Name: *Partners' Names:*
Laboratory Section:
Laboratory Section Date: *Grade:*

Last Revised on March 29, 2018

EXPERIMENT 5

Equivalence of Energy: Heat, Electrical, Light

0. Pre-Laboratory Work [20 pts]

1. As discussed in section 2.1, the speed of electrons entering an area of high resistance (like a bend in the wire, for instance) is higher before the bend and lower after it. From this, we might be inclined to think that the current is greater before the bend and lower after it. Why (after the current has been turned on for some time) can't this be true? Hint: one way to answer this is to think about what it would mean for the structural integrity of the wire if the current entering part of the wire was much greater than the current leaving that part. [10 pts]

2. In the circuit you build in this lab it is very important that the power not exceed 35 W in the lightbulb, otherwise you may destroy it. Let's say that during the experiment you look at your multimeters and see that there is a voltage drop $V = 14$ V across the lightbulb and current $I = 3$ A running through it.

a) How much power, P, is going into the lightbulb? [5 pts]

b) Does the power exceed the 35 W it is safe to send into the lightbulb? [5 pts]

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EXPERIMENT 5

Equivalence of Energy: Heat, Electrical, Light

1. Introduction and Purpose

Conservation of energy is one of the foundational principles of physics. It tells us that when energy changes forms there should be the same amount of energy before and after the change. In this lab, you will be converting electrical energy to thermal energy (heat) and electromagnetic energy (light). Energy is usually measured in joules (J), but thermal energy is sometimes measured in the obsolete unit the calorie (cal).

In this lab you will measure the proportionality constant between joules and calories, which allows you to convert from one unit to the other. It is known as Joule's constant, and it has an accepted value of $J = 4.19$ J/cal. So, 1 cal is equivalent to 4.19 J. A calorie is defined as the amount of energy required to heat up 1 gram of water by 1ºC. You will calculate J by heating up a jar of water by sticking a lightbulb in it.

You will also estimate the efficiency of your lightbulb at producing visible light. To calculate this, two different experiments will be run by different groups. In one, dark ink will be added to the jar of water so that all the lightbulb's energy will be turned into heat, and you will measure the change in temperature, and from this how much heat was added to the water. In the other version of the experiment, you will not add any ink to the jar, which allows the visible light to escape. Thus, this time, the light energy will not contribute to the change in temperature of the water. Using the difference between the temperature change in the water with ink and without ink, you will calculate how efficient the lightbulb is at producing visible light. Then you will hand in your lab report, and never have to worry about this lab again!

2. Theory

2.1 Introduction to electric circuits

Since most of you have probably never taken a circuits class before, we begin with a brief introduction to electric circuits. If you still have any questions after reading this, please feel free to ask your TA or TI for clarification! If you already know what voltage, current, and resistance are you can skip ahead to section 2.2.

Electricity in a wire is just the flow of small particles, called electrons, down the wire. Like the flow of particles of water down a pipe, say. To make the electrons flow, we need to apply a force to push them down the wire. The device that forces the electrons to move down the wire is called a battery. The battery forcing electrons to flow can be thought of like gravity forcing water to flow down a pipe (Figure 2.1).

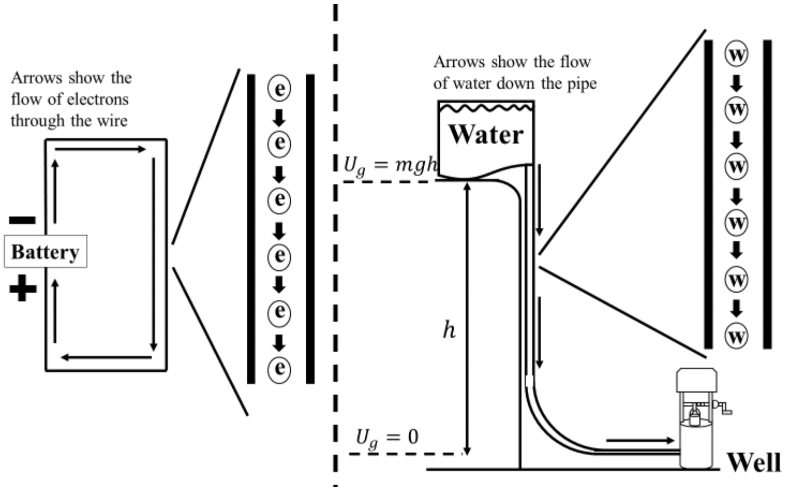

Figure 2.1. Electric circuits and water flowing down a pipe: intimately related.

If you think back to when you studied gravitational potential energy, you learned that the potential energy difference between two different points is given by,

$$U_g = mgh \tag{1}$$

where m is the mass of the object, g is the acceleration due to gravity, and h is the vertical distance between the two points. If we imagine having a magical dial that allows us to vary the value of g, turning it up would increase the force of gravity, because $F_g = mg$. This would cause the water to flow more quickly down the pipe, since the water molecules are experiencing a greater force. From this we see that a larger potential difference $\left(\Delta U_g = mgh\right)$, means that the water molecules will travel faster from $y = h$ down to $y = 0$.

