Lab #0: This Little Light of Mine
ENGN/PHYS 207—Fall 2019
The big three: KVL, KCL, and Ohm's Law.

Stuff You'll Learn

1. Breadboarding Circuits–quick way to build and reconfigure circuits
2. Making DC voltage, current, and resistance measurements
3. Building intuition for how KVL, KCL, and Ohm's law work
4. Linear (resistors) vs. non-linear (LEDs) circuit elements

1 Classic LED circuit

This is a beautiful little circuit. Elegant in its simplicity, exploring this humble little circuit can give us profound insights into the 'laws' governing circuits relating ***voltage*** and ***current*** that we can learn from it. Current is the stuff flowing through the circuit–mobile electrical charges, of course. Voltage is what pushes the charges along—fundamentally, how much work was done to move a charge from point a to b.

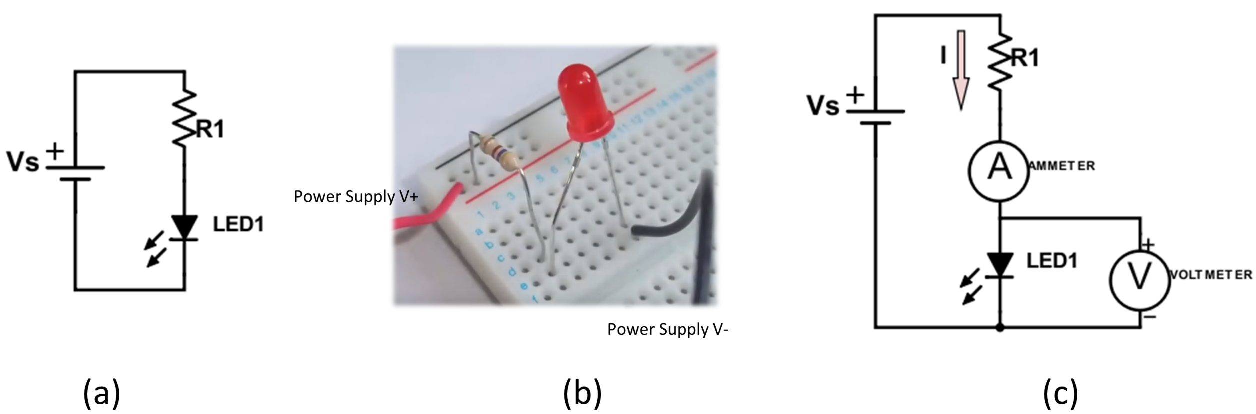

Figure 1: Basic LED circuits. (a) Schematic showing the power supply, LED, and current limiting resistor. (b) Example of actual circuit build on breadboard. Image adapted from QuickStartWorkbook.com. (c) Schematic with current and voltage measurement. The ammeter is inserted directly measure current flow *through* the LED. The voltmeter probes are placed *across* the LED.

1.1 Build and Measure

1. Build the circuit shown in Figure 1a.
   (a) Use a red or blue LED. Your choice!

(b) Select a resistor with ***nominal value*** $R_1 = 220\Omega$. You can use value that's a little higher, but not too much lower (or you risk blowing out the LED). Measure the ***actual value*** with the multi-meter set to the Ω-meter setting. Write down this number—you'll need it later.

(c) V_s is lab bench power supply (BK precision). Red is the 'positive' lead; black is the 'negative' lead. This power supply acts like a battery with variable voltage. Dial in the desired voltage by turning the appropriate knob.

2. Get a quick feel for how the circuit works by turning the voltage knob from about 0 - 10 V. Write down at what voltage the LED illumination is low, medium, and high (barely perceptible, obviously perceptible, and very bright—your judgment call). How does the brightness of the LED vary as the voltage varies? Why should this be so?

3. Now time to get quantitative and make careful measurements.

   (a) You'll set the power supply to each of the following values: $V_s = \{0, \pm1, \pm2, \pm3, \pm5, \pm7, \pm9\}$ Volts. Note: a negative value is achieved by swapping the red and black leads. Note: a value of 0 means the power supply is ON with voltage turned all the way down; this is a very different scenario than turning off the power supply. Thus, suggest doing all the positive values, then swap leads and do all of the negative values.

   (b) For each value, directly measure the current flow through the circuit I using an ammeter. Refer to the schematic in Figure 1c to see how to properly connect the ammeter and voltmeter in the circuit. Also, measure the voltages V_{R_1} and V_{LED1}. In circuits parlance we call ***voltage drops*** across the resistor and LED, respectively. Enter these values in an Excel table (or another software of your choosing) as you go; you'll **make live plots of your results**.

   (c) Make 2 plots as you go: 1) I vs. V_{R_1} and 2) I vs. V_{LED1}. Note: current is plotted on the vertical axis.

1.2 Analysis: Ohm's Law, KVL, and KCL

Time to analyze and think hard about what these results are telling us!

1. ***Ohm's Law***. This often written in deceptively simple form as $V = IR$ or $I = V/R$. This says the current flowing through a resistor is linearly proportional to the voltage across it; and higher resistance implies lower current and vice-versa. We will revisit the meaning of this little equation approximately 7386723462346 times during the term.

