



Lab 1: Measuring Circuit Values

Lab Equipment List:

- Breadboard, wires, and resistors from your lab kit
- Triple Output DC Power Supply
- Digital Multimeter (DMM)
- Wires with connectors on one end and alligator clips on the other

Partnering:

- ◆ Everyone must create their own lab report (fill out this document).
- ◆ Everyone must build their own circuits, but you may use the same measurement equipment.
- ◆ Discussions are encouraged, and you are also encouraged to answer each other's questions!
- ◆ Seek out the TA if you get stuck or need help.

Lab Procedures:

Today we will build our first circuits and learn how to perform some voltage, current, and resistance measurements. We will also test Ohm's Law, compare nominal vs. measured vs. calculated resistances, test an equivalent resistance, test Kirchoff's Voltage Law, and test Kirchoff's Current Law.

The parts below that you need to fill in are highlighted. Please leave the text that you add highlighted so that we can easily find your answers and grade them (you don't need to highlight your plots – we'll be able to find them.)

Part 0: Choose a Workbench

Choose a workbench that has an Agilent or HP 34401A multimeter and an Agilent or HP E3631A DC power supply, like the ones shown in Fig. 0 (in the lab these are side-by-side rather than stacked vertically as in the figures). (You may use different equipment but then you will need to modify the specific instructions found in this lab. You may also then need an additional multimeter and additional help from your lab TA.)

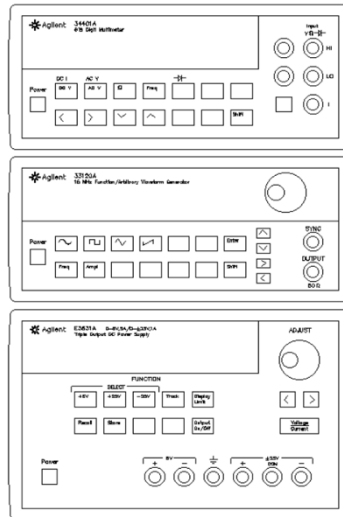


Fig. 0 The multimeter (top) and power supply (bottom) that we will be using today. We will not be using the waveform generator (middle) in this lab1.

Part 1: Create a Circuit and Measure Voltages and Currents

SET UP A CIRCUIT

Throughout this lab, we will be taking some measurements of some basic circuits. So, let's first learn how to build a basic circuit, like the one shown in Fig. 1.

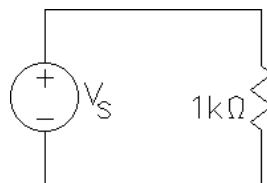


Fig. 1 The first circuit we will test.

1. It's good practice to wire up our circuit before turning on the voltage source. So first, find a $1\text{ k}\Omega$ resistor from your lab kit. In this case, reading from left to right, the color bands you need to see on the resistor are brown (which gives us a "1" as the first digit using the "sig fig" or significant figures column of the "Resistor Color Code" table), black (which gives us a "0" as the second digit using the "sig fig" or significant figures column), and then red (which gives us a "100" for the multiplier using the "Decimal Multiplier" column). So a resistor with brown, black, and then red stripes is a $10 \times 100 = 1,000\ \Omega$ resistor. The last stripe of the resistor (on the right side) will always be gold in this class, because we will be using resistors with a 5% tolerance, meaning the actual resistor value can vary by $\pm 5\%$ of the expected value.
2. For now, don't use your breadboard. Instead, use alligator clips to connect this $1\text{ k}\Omega$ resistor to the +25V and COM outputs of the power supply as shown in Fig. 2 (COM stands for common, so +25V is 25 volts higher than the common port). Connecting

the resistor to these ports will give you the option of adjusting the power supply to any value between 0 and +25 volts.

