

Electrical Equivalent of Heat (Power Amplifier, Temperature Sensor)

Object:

To heat water and to show that the energy dissipated by a heating resistor in the water is equal to the energy absorbed by the water. This concept is referred to as joule heating. From the law of conservation of energy the electrical equivalent of heat can be found. This is the number of joules of electrical energy that are equivalent to one calorie of thermal energy.

Apparatus:

Science Workshop Interface, Power Amplifier, Stainless Steel Temperature (SST) Sensor, Balance (for measuring mass), (2) Patch Cords, Resistor for heating water (10Ω , 1W), Styrofoam cup, Calorimeter, and water.

Theory:

The water is heated by submerging a heating resistor in water and running a current through the resistor. The Joule heat from the resistor is transferred to the water and the Temperature Sensor records the resulting temperature rise.

Using the law of 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

$$P = VI$$

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 ($1\text{ cal} / \text{g}^\circ\text{C}$), and ΔT is the change in temperature of the water.

Procedure:

In this activity, the Power Amplifier supplies electrical energy to a heating resistor at a set voltage. The energy dissipated by the resistor warms a measured quantity of water. The Temperature Sensor measures the change in temperature of the water. The Power Amplifier measures the current through the heating resistor.

The Science Workshop program records the voltage and current supplied by the Power Amplifier to the heating resistor as well as the change in temperature of the water. The program calculates the electrical energy by integrating the electrical power (voltage x current) over time. You will calculate the thermal energy gained by the water based on the known mass of water and its measured temperature change. The electrical energy (in joules) is set equal to the energy gained by the water (in calories) to determine the electrical equivalent of heat.

Part I: Computer Setup

1. Connect the Science Workshop 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 Science Workshop document titled as shown:
Windows: P39_ELEC.SWS

* The document opens with a Signal Generator window, a Digits display of Temperature, and a Graph display with plots of Temperature vs. Time and Power Output vs. Time. The Power Output is a calculation based on the voltage and current measurements for the heating resistor. The area under the Power Output vs. Time plot will be the electrical energy.

* Activate the Signal Generator Window. The Signal Generator is set to output 10 volts DC. It is on Auto so it will automatically start when you simultaneously press the "alt" and the "R" keys to begin recording data and automatically stop when you simultaneously press the "alt" and the "." (period) keys.

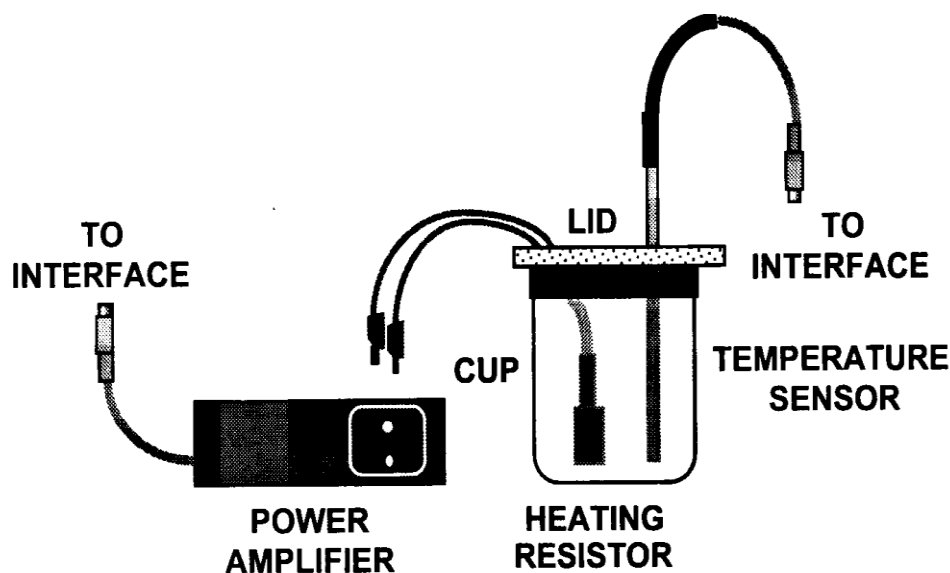
Part II: Sensor Calibration and Equipment Setup

* You do not need to calibrate the Temperature Sensor or the Power Amplifier. The Temperature Sensor produces a voltage that is proportional to temperature ($10 \text{ mV} = 1.0 \text{ Celsius}$). The default calibration is $110.000 \text{ C} = 1.100 \text{ V}$ and $-10.000 \text{ C} = -0.100 \text{ V}$.

