

PHYSICS 202 LAB 5: THE EQUIVALANCE OF HEAT AND ELECTRICAL
ENERGY
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THEORETICAL DISCUSSION

When a charge q transits a potential difference of V , its potential energy changes by $U = qV$. If a current $I = \frac{dq}{dt}$ transits the circuit, then the power P generated by this current—which is the energy per unit time lost by the charges as they transit V —is given by

$$P = \frac{dU}{dt} = \frac{dq}{dt}V = IV$$

If the potential change is across a resistor, then the power developed across the potential drop is dissipated as heat. Since $V = IR$ across a resistor, the following are equivalent expressions for the power dissipated by a resistor¹:

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

Resistive heating elements are quite common, and are used in coffee makers, stoves, cheap space heaters, etc. Incandescent light bulbs use resistive heating to cause a carbon filament to glow and emit light (and heat). In today's experiment, we will use the thermal power generated in a resistor to heat water. In the approximation that the rate of power dissipation is constant over the time interval Δt , the energy generated by the resistor in this time is

$$U = P\Delta t = IV\Delta t$$

The total electrical energy deposited over N such time intervals is the sum of the energy deposited in each interval.

$$U_E = \sum_{j=1}^N U_j = U_1 + U_2 + \cdots + U_N$$

or

$$U_E = \sum_{j=1}^N I_j V_j \Delta t_j = I_1 V_1 \Delta t_1 + I_2 V_2 \Delta t_2 + \cdots + I_N V_N \Delta t_N \quad \text{Equation 1}$$

¹ Recall that the SI unit of heat or energy is Joules, and the SI unit of power is Watts. One Watt is equal to one Joule per second.

If this energy is transferred to an aluminum cup (calorimeter) filled with water as heat Q , then the relation between the heat transfer Q and the temperature change in the water/cup system ΔT is

$$Q = (m_{water}c_{water} + m_{cup}c_{cup})\Delta T \quad \text{Equation 2}$$

where c_{water} and c_{cup} are the specific heats of water and the calorimeter cup, respectively. If we assume that all of the heat generated by the current going through the resistor is absorbed by the water/cup system, then

$$U_E = Q$$

It is this assumption that we are going to test, by comparing the energy dissipated in the resistor to the heat absorbed by the water/calorimeter system.

EXPERIMENTAL PROCEDURE

Synopsis: We are going to use a circuit that sends a current through a resistive heater, which is immersed in a calorimeter cup filled with water, as shown in Figure 1. With the power supply on, we will monitor the temperature T , the current I and the potential V at frequent intervals. We will also record the time interval Δt over which we “cook” the water. We are going to need to know the mass of the water in the cup as well as the mass of the cup itself. The specific heat of aluminum (the material the calorimeter is made from) and the specific heat of water are respectively,

$$c_{cup} = 900 \frac{\text{J}}{\text{kg} \cdot \text{K}} \quad \text{and} \quad c_{water} = 4190 \frac{\text{J}}{\text{kg} \cdot \text{K}}$$

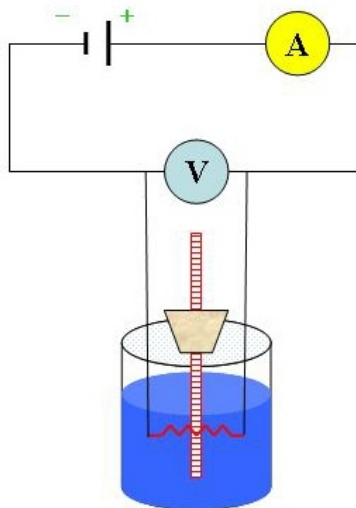


Figure 1: Experimental setup for measuring the conversion of electrical to thermal energy.

Detailed procedure:

1. Weigh the calorimeter cup.
2. Fill the cup with cold water so that it just covers the heating element. Weigh the cup with the water in it.
3. Insert the thermometer into the cork at the top of the calorimeter and adjust its depth so that it doesn't touch the heater but nonetheless sits well below the surface of the water. When the thermometer equilibrates with the water, record the temperature.
4. Simultaneously start your watch and turn the power supply on to a current of 1.5 A. Record the potential on the voltmeter. Adjust the power supply as needed to maintain a current of 1.5 A.
5. Record the potential at one minute intervals. Occasionally stir the water without touching the heating unit. Continue until the temperature of the water has increased by about 15°C, then turn off the current and record the elapsed time.
6. Wait about 30 s for the system to reach thermal equilibrium and record the final temperature. Don't wait any longer than this as the system will rapidly begin to cool.
7. Calculate the power deposited in the system in each one-minute time interval.
8. Multiply the power deposited in each time interval by 60 seconds to determine the energy deposited in each time interval.
9. Add together the energy deposited in all the time intervals to determine the total electrical energy deposited in the system, U_E , using Equation 1.
10. Calculate the heat absorbed by the water/cup system, Q , using Equation 2.
11. Numerically compare the heat absorbed by the system, Q , to the energy generated by the circuit U_E , by calculating the fractional discrepancy between them.