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Activity P47: Electrical Equivalent of Heat (Voltage Sensor and Power Amplifier)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	P47 EEH.DS	P39 EEH	P39_EEH.SWS

Equipment Needed	Qty	Other	Qty
Temperature Sensor (CI-6505A)	1	Styrofoam cup with lid	1
Power Amplifier (CI-6552A)	1	Water	200 mL
Balance (SE-8723)	1	Protective gear	PS
Heating resistor,10 Ω, 1 W (CI-6514A)	1		

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?

Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

The purpose of this activity is show that the energy dissipated by a heating 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

$$Q = mc\Delta T$$

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 heating resistor is in the water before you turn on the power supply.

For You To Do

Use the Power Amplifier to supply electrical energy to a heating resistor at a set voltage. (The energy dissipated by the resistor warms a measured quantity of water.) Use the Temperature Sensor to measure the change in temperature of the water.

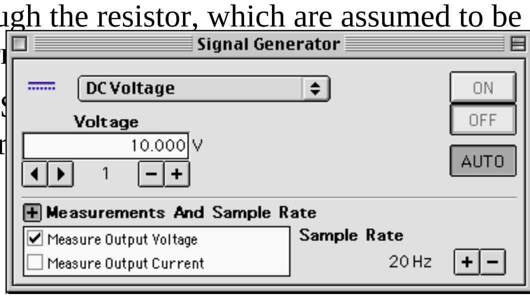
Use *DataStudio* or *ScienceWorkshop* to record the voltage and current output by the Power Amplifier and the change in temperature of the water. Use the program to calculate the electrical energy by integrating the electrical power (voltage multiplied by current) over time. Calculate the thermal energy 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.

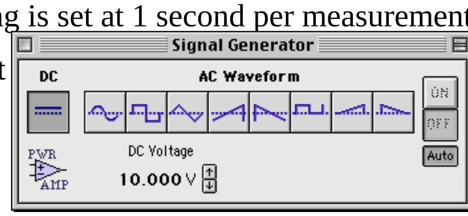
PART I: Computer Setup

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, and the Power Amplifier DIN plug to Analog Channel B.
3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P47 EEH.DS	P39 EEH	P39_EEH.SWS

- The *DataStudio* document has a Graph display, a Digits display, and a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Digits display of Temperature and a Graph display.
- 'Power Output' is a calculation based on the voltage across the resistor and the current through the resistor, which are assumed to be the same as the 'Output Voltage' and 'Cur[...]rding is set at 1 second per measurement.
- The S[...]utput [...]gin recor[...]





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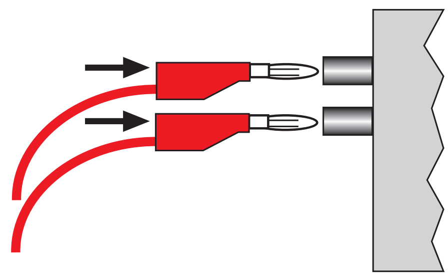
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Temperature Sensor.

1. If you have a lid that will fit over the top of the cup, make one hole in the lid for the Temperature Sensor, and a second hole in the lid for the heating resistor. Measure the mass of the Styrofoam cup and lid. Record the mass in the Data Table.

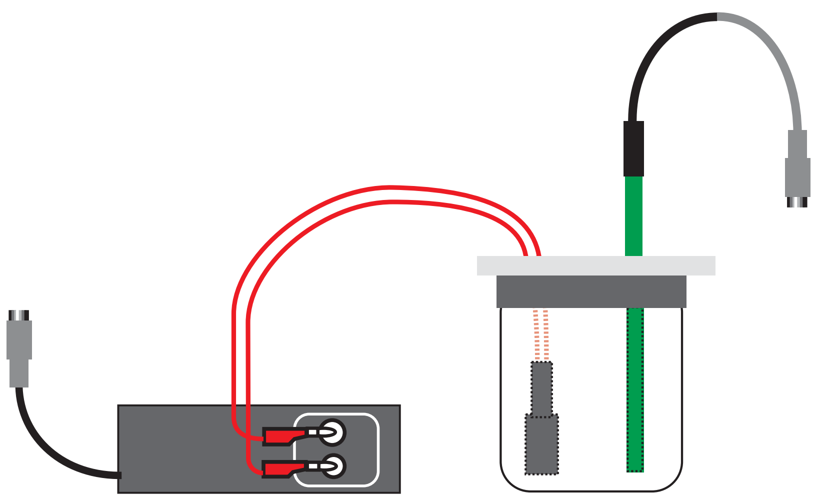
- NOTE: Use water that is about three degrees Celsius below room temperature when data collection begins. Take data until the temperature of the water is about three degrees above room temperature. This minimizes the effect of the surroundings because the water gains energy from its surroundings for 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 cup and weigh the cup, lid and water. Measure and record the total mass. Subtract the mass of the cup and lid from the total mass of the cup with water to find the mass of the water. Record the water's mass in the Data Table.



