

# Electrical Equivalent of Heat

## 1 Object

To determine the conversion factor between Joules and kilo-calories and develop an understanding of electrical heating.

## 2 Apparatus

Ammeter, voltmeter, calorimeter, power supply, resistance coils, timers, rheostat, rubber stopper, two thermometers, wires, beaker.

## 3 Theory

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  $\Delta t$  using the relationship  $P = \frac{Q}{\Delta t}$ . 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

$$P = \frac{Q}{\Delta t} = IV = I(IR) = I^2R, \quad (1)$$

which we can rearrange to get

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

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  $\Delta t$  while a given current  $I$  is flowing through the resistance  $R$ . In our experiment, this heat is then transferred to a container of water, causing the temperature of the water, cup, and brass to rise according to the formula

$$Q = M_w c_w \Delta T_w + M_c c_c \Delta T_c + M_b c_b \Delta T_b, \quad (3)$$

where  $Q$  is the amount of heat transferred from the wire to the water, the first term on the right side represents the heat used to increase the temperature of the water, the 2nd term is for the calorimeter cup, and the third term is for the submerged brass.

Since electrical energy and heat were studied independently they have come to have different units: joules ( $J$ ) and calories ( $cal$ ), respectively. Thus, when one sets the two expressions equal (conservation of energy) there must be a conversion factor. This is given the symbol  $J$  and has been found to be  $J = 4.186 J/cal$ . We can determine  $J$  as follows

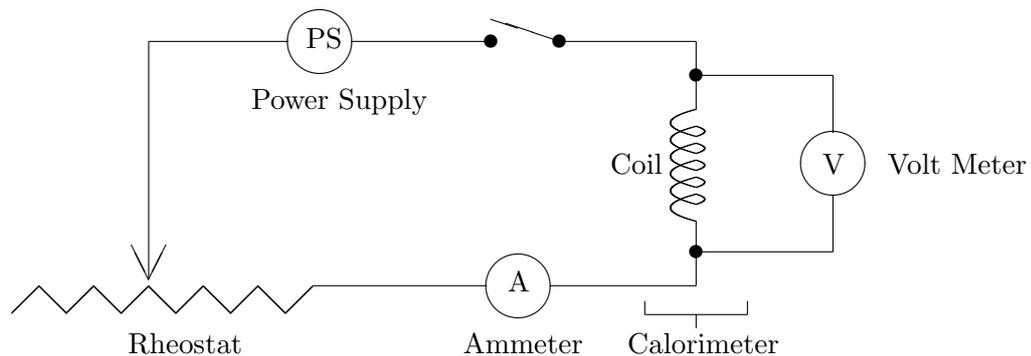
$$IV\Delta t = J(M_w c_w \Delta T_w + M_c c_c \Delta T_c + M_b c_b \Delta T_b) \quad (4)$$

or

$$J = \frac{IV\Delta t}{(M_w c_w \Delta T_w + M_c c_c \Delta T_c + M_b c_b \Delta T_b)}. \quad (5)$$

## 4 Procedure

1. Set up the circuit shown. Record the mass of the brass, which is on a sticker on the apparatus (new PASCO use  $14.2\text{ g}$ ). Insert a thermometer into a rubber stopper and put it into the top of the calorimeter. Record the mass of the inner cup of the calorimeter. Add water to the cup and then record the combined mass so that you will be able to determine the mass of water. Record the temperature of the water just prior to completing the circuit. This temperature should be at least  $5^\circ\text{C}$  below room temperature. Record room temperature, the specific heat of the calorimeter cup, and the brass.
2. Connect the circuit, set the power supply voltage so that the ammeter reads about  $2.5\text{ A}$ . Note the initial temperature of the water and start a stopwatch. Allow the current to flow until the temperature of the water is as much above room temperature as it was below when the trial started. You will want to keep stirring the water so that it is always well mixed. In this manner, the temperature reading should slowly rise. Record the total elapsed time to reach this final temperature as well as the final temperature. As the calorimeter passes through *room temperature*, record the current flowing in the circuit. At this time, also record the voltage across the posts of the calorimeter. Repeat this process 5 times, using different starting temperatures, amounts of water, and currents ranging from  $0.8\text{ A}$  to a maximum of  $3.0\text{ A}$ . **The water should always cover the entire brass coil.**



## 5 Calculations

1. Using equation 5, calculate your experimental value for  $J$  for each of the trials. Calculate the mean and resulting associated error with this mean value. Check for agreement with the theoretically expected value for  $J$ .
2. Construct a graph using the results from your trials with the quantity  $I^2 R \Delta t$  on the vertical axis and the total heat gained by the calorimeter, water, and brass on the horizontal axis. Basically, the numerator of equation 5 is on the vertical axis and the denominator of equation 5 on the horizontal axis. Perform a linear regression to determine the best fit line to the resulting points and compare the slope and y-intercept with the theoretically predicted values.

## 6 Questions

1. Why are the current and voltage read at room temperature?
2. Explain on an atomic level, how the heat is produced in the coil in this experiment.
3. A typical daily energy intake is  $2000 \text{ kcal}$ . To what height could you lift a person with this amount of energy?
4. If the coil produced light which escaped the calorimeter, how would this affect your results? Explain.
5. Why does a  $40 \text{ W}$  incandescent light bulb give off less light than a  $40 \text{ W}$  fluorescent bulb?
6. What is the largest source of error in this lab? How would this error affect the plot you made?
7. Estimate the amount of heat loss by the calorimeter. Justify your answer.

## Electrical Equivalent of Heat Data Sheet

	Cup	Brass
$M$ (g)		
$c$ (cal/g°C)		

$T_{room}$ (°C)	
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Trial	$M_c + M_w$	$T_0$	$T_f$	$I_{roomT}$	$V_{roomT}$	$\Delta t$
Units						
1						
2						
3						
4						
5						
6						