EXPERIMENT 8
THE JOULE CONSTANT

I. THEORY

One of the unifying concepts of nineteenth century physics was the concept of energy. Three common forms of energy are mechanical, electrical and heat.

In metric units, mechanical, electrical and most other forms of energy are most often measured in joules (J). Until recently, heat energy was most often measured in calories (cal).

The Joule constant J is defined as the number of joules equivalent to one calorie. This constant is sometimes called the "mechanical equivalent of heat", because early experiments usually involved the conversion of mechanical energy to heat. In this experiment we will measure the Joule constant by converting electrical energy to heat.

The calorie is defined as the amount of heat energy required to raise the temperature of one gram of liquid water one Celsius degree. This amount of heat is nearly independent of the initial temperature. It follows that if a mass m of water is heated from an initial temperature T_i to a final temperature T_f, the heat required is

$$Q = mc_w(T_f - T_i)$$

where $c_w = 1$ cal/g·°C.

In this experiment, the Electrical Equivalent of Heat (EEH) is experimentally determined. An incandescent lamp is immersed in a known quantity of water and a few drops of India ink are added to the water so it is opaque to visible light. The temperature of the water is measured. The lamp is then illuminated with a fixed current and voltage for a measured time interval, so the electrical energy into the lamp can be calculated. By monitoring the temperature of the water, the heat produced by the lamp can also be calculated. The ratio between the electrical energy that flows into the lamp and the heat produced by the lamp determines the electrical equivalent of heat.

In order to determine the electrical equivalent of heat (J_e), it is necessary to determine both the total electrical energy dissipated by the lamp (E) and the total heat absorbed by the water and the EEH jar (Q). The total electrical energy dissipated by the lamp is

$$E = V \cdot I \cdot t$$

where V = the applied voltage, I = the current, and t = the time during which power was applied to the lamp.

The heat transferred to the water and the EEH Jar is

$$Q = (M_w + M_e)c_w(T_f - T_i)$$

where $M_w = M_{jw} - M_j$ is the mass of water heated (M_{jw} is the mass of the jar and water and M_j is the mass of the jar) and M_e = 23 grams. Some of the heat produced by the lamp is absorbed by the EEH Jar. For accurate results, therefore, the heat capacity of the jar must be taken into account; the heat capacity of the EEH Jar is equivalent to that of approximately 23 grams of water.

Finally, the Electrical Equivalent of Heat is the ratio of these two quantities:

$$J_e = E/Q.$$

II. LABORATORY PROCEDURE

1. Measure and record the room temperature.

2. Measure the mass of the EEH Jar (with the lid on), and record its mass.

3. Remove the lid of the EEH Jar and fill the jar to the indicated water line with cold tap water. **DO NOT OVERFILL.** The water should be approximately 10°C below room temperature, but the exact temperature is not critical. Replace the lid and measure the mass of the EEH Jar with the water and record the value.

4. Using leads with banana plug connectors, attach your power supply to the terminals of the EEH Jar. Connect a voltmeter and ammeter as shown in Figure 1.1 so you can measure both the current through the lamp and the potential difference across the lamp. **NOTE:** For best results, connect the voltmeter leads directly to the binding posts of the jar.

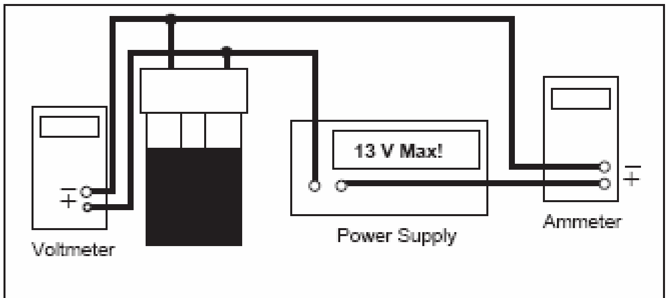

Figure 1.1 Electrical Connections

5. Add about 10 drops of India ink to the water. Turn on the power supply and quickly adjust the power supply voltage to about 11.5 volts, then shut the power off. The lamp filament should have barely been visible when the power was on. If this is not the case, add a few more drops of India ink to the water and briefly turn on the power supply to check again. **NEVER LET THE VOLTAGE EXCEED 13 VOLTS. ILLUMINATE THE LAMP ONLY WHEN IT IS SUBMERGED IN THE WATER.**

6. Insert the EEH Jar into one of the styrofoam calorimeters.

7. Insert your thermometer or thermistor probe through the hole in the top of the EEH Jar. Stir the water gently with the thermometer or probe while observing the temperature. When the temperature warms to about 6 or 8 degrees below room temperature, turn the power supply on and start your stopwatch. Record the temperature.
   NOTE: You may want to turn the lamp on to help the cold water reach this starting temperature. If you do, be sure that you turn the lamp off for several minutes before you begin your measurements, so you are sure the water temperature is even throughout the jar.

8. Record the current and voltage. Keep an eye on the ammeter and voltmeter throughout the experiment to be sure these values do not shift significantly. If they do shift, use the average values in your calculations.

9. When the temperature is as far above room temperature as it was below room temperature, shut off the power, stop the stopwatch, and record the time. Continue stirring the water gently. Watch the thermometer or probe until the temperature peaks and starts to drop. Record this peak temperature.

III. CALCULATIONS

1. Calculate the time during which power was supplied to the lamp.

2. Calculate the total electrical energy that was dissipated in the lamp.

3. Calculate the total heat absorbed by the water.

4. Calculate the electrical equivalent of heat. Calculate the percent error in this value.

5. What effect are the following factors likely to have on the accuracy of your determination of J_e, the Electrical Equivalent of Heat? Can you estimate the magnitude of the effects?
   (a) The inked water is not completely opaque to visible light.
   (b) There is some transfer of thermal energy between the EEH Jar and the room atmosphere. (What is the advantage of beginning the experiment below room temperature and ending at an equal amount above room temperature?)

6. How does J_e compare with J, the ***mechanical equivalent of heat***. Why?