Joule Heating

Lab #2

Name: Aidan Fitzgerald
Partners: Margaret Burkart and Kristi Fok

May 31, 2016

Joule Heating

Objective

Measure Joule heating experimentally.

1 Introduction

Joule heating is a process by which electrical energy is converted to thermal energy. It occurs because conductors (excluding superconductors) have resistance, which means that a constant supply of power must be added just to maintain a constant current. The relationship between input power, voltage, and current is given by

$$P = IV = I^2R = \frac{V^2}{R} \tag{1}$$

Multiplying through by time, t, we obtain an equation for the work done on all the charges in the conductor over a period of time to produce a current:

$$W = IVt \tag{2}$$

Ideally, the work done on the electric charges should equal the heat generated by the current, $W = \Delta H$, because of conservation of energy. The Joule heat produced by the wire can be measured using a calorimeter, according to the diagram below:

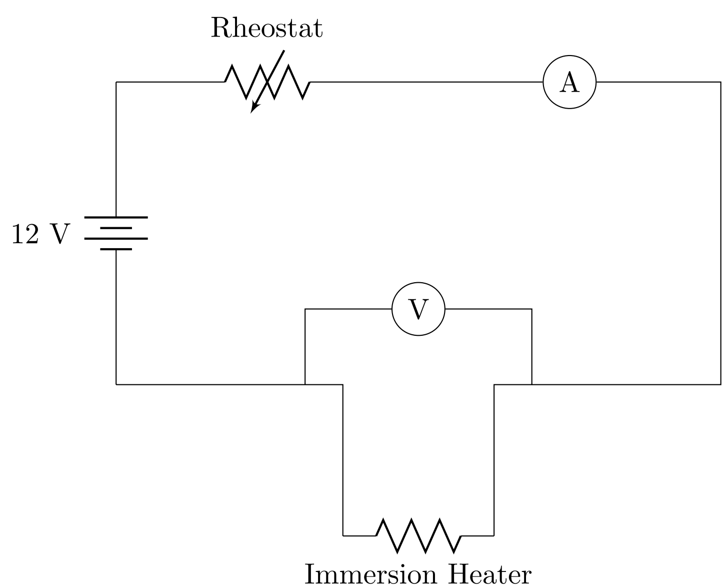

Figure 1: Calorimeter setup

When the heat is measured using a calorimeter, it is given by

$$\Delta H = (m_w c_w + m_{cal} c_{cal} + m_{coil} c_{coil})(T_f - T_i) \tag{3}$$

where (m_w, c_w), (m_{cal}, c_{cal}), and (m_{coil}, c_{coil}) are the mass and specific heat of the water, calorimeter cup, and coil, and T_i and T_f are the initial and final temperatures of the system.

2 Procedures and Results

We built the setup shown in Figure 1 and recorded the masses and specific heats of the calorimeter cup, coil, and water.

	Mass	Material	Specific heat
Calorimeter cup	105.3 g	Copper	0.385 J/(g · °C)
Immersion coil	1.4 g	Nichrome	0.107 J/(g · °C)
Calorimeter cup and water	254.4 g		
Water	149.1 g	H_2O	4.186 J/(g · °C)

We filled the calorimeter cup two-thirds full with cool tap water and measured the temperature of the system to be 25.2 °C. We set the input voltage to 12 V and turned on the power supply, adjusting the rheostat until the current was between 2 and 3 A. We took current and voltage readings every 60 s. After 300 s, the temperature of the system had risen to 30.1 °C.

Time	Voltage	Current
0 s	5.46 V	2.66 A
60 s	5.32 V	2.69 A
120 s	5.30 V	2.60 A
180 s	4.16 V	2.51 A
240 s	4.41 V	2.39 A
300 s	4.41 V	2.22 A

3 Discussion

The averages of the voltage and current measurements are 4.84 V and 2.51 A. Substituting into Equation 2, we obtain the work done to produce the electric current:

$$\begin{aligned} W &= IVt \\ &= (2.51\,\mathrm{A})(4.84\,\mathrm{V})(300\,\mathrm{s}) \\ &= 3640\,\mathrm{J}. \end{aligned}$$

Substituting the mass measurements, accepted specific heat values, and initial and final temperatures into Equation 3, the heat generated by the electric current in the calorimeter is:

$$\begin{aligned}\Delta H &= (m_w c_w + m_{cal} c_{cal} + m_{coil} c_{coil})(T_f - T_i) \\ &= (149.1\,\mathrm{g} \cdot 4.186\,\mathrm{J}/(\mathrm{g} \cdot {}^\circ\mathrm{C}) + 105.3\,\mathrm{g} \cdot 0.385\,\mathrm{J}/(\mathrm{g} \cdot {}^\circ\mathrm{C}) + 1.4\,\mathrm{g} \cdot 0.107\,\mathrm{J}/(\mathrm{g} \cdot {}^\circ\mathrm{C}))(30.1^\circ\mathrm{C} - 25.2^\circ\mathrm{C}) \\ &= 3260\,\mathrm{J}.\end{aligned}$$

The percent difference between W and ΔH is

$$\%\,\mathrm{diff} = \frac{|W - \Delta H|}{\frac{W+\Delta H}{2}} = \frac{380\,\mathrm{J}}{3450\,\mathrm{J}} = 11\%.$$

The rheostat cannot account for this inconsistency because the voltmeter only runs parallel to the immersion heater. However, the presence of the voltmeter itself may account for it: because the voltmeter is not an ideal voltmeter, some current is allowed to flow through it, so some heat is dissipated through the voltmeter instead of the heating coil. That heat loss is given by $W - \Delta H = 380\,\mathrm{J}$.

4 Conclusion

The heat generated by a live conductor with nonzero resistance, ΔH, is equal to the work done on the charges in the conductor, W.