Lab 2
Electrical Safety, Breadboards, Using a DMM

Objectives

- *concepts*

1. Safety hazards related to household electricity and electronics equipment
2. Differences between schematic and breadboard representations of a circuit
3. Resistor color codes
4. Digital Multimeter principles

- *skills*

1. Practicing safe laboratory procedures
2. Wiring a circuit on a breadboard based on a schematic representation
3. Measuring quantities of resistance, voltage and current
4. Verifying Ohm's Law, Kirchoff's Current Law, and Kirchoff's Voltage Law

Key Prerequisites

- Chapter 1 (Circuit Variables)
- Chapter 2.1-2.4 (Ohms Law, Kirchoff Current and Voltage Laws)

Required Resources

- Circuit Lab Kit
- Digital Multimeter (DMM)

Circuit theory can be very abstract unless it's accompanied by practical applications. In this lab we are going to develop fundamental skills in building and measuring circuit variables in a real circuit.

As you complete the lab, please record your measurements and calculations on the Lab 2 data sheet available online.

Vocabulary

All key vocabulary used in this lab are listed below, with closely related words listed together:

resistor color band, multiplier band, tolerance band
breadboard, power strip
IC, DIP, DIP Mounting channel
DMM, jack, COM, fuse

Discussion and Procedure

Prelab - Inventory your Lab Kit

Before beginning the hardware portion of the class, you should take a few minutes to verify all of the components that were shipped or handed to you in your circuit kit as shown on this packing list and illustrated pictorially here. You can also find a video inventory here. If you find you are missing any items, please contact the instructor immediately.

At the end of each class (and the semester), you should replace all of the components in their correct locations so that you or someone else can locate the items easily next time by referring to the packing list.

Part 1. Electrical Safety

Although the circuits we will be building in this class are all designed to be safe to handle, in a typical laboratory environment you should be aware that electrically powered equipment can pose serious risks to health and safety. Many laboratory electrical devices have high voltage or high power requirements, carrying even more risk. Large capacitors found in many laser flash lamps and other systems are capable of storing lethal amounts of electrical energy and pose a serious danger even if the power source has been disconnected.

Electrical Hazards. Electricity can cause fatal burns or cause vital organs to malfunction. In general, a current of 5 mA or less will cause a sensation of shock, but rarely any damage. Larger currents can cause hand muscles to contract. Currents on the order of 100 mA are often fatal if they pass through the body for even a few seconds. The chart below shows the general relationship between the degree of injury and amount of current for a 60-cycle hand-to-foot path of one second's duration of shock.

Current	**Reaction**
1 Milliampere	Perception level
5 Milliamperes	Slight shock felt; not painful but disturbing

6-30 Milliamperes	Painful shock; "let-go" range
50-150 Milliamperes	Extreme pain, respiratory arrest, severe muscular contraction
1000-4,300 mA	Ventricular fibrillation
10,000+ mA	Cardiac arrest, severe burns and probable death

Table 1. Effects of a range of electrical current passing through the human body

How do the results of table 1 translate into voltages? Is it OK to touch a wire on our breadboard if it has a voltage potential of 12 V? Ohm’s law applies to the human body as well; however, the resistance of the contact point where skin meets wire varies significantly based on the moisture level present and the integrity of the skin. Generally speaking, 50V or lower are safe handling levels (some would argue more and some less) for AC and DC voltages.

However, during your work on these labs you should follow safe electronics practices and *always turn off power to your circuit before building it or modifying the wiring.* This will prevent you from “frying” circuit components as well – many components are less tolerant of moderate voltage levels than humans are. Here are some additional rules.

Electronics Lab Safety Rules.

The following list of rules will prevent injury to yourself or damage to electrical components during your work on your electronics circuits in this class.

1) **Never work on a circuit while power is applied.**

2) **Do not connect power to a circuit until the circuit is finished and you have carefully checked your work.**

3) **If you smell anything burning, immediately disconnect the power and examine your circuit to find out what went wrong.**

4) **Keep your work area dry.**

5) **Always use common sense and pay attention to the task you are working on.**

6) **If at any time you are not sure how to handle a particular situation, ask the instructor for advice. Online students should email a photograph of the circuit for inspection.**

Part 2. Resistor Color Codes

What number is your color? If you've worked with electronics before, you've probably encountered the mysterious color bands encircling most resistors. These bands help us identify the value of resistance without resorting to an ohmmeter. For resistors with four color bands, the first two bands specify the numeric value of the resistance, the third band specifies the multiplier, and the fourth band specifies the tolerance. The resistors we will be working with have a tolerance (accuracy) of 5% and four color bands. Higher precision 1% tolerance resistors have a fifth color band (3 numeric bands) to specify the value more precisely.

