ECE 1245: Lab 2
Voltage Dividers and LEDs

Learning Objectives:

- Use the +5V supply on the Analogy Discovery 2.
- Characterize a voltage divider.
- Learn how to use a light-emitting diode.
- Measure current with the ammeter.

Materials Needed:

- Digital Multimeter
- Breadboard and Parts Kit
- Analog Discovery 2

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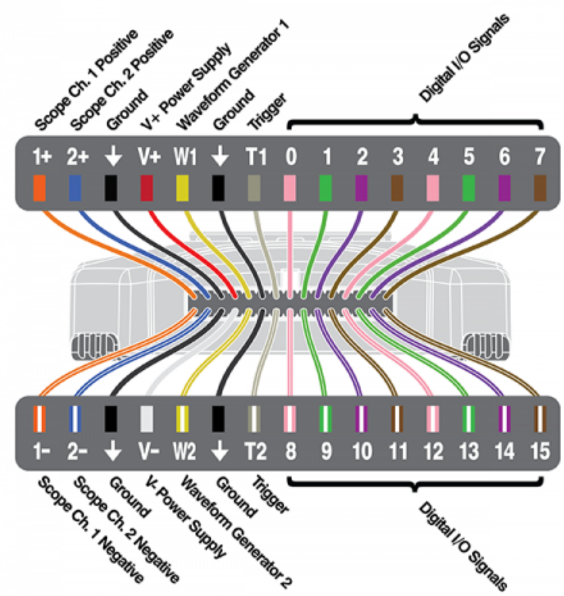
Part 1: Supply Voltage (10 points)

For the first part of this lab, you will need to activate the +5V supply on your Analogy Discovery 2 (AD2). Keep in mind that 5.0 V is a perfectly safe level for human contact, and you probably would not even feel anything if you touched it directly with your fingers. The most important thing to be mindful of is accidentally making contact (i.e., *shorting*) between the +5V lead and the ground return. When powered by a USB, the maximum current from the +5V supply should never exceed 50 mA (250 mW). Any higher, and it may be possible to damage your AD2.

Start by connecting the big bundle of wires (called *Flywires*) like in the picture below. For reference, we have also included a pinout diagram to indicate which wire corresponds to which purpose. When finished, connect the AD2 to your laptop by plugging in the USB cable.



Next, activate the WaveForms software that you installed during the pre-lab.

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WaveForms (new workspace)
Workspace Settings Window Help
Welcome
Help
Scope
Wavegen
Supplies
Voltmeter
Logger
Logic
Patterns
StaticIO
Spectrum
Network
Impedance
Protocol
Script
Open Workspace
To create custom application see the WaveForms SDK.
For more information visit Digilent Instrumentation Reference.
Observations are welcome on Scopes & Instruments Forum.
Recent:
New
Save
Save As
Open last workspace on start
DIGILENT
ANALOG DEVICES
Manual Trigger
Discovery2 SN:210321A7FE90
Status: OK

