ELECTRICAL ENERGY

OBJECTIVES:

      1)   Calculate the electrical power dissipation in a resistor.

      2)   Determine the heat added to the water by an immersed heater.

      3)   Determine if the energy dissipated by the immersion resistor is completely transferred to heat added to the water.

      4)   Measure the resistance of an immersion heater and verify that the relationship between current and voltage obeys Ohm's Law.

INTRODUCTION

When a voltage is applied across a resistor, an electrical current will flow through the resistor. As an electron travels along, it occasionally collides with the ions of the resistor and causes these ions to vibrate with greater amplitude than they had before the collision. In this way, the collisions increase the vibrational amplitude and thus the vibrational energy of the ions. This increase in vibrational energy corresponds to a change in thermal energy (heat). Electrical energy has been converted into heat. This is one example of the conversion of energy from one form to another. In this experiment you will calculate the electrical energy dissipated by the immersed resistor and measure the amount of heat added to the water, then determine if the energy conversion is complete.

The electrical power (P) dissipated by a resistor is given by

$$P = VI$$

where, P (in watts)= power
                       V (in volts)= voltage
                       I (in amps)= current

From the power, we can calculate the work done by the resistor, which is given by

$$W = P\Delta t$$

where, W (in joules)= work
                       P (in watts)= power
                       Δt (in sec)= time elapsed when the voltage is applied to the resistor

Heat is a form of energy. Traditionally, heat is measured in units of calories (cal) instead of joules. One calorie is defined as the amount of heat necessary to raise the temperature of 1 gram of water by one degree Centigrade (°C). The conversion factor between calories and joules is:

$$1 \text{ cal} = 4.18 \text{ joules}$$

When a resistor is immersed in a cup of water and a current is passed through it, the electrical energy dissipated by the resistor will be converted into heat, and the heat may be absorbed by the water, the cup, the resistor, etc. The amount of heat can be calculated by using the following equation:

$$H = m_w * c_w * ? \, T + S \tag{1}$$

where, m_w = mass of the water
  c_w = specific heat of water

S represents the heat dissipated in the resistor, the cup, etc. In this experiment, S will be very small compared to $m_Wc_W? \, T,$ and will be assumed to be zero (S=0).

Converting the unit from calories to joules, we have

$$H_W = 4.18 * m_w * c_w * \Delta T \qquad \text{(joules)} \tag{2}$$

where c_w is in units of cal/gm°C.

We will be using deionized water that has been refrigerated to cool it to below room temperature. We will do this to compensate for heat that was transferred to the air in the room from the calorimeter. To do this, We will not start to take data until the water has heated up to about 4° C below room temperature. Then, we will continue to take data until the water as reached about 4° C above room temperature. This way, the heat that was absorbed by the water when it was below room temperature will be offset by the heat that was absorbed by the room when the water was above room temperature. This should help to balance out and eliminate most of the error that was caused by using a calorimeter that is not a perfect insulator.

We assume that energy will be conserved. If this is true, then the energy that was produced by the resistor will all be absorbed by the water. By comparing the energy produced by the resistor and the heat energy gained by the water, we can verify this.

APPARATUS   (figure 1)
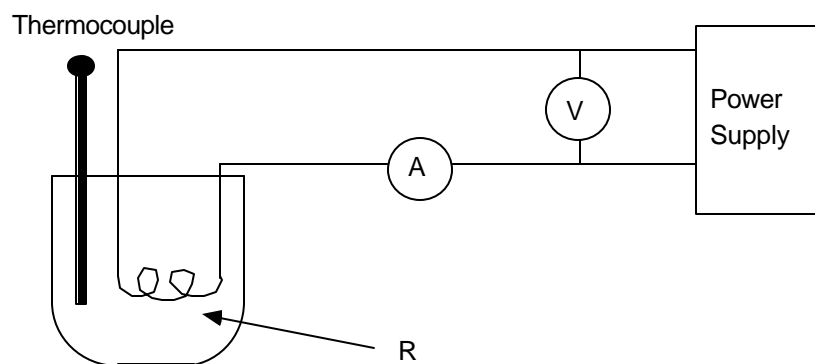
Partner   _____   Name _____

           _____   Section _____

PROCEDURE

1. Weigh the cup using the scale provided (ask your TA where the scale is located in the room.) Using chilled water from the refrigerator, fill your cup with enough water to cover the resistor coil if the lid were on. Now reweigh the cup (now filled with water) and determine the mass of just the water. Record your results below.

