

EXPERIMENT #2: DC Circuits and Tools

Laboratory Outline

In today's lab we'll begin developing the fundamental knowledge and skills you'll need to conduct basic experiments. You will learn much about the terminology, tools, and basic laws that govern circuits in an electrical engineering laboratory.

We will discuss specific equipment found in the ECE 110 Lab. Keep in mind that while each piece of equipment can come in different shapes and forms based on the manufacturer and the model number, the basic principle of operation remains the same. The next few lab meetings will continue to build your skillset on these specific models in a way in which you can easily utilize other models in later labs. With the skill to use this equipment, you will be ready to analyze the behavior of electronic components and use those components to build interesting circuits such as those required of autonomous vehicles!

In lecture, we will generally assume that bench equipment are ideal devices. Sources will provide whatever voltage and current is demanded of it and measuring devices will not affect the characteristics of the circuit in which it is embedded. In lab you will investigate what happens when other devices are used in circuits for which the ideal-device assumption applies. For example, motors might demand more current than the power supply or batteries can supply thus exposing non-ideal behavior.

*Please use the **Notes** margin on the right for both notes to yourself about the experiment as well as for feedback to your TA on the quality or clarity of the lab procedure. Thanks!*

Learning Objectives

- Identify the features of a voltage source and configure one for DC experimentation.
- Identify the features of a voltmeter and utilize one properly for DC measurements.
- Identify the features of an ohmmeter and utilize one properly for resistive measurements.
- Identify the features of an ammeter and utilize one properly for DC measurements.
- Use data measured in the lab (empirical data) to validate nominal resistor labels and tolerances.
- To complete the objective of an **Explore More! Module** self-selected by the student.

Name/NetID:

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Section AB/BB:

0	1	2	3	4	5	6	7
8	9	A	B	C	D	E	F

(circle one)

The Power Supply as an Ideal Voltage Source

It is important that you become familiar with both the physical diagrams and the more-abstract circuit schematics and recognize the one-to-one relationship between them. **Figure 1** introduces the symbols used for the ideal voltage source. While physical representations are often used in training, professionals will use the more-succinct circuit schematic.

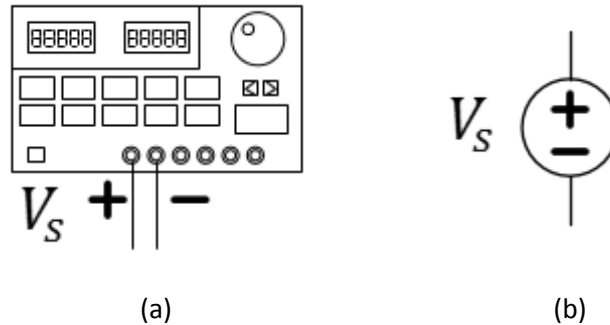


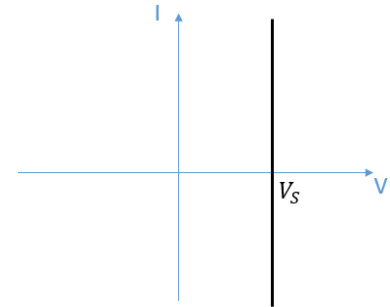
Figure 1: Circuit symbol of (a) a physical symbol of model HP3631A and of (b) an ideal voltage source.

An **ideal voltage source** provides a constant voltage no matter what circuit is connected between its terminals and no matter how much current is drawn from it. Unfortunately, cost and physical limitations make this impossible in practice. However, a great deal of the circuitry inside the DC power supply is dedicated to approximating an ideal device over a very wide range of voltages and a very wide range of load resistances. As you learn more about loads and how they affect the current drawn from a source, you will gain a better understanding of the difficulties.

The Multimeter as an Ideal Measuring Device

In ECE110, we will use a *digital multimeter (DMM)* model HP34401A to measure voltage (**voltmeter**), current (**ammeter**), and resistance (**ohmmeter**). **Figure 2** introduces the symbols used for the ideal measuring device in each of these modes. Note that the polarity of the physical symbols is suggested by the terminal names (COM means “common”. It is akin to “ground”, “negative”, or the pointy end of the current arrow).

Notes:



The ideal voltage source can provide any current asked of it without affecting the supplied voltage. This is demonstrated by the current-voltage (IV) curve above. The IV operating point of an ideal voltage source must fall on this vertical line.

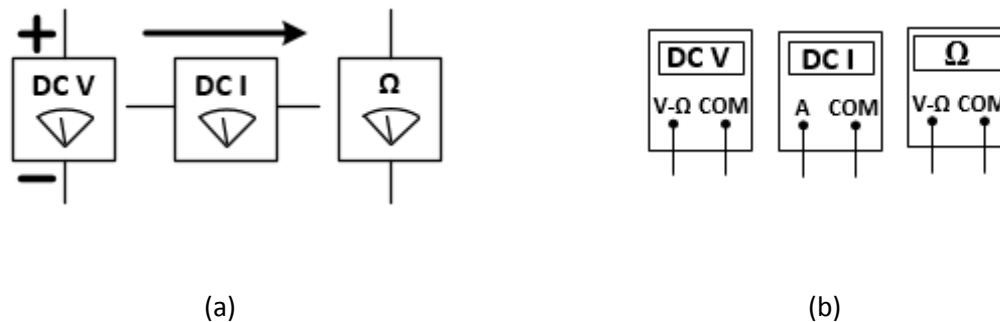


Figure 2: Circuit symbols (a) and physical symbols (b) of the digital multimeter used in three modes: voltmeter, ammeter, ohmmeter, respectively.