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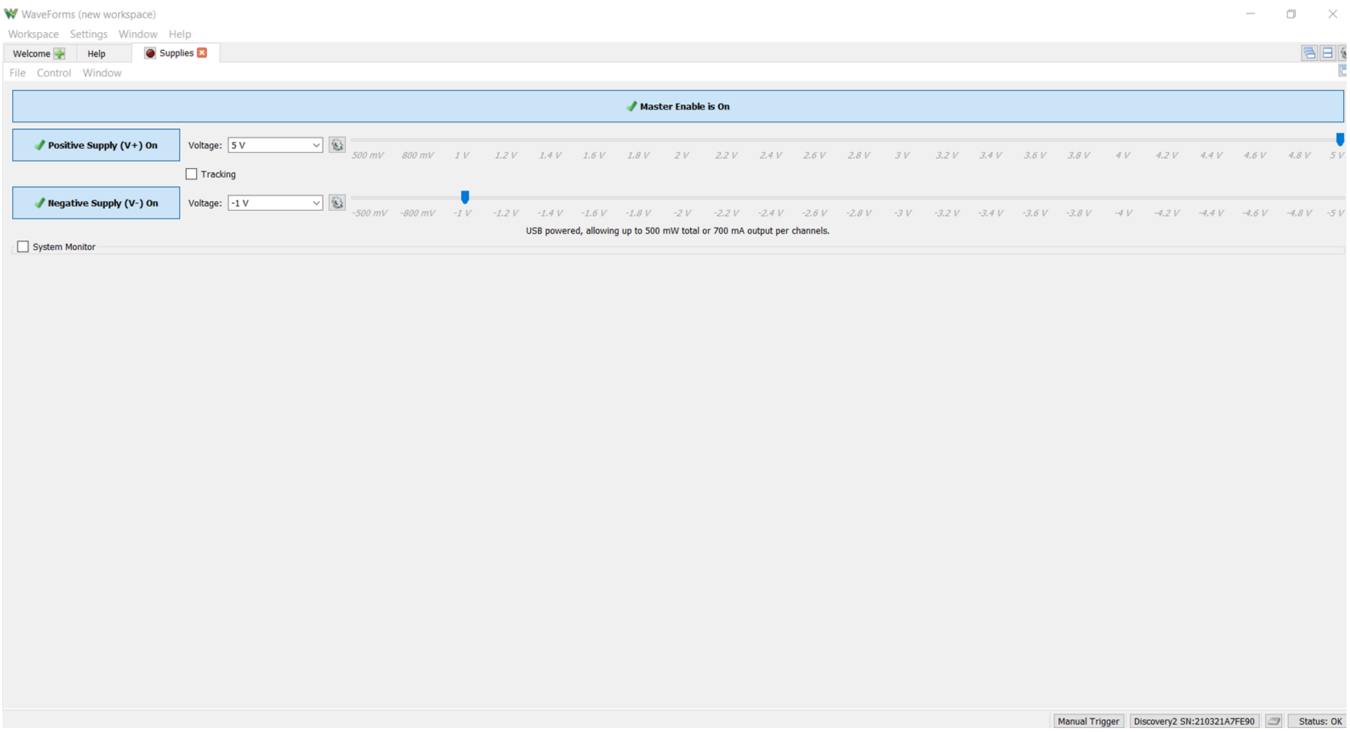
Select the tab labeled "Supplies" to open up the supply voltage control panel. Select the Voltage drop-down menu next to "Positive Supply" and set it to 5 V. Do not worry about the Negative Supply voltage, as we will not be using it in this lab. When you are ready to excite your circuit, select the "Master Enable" to activate the 5-V supply. If all is working well, your screen should look like the one below:



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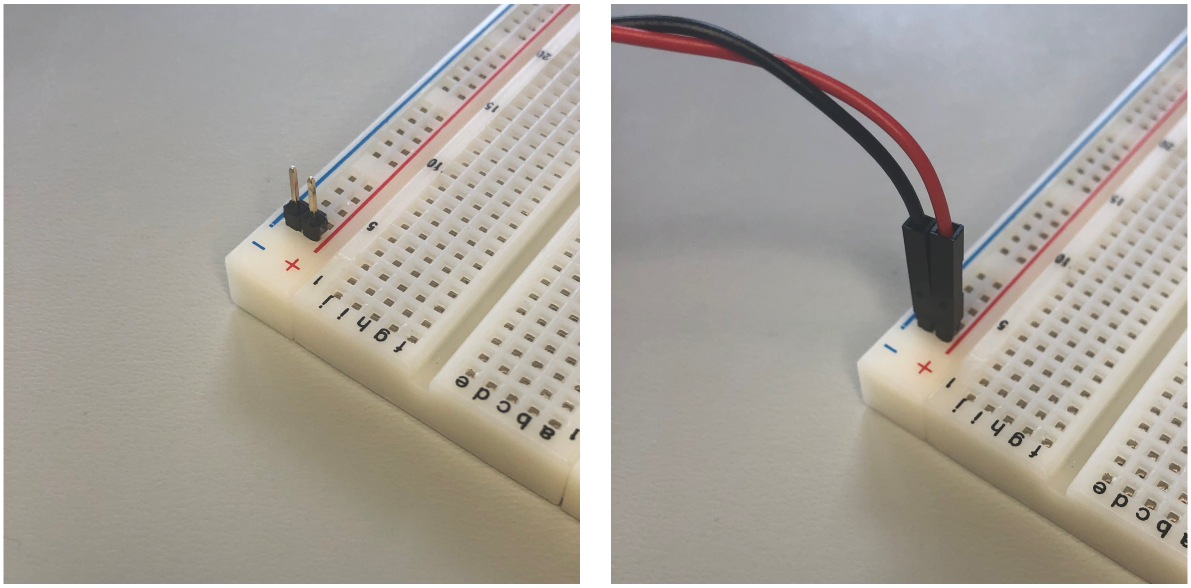