In electric circuits the battery allows us to set the potential difference in the wire (Fig. 1). The larger the potential difference, the faster the electrons will flow in the wire. Because we can't (easily) watch the electrons moving in the wire, the battery is labelled so that we can tell which direction the electrons are flowing. One end of the battery is labelled with a negative sign, and one with a positive sign. Perhaps counter-intuitively, the electrons flow from the negative end of the battery, around to the positive end. The positive end corresponds to higher potential and the negative end to lower potential, so it would be like water flowing from the ground up the pipe! The reason for this is that electrons have negative electric charge, which would be like something having negative mass, and thus moving up instead of down under the influence of gravity. You won't have to use charge in this lab, so don't worry too much about it! Just remember that electrons flow between electric potential differences like how water flows between gravitational potential differences.

The electric potential is given a special name, because why not? An electric potential difference between two points is called a **voltage difference**, which is measured in volts (V). If the battery is set to 0 V, then there won't be any potential difference and the electrons won't flow. If we then start turning up the voltage, the electrons will feel a stronger and stronger force, which will cause them to flow faster and faster in the wire.

Imagine if we decided to sit and look at one point on the wire. We could count how many electrons flowed past us every second (Fig. 2.2). This quantity, the number of electrons that flow past a point every second, is called the **current**, and its unit of measurement is amperes (A). 1 A is defined to be about 6.24×10^{18} electrons per second. The reason for this number is obvious. 5×10^{18} would have been absurdly low. And don't even get me started on what a nightmare

7×10^{18} would have been. 6.24×10^{18} is right in the sweet spot. And it means that if 6×10^{18} electrons flow past the point we're looking at every second, then we'll measure a current of around 1 A.

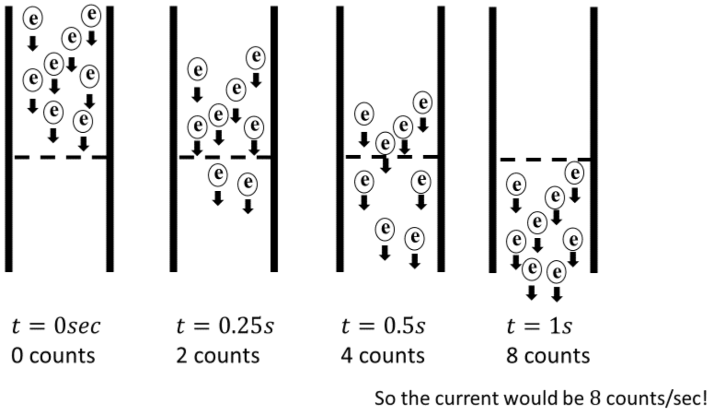

Figure 2.2. Measuring the current in a wire.

But what exactly do we mean when we say that a current is electrons flowing in a wire? You might think that before we turn on the voltage all the electrons are sitting in the battery, and then when we flip the switch they flow out of the battery and around the wire. But this is not quite right. If you think back to high school, you probably learned that an atom is made up of a nucleus with at least one electron orbiting the nucleus (Fig. 2.3).

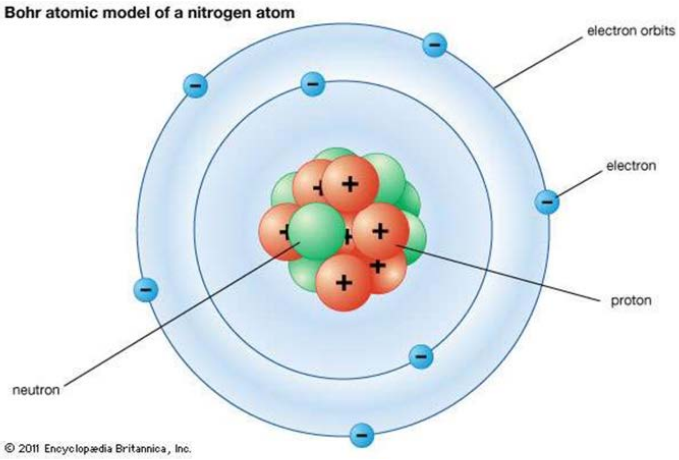

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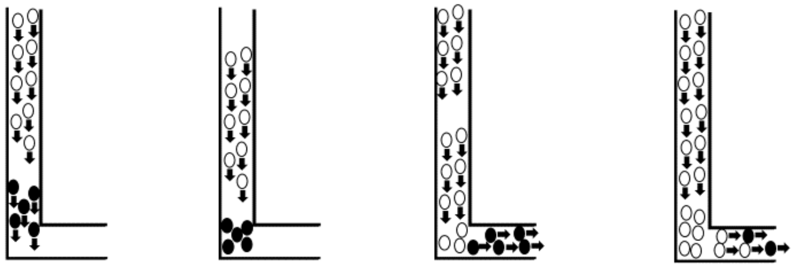
Figure 2.3. Bohr model of the atom.

A single copper atom, for instance, has 29 electrons orbiting the nucleus. So, before the voltage is turned on, the wire has many billions of electrons in it already! But without any force to push the electrons, their average velocity will be zero. Once we turn the battery on the electrons in the wire will begin to move towards the positive end of the battery. And as they enter the positive end more will leave the negative terminal, keeping the number of electrons in the wire approximately constant as they loop around the circuit forever (or until the battery dies, whichever comes first).

