

## EXPERIMENT 6: POWER, RESISTORS, AND TEMPERATURE DEPENDENCE IN RESISTIVE CIRCUITS

Conservation of energy is one of the fundamental principles of physics. It occurs in each of the three semesters of our physics sequence, and in many other science areas as well. We have also seen it in capacitors and in the RC circuit theory. Here we want to examine conservation of energy in DC resistive circuits (meaning only an emf and resistor, no capacitors or other types of circuit elements).

### BACKGROUND

We have studied several power expressions for resistive circuits,  $P = iV$ ,  $P = i^2 R$ , and  $P = V^2 / R$ . The first of these applies to any case, the last two to ohmic devices. To use conservation of energy, we multiply these power terms by time to obtain an energy term. If we are dealing with a resistor, then we say the energy is dissipated, or is a Joule heating loss. Of course the energy is not lost, but is turned into internal energy, also commonly called heat energy or thermal energy. In Physics 237 we study ways to determine this internal energy, which is explained briefly below.

For a given object, we speak of a heat capacity,  $C$ , which is the amount of energy (measured in Joules in the SI system of units) needed to raise the temperature of an object by one Kelvin, or equivalently by one degree Celsius (or Centigrade in the old terminology). In an equation, we have

$$(1) \quad Q = C \Delta T,$$

where  $Q$  is a quantity of energy,  $C$  is the heat capacity, and  $\Delta T$  is the change in temperature associated with the energy flowing into or out of the object with heat capacity  $C$ . Solving this equation for  $C$  allows us to find the heat capacity of any object. The object may be an amount of water, a building, a container and liquid it holds, or any other system we decide.

If the object is of one type of material only (all water, or all brass, for example), it is convenient to speak of heat capacity per unit mass. Then we define specific heat:  $c \equiv C/m$ . Note the units of specific heat are energy per mass per degree of temperature change, or  $J/kg/K = J/kg/^\circ C$  (SI units). With equation (1) above, this definition of specific heat leads to

$$(2) \quad Q = m c \Delta T.$$

In physics 217 we saw many examples of conservation of mechanical energy, and conservation of energy with frictional forces. In physics 227 we have seen examples involving electrical circuits, with energy supplied by an emf, and transferred to capacitors, other emfs or dissipated by resistors. With this concept of internal or thermal or heat energy, we can now calculate quantitatively the conservation of energy involving resistors, and verify that that energy involving resistors appears as thermal energy in the resistors, or their environment.

### ADVANCED STUDY ASSIGNMENT

1. The specific heat of aluminum is  $921 J/kg/K$  and of water is  $4186 J/kg/K$ . Find the heat capacity of the following objects: a block of aluminum of mass  $255 g$ ;  $100 g$  of water; and a  $255 g$  cup of aluminum containing  $100 g$  of water.
2. If the cup of aluminum and the water it contains is placed in a refrigerator and cools from room temperature ( $20^\circ C$ ) to  $5^\circ C$ , how much heat does the cup and water lose to the refrigerator?
3. If a battery supplies a steady current of  $0.55 A$  with a potential difference of  $12.0 V$  for  $25 s$ , how much energy does the battery supply?

## PROCEDURE A (energy method)

1. Open Data Studio as usual and connect the Power Amplifier (virtually and physically). Move the Signal Generator (SG) window to the bottom of the screen, so it will not be hidden later. Now connect the Voltage Sensor and the Current Sensor, to Channels B and C respectively. Set the Power Amplifier to DC Voltage (by using the down arrow to the right of the words “sine wave”) and 5.0 V (on the SG window), but do not turn the Power Amplifier on yet.
2. Drag a separate graph icon (from Displays window) onto the Voltage Sensor and Current Sensor icon (in Experiment Setup window).
3. Set up the calorimeter and measure and record the mass of the inner, empty cup in Data Table A. Fill the cup about half way with water (make sure the heating element will be completely covered). Place the thermometer in the water and note the temperature.
4. Add a small amount of ice (half a spoonful is probably enough) to the water, and measure the temperature again when all the ice is melted. Add more ice, if needed, until the temperature is about 2° below the initial temperature. Now measure and record the mass of the cup and water. Subtract to determine the mass of the water and record, both in Data Table A.
5. Now place the inner calorimeter cup, with the water, inside the outer calorimeter cup, insert the coil, and then the thermometer. Connect wires from the Power Amplifier to the coil which is in the calorimeter cup, with the Current Sensor connected in series. Don't forget to observe polarity. Now connect the Voltage Sensor in parallel across the resistor, again observing polarity. Use the stirrer to stir the water, being careful not to damage the resistor coil. Measure and record the temperature (to a tenth of a degree) after the set up is complete (but before you turn on the Power Amplifier) and raise the stirrer out of the water, using a paper clip or clothespin to hold it up.
6. Immediately turn on the Power Amplifier (both physically and virtually; to turn the Power Amplifier on virtually means clicking ON on the SG window, and you may need to click the AUTO button first, and then click ON). Now click Start to start recording the current and the voltage. Check to make sure there is a voltage and current being recorded on the graphs. Also check that the current and voltage values are reasonable. (If you have a bad wire, the voltage may read 0.0073 V – essentially 0, for example, which is not reasonable when the power amplifier is set to 5.0 V.)
7. Now sit back and wait about 20 minutes. While you are waiting, calculate the heat capacity of the calorimeter cup, and the water. We will ignore the heat capacity of the stirrer and thermometer. When the time is up, click STOP, stir the water and take an accurate temperature reading. Record in Data Table A.
8. Enable the statistics function (looks like a  $\Sigma$  symbol). Now find the average (or mean) voltage and current, and record in Data Table A. (If the voltage and current values have a period – or time interval – when they were 0 at the beginning or end of the experiment, then draw a box around the times when they were constant, and record the mean values within that box.) Also record the time from either the current or voltage graph as  $\Delta t$  in Data Table A, but only the time in the box, if you used a box to find average  $i$  or  $V$ .
9. Calculate the energy dissipated by the resistor, and compare it with the calculated energy needed to raise the temperature of water by the recorded amount. Calculate a percent difference.