Figure 1: *(Left) A 2x1 pin header is inserted into the breadboard rails. (Right) The red and black cables from the Analogy Discovery 2 inserted over the pin header.*

Let us now verify that your 5-V supply is working. Start by unpacking the 2x1 *pin header* from your lab kit and inserting it into the rails of your breadboard as shown in Fig. 1. Next, find the red wire and the black wire in the tangled mess of wires in your kit. The red wire corresponds to the +5V power supply while the black wire is ground (all the black wires are the same, so it will not matter which one you use). Connect the wires to the pin header as also shown in the figure. Make sure the wires are connected to your AD2 and that the "Master Enable" is on. When ready, use your digital multimeter to measure the actual voltage being delivered from your AD2. Do this by selecting the DC voltage setting on the meter (usually a capital "V" with a flat bar next to it) and then inserting the probes into the rails of your breadboard.

What voltage did you measure from the AD2? It should be something very close to 5.0 V.

$$V_{measured} = \underline{\hspace{2cm}} \text{ V}$$

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Part 2: The Voltage Divider (20 points)

2a: Theory (5 points)

One of the most prolific circuits in electrical engineering is known as the *voltage divider*. Depicted in Fig. 2 the voltage divider is essentially just an arrangement of two resistors in series where the output voltage V_{out} is of special interest. Often times, V_{out} may be a signal voltage that is used to control other parts of a circuit. In other situations, R_1 may represent the equivalent internal resistance of some power source (e.g., amplifiers, batteries, etc.) while R_2 is the equivalent resistance of some desired load (e.g., speakers, light bulbs, etc.).

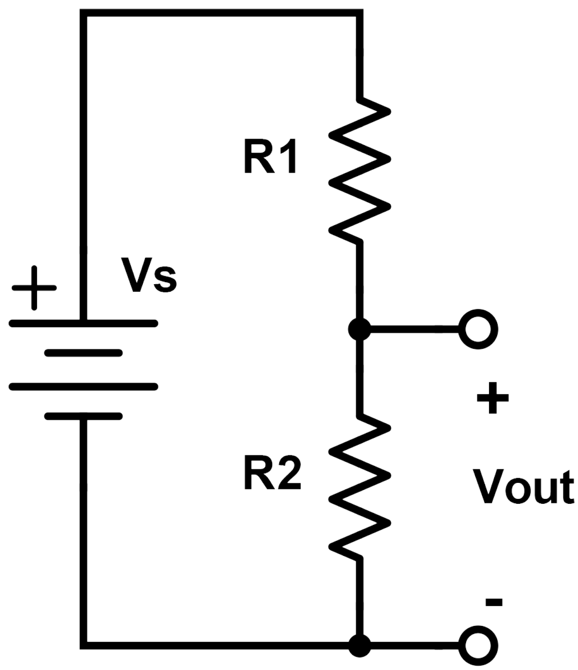

Figure 2: *Basic voltage divider circuit.*

Let us now derive the voltage V_{out} across the resistor R_2. Recall from last time that the equivalent series resistance between R_1 and R_2 is simply

$$R_s = R_1 + R_2 \ .$$

If we now apply Ohm's law, the total series current I_s that flows through the circuit is

$$I_s = V_s/R_s \ .$$

Notice that the same current I_s is passing through both R_1 and R_2. Since the voltage drop across R_2 likewise follows Ohm's law, the output voltage satisfies

$$V_2 = V_{out} = I_s R_2 \ .$$

If we now substitute from the previous expressions, we arrive at

$$V_{out} = V_s \left(\frac{R_2}{R_1 + R_2} \right) \ ,$$

which is the classic voltage divider equation.

Now consider a source voltage of $V_s = 5.0\ V$ with resistor values of $R_1 = 1.0$ kΩ and $R_2 = 1.5$ kΩ. Calculate the total series current I_s and the output voltage V_{out}.

$I_s =$ 2 mA

$V_{out} =$ 3 V

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2b: Experiment 1 (5 points)

Let us now construct a real voltage divider. Find the 1.0 kΩ (brown-black-red) and 1.5 kΩ (brown-green-red) resistors from the ECE 1245 parts kit and use the ohmmeter setting on your digital multimeter to measure their actual resistances. Use the measured voltage from your AD2 and apply the voltage divider equation to calculate the expected output voltage across R_2.

