Electrical Equivalent of Heat

Object: To determine the electrical equivalent of heat.

Apparatus: Power amplifier, temperature sensor, balance, resistor for heating water (10 Ω, 1W), calorimeter, wires, water, PASCO Interface, computer, and Data Studio Software.

FOREWORD

The electrical equivalent of heat J is the number of joules of electrical energy that are equivalent to one calorie of thermal energy. This is stated mathematically as follows:

\[ J = \frac{\text{Electrical Energy in Joules}}{\text{Thermal Energy in calories}} \]

In this experiment we will submerge a heating resistor in water, supply a current I at constant voltage V for some time t, and monitor the change in temperature \( \Delta T \) of the mass m of water. From the data we will determine the electrical energy (in Joules) supplied to the heating resistor, the thermal energy (in calories) that this electrical energy produces, and then the electrical equivalent of heat.

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 and the calorimeter cup. The energy, E, dissipated by the resistor is:

\[ E = Pt \]

In equation (2), t is the time during which the current flows through the resistor and P is the power given by:

\[ P = IV \]

In equation (3), I is the current through the resistor and V is the voltage across the resistor.

The energy gained by the water is given by:

\[ Q = mc\Delta T \]

In equation (4), m is the mass of the water, c is the specific heat of water (1 cal/g˚C), and \( \Delta T \) 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 and the calorimeter cup. The Temperature Sensor measures the change in temperature of the water and cup. The Power Amplifier measures the current through the heating resistor.

The Data Studio software records the voltage and current supplied by the Power Amplifier to the heating resistor as well as the change in temperature of the water. We will write a mini-program to determine the electrical power delivered to the heating resistor at any time. We will instruct the computer to plot a graph of electrical power delivered to the heating resistor as a function of time. The area under this curve (determined by integration) is the total electrical energy supplied to the heating resistor. We will calculate the thermal energy gained by the water and the cup based on the known mass of the water and cup and the temperature change. Finally, the total electrical energy (in joules) supplied to the heating resistor is divided by the energy gained by the water (in calories) to determine the electrical equivalent of heat.
Part I. Initial Software Set-up

1. Start Data Studio, and select Create Experiment.

2. Connect the Power Amplifier to the computer via an analog port on the PASCO interface. Plug the Power Amplifier into an AC outlet and turn the power amplifier on. Connect the heater unit to the Power Amplifier.

3. Inform the software which analog port you plugged the Power Amplifier into by selecting the Power Amplifier icon and dragging it to the appropriate analog port.

4. A signal generator box should appear. Change the wave pattern from the default Sine Wave to a DC voltage, set the voltage to 10.0 V. Click on the auto button to deselect the default auto setting. This will allow you to control when the Power Amplifier is on and/or off. The software will monitor to voltage and current output of the power amplifier – which in this case is delivered to the heater unit.

5. Connect the temperature sensor to the computer via an analog port on the PASCO interface.

6. Inform the software which analog port you plugged the temperature sensor into by selecting the temperature sensor icon associated with the temperature sensor you are using (the CI-6505A) and dragging it to the appropriate analog port. For the version of Data Studio software we are using, this is presently the first temperature sensor icon. To make sure you have the correct icon, double click on it and you will be able to find information about the temperature sensor it is associated with.

7. Inform the software that you would like a plot of Temperature vs. Time. This is done by clicking on the graph icon and dragging it to the temperature sensor icon.

8. Next we need to calculate the electrical power delivered to the heater unit. From the experiment pull down menu, select calculator. Replace the y to the left of the equals sign with the name of the quantity you wish to calculate (Power) and to the right of the equals sign enter the expression to calculate this quantity (V*I) and then click the green check. At this time the software will ask you to identify the variables V and I. Inform the software that they are both experimental data and that they are collected from the power amplifier. Under the properties tab, again inform the software that you are determining the power and that the units are Watts. Click the green check.

9. Next we need a plot of the power delivered to the heater unit as a function of time. This may be accomplished by dragging the icon for the power calculation onto the existing graph of temperature vs. time. The area under this curve is the electrical energy supplied to the heater unit.

10. At this point we will lock the two graphs together so that the time axis is the same for both plots. This is done by selecting the align x-axis lock button.