3. Connect the banana plugs of the heating resistor into the output jacks of the Power Supply.
4. Put the heating resistor through its hole in the lid. Submerge the resistor in the water.
5. Put the Temperature Sensor through its hole in the lid of the cup.

CAUTION: Be sure the resistor is submerged in water when the current is flowing through it.



Otherwise it can burn up!

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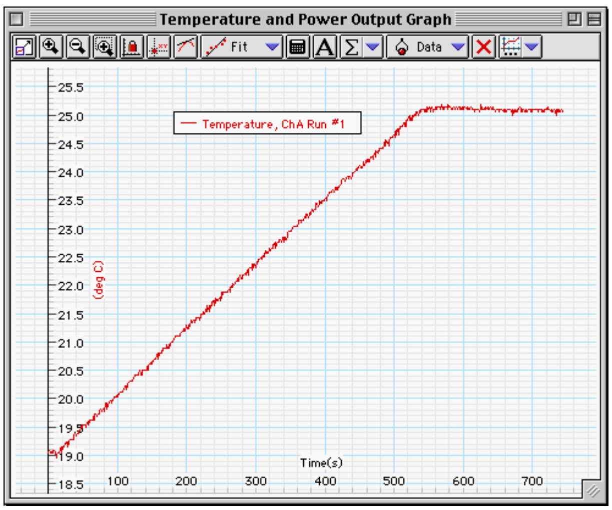
PART III: Data Recording

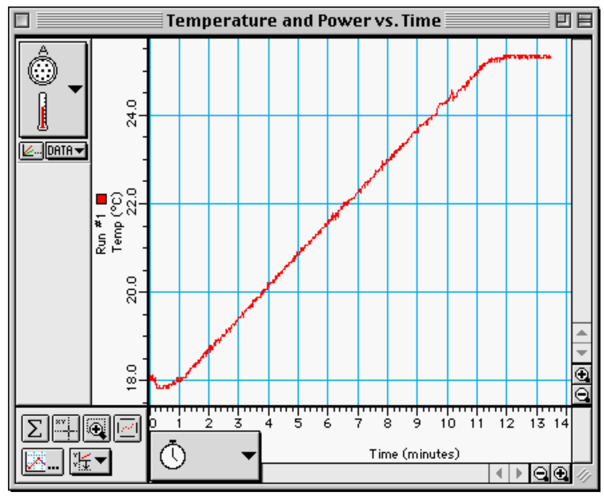
1. Turn on the Power Amplifier (the power switch is on the back panel).
2. Start recording data. (The Signal Generator turns on automatically when you start recording.) Note the beginning temperature.

- IMPORTANT: While the data is being taken, gently swirl 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 three degrees <u>above</u> room temperature, turn off the Power Amplifier, but continue to swirl 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.

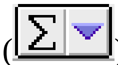
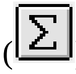




4. When the water temperature stops rising and levels off, stop recording data.

Analyzing the Data

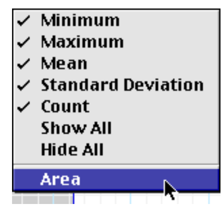
1. Set up your Graph display so it shows statistics.

- In *DataStudio*, click the plot of Temperature to make it active. Click the 'Statistics' menu button () in the Graph toolbar. **Result**: The Graph legend shows 'Min' and 'Max'.
- In *ScienceWorkshop*, click the 'Statistics' button () to open the Statistics area on the right side of the graph. Click the 'Autoscale' button to rescale the graph to fit the data. Click the 'Statistics Menu' button () in the Statistics area for the plot of Temperature vs. Time. Select 'Minimum' and 'Maximum' from the Statistics menu. **Result**: The Statistics area shows the minimum and maximum values of x and y.

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'.
- In *ScienceWorkshop*, click the 'Statistics Menu' button in the Statistics area for the plot of Power Output. Select 'Integration' from the Statistics menu.



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

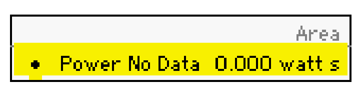
- Hint: In *DataStudio*, the 'Area' value is in the Graph legend.

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 ΔT 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:

$$E.E.H.\ \left(\frac{J}{cal}\right) = \frac{Electrical\ Energy}{Thermal\ Energy}$$



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.

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Lab Report - Activity P47: 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

Item	Amount	Item	Amount
Mass of Foam Cup		Temperature (max)	
Mass of Foam Cup with Water		Temperature (min)	
Mass of Water		Change in Temp. (ΔT)	

Item	Amount
Electrical Energy, $E = Pt$	
Thermal Energy, $\Delta Q = mc\Delta T$	
Electrical Equivalent of Heat	

Accepted Value = 4.184 J/cal

Percent difference = ________ %

Questions

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

2. The heating resistor is rated at 10 ohms and 1 watt. By how much was its power rating exceeded during this activity? Why didn't the resistor burn up?

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

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