Using your breadboard, construct the voltage divider as shown in Fig. 3. Notice how the red and blue rails make for a nice, convenient connection to your +5V supply and the ground return. Notice also how the resistor legs have been cut to fit neatly against the breadboard. This is an important habit to get into when using a breadboard, especially when your circuits grow in complexity. Use the wire cutters in your lab kit to snip your resistors in a similar fashion and include a picture of your circuit in your final lab report. When ready, measure the output voltage V_{out} across R_2 with your voltmeter and record its value. How well did it agree with your prediction?

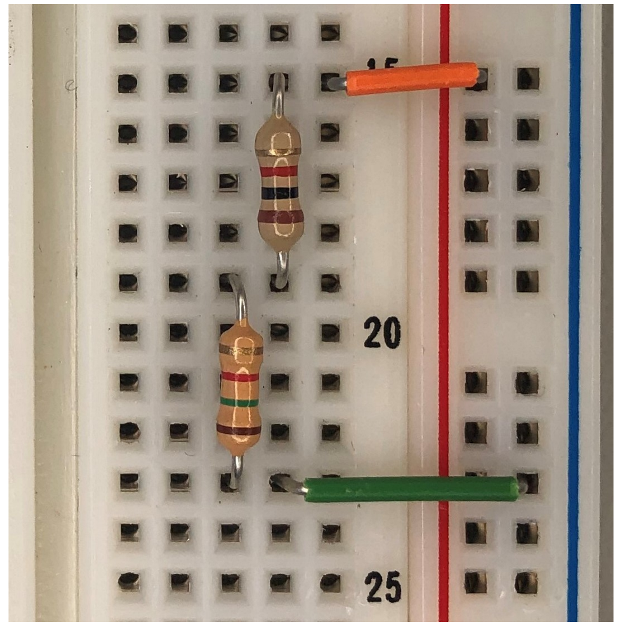

Figure 3: *Voltage divider circuit implemented on the breadboard.*

$R_1 =$ .99 kΩ

$R_2 =$ 1,49 kΩ

$V_s =$ ________ V .

$V_{out} =$ ________ V (theory)

$V_{out} =$ ________ V (measured)

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2c: Experiment 2 (10 points)

One common application for the potentiometer is a kind of continuously-variable voltage divider. To demonstrate, take the 100 kΩ trim pot from your lab kit and install it into your breadboard as shown in Fig. 4. Adjust the knob to set the resistance R_{23} to the specific values in the table below and then measure the voltage V_{out} between ports 2 and 3.

CAUTION: Be careful not to accidentally measure resistance when the +5V rail is activated. Measuring resistance across a live voltage is generally bad for the ohmmeter. For low voltages, it will most likely just scramble the measurement. However, it can also potentially damage the device if voltage is large enough. So be sure to always **deactivate** the +5V rail when measuring resistance. When you are ready to measure voltage again, be sure to switch the multimeter back to the voltmeter setting before reactivating the supply voltage.

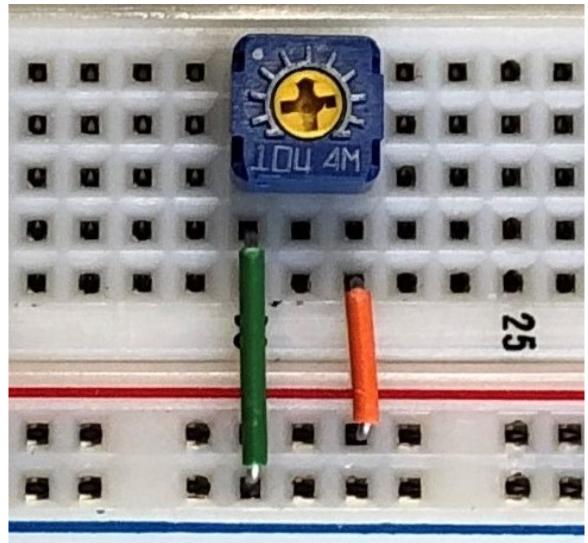

Figure 4: *Potentiometer rigged as a voltage divider.*

When measuring voltage and resistance, you should be able to just cram the probes of the multimeter into the breadboard holes and get a decent electrical contact. However, this is somewhat flimsy and may not work well for you. If you have any trouble, try adding some extra wires to the breadboard and use them as contact points instead of poking directly into the holes. Alternatively, you can try using alligator clips to maintain contact with your ohmmeter and the wires. Feel free to ask your TA for help if you are struggling.