Finally, we arrive at the last concept needed to understand this lab: **resistance**. As electrons travel through the wire they encounter imperfections, defects, and twists and turns in the wire, which cause them to slow down as they have to force their way through. Going back to the water in a pipe analogy, imagine the water came up to a sharp bend in the pipe (Fig. 2.4). When the first bit of water reaches the bend it will slam up against the wall, slowing down considerably. It is soon followed by more water, though, which will force it to continue flowing down the pipe.



t = 0: water molecules are all moving quickly down the pipe

t = 1s: Water molecules slow down as they slam into the bend in the pipe

t = 2s: The molecules are pushed out of the bend by the water behind them, allowing current to continue flowing

t = 3s: Water continues to flow, always slowing down in the bend, but then getting pushed out of it by the water behind it

Figure 2.4. Water flowing around a bend in a pipe.

So, we see that the water entering the bend is moving faster than the water leaving the bend. Thus, the water has more kinetic energy $\left(K = \frac{1}{2}mv^2\right)$ when it enters the bend than when it exits. Non-rhetorical question: where does this energy go?

Answer: into the pipe (mostly). When the water slams into the pipe and loses most of its speed, this kinetic energy is transferred to the pipe wall. Electrons in a circuit operate in the same way. When they encounter some form of resistance to their flow (like a turn in the wire) they will lose kinetic energy, which will be transferred into the wire. The more obstacles the electrons must get past (i.e. the more resistance a circuit has) the more kinetic energy they will lose as they move around the circuit, and the more energy will be transferred into the wire.

A lightbulb has a much higher resistance than the wires that make up the circuit, so most of the energy lost by the electrons goes into the lightbulb. As the atoms in the filament of the lightbulb steal energy from the passing electrons they give off photons, which are particles of light. Why do the atoms give off light to release this energy, you ask? I have no idea, and I'm not sure that anyone else does either. Maybe string theorists. Anyway, the main point is that when electrons cross some circuit element (like a lightbulb), which has nonzero resistance, they will slow down, losing some of their kinetic energy.

And that wraps up all the basic circuit stuff you'll need for this lab! Below is the circuit vocabulary we went over, and if you still have questions please feel free to ask your TA/TI for help! They probably know circuits better than I do anyway.

- **Voltage:** difference in electric potential energy between two points. The larger the voltage the stronger the force pushing on the electrons in a wire. Measured in volts (V).
- **Current:** number of electrons flowing past a cross-section of the wire per second. Measured in amperes (A).
- **Resistance:** a measure of how difficult it is for electrons to flow. The higher the resistance the more kinetic energy is lost by the electrons. This lost energy is transferred into thermal energy in the wire. You won't have to measure it in this lab, but, in case your curious, the unit of measurement is called ohms, and is denoted by the Greek letter **Ω**.

2.2 Conversion of Electrical Energy into Heat and Light

The first thing we want to be able to do is to calculate the amount of energy consumed by the lightbulb, $E_{Consumed}$, when we run a current through it. Recall that the voltage is the difference in potential energy between two points. So, if the electrons flow across a lightbulb filament, say, and we take the energy that each one loses crossing the lightbulb, V, and we multiply it by the number of electrons that crossed the lightbulb, n, then we have an expression for the total amount of energy the lightbulb gains: $E_{Consumed} = nV$. But how do we find n? We know that the current is the number of electrons that flow past a section of the lightbulb per second, and, if we multiply the current by the total time that we had current flowing through the lightbulb, Δt, we'll find out what n is: $n = I\Delta t$. Thus, we have our equation for the energy consumed by the lightbulb:

$$E_{Consumed} = nV = IV\Delta t \tag{5.5}$$

Remember that power, P, is just work divided by time, so the power going into the lightbulb due to the electric current is just $P = IV$. If V is measured in volts, I is in amps, and Δt is in seconds, then P is in watts (W) and the energy E is in joules.

If the light bulb is surrounded by material that will absorb almost all the energy it gives off and whose specific heat is known, the total heat can be found by using $\Delta Q = mc\Delta T$. In this experiment, the materials that surround the light bulb are the water and the jar. The amount of heat ΔQ associated with the temperature change ΔT is

$$\Delta Q = D\Delta T \tag{5.6}$$

where for this setup D is given by

$$D = m_{water}c_{water} + 23\left(\frac{cal}{°\mathrm{C}}\right) \tag{5.7}$$

This is a generalization of $\Delta Q = mc\Delta T$; instead of one term $mc\Delta T$, we now have multiple terms playing the role of mc for each of the different substances and objects surrounding the lightbulb.

In Part 3.2.1 of the experiment (*Conversion of Electrical Energy into Heat*), a small amount of India ink is added to the water to capture the otherwise escaping visible spectrum of light. In order to further reduce the heat lost to the air, the water jar is inserted into a Styrofoam Calorimeter insulator. The electrical Joule's constant, $J_{electrical} = J_e$, can then be calculated using

$$J_e = \frac{E_{Produced}}{\Delta Q} = \frac{IV\Delta t}{D\Delta T} \tag{5.8}$$

In Part 3.2.2 of the experiment (*Conversion of Electrical Energy into Heat and Light*) no India ink is added and the jar is not insulated. Because the visible light is not absorbed in this case, all the lightbulb's energy does not go into producing heat and thus *Equation 5.8* is not applicable. However, the visible light producing efficiency can be calculated from the following,

$$Efficiency_{Visible\ light} = \frac{E_{Visible}}{E_{Produced}} = \frac{E_{Produced} - E_{Absorbed}}{E_{Produced}}, \tag{5.8}$$

where $E_{Visible}$ is the energy of the visible light and $E_{Absorbed}$ is the energy that is absorbed by the water. Since the absorbed radiation energy $E_{Absorbed}$ is the heat absorbed by the water, $E_{Absorbed}$ can be calculated according to

$$E_{Absorbed} = J\Delta Q \tag{5.9}$$

Where $J = 4.19$ J/cal is the accepted value of Joule's constant.