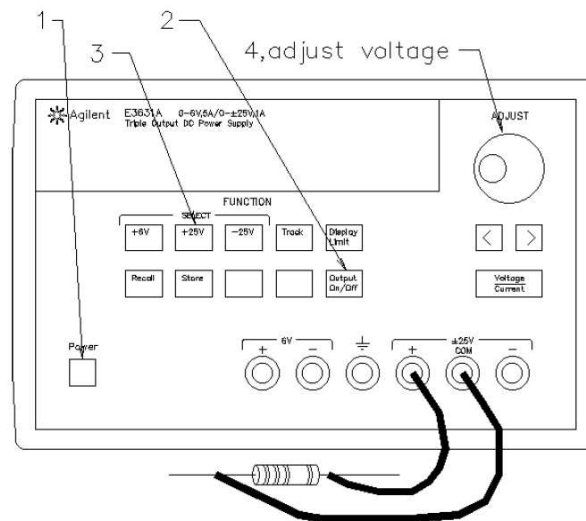


Fig. 2 Diagram of a resistor connected to the +25 and COM ports of the Agilent Triple Output DC Power Supply. The power supply serves as V_s in the circuit diagram of Fig. 1.

- Now that our circuit is built, we can turn on the power supply (voltage source). To turn the power supply on, press the power button (see #1 in Fig. 1), then select the +25 V output since we're using +25 V and COM ports (#3 in Fig. 1), and then turn on the output (#2 in Fig. 1).
- Set the voltage to a value between 0 and 5 V using the adjustment knob (#4 in Fig. 1). Notice that the adjustment knob changes the digit that is flashing. To change which digit you are working on, use the left and right buttons underneath the knob. The circuit is now active.

PERFORM A VOLTAGE MEASUREMENT

We will use the benchtop multimeter to measure the voltage drop across the resistor. An ideal voltmeter has an infinite resistance (so that no current from the circuit goes through it), and it measures the potential difference between two points. Because of this, as shown in Fig. 3, we should hook it up in parallel (not in series) to the resistor in order to measure the voltage drop across the resistor. Let's go through the steps needed to set up the measurement shown in Fig. 3.

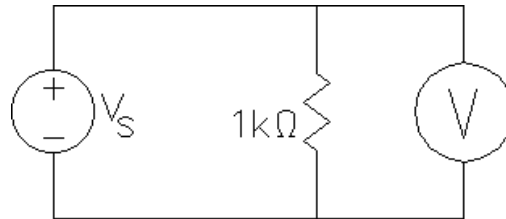


Fig. 3 Voltmeter measurement setup.

1. Turn off the power supply.
2. Using alligator clips, connect the multimeter's 1000 V Max HI and LO ports to the resistor as shown in Fig. 4.

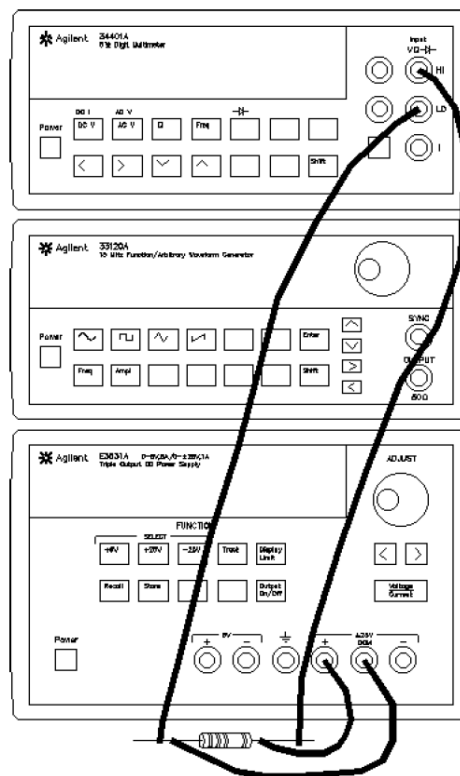


Fig 4 Implementation of the circuit shown in Fig. 3 with the power supply serving as V_s and a voltage measurement being performed by the multimeter (in parallel with the resistor).

3. What do you expect your voltage measurement to be as V_s changes from 0 to 5 V?

<fill in and leave highlighted>

4. Now turn on the multimeter and select the DC V (Voltage) option.
5. Turn the power supply back on.

6. Check how close your voltage measurement on the multimeter is to your expected value as you change the source voltage from 0 to 5 V. Hopefully you will observe that the voltage displayed on the multimeter is very nearly equal to the voltage displayed on the power supply, even as the source voltage is changed.

