PHSX 222L **Electrical Equivalent of Heat** **Name:**______________________

Object: The calorie is a common unit of thermal energy and the energy of foods (though a food Calorie is 1000 physics calories) and the joule is the common unit of chemical, mechanical, or electrical energy. Of course, because of the relationship between energy and work, these units are also used for both energy and work.

In this experiment we intend to compare the calorie with the joule by comparing a measured decrease in the level of electrical energy (in joules) with the equivalent increase in thermal energy (in calories).

Theory: When an electric current flows from a high potential to a low potential through a circuit, the energy of the flowing electrons is reduced because negative work is done on the electrons. But comparable positive work must be done by the electrons on some other part of the system and hence the energy of that part of the system increases. The atoms do negative work on the electrons and decrease their energy but the electrons do equal positive work on the atoms and increase their energy.

In this experiment the electric current flows through a resistive Nichrome wire (with resistance R). The current interacts with the metal atoms of the wire, does work on those atoms, and increases their average energy and thereby heats it. Thus, some of the energy of the electrons now appears as thermal energy of the atoms. The atoms of the metal, which are in contact with the water, do work on the water molecules and thereby increase their energy as well.

$$\begin{aligned}
\text{(decrease in electrical energy)} &= \text{(increase in thermal energy)} && (1)\\
\text{(power)(time)} &= \text{(specific heat)(mass)(temperature change)} && (2)\\
\text{(current)(voltage)(time)} &= \text{(specific heat)(mass)(temperature change)} && (3)\\
IVt &= cm\Delta T, && (4)
\end{aligned}$$

where I is the current and V the voltage, c is the specific heat, m the mass, and ΔT the temperature change. Assuming $V = IR$, the equation can be written two other ways:

$$I^2Rt = cm\Delta T \tag{5}$$

$$\frac{V^2}{R}t = cm\Delta T \tag{6}$$

The left hand side of this equation is in joules (the official S.I. unit of energy), while the right hand side is in calories ($c_{\text{water}} = 1.0$ cal/g °C); thus the number of joules in one calorie can be determined.

A double-walled calorimeter is an excellent way to isolate the experiment from the surroundings.

Procedure:

1. Draw a diagram of the apparatus; include a wiring diagram.
2. Determine the resistance of the coil by measuring the current and voltage (check with an ohmmeter).
3. Fill the calorimeter can 3/4 full of cold water (about 10°C below room temperature).
4. Connect the voltmeter, ammeter, and heating coil into the circuit with the power supply. (Do not turn on the power until checked by the instructor.)
5. Adjust the current to about 4.5 amps and begin to time the experiment. Monitor the current closely throughout the experiment to keep it constant. (Why is this necessary?)
6. Heat the water until it is as much above room temperature as it started below.
7. Record time, current, voltage, mass of water (take the water mass equivalent of the calorimeter, 14.7 g, into account), and temperature rise.
8. Divide the electrical energy consumed (in joules) by the thermal energy generated (in calories) to determine the number of joules in a calorie.
9. Compare with the accepted value.

Questions: A typical 50 gallon household hot water heater contains 189 kg of water. Water from the water line is about 15°C, and is heated by an electrical heating element having a resistance of 11 Ω. The supply line voltage is 220 V. (See similar problems in P27.39 and P27.48 in Serway.)

1. How many calories of thermal energy must be delivered to the tank of water to heat it to bath temperature (40°C)?
2. Calculate the power of the electric heating element.
3. Calculate the time required to heat up the water in the tank.
4. Calculate the cost of heating the water if the utility company charges 8 cents per kW-hr.
5. How much does your utility company charge per kW-hr?

Conclusions:

1. Discuss any sources of error that you feel might have affected your results. Are some of these avoidable? What effect would they have on your value? Try to estimate the magnitude of the effects.