## PROCEDURE B (power method)

10. Disconnect the Voltage Sensor from the Pasco interface (but leave it connected to the resistor. Delete the Voltage Sensor icon from the experiment window (by highlighting the icon first, then clicking delete). Also delete the Voltage graph. On Experiment Setup window, select

Temperature Sensor (for Analog Channel B). Then drag the graph icon (from Displays window) onto the Temperature sensor icon for Data Channel B (on Experiment Setup window).

11. With the same water in the calorimeter cup click Start and collect data for 5 minutes. Look at the current graph to make sure there is a current after you click START. Click STOP at the end of 5 minutes. Examine the graph of temperature vs time, and, if there the graph looks like a straight line, find its slope using the “FIT” button, choosing linear fit. Record the slope in Data Table B (in the  $dT/dt$  line).
12. Disconnect the Temperature Sensor, and reconnect the Voltage Sensor, both physically and virtually (on the Experiment Window). Drag the icon for graph onto the icon of the voltage sensor. Again click START, and allow data to be collected for two or three minutes. Click STOP.
13. As before, determine the average values of  $i$  and  $V$ , from the graphs. Record in Data Table B, and calculate and record average  $P$  for the resistor ( $P = i V$ ).
14. Now calculate  $P$  ( $=dU/dt$ , or  $dQ/dt$ ) for the water and calorimeter cup, using the slope of the temperature vs time graph to determine  $dT/dt$ , and then calculating from  $Q = C \Delta T$ . (Note differentiating both sides with respect to  $t$  allows us to use  $dT/dt$  (or  $d\Delta T/dt$ ) to find  $P$ .)
15. Compare the two values of average power.

### PROCEDURE C

16. Now use the RLC circuit board and make a series circuit of the light bulb, the Power Amplifier and the Current Sensor. Connect the Voltage Sensor across the terminals of the light bulb. Be sure to observe polarity for the sensors. Be sure the Power Amplifier is turned off before changing connections.
17. Delete the temperature graph and all data. On graphs you want to keep, you can delete data by highlighting the data to be deleted in the Data Window, and pushing the delete key on the keyboard. Next click on Options on the Experiment Setup Window. In the next window which appears, place a check in the box next to the words “Keep data only when commanded”, remove all other checks (that is, Uncheck “Enter a keyboard value...” and “Prompt for a value”) and then click OK.
18. Drag icons for table (from Displays window) onto the device icons for Analog Channels B and C. Set the voltage of the Power Amplifier to 0.10 V (by highlighting the numbers and typing in the given value, and then pushing Enter on the keyboard; you may also use the arrows under the window to change initial value to 0 and step values of 0.10). Make sure the Power Amplifier is turned off while you are doing this setup.
19. Turn on the Power Amplifier (virtually and physically), click START, and then click KEEP on the sampling window. This should give you readings on the two data tables. Note the voltage across the resistor is close, but not equal to 0.10 V (can you think why?). Change the voltage on the Power Supply to the next value indicated on the Data Table C, and again click KEEP. Enter successively all the values of voltage on Data Table C, up to 7.00 V. The red square button is the STOP button under this option.
20. Either record the data from the monitor onto your paper, or open an Excel spreadsheet and copy the values there. (You may have to recopy in Excel, since the copy from DataStudio may give you time values which you do not want.) Now construct a graph of  $V$  vs  $I$ , either by hand or from the Excel spreadsheet. If you use Excel, print a copy of your data and graph onto a single page.

## QUESTIONS

1. Is conservation of energy confirmed in Procedure A? Of course, we expect that there are in fact some transfers of energy which are not measured in our experiment. Identify some of these energy transfers, and explain whether they help to explain any discrepancies in your data, or do they make the discrepancies worse?
2. Comment on the meaning of  $dQ/dt$  and  $P$  in Procedure B. (Explain what these two rates are.) Are they close, and should they be?
3. Why is the voltage of the Power Amplifier not equal to the voltage across the resistor in Procedure C?
4. What is the nature of the resistor in the light bulb? Is it ohmic or not? Is the resistance of the light bulb constant? Comment and explain.

### DATA TABLE A

$m_{\text{cup}}$	_____
$m_{\text{cup and H}_2\text{O}}$	_____
$m_{\text{H}_2\text{O}}$	_____
$T_o$	_____
$T$	_____
$C$	_____
$i$	_____
$V$	_____
$\Delta t$	_____
$Q$	_____
$W$	_____
% diff	_____

### DATA TABLE B

$i$	_____
$V$	_____
$dT/dt$	_____
$dQ/dt$	_____
$P$	_____
% diff	_____

### DATA TABLE C

$V_{\text{PA}}$ (V)	$V_{\text{R}}$ (V)	$i$ (A)
0.10	_____	_____
0.20	_____	_____
0.30	_____	_____
0.40	_____	_____
0.50	_____	_____
0.60	_____	_____
1.00	_____	_____
2.00	_____	_____
3.00	_____	_____
4.00	_____	_____
5.00	_____	_____
6.00	_____	_____
7.00	_____	_____