PERFORM A CURRENT MEASUREMENT

A current measurement can be more exciting if wired incorrectly, so please be mindful. This is because an ideal ammeter has no resistance, so it can create a short circuit if it is connected incorrectly (e.g. incorrectly would be in parallel with any circuit element). Instead, an ammeter must be wired *in series* with the circuit element where we want it to measure a current.

1. As is good practice, turn off the power supply before modifying your circuit.
2. Modify your circuit so that it is wired according to Fig. 5. We will be using the multimeter to perform the current measurement (using the same ports of the multimeter as for the voltage measurement). As a result, your setup should look like that shown in Fig. 6.

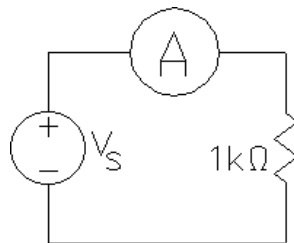


Fig. 5 Circuit diagram for the current measurement.

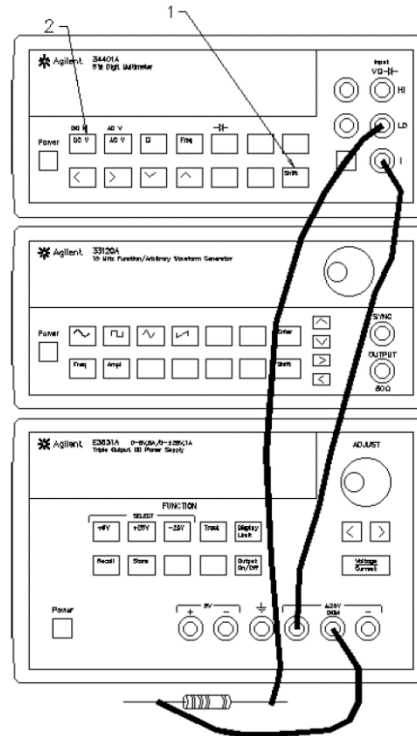


Fig. 6 Implementation of the circuit shown in Fig. 5 with the power supply serving as V_s and the current measurement being performed by the multimeter (in series with the resistor).

3. What do you expect your current measurement to be as you change the voltage from 0 to 5 V?

<fill in and leave highlighted>

4. Turn the power supply back on and change the mode of the multimeter to DC I (Current) mode. This is a second function of the multimeter, so you will need to press Shift (see #1 in Fig. 6) and then the button with DC I above it (#2 in Fig. 6).
5. Now check how close your current measurement is to your expected value. While doing this, adjust the source voltage between 0 and 5 V.

As you do this, you'll probably notice that the *multimeter's* current measurement is much more accurate than the current value displayed on the *power supply*, especially when the current is extremely low.

Based on this current measurement result as well as our earlier voltage measurement result, we can: (1) regard the voltmeter in the power supply as being accurate; and (2) regard the ammeter in the power supply as *not* being very accurate (because we are not pulling enough current from the power supply to get a good enough result).

Part 2: Test Ohm's Law

In general, we will want to perform measurements on more than just one circuit element (more than just one resistor as we have so far). A simple and fast way to build more extensive circuits without needing to go to the trouble of soldering components together is to use a breadboard. Fig. 7 has two diagrams of a breadboard. By plugging circuit components into different holes of the breadboard, we can establish electrical connections between those components as seen in the right panel of Fig. 7. The electrical connections between the holes of the breadboard are established by metal strips (see the right panel of Fig. 7) and by metal shapes that pinch wires and metal leads (as shown in Fig. 8). Metal conducts electricity very well, whereas the plastic housing of the breadboard and the rubber insulator around wires do not.

