr>
<tr>
<td>Low Voltage Power Supply</td>
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</tbody>
</table>

What Do You Think?

Many households have a kitchen appliance or dispenser that delivers hot water. When operating, electrical energy is dissipated as thermal energy by a metal coil of moderate resistance. The thermal energy is then transferred to the water. How is the increase in thermal energy of the water related to the electrical energy supplied to it?

The purpose of this activity is to show that the energy dissipated by heating a resistor in water is equal to the energy absorbed by the water. This concept is known as Joule Heating. You can find the electrical equivalent of heat from conservation of energy. The electrical equivalent of heat is the number of Joules of electrical energy that are equivalent to one calorie of thermal energy.

Background

When water is heated by submerging a heating resistor in the water and running a current through the resistor, the Joule heat from the resistor is transferred to the water and causes the temperature to change.

Using Conservation of Energy, if there are no energy losses to the surroundings, all the energy given off by the resistor should be absorbed by the water. The energy, $E$, dissipated by the resistor is

$$E = Pt$$

where $t$ is the time during which the current flows through the resistor and $P$ is the power given by

$$P = IV$$

where $I$ is the current through the resistor and $V$ is the voltage across the resistor.

The energy gained by the water is given by

$$Q = mcΔT$$

where $m$ is the mass of the water, $c$ is the specific heat of water (1 cal/g °C), and $ΔT$ is the change in temperature of the water.
SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Be sure that the light bulb is in the water before you turn on the power supply.

For You To Do

Use the Power Supply to provide electrical energy to a heating resistor (light bulb) at a set voltage. (The energy dissipated by the resistor warms a measured quantity of water.) Use the Thermistor and Thermistor Sensor to measure the change in temperature of the water.

Use DataStudio to record the voltage across and current through the light bulb provided by the Power Supply and the change in temperature of the water. Use the program to calculate the electrical energy by integrating the electrical power (voltage multiplied by current) over time. Calculate the thermal energy gained by the water based on the known mass of water and its measured temperature change. Use the electrical energy (in joules) and the energy gained by the water (in calories) to determine the electrical equivalent of heat.

PART I: Computer Setup

1. Connect the ScienceWorkshop interface to the computer, turn on the interface, and turn on the computer.

2. Connect the Temperature Sensor DIN plug to Analog Channel A on the interface, the Voltage Sensor DIN plug to Analog Channel B and the Current Sensor DIN plug to Analog Channel C.

3. In the file Phys 2212L, open the document entitled "Electrical Equivalent of Heat.ds ."

- ‘Power Output’ is a calculation based on the voltage across the light bulb (resistor) and the current through the light bulb in the calorimeter. The current through the light bulb is actually a calculation. Since the Current Sensor should not exceed 1 amp and the calorimeter requires a higher current in order to operate properly, a 15Ω resistor is connected in parallel to the light bulb of the calorimeter. See the circuit diagram below. The current through this parallel resistor is measured and subtracted from the current supplied by Power Supply to the parallel combination yielding the current through the light bulb of the calorimeter. Data recording is set at 1 second per measurement.

- Connect the Digital Multimeter, which should be set to read current on the 20 amp scale, between the Power Supply and the parallel combination of the calorimeter light bulb and the 15Ω resistor.
PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor. However, you must determine Room Temperature by placing a notebook or lab manual on top of the Sensor on the lab table. Click on START. When the temperature reading as displayed in the graphical display or the digits display has stabilized, click on STOP, and record your temperature reading in degrees Celsius.

1. Measure the mass of the Calorimeter Jar including its lid. Record the mass in the Data Table.

   • NOTE: Use water that is about six degrees Celsius below room temperature when data collection begins. Take data until the temperature of the water is about six degrees above room temperature. This minimizes the effect of the surroundings because the water gains energy from its surroundings for half the activity and loses energy to its surroundings for the other half of the activity.

2. Put about 200 mL of water in the calorimeter jar. Add approximately 20 drops of India ink to the water making it opaque. Place the Temperature Sensor in the jar of water and click on START. Add crushed ice to the water and stir the mixture continuously until the temperature of the water is approximately 6 degrees below Room Temperature and all the crushed ice you added has melted. When that temperature is reached, press STOP.

3. Weigh the jar, lid and water. Measure and record the total mass. Calculate and record the water’s mass in the Data Table.

4. Connect positive output of the Power Supply to the 20A input of the digital multimeter. Connect the Common jack of the multimeter to the red jack of the Calorimeter. Connect the black jack of the Calorimeter to the negative (black) jack of the Power Supply. Connect one end of the 15Ω resistor to the Current Sensor then connect the series combination of the Current Sensor and 15Ω...
resistor in parallel with the light of the Calorimeter. Connect the Voltage Sensor across the light of the Calorimeter. Refer to the circuit diagram.

5. Put the Temperature Sensor through the hole in the lid of the jar.

**CAUTION: Be sure the resistor (bulb) is submerged in water when the current is flowing through it. Otherwise it can burn up!**

**PART III: Data Recording**

1. Turn on the Power Supply (the power switch is on the front panel). Quickly adjust the current and voltage as necessary so that the digital multimeter reads 2.50 amp. Turn off the Power Supply with the panel switch.

2. Prior to beginning to record data, click on **Experiment** on the upper menu bar of the DataStudio display and select "Delete all Data Runs." Click **Start** to begin recording data. Immediately turn on the Power Supply adjusting the output so that the multimeter reads 2.50 amps. Note the beginning temperature.

   - Continuously monitor the current on the multimeter keeping it at 2.50 amps

   - **IMPORTANT:** While the data is being taken, gently stir the water in the cup so the water will be heated evenly. Watch the Digits display to keep track of the temperature.

