EXPERIMENT 3
Electrical Energy

Objectives

1) Calculate the electrical power dissipated in a resistor
2) Determine the heat added to the water by an immersed heater.
3) Determine if the energy dissipated by an immersion resistor is completely transferred to heat added to the water.
4) Measure the resistance of an immersion heater.

Apparatus: Calorimeter (is a container that is a very good insulator, it is assumed that no energy is transferred out of such a container), power supply, digital multimeter, thermometer and a power supply. See Figure 1 below.

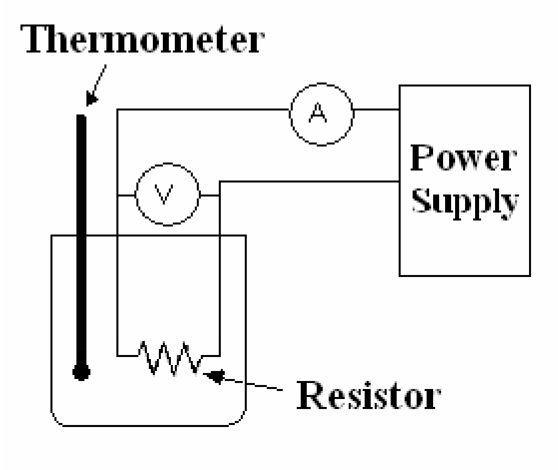

Figure 1

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 an example of the conversion of energy from one form to another. In this experiment you will calculate the electrical energy dissipated by a resistor immersed in water 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

$$P = VI \tag{1}$$

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

$$W = P\Delta t \tag{2}$$

where, W (in joules) = work
P (in watts) = power
Δt (in seconds) = 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 cal = 4.18 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:

$$H = m_W * c_W * \Delta T + S \tag{3}$$

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

$m_W * c_W * \Delta T$ is the heat absorbed by the water, while S represents the total heat absorbed by all other parts of the apparatus. The calorimeter is a very good insulator therefore, S will be very small compared to the heat gained by the water; hence, we will assume S ≈ 0.

Converting the unit from calories to joules, we have

$$H_W = 4.18 * m_W * c_W * \Delta T \quad \text{(joules)} \tag{4}$$

where c_w is in units of cal/gm°C.

We will use deionized water that has been refrigerated to cool it to below room temperature. We will not start to take data until the water is about 4^o C below room temperature. Then, we will continue to take data until the water as reached about 4^o C above room temperature.

We do this because our calorimeter (a cup) is not in fact a perfect insulator, and heat from the surroundings (i.e. the room) introduces a systematic error in our measurement. This way, heat absorbed by the water from the room while the water is below room temperature will be offset by the heat lost to the room while the water is above room temperature. Using this method balances out the systematic error and allows us to measure only the heat transferred to the water by the resistor.

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 electrical energy (work done) produced by the resistor and the heat energy gained by the water, we can verify this.

Procedure

1. Weigh the cup using the scale provided (ask your TA where the scale is located in the room.) Chilled water, that is well below room temperature is in a refrigerator in the room.. Therefore, you should use a mixture of chilled water and room temperature water in the calorimeter. The temperature of the mixture should be around 3.5 to 4.0 °C below room temperature. Fill your calorimeter with enough water to cover the resistor coil if the lid were on. **When running the experiment, the resistor must be completely submerged in the water.** Now reweigh the cup (now filled with water) and determine the mass of just the water. Record your results in Data Table 1 of your Excel spreadsheet..

2. Measure the resistance of the coil ($R_{initial}$) with the digital multimeter, using the Ohm scale. Set the meter back to volts. Place the resistor in the calorimeter. 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 approximately 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 calorimeter(V_{cal}). Use the voltage at the calorimeter for your calculations.

3. Turn on the power supply and let the resistor begin to heat the water in the calorimeter. One member of the team **must** continuously and gently shake the cup to dissipate the heat uniformly in the water.)

4. With a starting temperature between 3.0 and 4.0 °C below room temperature (T_{start}), record the current I_{start}, the temperature and start watching the clock. Record the temperature in the "electrical energy" spreadsheet 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 a temperature of $T_{room} - T_{start}$ above room temperature, record the current from the power supply (this will be I_{stop}) and turn off the power supply. Disconnect the resistor from the power supply and use the multimeter to measure its resistance again (this will be R_{final}).

Questions

1. Calculate the temperature change (ΔT) and the time span (Δt) from start to stop.
2. Calculate the power dissipated in the resistor, using V_{Cal}, and the associated error using $P=VI$, $\delta P=P(\delta V/V+\delta I/I)$ and $P = V^2/R$, $\delta P=P(2\,\delta V/V+\delta R/R)$.
3. Which gives a more accurate power value? Explain why.
4. Were V_{cal} and V_{PS} different? Why? Why should you use V_{cal}?
5. Determine the work done by the resistor (in Joules) and the associated error using $W=P\Delta t$ and $\delta W = W(\delta P/P + \delta(\Delta t)/\Delta t)$.
6. Which uncertainty is more important, the uncertainty in time or in power? Justify your answer.
7. Construct a temperature versus time using graph your data. Was the power constant? Justify your answer.
8. Calculate the heat added to the water using equation (4) and the associated error.
   Specific heat of water $C_w = 1.0$ cal/gm°C
   $\delta H_w = H_w\,[\delta m/m+\delta(\Delta T)/\Delta T]$
9. Compare the work done by the resistor and the heat added to the water. Is energy conserved? (You should take into account the uncertainties.) 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.