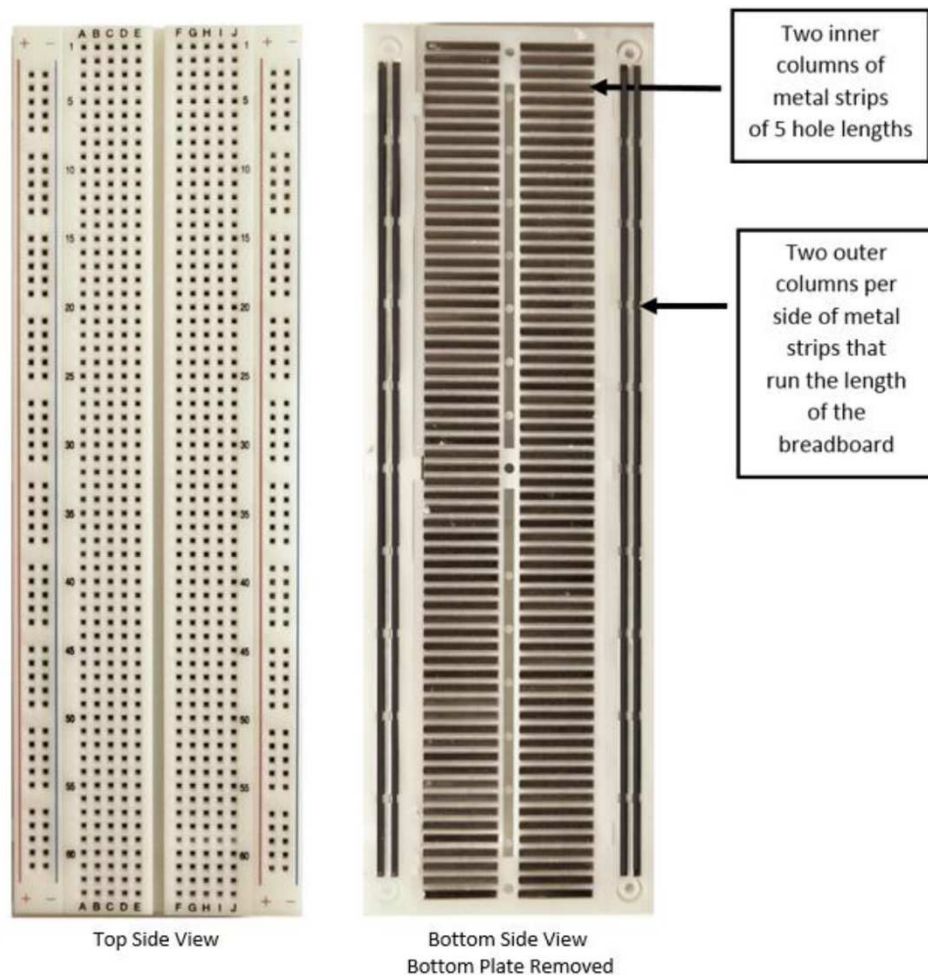


Fig. 7 Top view of a breadboard (left panel). The same breadboard with the internal connections shown (right panel). Metal conducts electricity very well, whereas the plastic housing of the breadboard does not. Courtesy of Seattle University.

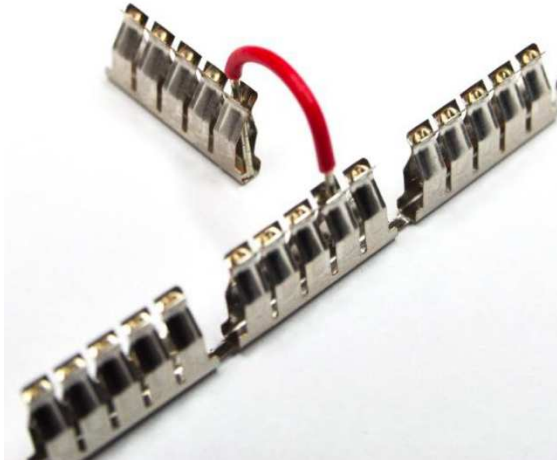


Fig. 8 *The tops of the metal strips are shaped so that they pinch any wire or component lead that is inserted into the holes of the breadboard. Courtesy of Seattle University.*

Let's get some experience with the breadboard.

