Batteries 'n Bulbs: Voltage, Current and Resistance (8/6/15) (approx. 2h)

Introduction

A simple electric circuit can be made from a *voltage* source (batteries), wires through which *current* flows and a *resistance*, such as a light bulb (also referred to as a *load).* In this lab you will use the multimeter to measure voltage and resistance and to begin to learn about simple DC circuits.

Voltage*:* Batteries are a source of "electromotive force" (EMF) for a circuit. Chemical reactions in the battery maintain a potential difference (i.e. a voltage) between the positive and negative terminals of the battery. If the battery is connected to a circuit with conducting wires then electrons will move from the negative terminal (a region of higher potential energy for negatively charged electrons) toward the positive terminal (a region of lower potential energy). The symbol for voltage is V and its units are Joules/Coulomb or Volts (V).

Current: Even though we now know it is the electrons which actually move, by convention current is defined as the direction of movement of positive charge. Thus the conventional positive current is said to flow from the higher voltage (i.e. positive) terminal to the lower voltage (i.e. negative) terminal. The symbol for current is I and its units are Coulombs/Second or Amperes also known as Amps (A).

Resistance*:* The *resistance*, R, between two points of a conductor is determined by applying a voltage V between those points and measuring the current, I, that results. The resistance is then defined by: $R \equiv V/I$. The unit of resistance, 1 Ohm (Ω) is therefore defined as 1 V/A. Electrical devices which have a linear relationship between voltage and current under usual conditions are said to obey "Ohm's Law", and may be assigned a single value for resistance. Circuit elements such as capacitors, transistors, etc. have a more complex relationship between voltage and current.

Equipment

- 3 D batteries
- battery holders
- 8 alligator clips
- 3 light bulbs (not all same)
- light bulb holder
- multimeter
- probes for meter
- battery tester

FOR CLASS, IN CASE MULTIMETER FUSES NEED REPLACEMENT: Spare 0.5 A fuses and Phillips screwdriver. (OR: There are more multimeters in equipment room 146, shelf A4.)
Note: Light bulbs should have different resistances.

Procedure

For each part follow the suggested procedure then stop and write your observations, answer questions and summarize conclusions. Your report should have a title page with the lab title, your name, date and time, lab partners and a brief introduction. Label each section of the report with a section heading.

***Make sure everyone in your group has a chance for hands on investigation*.**

Part 1: Investigation of Batteries

Examine the batteries. They will have terminals labeled + and -. Determine which end is positive and which end is negative.

Set the multimeter as a voltmeter to measure DC Voltage (V). Make sure the leads are in the proper sockets and if there is a switch it is set to DC rather than AC voltage. Be careful to note whether the voltage reading is in V or mV (10^{-3} V). A voltmeter measures a voltage difference between to points. Measure the voltage difference between the positive and negative terminals of the batteries. If you switch your leads you should notice that the reading on the meter changes sign since the voltage difference changes sign.

Now you will investigate different configurations of batteries. Place the batteries in the holders and use double sided alligator clips to connect them as shown in Figure 1. For each configuration measure the voltage between the bottom of the batteries (the point labeled (A)) and the top of each battery (B) and (C). Make sure that the Common or Negative terminal of the voltmeter is connected to point (A). Note: since wires in our circuit are considered ideal conductors, if a wire is connecting two points in a circuit they should have the *same potential* (voltage). Verify this. To make your voltage measurements you can touch or clip your multimeter probes to the battery holders. Make sure you have good electrical contact.

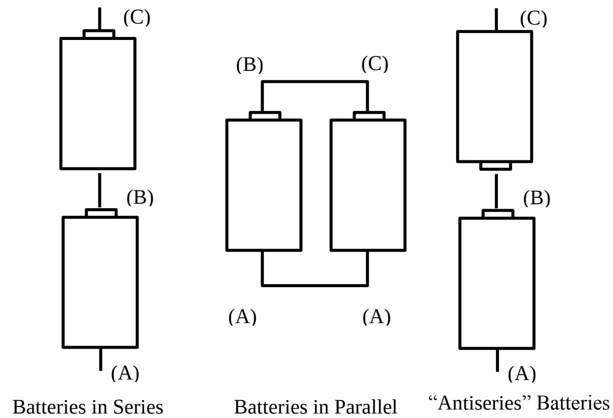

Figure 1: Battery configurations

For your report:

Make a sketch of each configuration *Make your sketches large and easy to read.* Label the points you use to measure voltages and record the voltage next to the sketch. (For example "Voltage between (A) and (B) = V_{AB} =).

Questions:

A chemical reaction in the battery tries to maintain a constant potential (voltage) difference between the negative and positive terminal of the battery. Do you observations support this? (Hint: for series and anti-series configurations the differences should be cumulative.)

Part 2: Anatomy of a light bulb

In this part you will investigate the anatomy of the light bulb and its socket. Your mission is to find out 1) why there are two electrical contacts on the bulb socket and 2) which parts of the light bulb contact which parts of the socket.

Remove one of the bulbs. Investigate the bulb socket. Determine which electrical connectors are connected to different parts of the bulb socket (There are nails holding the socket holder to the board: these are not part of the bulb socket! The inside of the bulb holder is important however!).

