

Joule's First Law and Heat Transfer

Introduction

In this experiment heat is produced by passing a current through a resistor which is immersed in a container of water. The purpose of this experiment is to compare the energy dissipated by the resistor to that absorbed by the water, thereby testing the principle of conservation of energy. The experimental arrangement is shown in Figure 1.

When an object is heated, the transfer of energy Q to the object results in an increase in the object's temperature, ΔT , according to the relationship

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

where m and c are the mass and specific heat of the object.¹ When a potential difference is applied across a resistor, a current passes through the resistor resulting in the generation of heat (Joule heating). The rate at which the resistor dissipates the energy (the heat) P is

$$P = VI , \quad (2)$$

where V is the potential difference across the resistor, and I is the current passing through the resistor. After an amount of time t has elapsed, the energy E dissipated in the resistor is

$$E = Pt = VIt . \quad (3)$$

Procedure

A resistor is immersed in water whose temperature is approximately 5°C below room temperature. A potential difference V is applied across the resistor resulting in a current I through the resistor. The resistor generates heat, which is transferred to the water and its container, causing the temperature of both to increase by an amount ΔT . The water is heated until its temperature has increased, approximately, 5°C above room temperature. The potential difference across the resistor is maintained at 6.0 V for the duration of the experiment, a condition which is satisfied by adjusting the potential

¹If the object is heated at constant pressure, typically atmosphere pressure, then c is denoted c_p , the specific heat at constant pressure.



Figure 1: Experimental arrangement. The equipment used in this experiment includes a calorimeter, voltmeter, and ammeter. The resistor is located in a cup within the calorimeter.

difference across the resistor, appropriately. The details of performing the experiment are as follows.²

1. Set the voltmeter to the 20 volt scale and the ammeter to the 10 amp scale.
2. Assemble the circuit. Perform the preliminary adjustments to the power supply as described in Appendix 1.
3. Measure the mass of the cup and stirrer. The cap on top of the stirrer can be unscrewed so that the stirrer can be slid through the hole in the calorimeter cover. Fill the cup with a sufficient amount of water to cover the resistor. The water should be colder than room temperature by approximately 5°C .
4. Measure the initial temperature of the water.
5. Simultaneously start the stopwatch, and turn on the power supply. Record the potential difference across the resistor and current passing through the resistor when you start the stopwatch and at one minute intervals, thereafter, for the duration of the experiment. Maintain the potential difference, as recorded by the voltmeter, at 6.0 V throughout the experiment. This can be accomplished by adjusting the fine/coarse current settings on the power supply.
6. Heat the water until its temperature has increased by approximately 5°C above room temperature or greater. Continue heating the water until the end of the

²It may be helpful to perform a mock-up of the start of the experiment. This will allow the voltage setting of the power supply to be adjusted to its requisite initial value. Thus, when the power supply is turned on at the beginning of the actual experiment, it will be unnecessary to make any voltage adjustments.

minute. Then, turn off the power supply. Stir the water. Wait until the water has attained its highest temperature, then record its value.

Analysis

1. Calculate the energy E dissipated in the resistor. Using Eq. 3 one can show that

$$E = 60 \sum_{i=0}^N V_i I_i ,$$

where V_i (I_i) is the potential difference (current) during minute i , and $N + 1$ is the number of minutes elapsed.

2. Calculate the heat, Q , transferred to the water and cup. Using Eq. 1 one can show that

$$Q = (m_{\text{cup}} c_{\text{cup}} + m_{\text{H}_2\text{O}} c_{\text{H}_2\text{O}}) \Delta T .$$

Here m_{cup} and $m_{\text{H}_2\text{O}}$ are the masses of the cup (including the stirrer) and water, and c_{cup} and $c_{\text{H}_2\text{O}}$ are their specific heats. Note: the specific heat of the cup or stirrer is $900 \text{ J}/(\text{kg} \cdot ^\circ\text{C})$; the specific heat of the water is $4190 \text{ J}/(\text{kg} \cdot ^\circ\text{C})$.

3. Calculate the percentage of energy δ which is not accounted for, where $\delta = 100 \times (E - Q)/E$.
4. Based on the value of δ what conclusions do you draw with regard to the principle of conservation of energy? The quantity δ can be either positive or negative. What is the significance of its sign?

1 Appendix

The following preliminary adjustment to the power supply may be useful in preventing damage to the ammeter, voltmeter, or resistor when performing the experiment.

1. Fill the the aluminum cup inside of the calorimeter assembly half full of water, and replace the cup in the calorimeter.
2. Set the coarse and fine voltage settings to zero.
3. Turn on the power supply.
4. Adjust the fine and course voltage settings to full scale, leaving the fine and course current adjustments at the lowest setting.
5. Slowly increase the current setting using either the course or fine setting until the voltmeter reads 6.00 volts.
6. When performing the experiment adjustments to the voltage should be made using only the fine current setting on the power supply. Empty the water from the aluminum cup and replace it in calorimeter assembly. Proceed with the experiment.