1. We will now construct the circuit shown in Fig. 5, but this time using your breadboard. To do this, first plug only your 1 k Ω resistor into the breadboard (make sure the two ends of the resistor are *not* electrically connected inside of the breadboard!).
2. Next, it is good practice to use red wires for the + side of your source and black wires for the - side of your source. So, find two red wires and two black wires from your kit.
3. To finish building the circuit in Fig. 5, we will be separately connecting each of the four power supply and multimeter's alligator clips to one of the four wires you just picked out. The other end of each of those four wires will be plugged into the breadboard. Make sure you choose the correct wire color for each of the alligator clips, and then connect the other end of those four wires to the correct places on the breadboard (depending on where you put your resistor).
4. We will be measuring the current, so keep the multimeter working as an ammeter.
5. Now perform 20 different current measurements on your circuit for different combinations of the source voltage and resistor value (i.e. fill in the table below). So, start with the 1 k Ω resistor and then switch out the resistor for other resistors as needed.

Resistance	1V	2V	3V	4V	5V
560 Ω (green, blue, brown)					
1 k Ω (brown, black, red)					

2 k Ω (red, black, red)					
2.2 k Ω (red, red, red)					

Table 1. *Current values for different combinations of the source voltage and resistor value. Don't forget to include units. Also, keep track of your resistors because we'll be using them again.*

6. Create a current vs. voltage plot for all of the resistors using the results you obtained in Table 1 (put all of the results on the same plot, so that you have all 4 lines – one for each resistor – on the same plot). Put a copy of the plot below (take a picture of your hand-drawn plot, or you could probably draw a plot in PowerPoint, MATLAB, or similar as desired).

<paste your plot here>

7. Let's analyze the graph you created. What is the shape of the graph? (It should be linear.)

<fill in and leave highlighted>

8. Find the slope and analyze what the slope means.

<fill in and leave highlighted>

9. In class, ohm's law was given as $V = IR$. Does this graph represent this law?

<fill in and leave highlighted>

Part 3: Nominal vs. Measured vs. Calculated Resistances

We will now compare the nominal, measured, and calculated resistance values for each of the resistors we studied in Part 2. The nominal resistance is the resistance reported on the resistor itself (by the color bands).

1. Switch the multimeter to measure resistance by pressing the " Ω " button.
2. Don't touch the resistors while recording these measurement results, or else your body resistance will effect the reading (although, this is not a big issue for these resistor values). Fill in the "Measured Resistance" column of Table 2.

Nominal Resistance	Measured Resistance	Calculated Resistance
560 Ω		
1 k Ω		

2 k Ω		
2.2 k Ω		

Table 2. Comparison of the nominal, measured, and calculated resistances. Use the same resistors that you used to create Table 1. Don't forget to include units.

- Using Ohm's Law ($V = IR$) and the measured current values in the 5 V column of Table 1, calculate the resistance and fill in the "Calculated Resistance" column of Table 2.
- Comment on the differences between the nominal, measured, and calculated resistances. How do they differ and why?

<fill in and leave highlighted>

Part 4: Test an Equivalent Resistance

- Using your breadboard, the power supply, and the multimeter, build the circuit shown in Fig. 9 having two 1 k Ω resistors in series.

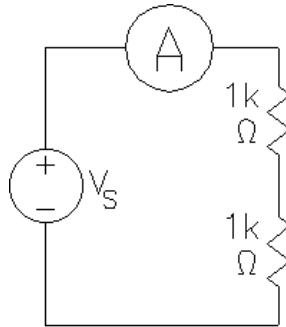


Fig. 9. Circuit with two resistors in series.

- Measure the current flowing through the circuit when 5V is applied. What value do you get?

<fill in and leave highlighted>

- Compare your answer to the values you obtained earlier in Table 1. The current should be remarkably similar to one of the values in Table 1. Which one? Why is it similar? (Consider the equivalent resistance of the circuit you built.)

<fill in and leave highlighted>

- Now build the circuit shown in Fig. 10 with two 2 k Ω resistors in parallel.

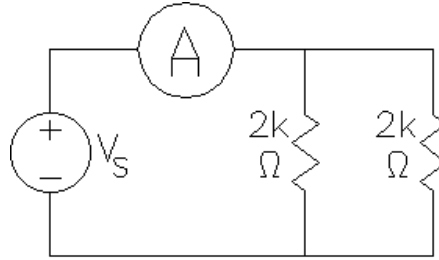


Fig. 10. Circuit with 2 resistors in series.