R_{23} (kΩ)	Expected V_{out} (V)	Measured V_{out} (V)
0		
25		
50		
75		
100		

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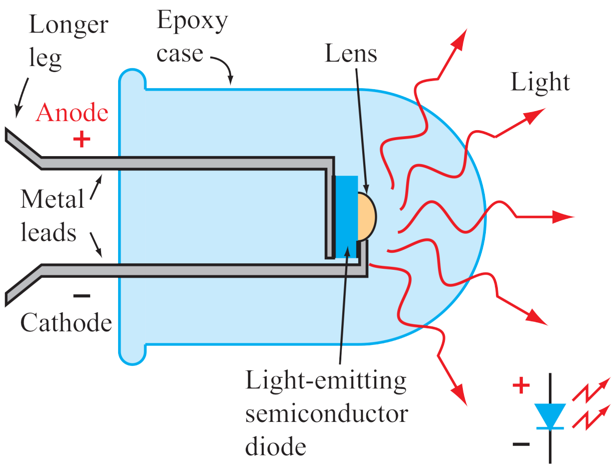

Figure 5: *Typical light emitting diode and its underlying anatomy.*

Part 3: Light Emitting Diodes (20 points)

As the name implies, a *light emitting diode* (LED) is an electrical device that emits light when excited by an electrical current. Depicted in Fig. 5, a typical LED is constructed out of a special semiconductor chip with two electrical contacts, called the *anode* and the *cathode*. Although the underlying physics of an LED is very complicated (take a course on solid-state physics someday if you *really* want to delve into that), the basic operation is relatively straightforward.

The first thing to understand about an LED is the term *diode*. In electrical engineering, a diode is a special device that only allows current to flow in one direction. When excited in the *forward-bias* configuration (anode-to-cathode), current is allowed to flow through the diode with only a small amount of resistance. If, however, the diode is *reverse-biased* (cathode-to-anode), then no current is allowed to flow at all, and the diode acts like a very high resistance (ideally infinite).

Unlike an ordinary resistor from your lab kit, the forward-biased resistance of a diode is not constant. Instead, the apparent resistance of a diode changes with voltage and current. Devices that behave like this are said to be *non-ohmic* because they do not follow Ohm's law in the traditional sense. Depicted in Fig. 6, a much better way to think of the a diode is a constant voltage source that points opposite to the direction of current. Thus, no matter how much current is flowing through the diode, this forward-biased voltage V_F tends to remain relatively stable. In contrast, Fig. 7 shows a reverse-biased LED, which simply behaves like an open circuit.

Another important feature of the LED is that its brightness is directly proportional to the current flowing through it. Eventually, however, the heat dissipation from the current will burn out the device if it gets too large. In today's lab, the maximum current your LED can tolerate is about 30 mA. To help ensure this limit, it is common practice to include a fixed resistance in series with the LED. The exact value of R is generally not very important, but anything between 200–1000 Ω tends to work fine with a 5.0 V supply.

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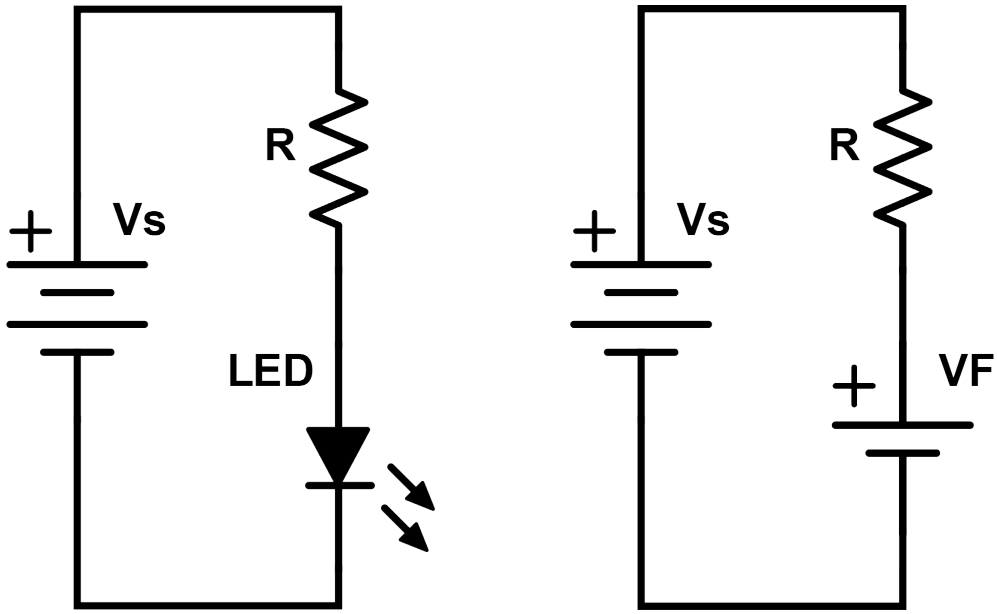