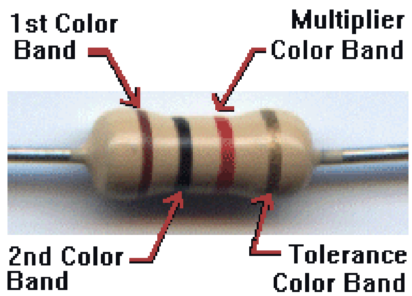


Figure 1. What value resistor is this?

The chart in Figure 1 shows the procedure for decoding resistors with 4 or 5 color bands, while Figure 2 shows some additional information related to the color codes on resistors.

To determine the value of a given resistor look for the gold or silver tolerance band and rotate the resistor as in Figure 1. (Tolerance band to the right). Look at the first color band and determine its color (Brown in Figure 1). This maybe difficult on small or oddly colored resistors. Now look at the chart below and match the color band color to the digit it represents (Brown represents the number 1). Write this number down. Do the same for the second color band. (Black, which represents 0, so we have 10 for the resistor in Figure 1).

The last color band is the number you will multiply the result by. Match the 3rd color band with the chart under multiplier. (Red in Figure 1, which represents 100 or 10^2) This is the number you will multiple the other 2 numbers by. Write it next to the other 2 numbers with a multiplication sign before it. So for the resistor in Figure 1, that would be: 1 0 x 100 or 1000 Ohms or 1 kOhm.

An Easier Trick. Since the multiplier band represents 10 raised the associated color band number for the first two bands, you can also just tack on that number of zeros to the end of the first two digits you came up with. In other words, the color **red signifies 2** for the first two color bands. So just **put two zeros** after the first two digits you decoded.

Find the Range. Resistors are never manufactured to exact values—it would be too expensive. Instead, the manufacturer guarantees that a resistor value will fall within the tolerance range specified by the last band. A resistor with a gold band for the tolerance will be guaranteed to fall within +/- 5% of the nominal value. So for our example resistor in Figure 1, which has a nominal value of 1000 Ohms, the actual value could be within 5% or 1000*(5/100) = 50 Ohms of that. Therefore the true value of the resistor should be somewhere between 950 and 1050 Ohms.

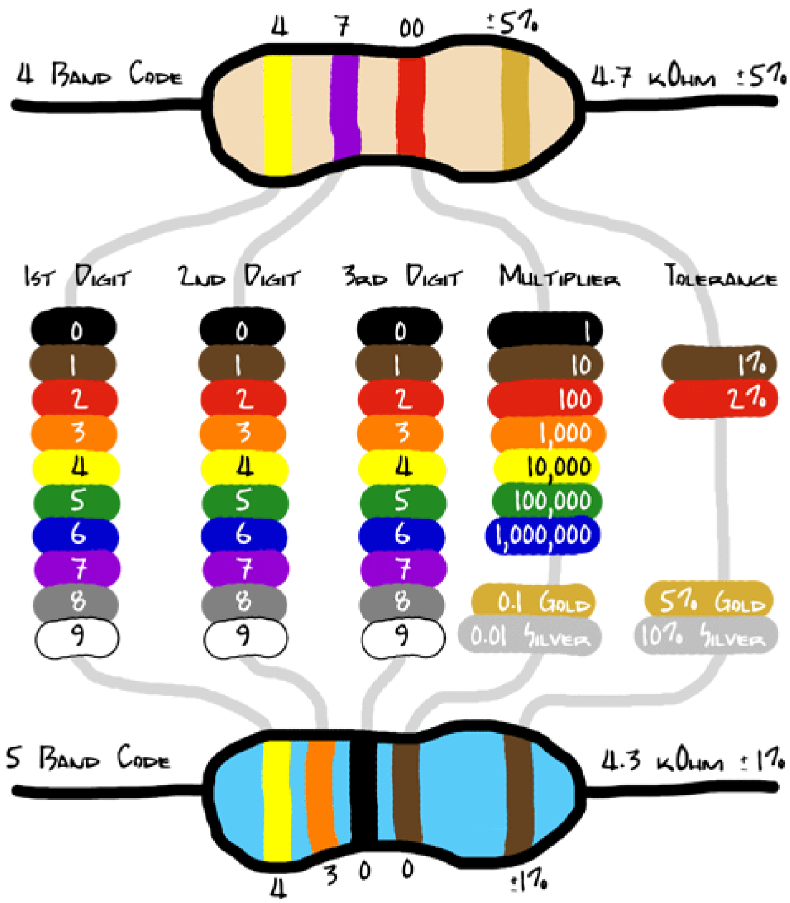


Figure 1. Decoding a resistor's color code, from http://www.ohmslawcalculator.com

The standard resistor color code table:

Color	Digit 1	Digit 2	Digit 3*	Multiplier	Tolerance	Temp. Coef.	Fail Rate
Black	0	0	0	$\times 10^0$			
Brown	1	1	1	$\times 10^1$	±1% (F)	100 ppm/K	1%
Red	2	2	2	$\times 10^2$	±2% (G)	50 ppm/K	0.1%
Orange	3	3	3	$\times 10^3$		15 ppm/K	0.01%
Yellow	4	4	4	$\times 10^4$		25 ppm/K	0.001%
Green	5	5	5	$\times 10^5$	±0.5% (D)		
Blue	6	6	6	$\times 10^6$	±0.25% (C)		
Violet	7	7	7	$\times 10^7$	±0.1% (B)		
Gray	8	8	8	$\times 10^8$	±0.05% (A)		
White	9	9	9	$\times 10^9$			
Gold				$\times 0.1$	±5% (J)		
Silver				$\times 0.01$	±10% (K)		
None					±20% (M)		

** 3rd digit - only for 5-band resistors*

Figure 2. From http://www.hobby-hour.com/electronics/resistorcolorcode.gif`

1. To make sure you understand the use of resistor color codes**, please complete Table 1 on your datasheet** by identifying the numeric values and color codes for the given resistors.

HINT: Given the nominal value and tolerance of a resistor, the formula for finding the min and max values of its range are

$$\text{min value} = \text{nominal} \times \left(1 - \frac{[\text{tolerance, in }\%]}{100}\right)$$

$$\text{max value} = \text{nominal} \times \left(1 + \frac{[\text{tolerance, in }\%]}{100}\right)$$

Part 3. Breadboards

Quick and easy prototyping. Breadboards are ubiquitous in electronics design, and being able to construct circuits on a breadboard is a key learning outcome of this class. The use of breadboards—originally, wooden boards used to hold bread—in electronics goes almost all the way back to the beginning of electrical experimentation. Modern breadboards are plastic tablets that provide rows of holes connected underneath with metal clips, as this video illustrates.

Breadboards provide a quick and easy way to build circuits for verifying circuit principles or proving a design idea. Circuits built on them can easily be rearranged, extended, and disassembled very rapidly—without the messiness, tedium and safety issues of soldering (attaching wires with drops of molten metal).

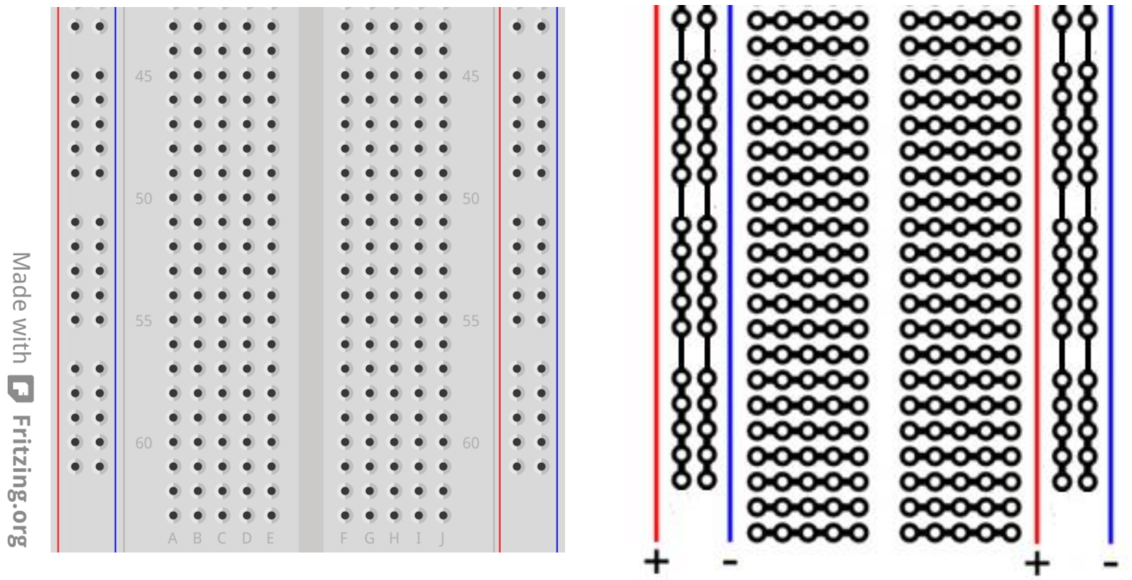


Figure 3. (a) Physical and (b) Electrical view of a section of a breadboard

Figure 3 shows a portion of a larger breadboard, both the way it looks in reality and how the holes are connected underneath. The basic principle of breadboard use is that whenever you wish to connect two components together, say a wire and one end of a resistor, the two leads should be inserted into two holes that are electrically connected.