3. Laboratory Work

3.1 Conversion of Electrical Energy

To be able to compare more data in the allotted time, you will be collecting data for only half this section and will be utilizing results from other groups to complete the analysis. **Before you begin this section, the Lab TA or TI will assign your group to complete EITHER Part 3.2.1 OR Part 3.2.2. DO NOT DO BOTH**. You are asked to share your data with the laboratory section by writing your results on the chalkboard as soon as you have them available, and in turn you will be using results of others to answer some of the questions.

Introduction

In Part 3.2.1, Conversion of Electrical Energy into Heat (With Ink & Insulator), we are assuming all the energy produced by the light bulb is absorbed by the water when calculating $J_{electrical}$. A 35-Watt incandescent lamp is immersed in a known quantity of water with a small amount of India ink added to make it opaque to the visible light, so as to absorb the visible light. The water jar is inserted into a Styrofoam Calorimeter insulator to prevent heat from escaping to the air. The temperature of the water is measured with a thermometer. By monitoring the water temperature, the heat produced by the lamp can be calculated. The ratio between the electrical energy that flows into the lamp and the heat produced by the lamp determines the Joule's constant for the electrical energy.

In Part 3.2.2, Conversion of Electrical Energy into Heat and Light (Without Ink & Insulator), the efficiency of the incandescent lamp is measured. The details are similar to the first part, but no India ink is added to the water and the jar is not insulated. Without the ink, some (not all) of the energy from the lamp is absorbed into the water, but the visible light energy escapes. To determine the amount of visible light energy, the heat transferred into the water is subtracted from the total energy produced by the light bulb, which is the same as the total electrical energy it consumed. The ratio between the light energy and the electrical energy gives the light producing efficiency of the bulb.

Note: for those doing **Part 3.2.2**, follow the instructions for section 3.2.1 and just skip **step 10**.

3.2.1 Conversion of Electrical Energy into Heat (With Ink & Insulator)

Procedure

1. First, weigh the jar assembly including the lid and record its mass m_{jar} in *Section 4.2.1* above Table 4.1.
2. Remove the lid of the jar and fill it to the indicated water level. *Do not overfill.* Filling beyond this level can significantly reduce the life of the lamp. Close the lid.
3. If you're already comfortable building circuits, you can follow Fig. 3.0 to construct the circuit and then skip to step 9. Make sure you set the voltage across the lightbulb to be 9.8 V and the current to 2.2 A, as determined by the multimeters.

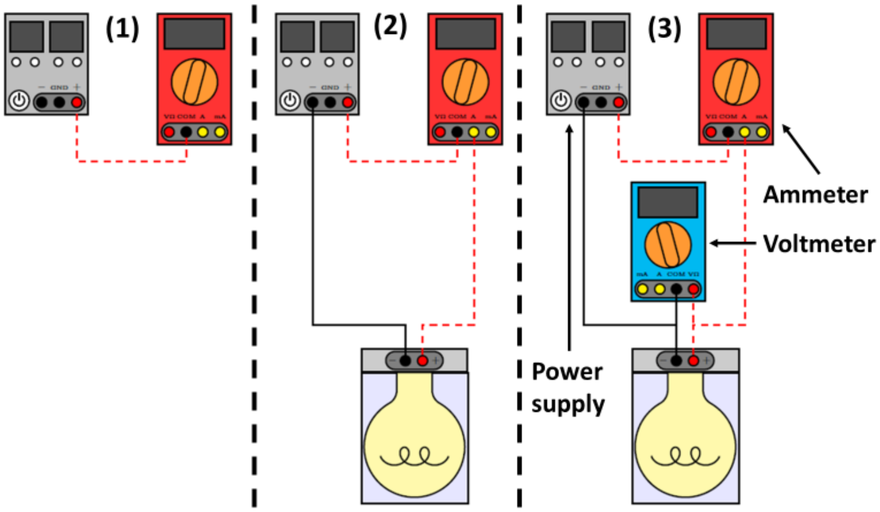
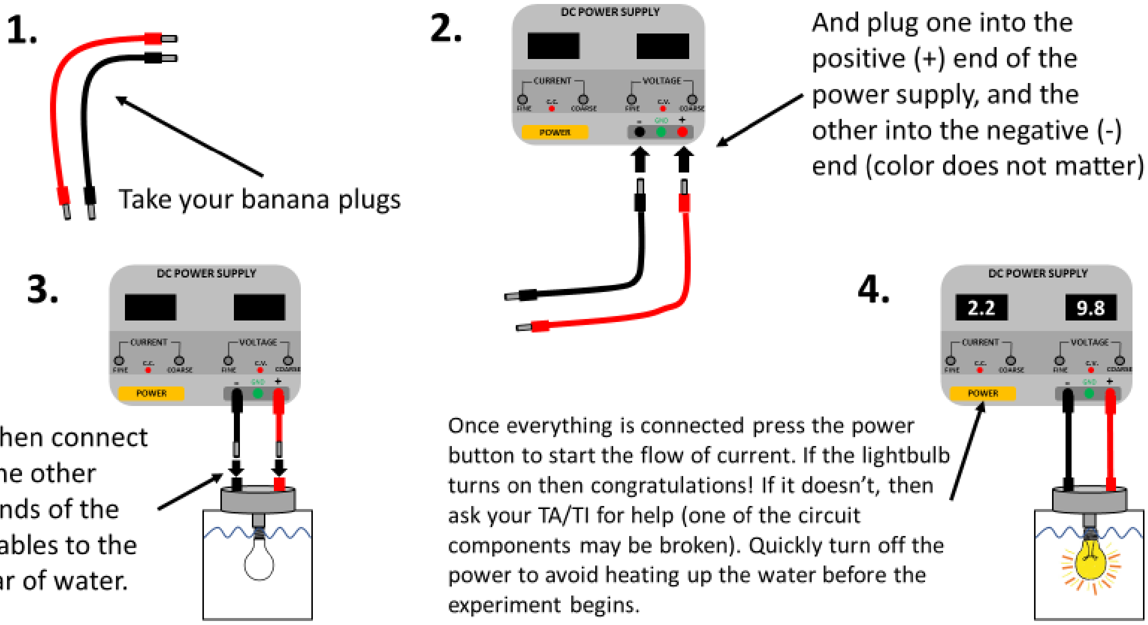