Figure 6: *(Left) Forward biased LED. (Right) Equivalent circuit model.*

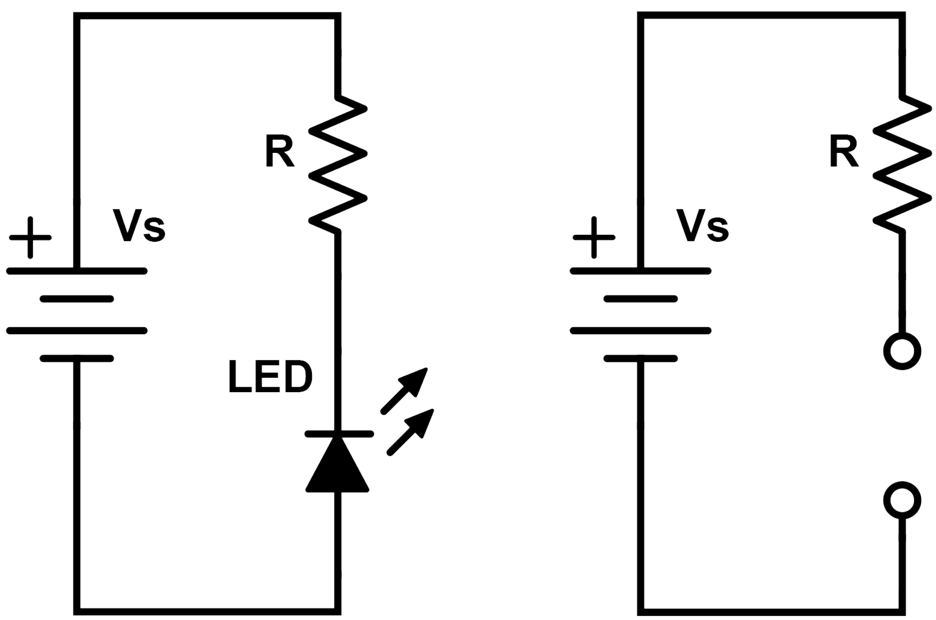

Figure 7: *(Left) Reverse biased LED. (Right) Equivalent circuit model.*

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Using your breadboard and parts kit, take out the red LED and create your own circuit like the one shown in Fig. 8. Make sure to cut the leads like you did earlier so that the circuit is nice and flush. For the first part of this experiment, place the LED in the forward-bias configuration and use a resistance of $R = 510\ \Omega$ (green-brown-brown). Measure the actual resistance of the part and record it in the table below.

