

Electric Joule Heating

Equipment: PC 486-DX2, PASCO Series 6500 interface, multimeter, temperature probe, voltage sensor, calorimeter, 10 Ω resistor, DC power source.

Objectives: To measure the flow of heat into an isolated system. To explore conservation of energy. To examine the equivalence of various forms of energy by studying the conversion of electrical energy to heat energy.

Definitions:

- Joule:* a unit of energy
Coulomb: a unit of electrical charge
Volt: a unit of electrical potential
Watt: a unit of power or energy per unit time
Ampere: a unit of current flow
Specific heat: the amount of energy required to raise the temperature of a given mass of a substance 1 degree C.

Introduction: As current flows through a resistor some electrical energy is converted to heat (much in the same manner as pulling a string through your fingers generates heat). The *power* (P) generated in this process is related to both the voltage across the resistor (V), and the current flowing through the resistor (I):

$$P = V \times I$$

Where P is measured in *watts* (a joule per second), I in *amperes* (a coulomb per second), and V in *volts* (a joule per coulomb). As heat is generated by the flow of current through the resistor, the total energy expended over a time of t seconds is:

$$V \times I \times t = E$$

providing that I and V are reasonably constant over the period of time.

Suppose that one constructs a simple circuit consisting of a power supply (a source of electrical potential) a resistor, a meter to read current (an ammeter) and a meter to measure potential (a voltmeter). If the resistor is immersed in water during the operation of the circuit, the heat produced by the resistor is absorbed by the water thus raising the temperature of the water. If one knows the mass of the water, its specific heat capacity, and the change in temperature, one may compute the amount of heat absorbed by the water. This value may then be compared to the heat being produced by the resistor. If this energy exchange occurs in a setting that is thermodynamically isolated from the

surroundings, these two values should be very close to the same.

Experimental: Your lab instructor will help you identify the various sensors and probes used in this procedure. Plug the temperature sensor into channel **A** of the interface box and the voltage sensor into channel **B**, and the power source into channel **C**. Determine the mass of the calorimeter, then pour water into it so that the resistor is covered by about an inch of water (since we are using distilled water, water covering the wire leads will not cause current to leak from the resistor). Next record the mass of the calorimeter with the water included. Attach the banana leads of the voltage sensor to the leads of the resistor. Connect the power supply and multimeter. Insert the temperature probe through the hole in the top half of the calorimeter and assemble the calorimeter so that the temperature probe *does not touch the resistor*. When you have finished, ask your lab instructor to approve your setup before going on.

Turn on the computer and start Windows. From the Windows environment click the group icon 213/214. Click the Data Monitor icon to start the Data Monitor program. Hit [ENTER] to get to the main menu.

You will first need to calibrate the temperature probe. To do this:

[Z] - **Calibration** (or toggle the down arrow until calibration is highlighted) [ENTER]

[L] - **Load calibration file** [ENTER]

[B] - Channel B [ENTER] (Toggle the spacebar to change from "On" to "Off")

[C] - Channel C [ENTER] (Toggle the spacebar to change from "On" to "Off")

The status of the interface should be:

On A - Channel A

Off B - Channel B

Off C - Channel C

[ENTER] - To confirm

Next you need to tell the computer which device to calibrate. To do so press the down arrow to highlight:

6505TEMP.CAL [ENTER]

The computer responds with:

6505TEMP.CAL has been loaded for Input [A]

[ENTER] - To confirm

[ENTER] - To return to the Main Menu

For this procedure you will not need all of the significant figures that this program can generate. Three significant figures will do nicely. To do this:

[O] - Other [Enter]

[D] - Set Rounding [Enter]

[3] [Enter]

Before exiting to the Main Menu you need to tell the computer what output voltage to use.

[Y] - Set Power Amplification Voltage [ENTER]

[2] [ENTER]

[ENTER] - To confirm

[ENTER] - To return to the Main Menu

You are almost ready to take data. Enter the monitor input screen:

[M] - [Enter]

Now set the following options to the given values:

On [S] - Store Data in Memory

Off [L] - Large Digit Display

Off [A] - Range Alarms

Off [V] - Sweep Voltage

[ENTER]

Set the data collection time by pressing the right arrow key (→) over to the minutes column. Type 45 then press [ENTER]. When the computer prompts you for the number of data points ("readings per channel") type 91 and press [ENTER].

Turn on the power supply and adjust it to between 3 and 6 volts (when the red light begins to glow back the voltage off). Be sure that the multimeter is set to DCMA and is on the 2000 mA range. Once this has been done you may turn on the multimeter. Adjust the voltage so that the current is below 200 mA and reset the multimeter to the 200 mA range.

Make a table in you lab notebook with the following headings:

Time Temperature Volts Current

When this has been done press [Enter] to start data recording. On the far left side of the screen is a column called "Row #". Every time a number appears (every thirty seconds), make an entry for each of the categories above in your lab notebook. The data for time, temperature, and voltage may be read from the computer screen. The current reading comes from the multimeter. The "channel C" data in the column on the far right need not be recorded. When the data recording is done (45 minutes) press [Enter].

Next you will need to determine the average value of the current. This should have remained fairly constant throughout the time that you were acquiring data, but may have varied slightly. Use your calculator to compute the average value of the current if necessary.

The voltage drop across the resistor should also have remained fairly constant. Since the computer has been keeping track of the voltage it is easier to determine it's average value:

- [T] - Display/Print Data Table
- [D] - Display Data Table
- [Page Down] (to the end of the table)

The average voltage is listed along with the minimum and maximum temperatures. The time should be 45 minutes.

Data Analysis: The values that you need to analyze your data are: average current, average voltage, minimum temperature, maximum temperature, and time (in seconds). The average power is given by:

$$P_{ave} = V_{ave} \times I_{ave}$$

Compute the average power and record it in your lab notebook. The heat energy dissipated by the resistor in this process is given by:

$$E = P_{ave} \times t$$

where t is the data acquisition time in seconds. Next compute the energy absorbed by the water: where m is the mass of the water (determined by subtracting the mass of the calorimeter empty from its

$$Q = mc\Delta t$$

mass with water), c is the specific heat of water ($4184 \text{ J/kg} \cdot \text{C}^0$, or $1.00 \text{ cal/g} \cdot \text{C}^0$), and Δt is the difference between the final and initial temperatures you recorded.

According to the law of conservation of energy, the energy dissipated by the resistor should equal the energy absorbed by the water. Do your findings support this? Compute the *percent variation* between the two values.

Recall that percent variation may be computed by:

$$\% \text{ variation} = \left(\frac{\text{difference of two measurements}}{\text{average of two measurements}} \right) \times 100$$

Subtract Q from E to compute the difference.

Questions:

1. Was the energy (Q) gained by the water greater than, equal to, or less than the energy lost by the resistor? Explain.
2. How would one, over a number of trials, verify question #1 statistically?
3. What is the purpose of the calorimeter in this experiment?
4. Name some factors that could affect the accuracy of the measurements in this experiment.
5. A resistor in an electrical circuit is analogous to a non-conservative mechanical force. What is this force?
6. The current and voltage should remain fairly constant throughout this experiment. Why?
7. The specific heat of the calorimeter is negligible but the specific heat of the ceramic resistor is about $800 \text{ J/kg} \cdot \text{C}^0$. Calculate Q_{total} as the sum of $Q_{\text{water}} + Q_{\text{resistor}}$. How does this affect the outcome of this experiment?