Electrical Equivalent of Heat 'J'

Aim: To determine the electrical equivalent of heat (J).

Apparatus: Electrical equivalent of heat jar, calorimeters, India Ink, regulated power supply of delivering up to 3A at 12 V, digital Volt-Ammeter, stop watch, thermometer and weighing balance

Theory: The theory for electrical energy and power was developed using the principles of mechanical energy, and the units of energy are the same for both electrical and mechanical energy. However, heat energy is typically measured in quantities that are separately defined from the laws of mechanics and electricity and magnetism. Sir James Joule first studied the equivalence of these two forms of energy and found that there was a constant of proportionality between them and this constant is therefore referred to as the Joule equivalent of heat and given the symbol J. The Joule equivalent of heat is the amount of mechanical or electrical energy contained in a unit of heat energy. The factor is to be determined in this experiment.

It is an experimental observation that when a current runs through a wire, the wire will increase its temperature. On a microscopic level, this is because the electrons constituting the current will collide with the atoms in the wire and in this collision process some energy is transferred from the electrons to the wire. The initial source of this energy is electrical and originates from a power supply. The final form of energy is heat as it radiates outward from and throughout the wire. The amount of electrical energy transformed into heat will depend on the current passing through the wire, the number and speed of the electrons and the resistance in the wire which is related to the above collision process.

We can relate the power P to thermal energy transfer (heat) Q during some time interval Δt using the relationship $P = Q/\Delta t$.

Combining the definition of electrical power in terms of current I and electric potential difference V with Ohm's law V = IR when applied to a resistance R yields

$$P = Q/\Delta t = IV = I(IR) = I^2R \qquad (1)$$

which we can rearrange to get

$$Q = P\Delta t = IV\,\Delta t. \qquad (2)$$

The expression arises from the definition of the relationship between energy and power. This amount of heat is being provided to the wire in a time Δt while a given current I is flowing through the resistance R (in our experiment, it is filament of the bulb). In our experiment, this heat is then transferred to a container of water, causing the temperature of the water and jar to rise according to the formula

$$H = M_w.c_w.\Delta T + M_e.c_e.\Delta T \qquad (3)$$

Where M_w is mass of water, c_w is specific heat of water, ΔT is temperature rise, M_e is mass of the jar and c_e is specific heat of the jar.

The electrical equivalent of heat (J) is

$$J = Q/H \qquad (4)$$

Important instructions: When using the Electrical Equivalent of Heat (EEH) Apparatus, always observe the following precautions:

① Do not fill the water beyond the line indicated on the EEH Jar. Filling beyond this level can significantly reduce the life of the lamp.

② Illuminate the lamp only when it is immersed in water.

③ Never power the incandescent lamp at a voltage in excess of 10 V.

Procedure:

1. Measure and record the room temperature (T_r).
2. Weigh the EEH (electrical equivalent of heat) Jar (with the lid on), and record its mass (M_j).
3. Remove the lid of the EEH Jar and fill the jar to the indicated water line with cold water. **DO NOT OVERFILL.** The water should be approximately 10°C below room temperature, but the exact temperature is not critical.
4. Add about 10 drops of India ink to the water; enough so the lamp filament is just barely visible when the lamp is illuminated.
5. 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 (I) and voltage (V) going into the lamp. NOTE: For best results, connect the voltmeter leads directly to the binding posts of the jar.
6. Turn on the power supply and quickly adjust the power supply voltage to about 10 volts, then shut the power off. **DO NOT LET THE VOLTAGE EXCEED 10 VOLTS.**
7. Insert the EEH Jar into one of the styrofoam Calorimeters.
8. 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.
9. Record the current, I, and voltage, V. 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 an average value for V and I in your calculations.
10. When the temperature is as far above room temperature as it was below room temperature (T_r - T_i = Temperature - T_r), shut off the power and record the time (t_f). Continue

stirring the water gently. Watch the thermometer or probe until the temperature peaks and starts to drop. Record this peak temperature (T_f).

11. Weigh the EEH Jar with the water, and record the value (M_{jw}).
12. Repeat the experiment twice with water temperature approximately 8°C and 6°C below room temperature, respectively, but the exact temperature is not critical. To maintain the desired temperature, appropriate normal water quantity can be calculated with formula

$$M_1.S.\ (x-T_1) = M_2.\ S.\ (T_2-x)$$

Where, M_1 = Mass of cold water
S = Specific heat of water
x= Desired Temperature (Temperature of the mixture)
T_1= Temperature of the cold water
M_2 = Mass of the normal water
T_2 = Temperature of the normal water

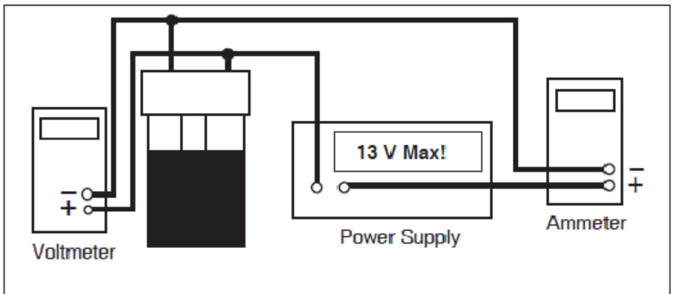

Figure 1.1 Electrical Connections

Data

T_r = ______________________

M_j = ______________________

M_{jw} = ______________________

V= ______________________

I= ______________________

t_i =______________________

t_f =______________________

T_i = ______________________

T_f =______________________

Calculations:

In order to determine the electrical equivalent of heat (J_e), it is necessary to determine both the total electrical energy that flowed into the lamp (E) and the total heat absorbed by the water (H).

E, the electrical energy delivered to the lamp:

E = Electrical Energy into the Lamp = $V \cdot I \cdot t$ = ___________________________

$t = t_f - t_i$ = the time during which power was applied to the lamp = ________

H, the heat transferred to the water (and the EEH Jar):

$H = (M_w.c_w + M_e.c_e)(T_f - T_i)$ = ___________________________________

$M_w = M_{jw} - M_j$ = Mass of water heated = _____________________________

$M_e.c_e$ = 23 grams and c_w = 1 cal/gm ° C. 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.)

J_e, the Electrical Equivalent of Heat:

$J_e = E/H$ = ____

Questions

1.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 it an equal amount above room temperature?)

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

3. How do you determine the light efficiency of incandescent lamp?

References: PASCO scientific manual