Connecting two components. For example, to connect a wire to a resistor as shown in Figure 4, you would insert the wire and the resistor into the same 5-pin row of the breadboard, as follows:

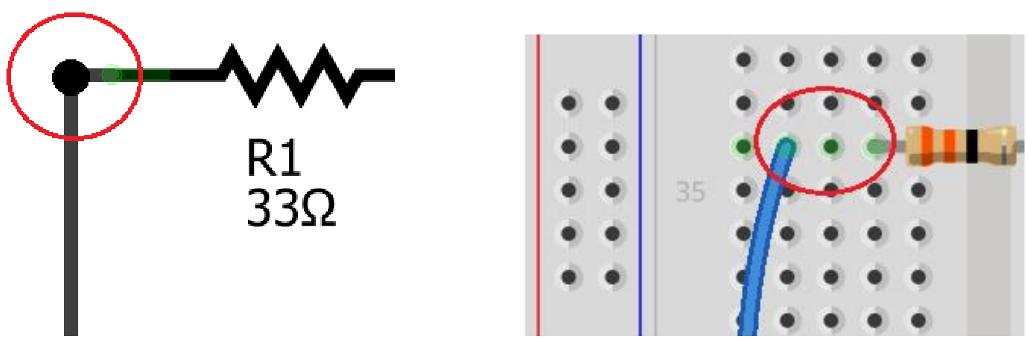


Figure 4. Connecting a wire to a resistor: a) schematic view, b) breadboard view

Power strips. The two vertical columns of pins on either side of the main area are reserved for source voltages and ground connections. These columns are available along the entire length of the board, since power and ground often need to be accessed at many points in a circuit.

Figure 5 shows a typical breadboard with +12 and -12V power supplies connected and two ground lines. The source voltages could come from a battery, an AC-DC adapter, or a bench supply.

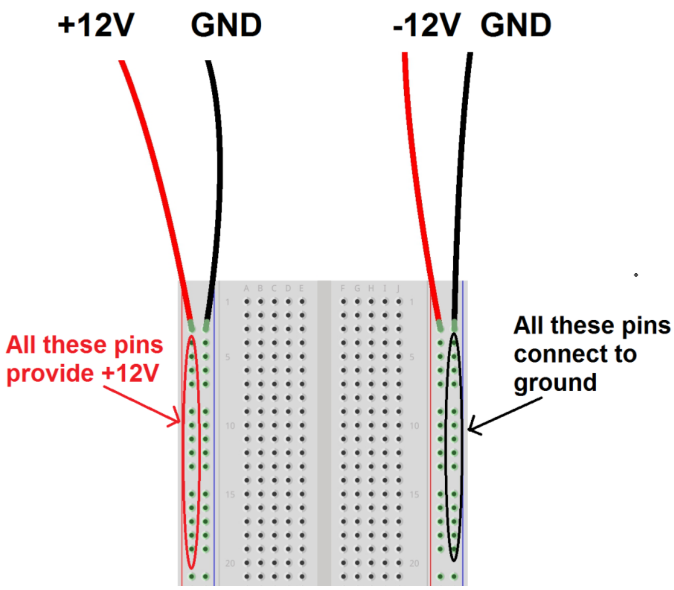


Figure 5. Breadboard with power strips connected to +12, -12 and Ground

DIP Mounting Channel. Many Integrated Circuits (ICs) such as Op-Amps and logic gates are fabricated in a Dual In-Line Package (DIP) form, which means they have two lines of pins separated by a gap to allow plugging into the central channel of the breadboard. Since the two sides of the breadboard are isolated, IC DIPs can be easily wired into power, ground, and the rest of the circuit. Figure 6 shows a sample breadboard with two ICs mounted and wired for power and ground.