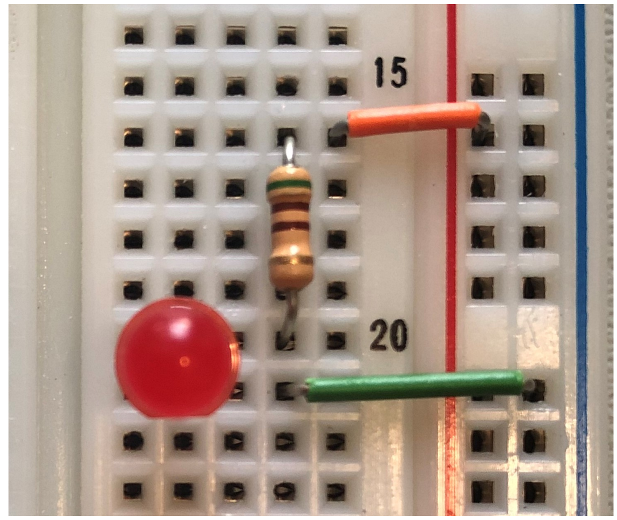

Figure 8: *A resistor in series with a red LED.*

Next, activate the +5V source from your AD2 and see if the LED lights up (if not, then you may have it in backwards). Once it is working, use your voltmeter to measure the forward-biased voltage V_F across the LED. Continue by measuring the voltage drop V_R across the resistor and use Ohm's law to calculate the series current I_s flowing through the circuit. Finally, use the ammeter setting on your digital multimeter to confirm the calculated current (see Appendix I if you are have never measured current before). Repeat the experiment using a 1.0 kΩ (brown-black-red) and then take a picture of your circuit to show that it is working. Include the picture with your final lab report.

When finished with the experiment, remove the LED from the circuit and then re-insert it in the opposite direction. This will reverse-bias the LED and prevent any current from flowing. Repeat the experiment for a third time to verify the results (it will not matter which value you pick for R, so you can just leave it alone).

	510 Ω Resistor	1.0 kΩ Resistor	Reverse-Bias	
R (Ω)				MEASURED
V_R (V)				MEASURED
V_F (V)				MEASURED
I_s (mA)				CALCULATED
I_s (mA)				MEASURED

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Appendix I: The Ammeter

In order to measure current, we must first adjust the digital multimeter to the proper *ammeter* setting. If you look closely at your meter, however, you may notice that there appear to be multiple versions of ammeter. All of them operate essentially the same way, except for the expected scale of the measurement. For this lab, we will be expecting a current on the scale of a few tens of miliamps, and so you will need to adjust the knob to the "mA" setting as shown in Fig. 9. At the same time, you will need to transfer the positive (red) cable from the voltage port ("INPUT") to the miliamp-scale current port ("μA mA"). Finally, the meter will need to be placed in series with your circuit so that current can flow through the device. A schematic of this is shown in Fig. 9, which you can implement on your breadboard.

It is worth nothing that the ammeter could, in principle, be placed anywhere in series along the circuit. In practice, however, it is generally desirable to pick a section of the circuit that is at low voltage. Remember that the ammeter will act like a short circuit between nodes, and so it is possible to accidentally short the circuit to random objects in the environment (including people!). By picking out a low-voltage section of the circuit, we help to guard against any possible accidents in case the probes are mistakenly touched to the wrong place.

Feel free to ask your TA for help if you have any further questions or concerns.

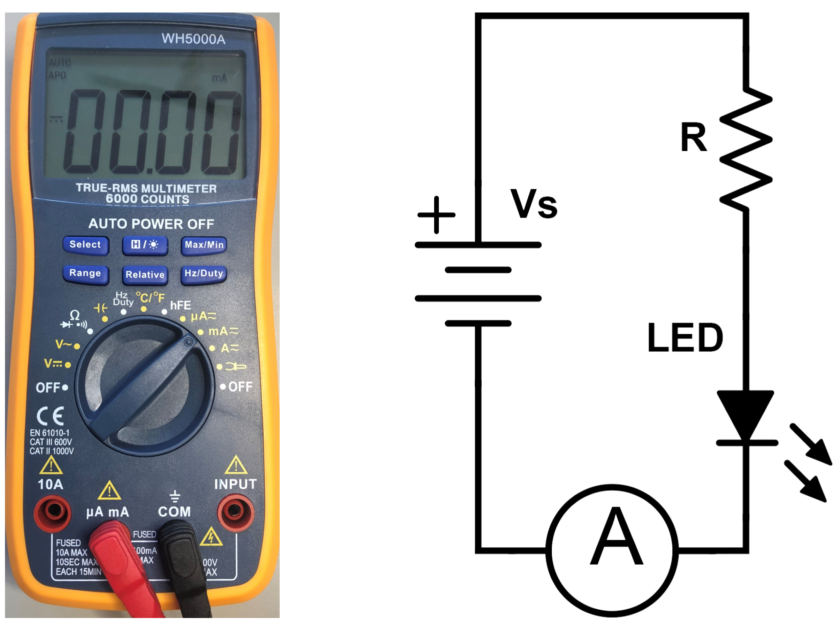

Figure 9: *(Left) Digital multimeter set to read current in the miliamp (mA) scale. (Right) Equivalent circuit model with the ammeter placed in series.*