   (a) For each of the plots you just made, is the relation between current and voltage linear? non-linear? Hint: you should see one of each.

   (b) For the linear plot, make a best fit line and write down the slope (you can ask Excel to print the value on the plot itself).

   (c) Compare the slope to the value $g_1 = 1/R_1$. Are these 2 values in reasonable agreement? Here, g_1 is the conductance, the "opposite" of resistance, and its units are ***Siemens*** [1 S = $1/\Omega$].

(d) **The takeaway**: hopefully analysis of your results for the resistor give showed you first-hand that ***current and voltage are linearly related via the resistance***. Note: This is true only for the resistor, but not the LED! The LED is a non-linear element whose operations is based on semiconductor principles we'll cover later in the term—fun times ahead.

(e) Think about water flowing through a pipe. What is the analogy to current flowing through a resistor? Things to think about while answering this question: What's the fluid flow equivalent of voltage? What physically causes water to flow from point a to b?instead of electrical charges, what current is flowing the pipe? How would you measure current flow?

2. ***Kirchoff's Voltage Law (KVL)***. KVL is fundamentally conservation of energy.

   (a) Which of the 3 circuit elements are putting electrical energy into the circuit? Hint: there is 1.

   (b) Which ones are taking electrical energy out of the circuit. Hint: there are 2. Where's all that energy going, what forms of energy was it converted into?

   (c) Finally, what is the mathematical relation between V_s, V_{R_1} and V_{LED1} that holds true (within experimental uncertainty, a few mV for us today) for any value of V_s?

   (d) The take home message is that, going ***around a loop, the sum of voltage gains have to be equal to the losses***. This is KVL.

3. ***Kirchoff's Current Law (KCL)***. KCL is fundamentally conversation of charge.

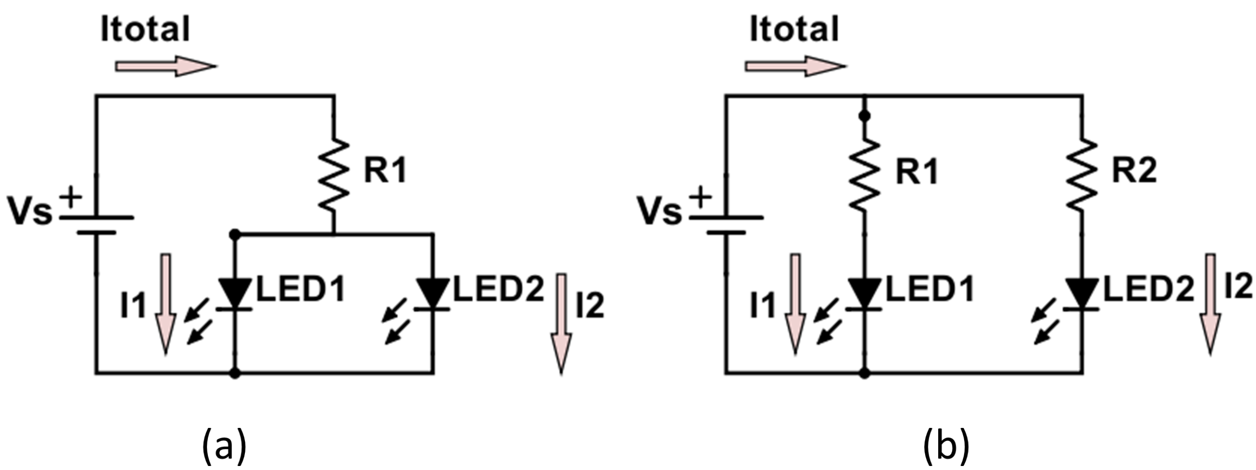

Figure 2: Circuit with two LEDs. (a) Resistor in ***series*** with two ***parallel*** LEDs. (b) Parallel resistor-LED branches.

   (a) Add another LED into your circuit, in parallel with the other, as shown in Figure 2a. Choose LED2 to be the same color as LED1, basically to have 2 identical LEDs.

   (b) Turn the power supply voltage knob through a range about 0 to +10 V. Record the voltages at which you judge the brightness to be low, medium, high (similar to what you previously did with the 1 LED circuit).

(c) How does the brightness of each LED of this 2 parallel LEDs circuit with single series resistor compare to the single LED circuit, given the same value for V_s. Hint: the 2 LED circuit should be less intense. Why? Hint: think about current flow, and how it splits at the ***node*** connecting the resistor and LEDs.

(d) How can we explain these general/qualitative LED brightness result in circuits terms?

(e) Now let's get a bit more quantitative. You'll set the power supply voltage to the following values: $V_s = \{0, 1, 2, 3, 5, 7, 9\}$ Volts. (No need to concern ourselves with the $V_s < 0$ in this experiment.)

(f) For each value of V_s measure and record (in an Excel table) values for the voltage across each LED, V_{LED1} and V_{LED2}. Also determine the amount of current flowing through each LED, I_{LED1} and I_{LED2}.

(g) Plot the current vs. voltage results (I_{LED} vs. V_{LED}) for both LEDs 1 and 2 on the same axes, overlaid.