Figure 3.0. Circuit diagram for circuit experts.

4. Now that we've gotten rid of those pesky electrical engineers, let's build this circuit from scratch. The goal is to provide power to the lamp, and to measure the voltage drop in the lamp as well as the current running through it. To start, we'll hook up the lamp to the power supply. You'll need to grab two banana-plug wires from the stand at the front of the room (you'll need five wires total to construct the whole circuit, if you want to grab them all at once). Choose whatever combination of colors makes you happy, the wires all operate exactly the same way. Refer below to Fig. 3.1 for instructions on connecting the jar assembly to the power supply.



1. Take your banana plugs

2. And plug one into the positive (+) end of the power supply, and the other into the negative (-) end (color does not matter)

3. Then connect the other ends of the cables to the jar of water.

4. Once everything is connected press the power button to start the flow of current. If the lightbulb turns on then congratulations! If it doesn't, then ask your TA/TI for help (one of the circuit components may be broken). Quickly turn off the power to avoid heating up the water before the experiment begins.

Figure 3.1. Connecting the power supply to the lightbulb.

5. Once you have the lightbulb hooked up turn it on and quickly adjust the current and voltage knobs so that the current reads around 2.2 A and the voltage 9.8 V. Once these are set turn off the power so that you don't heat the lightbulb up before the experiment begins. Also, minor note here, be very careful that the power (voltage multiplied by the current) does not

exceed 35 W. If it does then your lightbulb may explode, which would be bad. So… watch out for that.

6. Next, we're going to try and measure the voltage drop across the lightbulb using a multimeter (see Fig. 3.2 for the two most common types of multimeters found in this lab). Recall that voltage is like gravitational potential energy. If we want to measure the gravitation potential energy of an object, you'll need a ruler to measure the distance from the object to the ground. Using a multimeter to measure the voltage difference across the lightbulb is the same idea: we'll need to measure the difference in electric potential between the two ends of the lightbulb. To do this take one of your multimeters, plug one wire into the port at the bottom marked with a V (for voltage), and another wire into the port marked COM (this stands for common, which is the same thing as ground), as shown in Fig. 3.2(b).

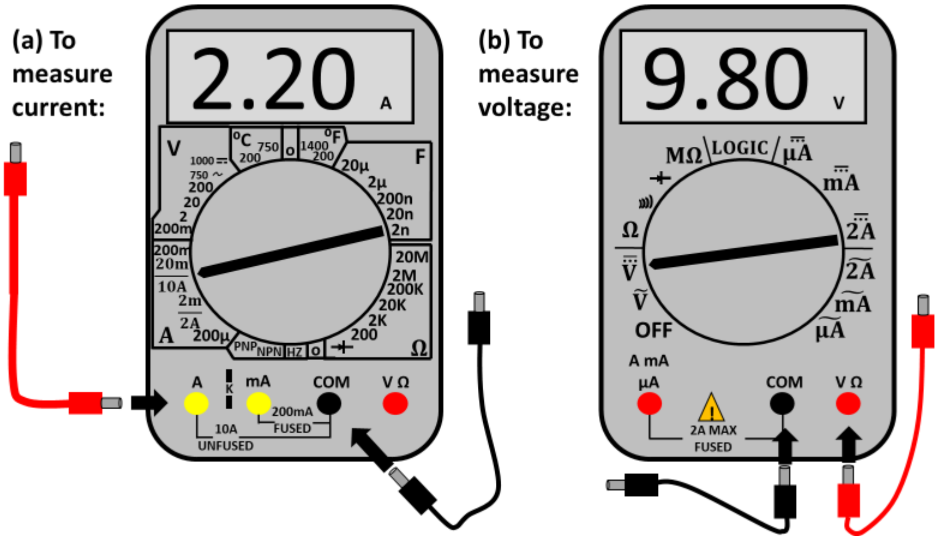


Figure 3.2: Using the multimeters to measure voltage and current. Note that it does not matter which type of multimeter you use to measure voltage and current. All that matters is you use the V port for voltage and the A port for current, and set the dial to the quantity you want to measure.