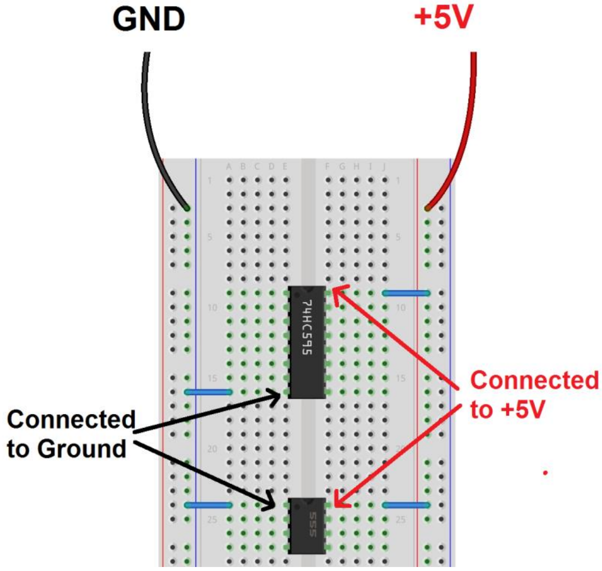
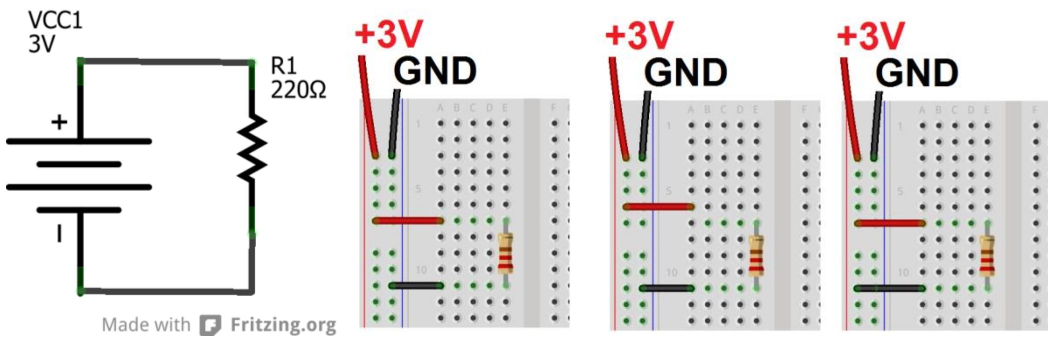


Figure 6. Breadboard with two IC DIPs mounted and wired for power

Breadboard Quiz. You may have guessed that there are many ways to wire a given circuit on a breadboard. Now you can test your understanding of how breadboards work. Please complete the following quiz questions working with your lab partner.

2. Given the schematic for a circuit we are trying to build, two of the breadboards that follow have an error. Only one is correct. Which of the following is correct? Enter your answer on the datasheet.

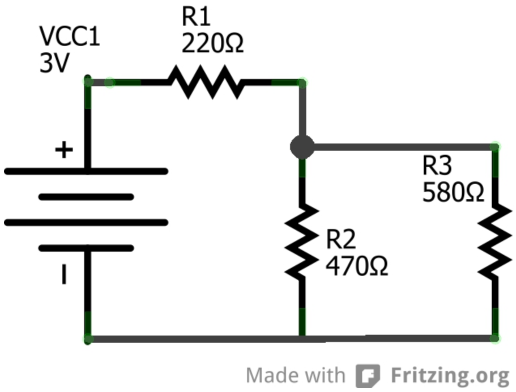
   Schematic:

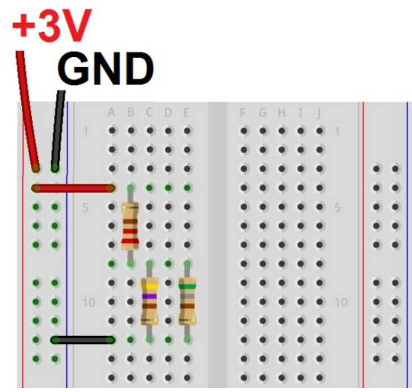


(a) (b) (c)

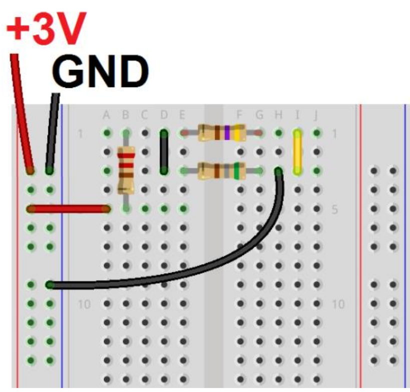
   If you guessed (a) you are right! Breadboard (b) has a broken circuit—the top of the resistor is plugged into a different row than the horizontal red wire bringing +3V across, so it does not make a connection. Breadboard (c) connects both ends of the resistor to +3V, so there is no potential drop across the resistor.

3. Here is a more complicated circuit. In the three breadboards that follow, two of them work, but one has an error. Find the the error and enter on datasheet.

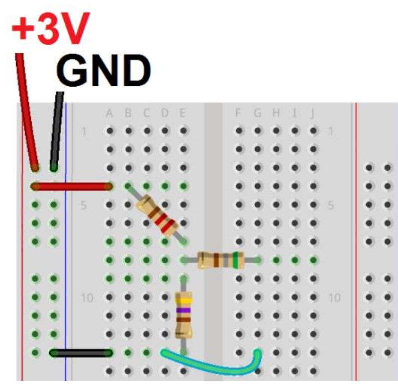




(a)



(b)



(c)

Part 4. Basic Circuit Measurements

This section must be worked in the lab with the lab kit. Record results in your data sheet

