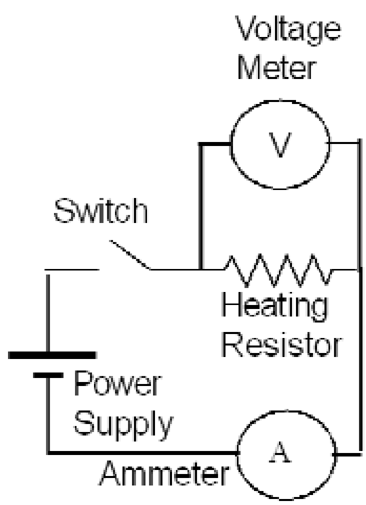
Electrical Equivalent of Heat



Produced by the Physics Staff at
Collin County Community College

Purpose

In this experiment, you will investigate the relationship between electrical power and joule heating in a resistor submerged in water.

Equipment

- Electrocalorimeter
- Temperature sensor
- Ammeter, 1 A
- Lab timer or stop watch
- Two long clip leads
- Voltage sensor
- DC Power supply, 10V, 1A
- Single pole switch
- Triple beam balance

Introduction

Energy can be transferred from one place to another by means of an electric current. One of the important effects of an electric current is its heating effect — whenever an electric current flows in a conductor, some electrical energy is converted into heat energy. In this experiment, you will send an electric current through a resistor submerged in water. This will convert electric energy into heat energy which will raise the temperature of the water. From the principle of conservation of energy, it follows that the work done in pushing electric charge through the resistor is proportional to the heat energy produced. This statement is the result of the First Law of Thermodynamics, which states:

$$W \propto H$$

or

$$W = J H \qquad \textbf{\textit{Equation 5.1}}$$

where the work *W* is in joules and the heat energy *H* is in calories. The conversion factor between electric energy measured in joules and heat energy in calories is called the *electrical equivalent of heat*. The use of the symbol *J* for this conversion factor is in honor of James Joule who first demonstrated the validity of Equation 5.1.

Electrons flowing in a circuit get their energy from the voltage source, whether it is a battery or an electronic power supply. As the electrons pass through a copper wire, they collide with the copper atoms in the wire and lose some energy in each collision.

The energy transferred to the atoms (electrical energy converted into thermal energy) results in a temperature increase of the wire. A charge *q* being pushed through a circuit by a potential difference *V* accumulates energy equal to *qV*. When the voltage is constant, the work done by the voltage source on the charge is therefore $W = qV$. The power dissipated in the wire is the rate at which this work is being done:

$$P = \frac{W}{t} = \frac{qV}{t} \qquad \textbf{\textit{Equation 5.2}}$$

Since the current I is the rate at which the charge is flowing through the conductor, Equation 5.2 can be written as

$$P = VI \qquad \textbf{\textit{Equation 5.3}}$$

The metric unit for power is joules per second, which is watts.

Using Ohm's Law, $V = RI$, the power can be expressed in two other forms:

$$P = VI = V\left(\frac{V}{R}\right) = \frac{V^2}{R} \qquad \textbf{\textit{Equation 5.4}}$$

used when the power supply has constant voltage, or

$$P = VI = (RI)I = I^2 R \qquad \textbf{\textit{Equation 5.5}}$$

used when the power supply has constant current.

The rate of thermal energy generated in a current-carrying conductor is sometimes referred to as Joule heat, or I^2R loss, which is the power dissipated or energy converted per unit time.

In this experiment you will find the average power P dissipated by the current and multiply it by the time the current was flowing in the circuit to get the electrical energy converted by the resistor.

$$W = Pt = V\,I\,t \qquad \textbf{\textit{Equation 5.6}}$$

where I is the average current in the resistor and V is the average voltage across the resistor. This dissipated energy is called heat, H, and it raises the temperature of the water according to the relationship

$$H = m\,c\,(T_f - T_i) \qquad \textbf{\textit{Equation 5.7}}$$

Where m is the mass of the water, c is the specific heat capacity of water (1 cal/g °C), T_f is the maximum temperature of the well-stirred water after the electrical power is turned off, and T_i is the water temperature at the instant the power is first switched on and the current is started. The heat energy H is measured in calories.