7. Now, take the other ends of the wires and plug them into the lightbulb as shown in Fig. 3.3. Notice that the banana plugs have ports on them that you can plug additional wires into. The dial on the multimeter should be set to V to read voltage. If your multimeter also has numbers on it then set the dial to 20. This represents the maximum voltage it can read. If your multimeter doesn't have numbers, then you just need to set the dial to $\overset{\dots}{V}$, which stands for DC voltage (which matches the DC Power Supply). Once you have all the wires connected turn on the power supply. The multimeter should hopefully read around 9.8 V (or whatever number is on the power supply). If it's more than 1 V off check your wiring or ask your TA/TI for help. Turn your power supply off once you've got everything working to avoid heating up the water.

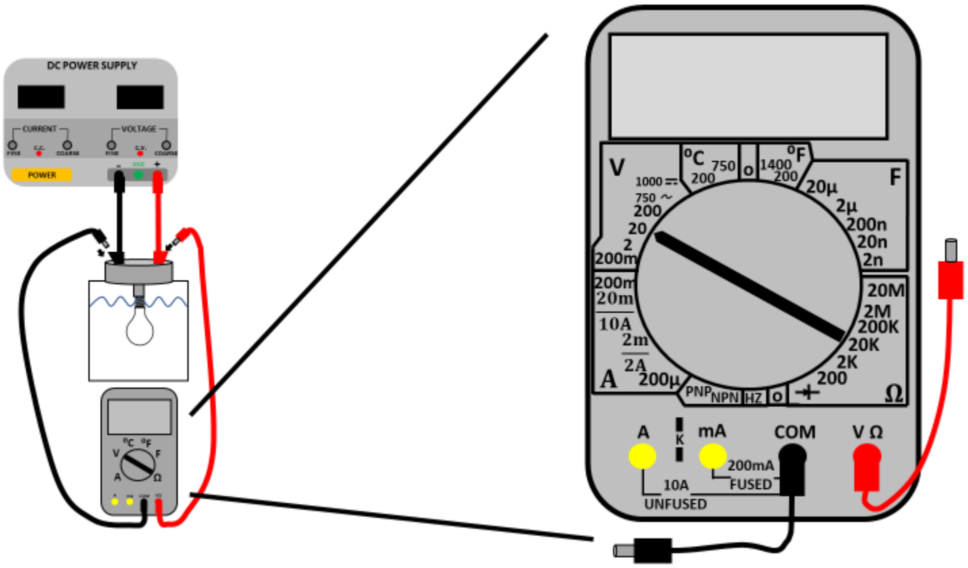


Figure 3.3: Measuring the voltage drop across the lightbulb.

8. Now that we can measure the voltage across the lightbulb we also want to measure the current running through the lightbulb (or at least, whoever wrote this lab wants you to measure it). For this we we'll need to use another multimeter, and add it to the circuit in such a way that all the current that runs through the lightbulb also runs through the multimeter. Follow Fig. 3.4 to make the correct circuit connections to measure the current through the lightbulb. Make sure that you use the port on the multimeter labelled A, not mA. The mA port only works for currents below 1 A, and we want our current to be around 2.2 A, so using the mA port would cause the multimeter to break. Needless to say, you should avoid breaking your multimeter if at all possible.

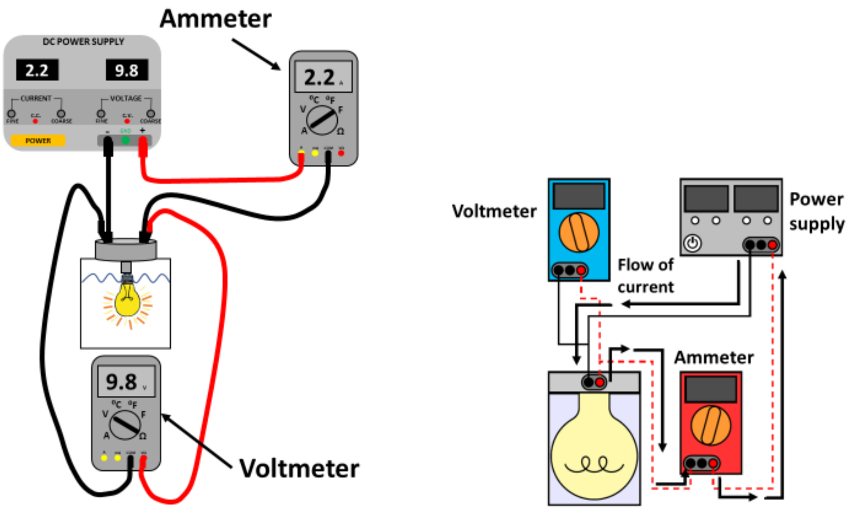
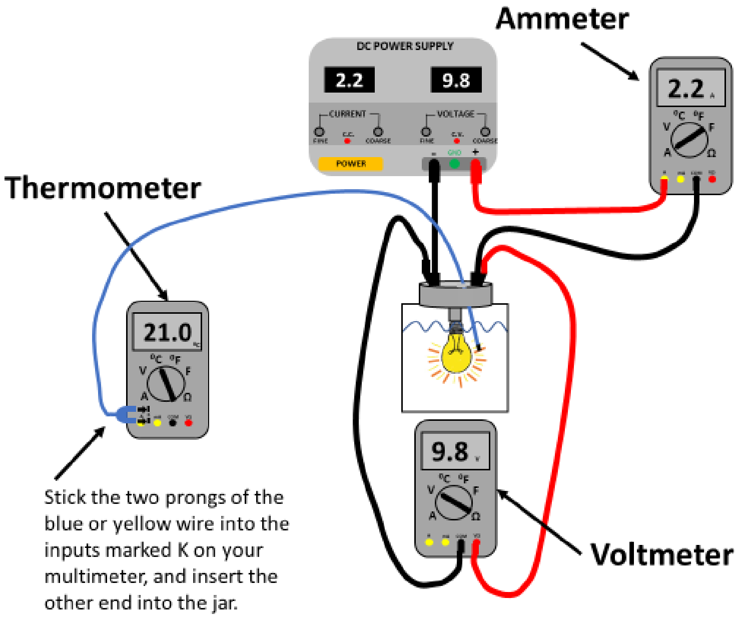