(h) On another set of axes make two plots overlaid: 1) current vs. voltage results for the previous 1 LED circuit experiment; and 2) for each value of V_s tested, plot summative current $I_{LED1} + I_{LED2}$ vs. the average voltage $(V_{LED1} + V_{LED2})/2$.

(i) Compare the results of these 2 plots you just made. Would the results reasonably support a conclusion that the sum of the currents in the 2 LED circuit (Figure 2a) is the same as for the 1 LED circuit? Justify.

(j) The take home message you will hopefully see is this: The total amount of current entering a *node*, equals the total amount leaving it. For the 2 LED case, the total current splits down the two branches. This is in contrast to the 1 LED circuit, where there is only 1 path for current to flow. Hence, why the 2 LED circuit appears dimmer given the same voltage V_s powering the circuit.

(k) In order to help visualize what's happening in the circuit, develop and describe an analogy with car traffic. Make a quick illustrative sketch of your traffic analogy.

4. ***Going loopy: A subtlety different circuit***. Last but not least, let's check out one more circuit that illustrates KVL, KCL, and Ohm's Law in a bit more subtle way.

(a) Build the circuit shown in Figure 2b.

(b) Set V_s to 7 Volts. Measure the currents I_1 and I_2 flowing through each LED-resistor branch of the circuit. You can (and should) make these current measurements *indirectly*. See section "The Multimeter" number 3 how to do this!

(c) Make a direct measurement of the I_{total}.

(d) Based on your empirical findings, write a math expression that relates I_{total}, I_1, and I_2.

(e) Identify how many complete circuit loops there are that involve traversing the power supply.

(f) Now for something a bit subtle: disconnect one branch of the circuit. Easy peasy–just take R_2 and pull one of its legs out of the breadboard. The light goes off. Why? How much current is flowing in this branch?

(g) Mesaure how much current is flowing in the LED1 (which should still be illuminated). How does this value compare to the one you just measured when 2 LEDs were illuminated? Hint: it should be the same! Why? Hint: THink about KVL. The full answer will keep us thinking hard in class next Monday!

What to Turn In

Turn in the plots you generated throughout this assignment. Make them pretty—science eye candy—with appropriate axis labels and nicely formatted data series. For each plot, include a caption for each one that briefly orients the reader to 1) what is shown in the plot; and 2) what it means in terms of circuits behavior. This will probably be about 3-5 sentences. As example caption would be something like this: "Figure 1. Current vs. voltage relation for a resistor. The relation remains linear throughout range tested, with a slope of 0.050 1/Ω. These results are in reasonable accord with Ohm's law, which also predicts a linear relation with a slope of 1/R = 0.047 1Ω, 6% lower than the empirically determined value."

The Multimeter

A multi-meter can be used to measure voltage, current, resistance, capacitance, etc. You will make extensive use of it in this lab, so it's important to know how to use it properly. The manual is linked here. It offers wonderful illustrative instructions on pages 6-9, so don't be bashful about consulting it as needed. Here are a few helpful hints/reminders:

Figure 3: Meet your new friend in Circuit lab: the Fluke multi-meter. Note: red probe plugged into the right contact is required to measure voltage, resistance, and capacitance. To measure current, the red probe must be plugged into the contact labeled "A" (for Amperes).

1. **Measuring Voltage: Volt-meter setting** The voltmeter measures the potential ***across two points***:

   $$V_{meter} = V_+ - V_- = V_{red} - V_{black}$$

   Take care to properly connect the probes of the voltmeter when making a measurement. By convention, the reference probe (V_-) is the one colored black and labeled COM. The probe (V_+), typically red in color, must be plugged into the proper port (see caption of Figure 3). Finally, make sure that the function dial is set to make a DC voltage measurement, the V with the straight bars above it. (The "squiggle V" is for making ac sine wave measurements.) Ideally the voltmeter has ∞ resistance, but in reality it only acts as a 10 MΩ resistor.

2. **Measuring Resistance: Ohm-meter setting** The mulitmeter can quickly tell you the resistance value of a resistor—or combination of resistors. You will find this feature to be incredibly useful (money back guarantee!). Set the big dial to the Ω symbol. Prior to measuring resistance, REMOVE whatever resistor(s) you from the breadboard and lay them flat on the table. FIRMLY connect the red probe to one side of the resistor and the black probe to the other end of the resistor. The polarity of the probes does not matter. The display reads out the resistance value. Be sure to *carefully note the units* on the right-hand side of the meter. Voila, you are done!

3. **Measuring Current: Ammeter setting** To directly measure DC current, set the dial to the proper setting (A with the straight bars above it). Make sure the red probe is plugged into the lower left port left labeled "A". The meter measures current running ***through*** it. This means you have to break open the circuit you are measuring and insert the ammeter into it. Your ammeter ideally has zero resistance, but in reality usually offers about 1Ω of resistance.

   Of course, breaking open a circuit can be a pain, so if you have access to a resistor, you can accurately measure the current indirectly. How, well, if you know the resistance value and make a measurement of voltage, then apply Ohm's Law $I = V/R$. Boom. Done.