How does your electric water heater work?

In the Ohm’s Law II experiment, you learned about electrical circuits where a power supply pumps electrons around a circuit. When the electrons pass through a resistor, the potential energy drops and energy is lost through heating. We can use this heating process in different applications. For example, in Ohm’s Law I you saw that the heating would cause a light bulb to glow. You can also heat your water in your house through resistive heating.

There are two heating elements in a water heater tank. They consist of a wire that is surrounded by filler material and then enclosed in copper or stainless steel. The wire has resistance so that the water can be heated through resistive heating. One element is placed at the upper part of the tank, and the other is placed at the lower part of the tank. Both are controlled by a control circuit that contains a thermostat for each element and a high limit control switch with a reset button. Usually the water heater is supplied with 220 V.

The water in the upper part of the tank is heated first by sending current through the upper element until the thermostat reaches its desired temperature. Then current is sent through the lower element to heat the lower part of the tank. The hot water is released from the top of the tank, and cold water replaces the used water by entering the bottom of the tank.
(through a long tube connected to the inlet pipe) so that the heated upper water is not cooled by the entering cold water. The cold water will mix with the hot water which will lower the temperature in the bottom part of the tank. The thermostat detects this decrease in temperature, and the control circuit then sends current to the lower element. If enough hot water is removed from the upper part of the tank, then the upper element will get kicked on first. If the temperature rises too high, then the high limit control switch is tripped which turns the power off to the elements. For the water heater to be operational again, the reset button must be hit (and any repairs made that may have caused the excessive temperature). There is also a pressure relief valve at the top of the tank that opens automatically if the pressure exceeds safe values. A magnesium anode may also be placed in the tank so that it will corrode rather than the stainless steel tank.

If the upper element burns out, then the water heater will not work because the water in the upper part will never be heated so that the lower element is kicked on. If there is no water in the tank, then the elements will quickly burn out.

In today's lab, you will pass a current through a resistor immersed in water and measure the change in temperature of the water. The resistor gets HOT so do not touch it while passing the current through it! Make sure that you do not flow the current through the resistor when it is not under water (or the resistor will burn out just like in your water heater). Please dry the resistor and can when you are done to avoid more corrosion to the resistor.

**Answer these questions for today's lab:**

1. Calculate the power dissipated by a resistor when the voltage across the resistor is 10 V and the current through the resistor is 1 A ($P=IV$). What is the resistance of the resistor ($V=IR$)?
2. Calculate the heat energy transferred to an aluminum cup when the temperature of the cup is heated from 20°C to 80°C
\( \Delta Q = m_c c_c \Delta T \) where the aluminum cup has a specific heat value of 0.21 kcal/kg\(^\circ\)C and the mass of the aluminum cup is 30 g or 0.030 kg.

3. Calculate the heat energy transferred to water when the temperature of the water is heated from 20°C to 80°C
\( \Delta Q = m_w c_w \Delta T \) where water has a specific heat value of 1.0 kcal/kg\(^\circ\)C and the mass of the water is 80 g or 0.080 kg.

4. When electrical energy is transferred to heat energy, the equivalence of the electrical energy and heat energy is given by
\( \Delta W = J \Delta Q \) where \( J \) is the Joule equivalent of heat and is 4186 J/kcal. You will find this value experimentally by measuring the increase in temperature of your aluminum cup filled with water as a function of time. From the slope of this graph you will find \( \Delta T/\Delta t \) and use equation (10) in the lab manual to calculate \( J \).

References:
1 http://www.whirlpoolwaterheaters.com/learn-more/electric-water-heaters/how-electric-water-heaters-work/standard-electric-operation/
2 https://www.popularmechanics.com/home/interior-projects/how-to/a153/1275141/