Figure 3.4. Measuring the voltage across and current in the lightbulb.

9. We're almost finished setting up the circuit, there's just one last quantity that we need to measure: the temperature of the water. This can go one of two ways. You should have a green thermometer which, if it turns on, you can stick into the jar of water and measure the temperature that way. If your thermometer does not power on, then you'll have to use your third multimeter. Choose a multimeter like the one shown in Fig. 3.5 (it needs to be one

where you can turn the dial to measure temperature).



Stick the two prongs of the blue or yellow wire into the inputs marked K on your multimeter, and insert the other end into the jar.

Figure 3.5. Final circuit diagram.

10. Those doing section 3.2.2 can skip this step. For those doing section 3.2.1, add a couple of drops of ink to the jar and swirl it around until the lightbulb is just barely visible when it is turned on. Then insert the jar into the Styrofoam container.
11. All right, if you've made it to this point and your lightbulb lights up when you turn the DC Power Supply on, your multimeters show numbers that are within 1 volt and 1 amp of the power supply's numbers, and your thermometer's reading is within a few degrees of room temperature (21ºC), then you are all set to begin the experiment!
12. When you're ready, turn on the power supply and start the timer. In *Table 4.1*, record the current, voltage, and temperature of water with respect to time in constant intervals of 60 seconds. Keep an eye on the ammeter and voltmeter throughout the measurement to be sure these values do not change significantly. *Continually swirl the jar gently the whole time!* Avoid touching the jar too much with your hands: the only thing we want heating up the water is the lightbulb.
13. When the temperature increases by about 8°C, *shut off the power but don't you dare stop the timer*. Record the time t_{stop} and the temperature.
14. Continue to take temperature readings in 60-seconds intervals until the timer reads $2t_{stop}$. Continue swirling the water gently.
15. Once the timer reaches $2t_{stop}$, turn off the power supply, remove the jar from the insulator, and remove the thermometer from the jar. Weigh the jar assembly including the water $m_{jar} + m_{water}$ and record it in *Section 4.2.1* above *Table 5.2*. Discard the water. Great job! You're done gathering data for this lab.
16. Give yourself a pat on the back.

Name: *Partners' Names:*
Laboratory Section:
Laboratory Section Date: *Grade:*

Last Revised on March 29, 2018

EXPERIMENT 5

Equivalence of Energy: Heat, Electrical, Light

4. Post-Laboratory Work [20 pts]

4.2 Conversion of Electrical Energy

CIRCLE WHICH SECTION YOU ARE ASSIGNED: Section 3.2.1 *With India Ink* Section 3.2.2. *Without India Ink*

m_{jar} (grams) = ___________
$m_{jar} + m_{water}$ (grams) = ___________
m_{water} (grams) = ___________

Time (sec)	Temperature (°C)	Voltage (V)	Current (A)	Time (sec)	Temperature (°C)	Voltage (V)	Current (A)

Table 4.1

1)

- **a)** Plot the water temperature versus time of the data from *Table 4.1* on *Graph 4.1*. [2 pts]
- **b)** As shown in *Fig. 4.1*, draw two best fit lines- one for the data points between $t = 0$ and $t = t_{stop}$, and one between $t = t_{stop}$ and $t = 2t_{stop}$. [1 pt]
- **c)** Next, mark on the y-axis the initial temperature, $T_{initial}$, which is your temperature reading at $t = 0$, the peak temperature, T_{peak} (the highest temperature reading), and then the final temperature, T_{final}, which is your last temperature reading (at $t = 2t_{stop}$) [1 pt]
- **d)** As always, make sure to include a title, and axis labels with units! [1 pt]