Part II. Equipment Set-up

1. We will conduct the experiment in a standard introductory lab calorimeter. Determine the mass of the calorimeter cup. Fill the cup about three fourths full of water (you must totally submerge the heater unit) and then measure the mass of the cup and water – you now know the mass of the water.
Note: Use water that is about three degrees Celsius below room temperature when data collection begins and take data until the temperature of the water is about three degrees above room temperature. This procedure will minimize the effect of the surroundings on your determination because the experiment will absorb heat from the surroundings during the first half of the experiment and radiate heat to the surroundings during the last half.

2. Put the heater unit (the heater unit must be totally submerged in water – otherwise it can burn up) and the temperature sensor in the cup (as shown below) and the cup into the calorimeter. You are now ready to heat the water and take data.

![Figure 1. Experimental arrangement for the electrical equivalent of heat experiment](image)

**Part III. Obtain Data**

1. Before and during the data taking process, gently agitate the water with the temperature sensor. This will ensure that we have thermal equilibrium before starting to heat the water and also ensure uniform heating of the water during the experiment.

2. Click the record button to begin data collection. When it is clear that you have reached thermal equilibrium (at a point about three degrees below room temperature), turn on the Power Amplifier (this is done by clicking the on button on the signal generator icon on the monitor) and start heating the water. When the temperature reaches three degrees above room temperature (this process will take ten to fifteen minutes), turn off the Power Amplifier (this is done by clicking the off button on the signal generator icon on the monitor), 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 you are confident that the system has reached its maximum temperature, click the STOP button to stop data collection. Run #1 now appears in the Data list in the Experiment Setup window.
Part IV. Analyzing The Data

1. Click the Temperature vs. Time graph to make it active. Click the autoscale button located on the graph tool bar button to rescale the graph.

2. Determine the temperature difference for the water and calorimeter cup between the initial and final equilibrium temperatures. Click on the Smart Tool button. When the smart tool curser has the following appearance, it can be moved to any location on the graph. Place the smart curser at the location where the system is at the initial temperature equilibrium value. By moving the mouse slightly to the 2nd quadrant of the smart tool curser, you should be able to change the curser to the delta curser. When the delta curser is present, left click and drag the curser to the point where the system is at the final temperature equilibrium value. The difference in temperature between these points is the value needed to perform the heat energy gained calculations.

3. Click on the Power vs. Time graph to make it active. From the statistics package request the area under the Power vs. Time plot. This area is the electrical energy (in Joule) supplied to the heater (E = Pt = VIt).

4. Print your plots in order to submit them with your report.

5. Calculate (in calories) the thermal energy gained by the water (Q_w = M_w c_w \Delta T) and the calorimeter cup (Q_{cup} = M_{cup} c_{cup} \Delta T) and hence the total thermal energy generated by the heater unit.

6. The area under the Power vs. Time plot tells us the amount of electrical energy (in Joule) supplied to the heater.

7. By conservation of energy, the electrical energy supplied to the heater in Joule should equal the thermal energy gained by the water and the calorimeter cup, neglecting energy lost or gained from the surroundings. Obtain the number of joules per calorie:

\[
\text{Electrical Equivalent of Heat (J/cal)} = \frac{\text{Electrical Energy (in Joules)}}{\text{Thermal Energy (in Calories)}}
\]

8. Calculate the percent difference between this experimental value and the accepted value (4.184 J/cal).
DATA AND CALCULATION SUMMARY

Mass of the calorimeter cup $M_{\text{cup}} =$ ________ grams

Mass of calorimeter cup and water $M_{\text{cup and water}} =$ ________ grams

Mass of water $M_{\text{water}} =$ ________ grams

Change in temperature $\Delta T =$ ________ C

Thermal energy gained by the water $Q_w =$ ________ calories

Thermal energy gained by the calorimeter cup $Q_{\text{cup}} =$ ________ calories

Total thermal energy gained by the water and cup $Q_{\text{cup and water}} =$ ________ calories

Total thermal energy generated by the heater $Q =$ ________ calories

Total electrical energy supplied to the heater $E =$ ________ Joules

Electrical Equivalent of Heat $J =$ ________ Joule/calorie

Accepted value for the Electrical Equivalent of Heat =$ ________ Joule/calorie

Percent difference between the accepted and experimental values =$ ________