Now study the light bulb: how is it constructed? Which parts of the bulb come in contact with which parts of the socket?

Connect a battery to the bulb by connecting an alligator clip from each end of the battery to each electrical contact of the socket. The bulb should light up at least a little. What happens when you disconnect one clip? Does it matter which clip you disconnect? What happens when you partly unscrew the bulb?

For your report:

Make a sketch of the light bulb (a side view showing the filament and how it is connected inside the bulb). When the light bulb is connected to the battery, the potential difference in the battery should cause positive current to flow through the wires and bulb from the positive terminal to the negative terminal. (It is actually electrons moving in the opposite direction). Draw the battery connected to the bulb and show on your sketch how current flows through the bulb. Label the current with an "I".

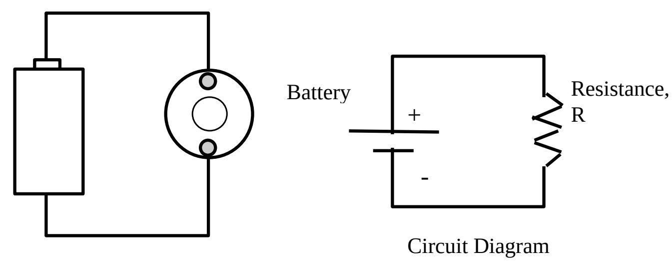

Figure 2: Circuit with a single battery and bulb. The circuit diagram symbols for a battery and a resistor are shown. Wires are represented as lines.

Question:

What is needed in order for the light bulb to light up?

<u>Bulbs in parallel and in series</u>

Now you will study light bulbs in parallel and in series. The circuit diagrams are shown in Figure 3. Note that the shape of the circuit diagram does not have to correspond to the physical shape of the circuit. What is important is 1) where the current flows and 2) which points are connected by wires (and therefore at the same voltage).

<u>Part 3: Bulbs in a Parallel Circuit</u>

Construct the top circuit.

If your bulbs have different brightnesses, move them around to determine whether the brightness depends on the position in the circuit. If it does not, then they are different brightnesses because the are different types of bulbs.

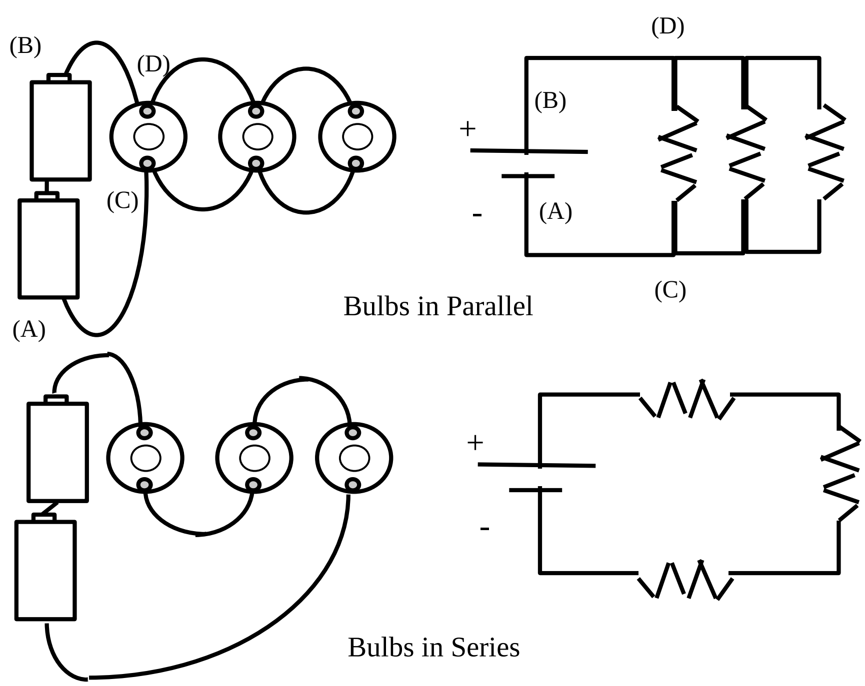

Figure 3: Light bulb Circuit One (top) and Circuit Two (bottom). Corresponding circuit diagrams on the right.

<u>Part 3 a) Observations</u>

For your report:

Make a (LARGE) sketch of the top circuit and label it "Parallel Circuit". Draw the circuit diagram next to it.

Label the points on each side of the battery and on each side of the bulbs (A), (B), (C), etc. Label the corresponding points on your circuit diagram (as shown in the top circuit in Figure 3). Set your multimeter up as a DC voltmeter and record the voltage differences across 1) the combination of the two batteries and 2) each of the bulbs. Record these values below your sketch. For example, the voltage between (A) and (B) should be measured with the negative probe at (A) and recorded as V_{AB} . Answer the following for this circuit:

Questions:

What happens when you unscrew one bulb? Two bulbs? Does the brightness of the remaining bulb(s) change?

How does the voltage across each bulb compare? How does it compare to the voltage across the battery.