- Compare your answer to the values you obtained earlier in Table 1. The current should be remarkably similar to one the values in Table 1. Which one? Why is it similar? (Consider the equivalent resistance of the circuit you built.)

<fill in and leave highlighted>

Part 5: Test Kirchoff's Voltage Law

- We discussed Kirchoff's Voltage Law in class. Briefly describe what it is here.

<fill in and leave highlighted>

- What is one simple way that we can test Kirchoff's Voltage Law? Briefly describe your idea here before going on to the next page.

<fill in and leave highlighted>

3. If we build the circuits shown in Figs. 11 and 12 with a voltage source, a multimeter (measuring voltage) and a couple of resistors, we can test whether the total voltage drop across the two resistors is equal to the source voltage (remember, at the end of Part 1 we decided that the voltmeter in the power supply is accurate).

Go ahead and build the circuits shown in Figs. 11 and 12 by placing two resistors (1 k Ω and 2 k Ω) in series with the power supply. Set the power supply to some nominal value, like 5 V. Then measure the voltage across each resistor individually and record your results below.

<fill in and leave highlighted>

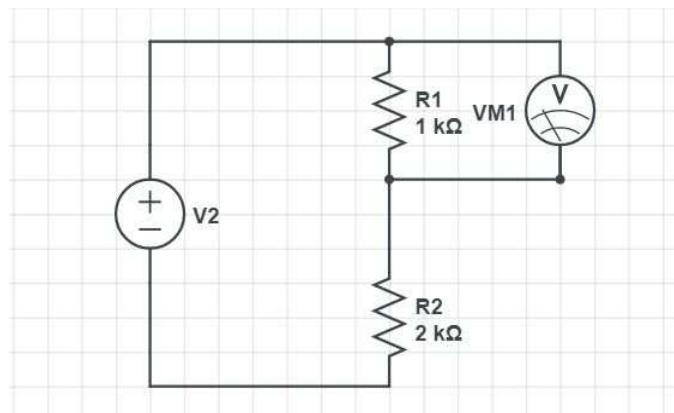


Fig. 11 First circuit for testing Kirchoff's Voltage Law.

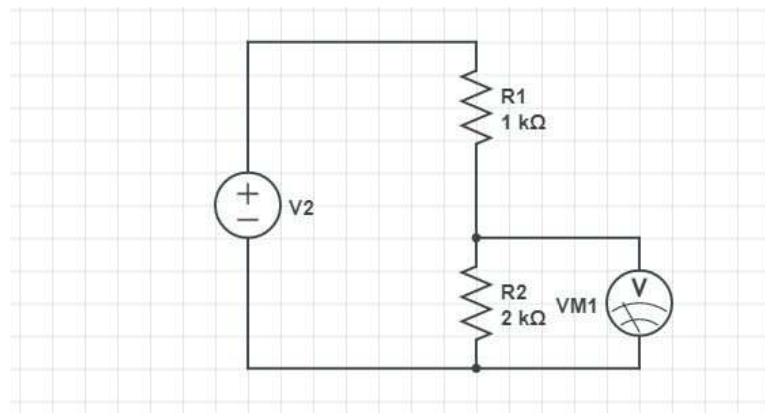


Fig. 12 Second circuit for testing Kirchoff's Voltage Law.

4. Does Kirchoff's Voltage Law stand for this example? How do we know?

<fill in and leave highlighted>

5. Why are the voltages across the two resistors different?

<fill in and leave highlighted>

Part 6: Test Kirchoff's Current Law

1. We discussed Kirchoff's Current Law in class. Briefly describe what it is here.

<fill in and leave highlighted>

2. What is one simple way that we can test Kirchoff's Current Law? Briefly describe your idea here before going on to the next page.

<fill in and leave highlighted>

3. If we build the circuits shown in Figs. 13 - 15 with a voltage source, a multimeter (measuring current) and a couple of resistors, we can test whether the total current from the source is equal to the sum of the currents flowing through the two resistors.