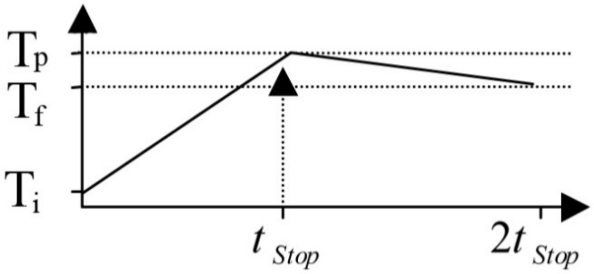


Figure 4.1: Temperature vs. Elapsed Time

Graph 4.1

2) After you turned the lightbulb off you probably found that the jar cooled off slightly due to heat being lost to the surroundings. This process was also taking place when the lightbulb was on, since the water started off at room-temperature and likely became hotter as the lightbulb was releasing heat. To try and correct for this energy loss, let's assume that the heat lost after the lightbulb was turned off is the same as the heat lost when the bulb was on. If this assumption is true (which it probably isn't, let's be honest), then the change in temperature of the water if it hadn't been losing heat to the surroundings would be $\Delta T = \left(T_{peak} - T_{initial}\right) + \left(T_{peak} - T_{final}\right)$. The first term is the observed change in temperature, and the second is our estimate for how much was lost to the surroundings. Calculate ΔT and record your answer in Table 4.2 below. Make sure to show your work and remember to include units! [1 pt]

3) From the wording of the previous question, it seems like whoever wrote it thinks that this method for correcting for the heat lost to the surroundings isn't ideal. What is one reason we might expect that the heat lost while the lightbulb heats up the water from $T_{initial}$ will be less than the heat lost while the lightbulb cools down from T_{peak}? Hint: try thinking about how quickly objects of different temperatures tend to cool off/lose heat. [2 pts]

4) Calculate the quantity D using *Equation 5.7***.** Use $c_{water} = 1$ cal/(gram ºC). Record your answer below and in Table 4.2. Include units and show your work. [1pt]

5) Using *Equation 5.5*, calculate the total amount of electrical energy consumed by the light bulb, $E_{Consumed}$. For the voltage, V, and current, I, use the values from any one of your measurements in Table 4.1. For the change in time, use $\Delta t = t_{stop}$(i.e. how long the lightbulb was on). If V is in volts, I is in amps, and Δt is in seconds, then $E_{Consumed}$ will be in joules. Record your answer below and in Table 4.2. Include units and show your work. [1pt]

Using your answers from the previous questions, fill in half of the table below. If your jar had ink in it, fill in section 3.2.1 (the left column), if your jar had no ink, then fill in section 3.2.2 (the right column). For whichever section you did not complete, fill it in with values from the chalkboard.

Section 3.2.1: With ink	**Section 3.2.2: No ink**
$(\Delta T)_{Ink} =$	$(\Delta T)_{None} =$
$D_{Ink} =$	$D_{None} =$
$E_{Consumed,ink} =$	$E_{Consumed,none} =$

Table 4.2

6)

a) First, using Equation 5.6, calculate the total heat absorbed by the setup with ink in the jar, $\Delta Q_{Ink} = D_{Ink}(\Delta T)_{Ink}$, with your values from Table 4.2. Remember to show your work and include units! [1 pt]

b) Now calculate the total heat absorbed by the setup without ink, $\Delta Q_{None} = D_{None}(\Delta T)_{None}$, with your values from Table 4.2. Remember to include units! [1 pt]

7) Using Equation 5.8, calculate your estimate for Joule's constant, $J_e = E_{Consumed,ink}/\Delta Q_{Ink}$. Don't forgot to include units! [1pt]

8)

a) Using the accepted value for Joule's constant, $J = 4.19$ J/cal, calculate the percent error between your estimate, J_e from question 7, and the accepted J (note the absolute value bars): [1 pt]

$$\frac{|J - J_e|}{J} \times 100 =$$

b) What is one experimental error that could have caused your measurement of J_e to be different from the accepted value of J? Assuming your percent error is not exactly 0, if it is, then congratulations! You may skip this question. Otherwise, if $J_e > J$, why might we have underestimated ΔQ_{Ink} (i.e. the actual amount of heat entering the water was greater than our calculated value). Or, if $J_e < J$, why might our ΔQ_{Ink} be too large? [2 pts]

9) Using Equation 5.10, calculate the total energy absorbed by the water without ink, $E_{Absorbed} = J\Delta Q_{None}$, with the accepted value of $J = 4.19$ J/cal and your value of ΔQ_{None} from question 6(b). Show your work and remember to include units. [1 pt]

10) Finally, the very last question of the last lab. This is exciting. Great job making it through the semester, by the way! All that stands in your way now is one final calculation.

a) Just kidding, we're going to make this a two-part question, just because we can.
So, let's say that you calculated the efficiency of your lightbulb at producing visible light, and found that it was 20% efficient at giving off light. Is your lightbulb better at producing visible light, or heat (i.e. of the energy we send into it, where does most of it go)? [1 pt]

b) Using Equation 5.9, with $E_{Absorbed}$ from question 9 and $E_{Produced} = E_{Consumed,None}$ from table 5.3, calculate the approximate efficiency of your lightbulb at producing visible light. [1 pt]

And with that, you are almost well and truly done. My sincerest congratulations! Now that you can calculate Joule's constant and know how to turn on and off a lightbulb, you are ready to go out into the world and convert between calories and joules. It's like having a super power, only better, because no one else wants it or even cares that you have it. But you must swear to only use this power for good, and never evil. Since we are unable to take this knowledge away from you, we instead make this pledge worth 1/20th of a percent of your final grade [1 pt].

Signature: __________________________ Date: __________________________

And now you are actually well and truly done with this lab. Great work!