Part 3 b) Measuring the resistance of the light bulbs

Set the multimeter as an ohmmeter to measure Resistance (Ohms or Ω). Make sure the leads are in the proper sockets. The resistance may be reported in M Ω (10^6 Ω), k Ω (10^3 Ω) or Ω. Resistance is a measure of how hard it is for current to flow. A good conductor will have (nearly) zero resistance, a good insulator will have very large resistance. Touch the two multimeter probes together to measure the resistance of the test leads. Hold them apart to measure the resistance of the air. (If the resistance is larger than the meter is capable of reading it should indicate this). Do your readings make sense?

Disconnect all of the alligator clips. The alligator clips will remain disconnected for this section. Change your multimeter to an Ohmmeter and measure the resistance across the first bulb. The value should be very small (an Ohm or a few Ohms, if you read kiloOhms your meter may be defective) Record this value as "R_1". Repeat for the second and third bulb and record "R_2" and "R_3". Label the resistors on your circuit diagram with the appropriate labels and values.

Now connect two alligator clips between R_1 and R_2 so they are in parallel again. Measure the Resistances across each bulb. You should get the same value for each. This is the effective resistance of the combination. Under the circuit diagram record this value as R_{1+2}. Connect up the third bulb in parallel (as in your original circuit) and measure the effective resistance across all three bulbs. Record this value under your diagram as R_{1+2+3}..

For your report:

You have measured the values for R_1, R_2 and R_3 and the effective values R_{1+2} and R_{1+2+3}. These are your experimental values. For resistors in parallel the effective resistances should be

$$\frac{1}{R_{1+2}} = \frac{1}{R_1} + \frac{1}{R_2} \qquad \text{and} \qquad \frac{1}{R_{1+2+3}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} .$$

These are the theoretical values for resistors in parallel. Use the measured values for R_1, R_2, and R_3 to calculate the expected theoretical value for R_{1+2} and R_{1+2+3} and record these labeled "theoretical values".

Questions:

Is there a correlation between the Resistances you measure and the brightness of the bulbs? (If you can't remember connect the battery up again) If Ohms Law predicts that V=IR how do you make sense of this? (Remember that you previously determined the voltage across each light bulb).

How do the theoretical values for expected resistance compare to the experimental value for R? (The agreement may not be exact, notice however if the effective resistance is larger or smaller than any of the individual resistance.)

Does resistance get larger or smaller when you combine resistors (or bulbs) in parallel?

Part 4: Bulbs in a Series Circuit

Construct the bottom circuit. (Note: depending on your bulbs some may light up very dimly here.)

4 a) Observations

For your report:

Make a (LARGE) sketch of the bottom circuit and label it "Series Circuit". Draw the circuit diagram next to it. Label the points on each side of the bulbs (A), (B), (C), etc. Label the corresponding points on your circuit diagram. Set your multimeter up as a DC voltmeter and record the voltage differences across 1) the combination of the two batteries and 2) each of the bulbs. Be sure to measure the voltage going the same direction around the circuit so that the measured voltages are all the same sign. Record these values below your sketch. Answer the following for this circuit:

Questions:

What happens when you unscrew one bulb? Any bulb?

How does the voltage across each bulb compare?

What is the sum of the voltages across all three bulbs? How does it compare to the battery voltage?

Do you think the same current is flowing through each bulb? Explain why or why not. (Do not rely on the brightness of the bulbs, consider the circuit diagram).

4 b) Measuring the resistance of the light bulbs

Disconnect all of the alligator clips. The batteries will remain disconnected for this section. Make sure that you remember which bulb is which and label the resistors on your circuit diagram with the appropriate labels and values for R_1, R_2, and R_3.

Now connect the alligator clips between R_1 and R_2 so that they are in series. Measure the resistance across BOTH bulbs. Under the circuit diagram record this value as R_{1+2}.

Connect up the third bulb and measure the effective resistance across all three bulbs. Record this value under your diagram as $R_{1+2+3..}$

For your report:

Record the three resistances, R_1 , R_2 and R_3 and the two effective resistances R_{1+2} and R_{1+2+3}. These are your experimental values. For a resistors in series the effective resistances should be

$$R_{1+2} = R_1 + R_2 \qquad \text{and} \qquad R_{1+2+3} = R_1 + R_2 + R_3 \,.$$

These are the theoretical values. Calculate the theoretical values and record them labeled as "theoretical values".

Questions:

How do the theoretical values for expected resistance compare to the experimental values?

Which circuit makes for brighter bulbs, the resistors in parallel or the resistors in series?

You have measured the voltages for each. Can Ohm's Law explain the relative brightnesses?

Does resistance get larger or smaller when you combine resistors (or bulbs) in series?

Does resistance get larger or smaller when you combine resistors (or bulbs) in parallel?

Conclusions:

If different circuit elements are in parallel, then *they have the same voltage (potential difference) across them.*
If different circuit elements are in series then, *they have the same current running through them.*

Write a paragraph summarizing your conclusions and comparing the two types of circuits (you may have recorded some of your observations earlier but you should summarize them at the end of your report as well).

Based on what you've learned in this Lab, how are the outlets in your home connected, series or parallel? Explain.