Familiarize yourself with the equipment. A digital multimeter (DMM) is one of the most important tools for an electrical engineer. Depending on the model and the specifications, a DMM can be used to measure parameters like voltage, current, resistance, capacitance, temperature, etc. The DMM used in this laboratory is the

EQUUS Innova 3320

There are three input jacks located at the bottom of each DMM. The jack in the center is labeled COM (for Common) and is used in all measurements. The rightmost jack and the leftmost jack are used for different measurements, depending on the meter. **Be careful to connect the red probe to the correct jack for the measurement you are performing, or you could damage the meter.**

Each meter has measurement limits in voltage and current **beyond which the meter will be damaged**. For the EQUUS Innova 3320, the maximum voltage is 600V and the maximum current is either 200 mA, when the red probe is plugged into the rightmost jack, or 10 A when the red probe is plugged into the leftmost jack.

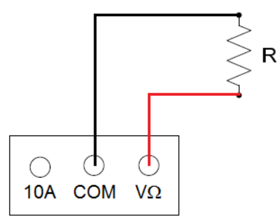
Measuring Resistance. Let's begin by using the DMM to measure the resistance of several resistors in your kit. Please complete **Table 2** below by following these steps:

1) From your kit, find the 3 resistors listed in the table based on their color code.

2) Based on each resistor's tolerance (they should all be 5% tolerance), determine the min and max resistance values they may attain and still be considered "within specification" (see formula on page 6) and enter these values into the table.

3) Measure the resistors with your DMM Ohmmeter and determine whether or not they are within specification. To measure resistance, the DMM selector should be pointing at the large Ω symbol on the dial.

   The following diagram shows the electrical connection you will make between your DMM and the resistor. Keep in mind that if your fingers are touching the leads you may distort the resistance measurement. You may find it easier to plug the resistor across two rows in your breadboard so you can connect the leads without touching them.



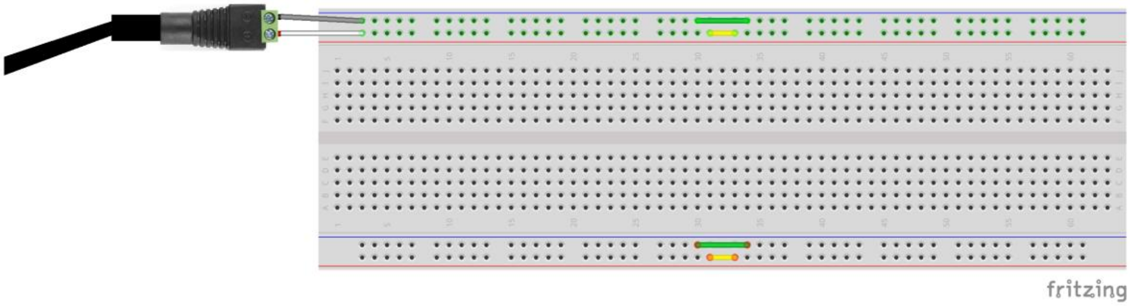
4) Complete Table 2 on the datasheet and use your measurements to determine whether or not each resistor is within specification.

Powering up the Breadboard. The lab components kit comes with two special adapters that will allow you to connect the 12V wall adapters to screw terminals and wires leading to the breadboard. When properly set up with grey and white wires, they look like this:

Note that the black wire should be wired to the (-) post and the white wire to the (+) post. Once configured, plug in a wall adapter and confirm you are getting about 12V at the wire leads (actually, it should be a little larger than 12V) with the voltmeter switched to DCV.

When you plug a power supply into the barrel jack, a voltage potential of +12V will extend along the red horizontal line marking the top “power strip” of the breadboard. Ground (0V potential) will run along the row marked with a blue line.

The breadboard also has four short jumper wires bridging the gaps on the power strip lines in the center, where there is a break in the connection. This ensures that power and ground extend all the way across the board. Make sure your breadboard looks like the following, making sure to add the short jumper wires in the middle of the board. Leave the wall adapter unplugged while you construct the rest of the circuit.



Measuring Voltage. We’ll now use the DMM to measure voltage in a simple circuit involving one voltage source and two resistors as shown below in Figure 7 in both schematic and breadboard form. Note the differences between the two representations of the same circuit.