1. Measure the mass of the Styrofoam cup. Record the mass in the Data section.
2. Put about 150 ml of water in the cup and weigh the cup and water. Measure and record the total mass. Subtract the mass of the cup from the total mass of the cup with water to find the mass of the water. Record the water's mass in the Data section.

NOTE: Use water that is about three degrees Celsius below room temperature (about 18 or 19 C) when data collection begins. Take data until the temperature of the water is about three degrees above room temperature (approximately 25 C). This minimizes the effect of the surroundings because the water gains heat from its surroundings for half the activity and loses heat to its surroundings for the other half of the activity.

3. Put the heating resistor through the hole in the calorimeter. Submerge the resistor in the water. Connect the banana plugs of the heating resistor into the output jacks of the Power Amplifier.
4. Put the Temperature Sensor through the hole in the calorimeter.



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

Part III: Data Recording


1. Turn on the switch on the back of the Power Amplifier. Simultaneously press the "alt" and the "R" keys to begin collecting data. Note the beginning temperature in the Data display.

IMPORTANT: While the data is being taken, gently agitate the water. This will ensure uniform heating.

2. When the temperature reaches six degrees above room temperature, turn off the Power Amplifier switch on the back panel, but continue to agitate the water and collect data.

* The temperature will continue to rise as the last thermal energy from the resistor is slowly dissipated.
3. When the water temperature stops rising, simultaneously press the "alt" and the "." (period) keys to stop collecting data. Run #1 will appear in the Data list in the Experiment Setup window.

Analyzing The Data:

1. Click the graph (Temp vs. Time) to make it active. Click the Statistics button (Σ) to open the Statistics area on the right side of the graph. Click the Autoscale () button to rescale the graph to fit the data.
2. Click Statistics Menu button in the Statistics area for the plot of Temperature vs. Time. Select "All of the above" from the Statistics menu.
3. Record the minimum and maximum temperatures (values of y) displayed in the Statistics (integrated) area. Calculate and record the change in temperature of the water.

4. Click the Statistics Menu button in the Statistics area for the plot of Power Output vs. Time. Select “Area” from the Statistics menu. Select the region of the Power vs. Time plot during which power was applied by clicking and dragging with the mouse. Record the integration value as the electrical energy (joules) used by the heating resistor.
5. Calculate (in calories) the 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 ($1\text{ cal} / \text{g}^\circ \text{C}$), and ΔT is the change in temperature of the water. Record this value in the Data section.
6. 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:

$$\text{Electrical Equivalent} \left(\frac{\text{J}}{\text{cal}} \right) = \frac{\text{Electrical Energy}}{\text{Thermal Energy}}$$

Calculate the percent error between this experimental value and the accepted value (4.184 J/cal).

Data: Mass of Foam Cup = _____ grams

Mass of Foam Cup with Water = _____ grams

Mass of Water = _____ grams

Water Temperatures (C)

Temp min	Temp max	ΔT Temp

Electrical Energy (E) = _____ joules

Thermal Energy (Q) = _____ calories

Accepted Value(J) = 4.184 J/cal

Percent error = _____ %

Induction-Magnet through a coil (Photogate, Voltage Sensor)

Object:

Measure the *electromotive force (emf)* induced in a coil by a moving magnet.