        Mass of cup $m_c =$ _____ ± _____

        Mass of cup and water $m_c + m_w =$ _____ ± _____

        Mass of water $m_w =$ _____ ± _____

        Room temperature $T_R =$ _____ ± _____

2. Measure the resistance of the coil (R_{coil}) with the digital multimeter, using the Ohm scale. Set the meter back to volts. Place the resistor in the cup. Connect the circuit as shown in figure 1. Turn the current knob (which is just a limit knob) all the way up and adjust the voltage until you have a current of 3 amps. Read and record the **current from the power supply meter**, and measure the **voltage with the digital multimeter** at the output of the power supply (V_{PS}) and at the cup(V_{cup}). Use the voltage at the cup for your calculations. Read the current again at room temperature and when you turn off the power.

R_{coil} _____ ± _____ $V_{PS} =$ _____ ± _____ $V_{cup} =$ _____ ± _____

4. Let the resistor heater warm up the water. (One member of the team **must** continuously shake the cup to dissipate the heat uniformly in the water.)

5. When the temperature reaches $4°C$ below room temperature, Record the current (I_{start}) and start watching the clock. Record the temperature in the table on the next page every 30 seconds. Read and record the current from the power supply when the temperature reaches room temperature (this will be I_{room}). Stop recording the temperature when it reaches $4°C$ above room temperature and turn off the power supply. Read and record the current from the power supply once again (this will be I_{stop}). Remeasure R at that time by disconnecting the resistor from the power supply and using the multimeter on the Ω setting just like you did to get R_{coil} (this will be R_{final}).

$I_{start} =$ _____ ± _____ $I_{room} =$ _____ ± _____

$I_{stop} =$ _____ ± _____

Start time _____:_____:_____   End time_____:_____:____   Rfinal___±_____

t (sec)	T (°C)	t (sec)	T (°C)
0		510	
30		540	
60		570	
90		600	
120		630	
150		660	
180		690	
210		720	
240		750	
270		780	
300		810	
330		840	
360		870	
390		900	
420		930	
450		960	
480		990	

6. Calculate the temperature change (? T) and the time span (? t) from start to stop.

? t = _____ ± _____ sec

? T= _____ ± _____ °C

7. Calculate the power dissipated in the resistor, using V Cup, and the associated error using both:
   P=VI,   ? P=P (? V/V+? I/I)   and $P = V^2/R$? P=P (2 ? V/V+? R/R)

Q: Which form gives a more accurate power value?   (Fill in that value below) Why did you choose that one?

P = _____ ± _____ watts

Q: Were V Cup and V PS different? Why? Why use V Cup?

8. Determine the work done by the resistor and the associated error
   W=P? t   ? W/W = ? P/P + δ(? t)/? t

W = _____ ± _____ joules

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Q: Which uncertainty is more important, the uncertainty in time or in power?

Q: If you have a computer plot T vs t. If not, compare the time from start to room temperature with the time from room temperature to stop. Was the power constant? Justify your answer.

9. Calculate the heat added to the water using equation (2) and the associated error
    Specific heat of water $C_w = 1.0$ cal/gm°C
    ? $H_w = H_w$ [? m/m+? (? T)/? T]

    Show your calculations: H_w = _____ ± _____ joules

10. Compare the work done by the resistor and the heat added to the water. Is energy conserved? (You should take into account the errors.) Was the heat energy found in the water less or more than the electrical energy? (Was energy lost or gained?) Discuss possible sources of apparent energy loss or gain in this experiment and its analysis.

11. Determine the resistance of the heating coil and verify that the relationship between current and voltage obeys Ohm's law for a constant resistance. (Use any method that you can think of.)