41 Electrical Equivalence of Heat
Let There Be Light!

Purpose

To determine the efficiency of an incandescent light bulb.

Required Equipment and Supplies

Electrical Equivalent of Heat Apparatus (EEH jar) (PASCO Model 8552)
regulated power supply (3 amps at 12 volts)
2 digital volt-ammeters
stopwatch
triple-beam balance
thermometer *or*
  Apple II Series computer
  temperature probe
  LabTools software

Discussion

INDIA INK

When electric current flows through the filament of an incandescent bulb, some of its energy is converted into light; the rest is converted into heat. In this experiment you will measure what fraction of electrical energy is converted into light and what fraction to heat. You will do this by comparing the amount of heat a submerged lamp gives to transparent water and the amount it gives to opaque water in the same time.

In the first part of the experiment, the water is made opaque and more absorbent by the addition of black (India) ink. You will measure the electrical power delivered to the bulb and the temperature increase of water. From the data you will calculate the electrical equivalence of heat, J_e.

The total energy dissipated by the bulb can be calculated by multiplying the power and the time. This is because power is the product of the current and voltage, $P = IV$, and the energy dissipated by the bulb is power multiplied by the time,

$$W = (IV)t$$

The heat transferred to the water is

$$Q = mc\Delta T$$

The electrical equivalence of heat, J_e, is the ratio of the electrical energy dissipated by the bulb to the amount of heat transferred to the water.

$$J_e = \frac{W}{Q} = \frac{(IV)t}{mc\Delta T}$$

However, if the experiment were performed with *clear* water, energy in the form of visible light would escape. Since water is a good absorber of infrared radiation, most of the energy that is not emitted as visible light will contribute to Q, the energy absorbed by the water.

Since the total energy dissipated by the bulb is the sum of the visible light energy and heat energy absorbed by the water, we can express the visible light energy as

$$\text{visible light energy} + \text{heat energy absorbed by water} = \text{total energy}$$

$$\text{visible light energy} = (\text{total energy} - \text{heat absorbed by water})$$

If we define the efficiency of the bulb as the energy converted into visible light divided by the total electrical energy dissipated by the bulb,

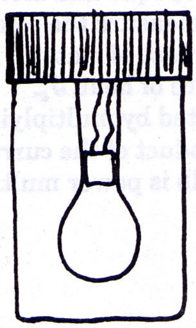
$$\text{efficiency} = \frac{\text{visible light energy}}{\text{total energy}}$$

$$= \frac{(\text{total energy} - \text{heat absorbed by water})}{\text{total energy}}$$

$$= \frac{(W - Q)}{W}$$

Thus, we can calculate the efficiency of the bulb by simply repeating the experiment *without* using the India ink. Neat!

Part A: The Electrical Equivalence of Heat



Procedure

Step 1. Measure and record the room temperature in Data Table 41.1.

Step 2. Measure the mass of the EEH jar and record it in Data Table 41.1.

Step 3. Fill the EEH jar to the indicated water line with water approximately 10°C *below* room temperature. Do NOT overfill the the jar.

Step 4. Add about 10 drops of India ink to the water. Add enough ink so that the filament of the bulb is just barely visible when the bulb is illuminated.

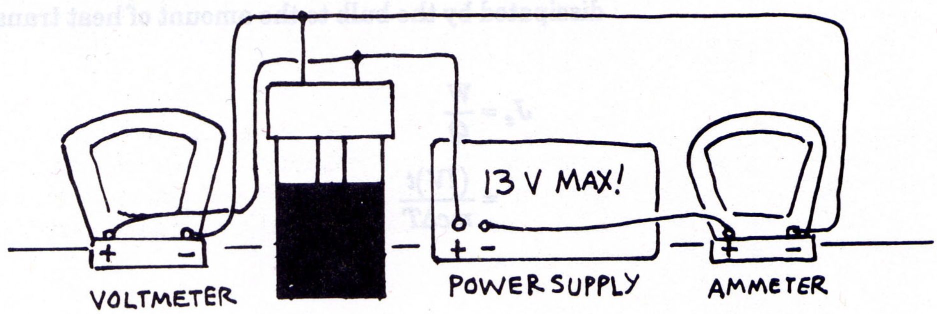


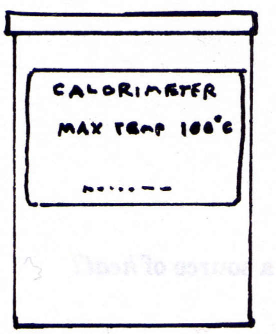
Figure 41.1

Data Table 41.1

	OPAQUE WATER (WITH INK)	CLEAR WATER (WITHOUT INK)
T_{room}		
$t_1 =$		
$t_2 =$		
$\Delta t = t =$		
$T_1 =$		
$T_2 =$		
ΔT		
$M_j + w$		
M_j		
V		
I		

Step 5. Using leads with banana plug connectors, attach the power supply to the terminals of the EEH jar. Connect a voltmeter and ammeter as shown in Figure 41.1 so you can measure both the current and the voltage of the bulb. For best results, connect the voltmeter leads directly to the binding posts of the EEH jar.

Step 6. Turn the power supply on and quickly adjust the power supply voltage to about 11.5 volts, then shut the power off. It is important not to let the voltage exceed 13 volts or damage to the bulb may result.



CALORIMETER

Step 7. Insert the EEH jar into the Styrofoam calorimeter. Insert a thermometer or temperature probe through the hole in the top of the EEH jar. Stir the water gently with the thermometer while observing the temperature. When the temperature of the water is 6–8 degrees below room temperature, turn the power supply on. Record the time you begin warming the water, t_1, and the initial temperature of the water, T_1, in Data Table 41.1.

Note: You may turn on the bulb to warm the water to this starting temperature. If you do, be sure that you turn the bulb off for several minutes before you begin your measurements to assure that the water temperature is uniform throughout the jar.

Step 8. Observe the current and the voltage as the water temperature increases. Carefully monitor the ammeter and voltmeter throughout the experiment. Try to maintain a constant current and voltage. If the current or voltage varies significantly, record the variation and estimate how long it occurred.

Step 9. When the temperature of the water is as many degrees above room temperature as it was below it when you started, turn off the power supply. Record the final temperature of the water, T_2, and the time, t_2.

Step 10. Perform the necessary calculations, complete Data Table 41.1, and calculate the electrical equivalent of heat, J_e.

Part B: The Efficiency of a Bulb

Step 11. Repeat the experiment without the India ink. Since you want the visible light to escape, do not use the Styrofoam calorimeter. Record your results in Data Table 41.1.

Analysis

1. List assumptions made in the electrical equivalent of heat experiment which could effect your results.

2. How does your calculated electrical equivalent of heat, J_e, compare with the mechanical equivalent of heat (4.18 J/cal)?

3. Some of the energy from the bulb goes into warming the EEH jar, and to a lesser extent, the calorimeter. What would be the value for the electrical equivalent of heat, J_e, if the heat capacity of the EEH jar is equivalent to 23 grams of water?

4. Is the bulb more efficient as a source of *light* or as a source of *heat*?