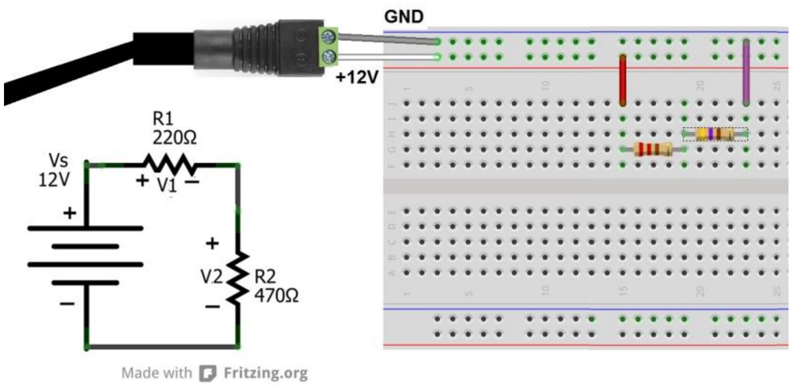


Figure 7. Circuit for Voltage Measurement Experiment –
a) schematic, b) breadboard implementation

Add the 220 and 470 Ω resistors to the breadboard with short wires as shown in the figure. Once the circuit has been constructed, connect the 12V DC Wall adapter to apply power to your circuit. To measure Voltage, switch the DMM to the DC Volts ($\overline{\mathbf{V}}$) position. Touch the VΩ probe to an exposed wire on the + side of the desired voltage quantity and the COM probe to an exposed wire on the – side, as shown in Figure 10 for Vs and V1.

The alligator clip probes can help in attaching the DMM leads to your circuit. It can also be helpful to connect a small wire to the end of an alligator clip to probe into the breadboard at the desired point.

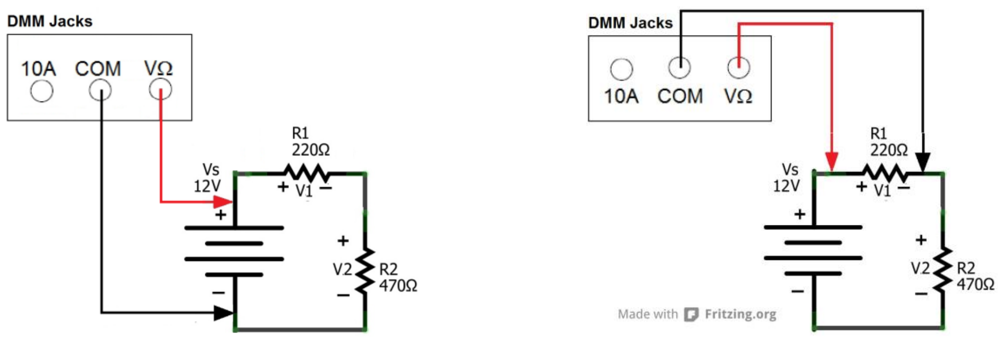


Figure 10. Voltage Measurement of Vs and V1

Record your measurments for Vs, V1, and V2 in Table 3 on the Lab 2 Datasheet, then Verify Kirchoff's Voltage law by computing –Vs + V1 + V2. If the answer is not very close to zero, go back and redo your measurements for the three voltages—you may have connected the DMM probe to the opposite terminals for one or more voltages, creating a sign error.

Measuring Current. Finally, we'll use the DMM to measure current in a slightly more complicated circuit. First, modify your circuit as shown in the diagrams below by adding a 1000 Ω resistor in parallel to the 470 Ω resistor, as shown in Figure 11.

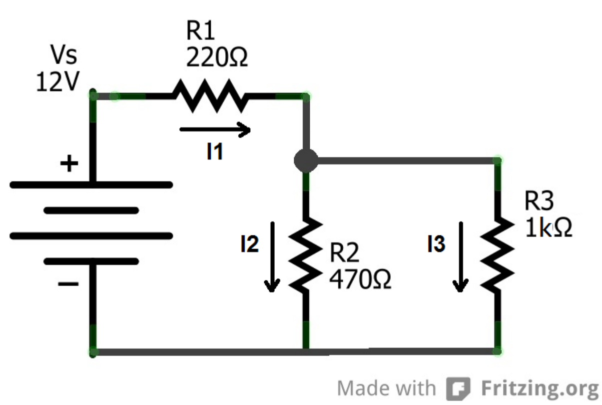


Figure 11. Adding a 1 kΩ Resistor to the circuit

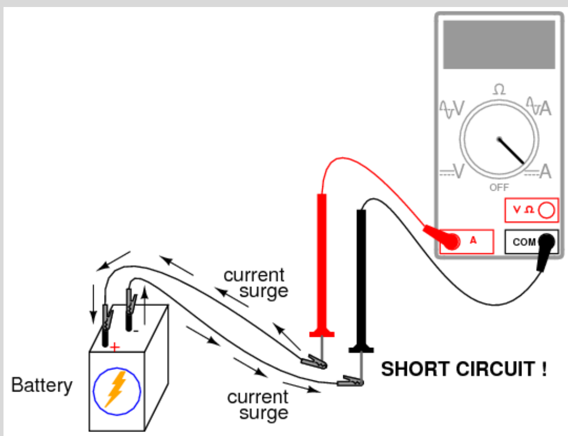
Measuring current is different from measuring voltage or resistance. In measuring voltages from the last step, we connected the meter ***in parallel*** to the component or voltage potential we wish to measure. That means we connect one probe to one node and the other probe to a second node.