Go ahead and build the circuits shown in Figs. 11 and 12 by placing two resistors (1 k Ω and 2 k Ω) in parallel with the power supply. Set the power supply to some nominal value, like 5 V.

4. Measure the current from the source (using the multimeter, since at the end of Part 1 we decided the ammeter in the voltage source is not accurate) according to the circuit diagram shown in Fig. 13. Also measure the current through each resistor according to the circuit diagrams shown in Figs. 14 – 15. Record your results below.

<fill in and leave highlighted>

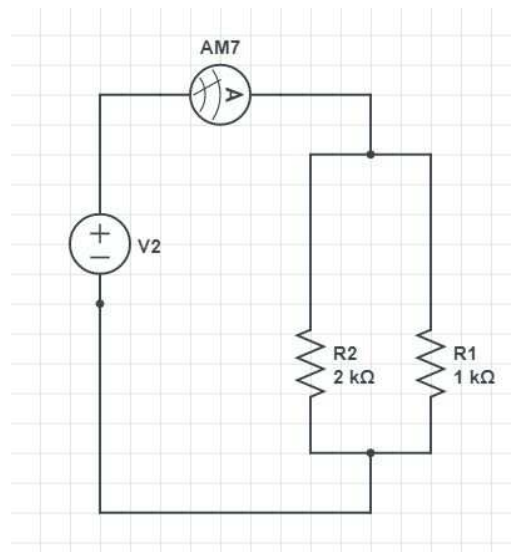


Fig. 13 First circuit for testing Kirchoff's Current Law.

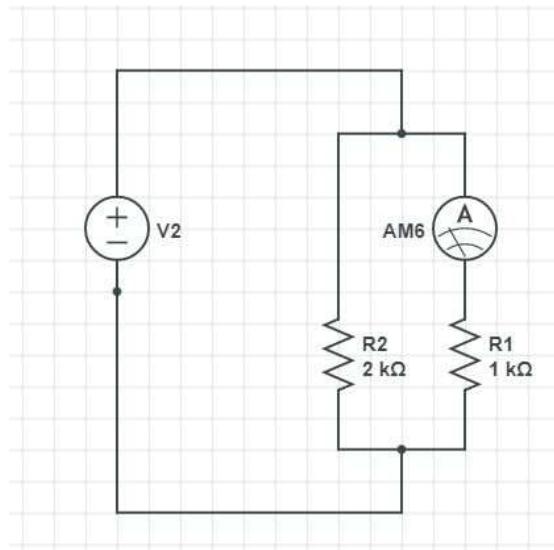


Fig. 14 *Second circuit for testing Kirchoff's Current Law.*

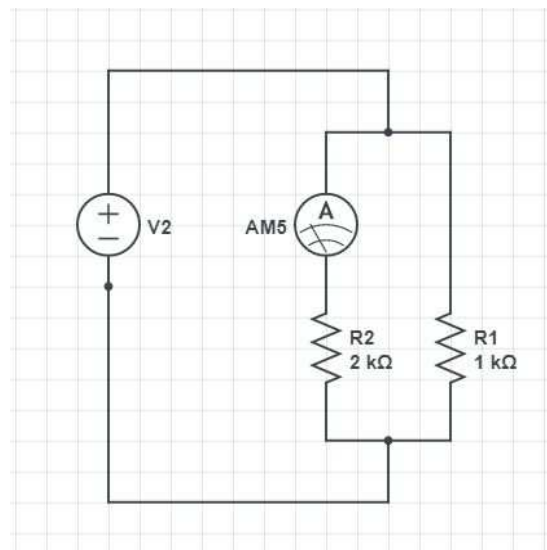


Fig. 15 *Third circuit for testing Kirchoff's Current Law.*

5. Does Kirchoff's Current Law stand for this example? How do we know?

<fill in and leave highlighted>

6. Why are the currents through the two resistors different?

<fill in and leave highlighted>

7. Before you tear down your last circuit and leave the lab today, make sure to have your Lab TA check off your lab by showing what you accomplished and demonstrate that you understand the concepts shown here.

8. Put all of the lab supplies away, including your own lab kit and anything you may have checked out!

9. Turn in this completed report to Canvas.