3. When the temperature reaches 6 degrees above room temperature, turn off the Power Amplifier, but continue to stir the water and collect data.

   - The temperature will continue to rise as the last bit of thermal energy from the resistor is slowly given off.

4. When the water temperature stops rising and levels off, click **STOP** and stop recording data.

**Analyzing the Data**

1. Set up your Graph display so it shows statistics.

   - In **DataStudio**, click the plot of Temperature to make it active. Click the ‘Statistics’ menu button \( \sum \) in the Graph toolbar. **Result:** The Graph legend shows ‘Min’ and ‘Max’.

2. Record the minimum and maximum temperatures (values of y). Calculate and record the change in temperature of the water.

3. Set up your Graph display to show the area under the curve of Power Output vs. Time.

   - In **DataStudio**, click plot of Power Output to make it active. Click the Statistics button in the Graph toolbar and select ‘Area’.

4. Record the ‘Area’ value as the electrical energy (‘watt * s’ or joules) used by the heating resistor.

   - **Hint:** In **DataStudio**, the ‘Area’ value is in the Graph legend.
5. Calculate (in calories) the thermal energy \((Q)\) absorbed by the water using \(Q = mc\Delta T\), where \(m\) is the mass of the water, \(c\) is the specific heat of water (1cal/g°C), and \(\Delta T\) is the change in temperature of the water. Record this value in the Data Table.

- By the Law of Conservation of Energy, the electrical energy used by the resistor should equal the thermal energy gained by the water, neglecting losses to the surroundings.

Solve for the number of joules per calorie:

\[
E.E.H. \ (\frac{J}{cal}) = \frac{\text{Electrical Energy}}{\text{Thermal Energy}}
\]

Calculate the percent difference between this experimental value and the accepted value (4.184 J/cal). Record the percent difference in the Data Table that follows.

Record your results in the Lab Report section.
Electrical Equivalent of Heat

Lab Report - Electrical Equivalent of Heat

What Do You Think?

Many households have a kitchen appliance or dispenser that delivers hot water. When operating, electrical energy is dissipated as thermal energy by a metal coil of moderate resistance. The thermal energy is then transferred to the water. How is the increase in thermal energy of the water related to the electrical energy supplied to it?

Data Table - Experiment 1

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<tbody>
<tr>
<td>Mass of Jar and Lid</td>
<td></td>
<td>Temperature (max)</td>
<td></td>
</tr>
<tr>
<td>Mass of Jar and Lid with Water</td>
<td></td>
<td>Temperature (min)</td>
<td></td>
</tr>
<tr>
<td>Mass of Water (M_w)</td>
<td></td>
<td>Change in Temp. (°T)</td>
<td></td>
</tr>
</tbody>
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<tr>
<td>Electrical Energy, ( E = Pt )</td>
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</tr>
<tr>
<td>Thermal Energy, ( \Delta Q = mc\Delta T )</td>
<td></td>
</tr>
<tr>
<td>Electrical Equivalent of Heat, ( J_e )</td>
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Note that some of the heat produced by the lamp is absorbed by the plastic jar. For accurate results, therefore, the heat capacity of the jar must be taken into account. The heat capacity of the jar is equivalent to that of approximately \( M_e = 23 \) grams of water so that mass, \( m \), as used in the equation above is given by \( M_w + M_e \).

Accepted Value = 4.184 J/cal

Percent difference = ________ %
EXPERIMENT 2

Efficiency of an Incandescent Lamp

Repeat Experiment 1, except use neither the India ink nor the styrofoam Calorimeter cup. Use the same calculations to determine $E$ and $\Delta Q$. Convert $\Delta Q$ to Joules by multiplying by $J$, determined in the first experiment.

In performing the experiment with clear water and no Calorimeter, energy in the form of visible light is allowed to escape from the system. However, water is a good absorber of infrared radiation, so most of the energy that is not emitted as visible light will contribute to $\Delta Q$, the thermal energy absorbed by the water.

The efficiency of the lamp is defined as the energy converted to visible light divided by the total electrical energy that goes into the lamp. By making the assumption that all the energy that doesn't contribute to $\Delta Q$ is released as visible light, the equation for the efficiency of the lamp becomes:

$$\text{Efficiency} = \frac{(E - \Delta Q)}{E}$$

Data Table - Experiment 2

<table>
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<td></td>
</tr>
<tr>
<td>Mass of Water</td>
<td></td>
<td>Change in Temp. ($^\circ T$)</td>
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<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td></td>
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</table>
Questions (Answer on a separate page.)

1. Was the thermal energy gained by the water greater, the same as, or less than the electrical energy dissipated by the resistor?

2. What effect are the following factors likely to have on the accuracy of your determination of \( J_e \), the Electrical Equivalent of Heat? Can you estimate the magnitude of the effects?
   a. The inked water is not completely opaque to visible light.
   b. There is some transfer of thermal energy between the system and room atmosphere. (What is the advantage of beginning the experiment below room temperature and ending it an equal amount above room temperature?)

3. How does \( J_e \) compare with \( J \), the mechanical equivalent of heat? Why?

4. What effects are the following factors likely to have on the accuracy of your determination of the efficiency of the lamp? Can you estimate the magnitude of the effects?
   a. Water is not completely transparent to visible light.
   b. Not all infrared radiation is absorbed by water.
   c. The styrofoam cup was not used, so there is some transfer of thermal energy between the jar and the room atmosphere.

5. Is an incandescent lamp more efficient as a light bulb or as a heater?

6. What are some factors that could account for the percent difference between the experimental and accepted values for the electrical equivalent of heat?