This kind of parallel connection will damage or at the very least, blow a fuse in your DMM or circuit when measuring currents.

WARNING

Never connect a DMM in ammeter mode across a resistor or voltage source. Since the ammeter acts like a short circuit, this connection would damage the meter or possibly blow a fuse that would need to be replaced.

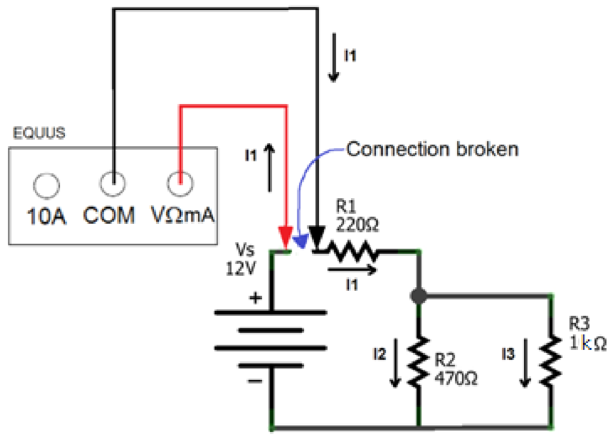
AVOID THIS CONNECTION in AMMETER MODE



For measuring current, we must connect the meter ***in series*** along the branch we are measuring current in. We have to break the circuit and allow the current to pass through the meter, flowing into the A probe and out of the COM probe.

CORRECT WAY TO MEASURE CURRENT

Using EQUUS meter



For many meters you also must move the probe from the VΩ jack to the A jack, and switch the DMM to DC Amps. The EQUUS meter has a uses a 10A jac as well for measuring high current, but the regular VΩmA jack allows measurement of currents to 200 mA, more than ample for this class.

This means you never have to switch probe jacks when working with the EQUUS meter, just leave the red probe connected to the VΩmA jack and turn the selector switch to DC milliAmps (DCmĀ).

1) Take the EQUUS DMM and connect the red probe to the VΩmA jack and the black probe to the COM jack
2) Switch the DMM to DC milliAmps (DCmĀ).
3) To measure I1, remove the horizontal red wire connecting 12V to R1 at the top of the breadboard and touch the red DMM probe to the Vs 12V wire as it goes into the breadboard (push the probe into the depression surrounding the wire hole). Then touch the black probe to the R1 resistor lead so current can flow out of the meter into the circuit, as shown below.
4) To get the correct sign on the current measurement, make sure the current you are trying to determine is flowing INTO the red probe and out of the black probe.

Complete the Table of Current Measurements. To measure I2 and I3 you will need to put the wire back that you removed to measure I1. Then measure R2 and R3 in similar fashion. To break the circuit for R2 you might try lifting one wire of the resistor out of the breadboard, then connect the DMM from that wire to the point it was removed from. You can also reposition the resistor wire to another row and complete the circuit through your DMM Ammeter.

Finally, verify Kirchoff's Current Law by computing the sum I1 – I2 – I3. If the answer is not close to zero, go back and remeasure the three currents, making sure you connected the probes in the correct orientation (Hint: all three currents should be positive given the way they are labelled on the circuit).

DMM Tips

1. **Always power the circuit down before measuring resistance with a DMM**
2. **To measure resistance for a single component embedded in a larger circuit, remove one wire to the rest of the circuit; otherwise, parallel current paths my provide an incorrect reading.**
3. **Voltage measurements are made in <u>parallel</u> to the component(s) measured.**
4. **Current measurements are made in <u>series</u> and always require breaking the circuit to insert the meter into the current path. You may also need to move the red jack from VΩ to A (depending on meter).**

Challenge Problem: Leaving your last circuit in place (re-insert the resistor you removed to do current measurement), create a second identical circuit on the right side of the breadboard with the only difference being the layout of the second circuit – it should visually look as different from the first circuit as possible, while still exhibiting the same voltage drop across R1 and R2 as the original circuit. Extra points if you can make a "letter" or "face" or other recognizable figure and still have the circuit work as before. Document your work with a photo inserted into your datasheet where indicated.

Online students, please either schedule a lab checkoff with the instructor online, or make a video lab demo with your lab partner appearing on skype. The tool Screencast-O-Maticis perfect for this. Post the video to YouTube and insert a link into your lab datasheet. Only submit one lab datasheet per team, making sure both team member names are in the datasheet.

Workstation Cleanup: Turn off the DMM, turn off power to your circuit, put all wires and components back in their bins, return circuit kits to the cart and upload your datasheet to the mpconline lab 2 submission site.