Apparatus:

Science Workshop Interface, Voltage Sensor, Photogate, RLC circuit board, two Alnico magnets

Theory:

When a magnet is passed through a coil there is a changing magnetic flux through the coil. This changing flux induces an *electromotive force (emf)* in the coil. According to Faraday's law of induction:

$$\varepsilon = -N \frac{\Delta\phi}{\Delta t}$$

Where ε is the induced *emf*, N is the number of turns of wire in the coil, and $\Delta\phi/\Delta t$ is the rate of change of flux through the coil. In this experiment you will plot *emf* vs. time and find the area beneath the curve. The area represents the flux through the coil since:

$$\varepsilon\Delta t = -N\Delta\phi$$

Procedure:

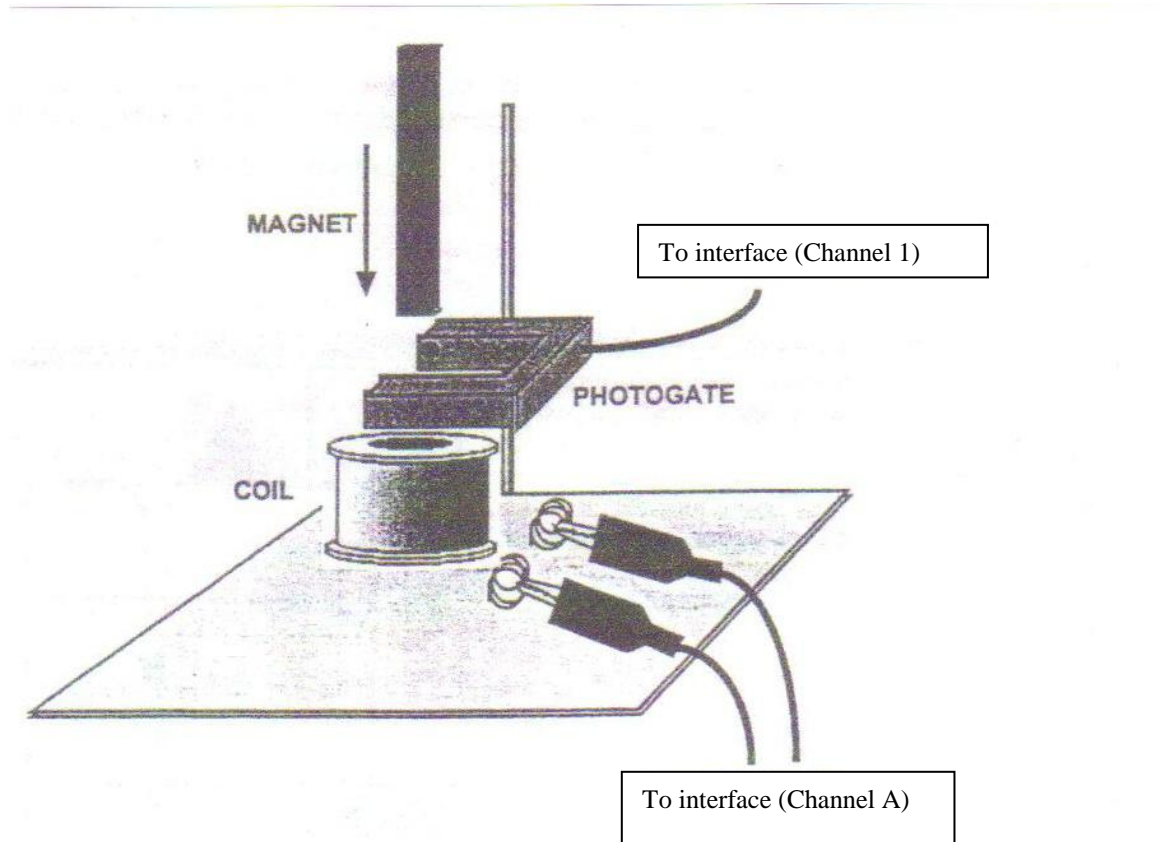
In this lab, a voltage sensor measures the voltage (V) induced in a coil as a magnet falls through the coil. Data collection begins when the falling magnet breaks the beam of the photogate. The science workshop program records and displays the induced voltage as a function of time, and integrates the area under the curve of voltage vs. time.