The total energy of the resistor/water system is conserved. In the ideal condition in which no heat energy is exchanged between the system and the surrounding air, all heat energy produced in the resistor is absorbed by the water. If you equate the energy produced in the resistor (in joules) to the energy gained by the water in (calories), you will determine the electric equivalent of heat.

$$\mathrm{W = J\,H} \qquad \textbf{\textit{Equation 5.8}}$$

or

$$\mathrm{J = W/H = 4.186\ joules/cal} \qquad \textbf{\textit{Equation 5.9}}$$

The electric equivalent of heat has the same value as the mechanical equivalent of heat, i.e., 1 cal = 4.186 joules.

Procedure

Equipment Setup

1. Connect the voltage sensor to analog channel A and the Temperature sensor to analog channel B on the interface. Switch on the interface and the computer. Open Data Studio and select *Create Experiment.*
2. Double-click on the Voltage sensor and then on the Temperature sensor (not RDT or Type K). .
3. Double-click on the Digits display and select Voltage. Double-click on the Digits display again and select Temperature. Drag the Digits displays to the bottom of the screen.
4. Plug in the cord for the power supply. Attach the voltage sensor leads across the resistor and connect the power supply output to the switch and the resistor as shown in Figure 5.1.

A. Manual Measurements

1. Weigh the empty calorimeter cup and record its mass to three sig. dig. Record this mass m_c in Table 5.1.
2. Pour about 200 ml of tap water into the calorimeter cup. Add a few grams of ice to the water to cool it. Record the mass of the cup and water m_{cw}, calculate and record the mass of the water alone m_w.
3. Submerge the resistor coil and the temperature sensor into the water. Cover the top of the electrocalorimeter to prevent heat transfer between the water and the room air.

Caution: *Be sure the resistor is completely submerged in the water when the current is flowing.*

4. Measure and record the initial temperature of the water T_i. This temperature should be 5 to 6 °C below room air temperature before you begin Part B.
5. After your circuit is checked by the instructor, switch on the power supply.

B. Automated Measurements

1. Simultaneously click Start to begin data collection, start the lab timer, and close the switch to start the current flowing in the resistor. While you are taking data, stir the water gently.
2. Every two minutes while the water is heating, measure and record the elapsed time t, the current I, the voltage V, and the temperature T in Table 5.2.

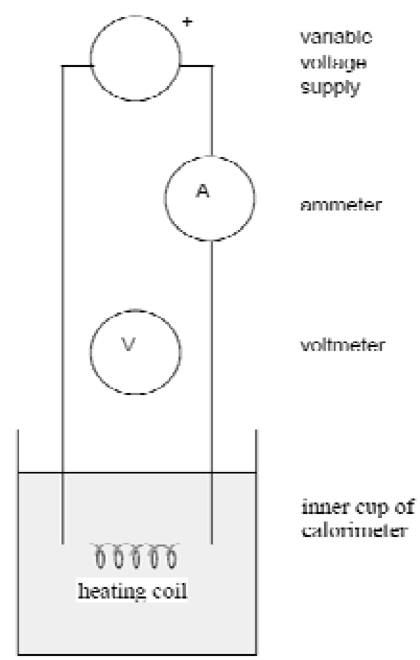


Figure 5.1

3. When the water temperature is 10–12 °C above the initial temperature, simultaneously open the switch, stop the timer, and switch off the power supply. *Do not stop Data Studio yet!* Continue stirring the water gently until it reaches its maximum temperature. The temperature will remain constant for a short while, then begin dropping as the water loses heat to its cooler surroundings.
4. When the water reaches its maximum temperature (when the temperature stops rising), click Stop to stop taking data. Read and record the final water temperature T_f.
5. Calculate and record the average values for the current I_{avg} and the voltage V_{avg} in Table 5.2.

C. Data Analysis

1. Calculate and record in Table 5.3 the average power P dissipated by the resistor.
2. Calculate and record the electrical energy U (in joules) converted by the resistor during the time the current flowed in it.
3. Calculate and record the thermal energy H (in calories) absorbed by the water.
4. Calculate and record the Electrical Equivalent of Heat.
5. Calculate and record the percent error in your calculated value of J.
6. Switch off the computer, dismantle your equipment and return it to the lab cart, and clean your area of the lab table.