Part I: Computer Setup

1. Connect the Science Workshop interface to the computer, turn on the interface, and turn on the computer.
2. Connect the voltage sensor DIN plug into Analog Channel A.
3. Connect the photogate stereo phone plug into digital channel 1.
4. Open the Science Workshop document titled: P41_INDU.SWS
5. The instrument opens displaying a graph of voltage vs. time as well as a meter display of voltage.
6. Check that your Sampling options are set as: Periodic sample = fast at 200 Hz, Start condition = Ch1, low (blocked), and stop condition= Time at 0.5 seconds.

Part II: Sensor Calibration and Equipment Setup

1. No calibration is required. Attach banana plugs to the terminals of the voltage sensor.
2. Attach the other end of the banana plugs across the coil in the LCR circuit board.



3. Arrange the circuit board so that the coil hangs over the edge of the lab table or is balanced on an empty cup. The dropped magnet must pass freely and completely through the coil.
4. Turn the photogate head so that it is horizontal. Position the photogate above the coil so that the falling magnet will break the beam.
5. The magnet will be dropped through the coil. Make sure to catch the magnet so that it does not hit the floor.

Part III: Data Recording

1. Hold the magnet so that the south end is about 2cm above the photogate. The south end is designated by the narrow groove near the end.
2. Click the “Start” button and drop the magnet through the photogate head and the coil
3. Data recording will begin when the magnet breaks the beam of the photogate. Recording will end automatically after 0.5 seconds.
5. Run #1 will appear in the data list in the experimental setup window.

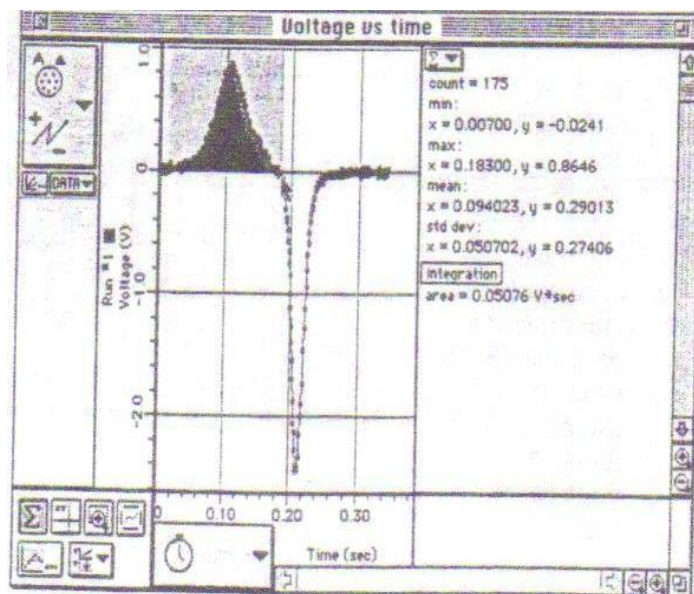
Analyzing the Data:

1. Click the graph to make it active.
2. Click the statistics button to open the statistics area on the right hand side of the graph. Click on the Autoscale button to rescale the graph to fit the data. In the statistics panel click statistics menu button. Select integration from the menu.
3. In the graph display, use the cursor to click and draw a rectangle around the first peak of the plot. The area under the curve for the first will appear in the statistics area.
4. Record the value of the integration for the first peak.

Integration first peak = _____ (VoltSec)

5. Repeat the process to find the area under the second peak. Record the value.

Integration second peak = _____ (VoltSec)



Questions:

Part I

- 1) Was the energy (Q) gained by the water greater than the energy (E) dissipated by the resistor? Explain why it was greater or less.
- 2) The heating resistor is rated at $10\ \Omega$ and 1 W. By how much was its power rating exceeded? (Remember, $P=V^2/R$.) Why didn't the resistor burn up?
- 3) What are some factors that could account for the percent error between the experimental and accepted values?

Part II

- 4) Is the incoming flux equal to the outgoing flux?
- 5) Why does the outgoing peak (the second peak) have a greater magnitude than the incoming peak?
- 6) Why are the peaks in opposite directions?