Measurement devices are not considered essential elements in most final circuit designs. Except in the academic setting, *a circuit schematic rarely expresses the locations of the measurement devices* but, rather, use labels to indicate which voltages and currents are to be measured. **Figure 3** demonstrates this with the common use of the + and – symbols to represent the direction of polarity in which to measure the voltage and the → symbol to represent the polarity of current. In simple terms, **polarity** refers to the location at which the positive and negative terminals of the measuring device are assumed to be placed. The positive terminal corresponds to the + side of the voltage measurement. The positive terminal corresponds to the base of the arrow (not the pointy side) for a current measurement.

Although the color of the insulation on our wires does not affect their electrical properties, it is standard procedure to use black wires when connecting to the negative side of a voltage source or measuring device and to use red wires when connecting to the positive side of a voltage source or measuring device. Maintaining a “standard” or a “convention” in your selection of wires will make you less prone to error when building a circuit and others less prone to mistakes when interpreting your circuit.

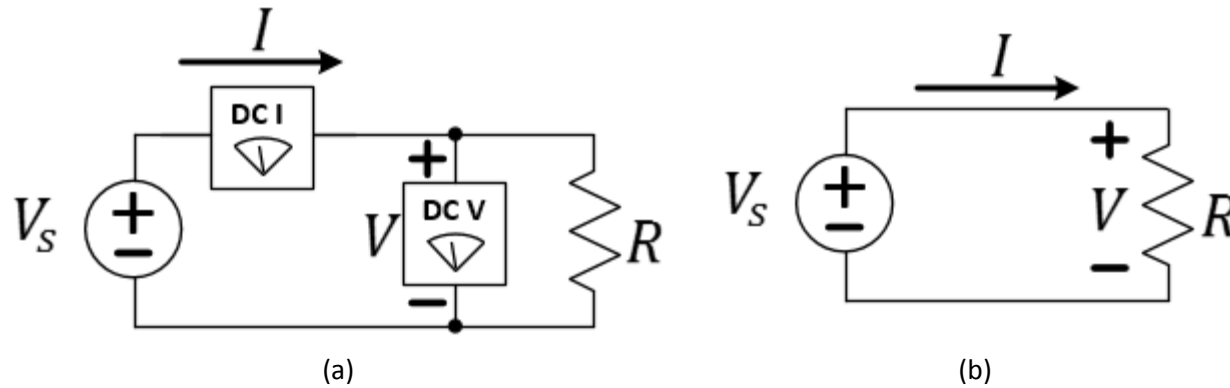


Figure 3: Explicit location of voltmeter and ammeters in a circuit schematic (a) and the typical *implied* expression (b). In the latter, a voltmeter is implied to probe the voltage V and an ammeter is to be inserted to measure the current I according to the polarities indicated by the \pm and the arrow, respectively.

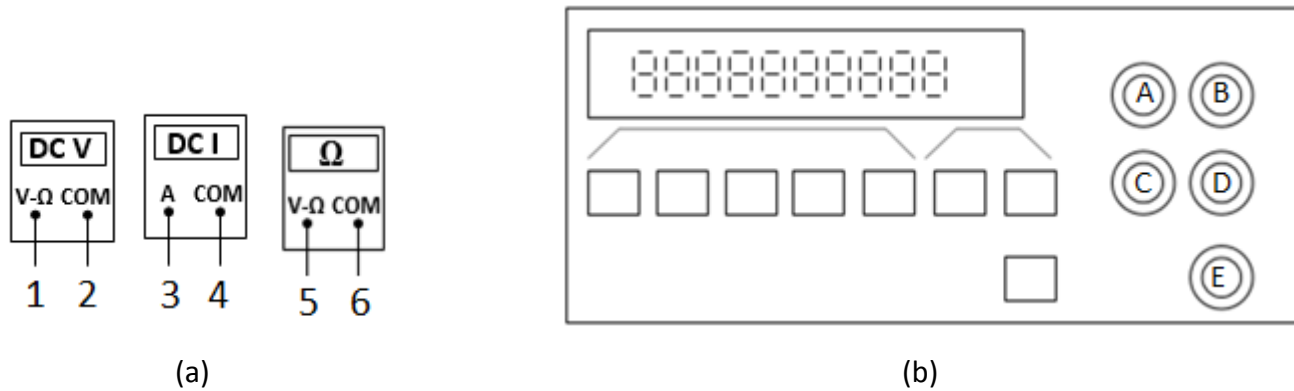


Figure 4: Common multimeter symbols (a) and the HP34401A multimeter (b). The alpha-numeric labels are provided for the following question.

Question 1: Find the HP34401A multimeter on your bench. Use the labels of **Figure 4** above and match the terminals 1-6 of the common multimeter symbols with the five labeled ports of the HP34401A multimeter. The first two have been done for you. You may need to discuss with other lab groups to make sure you know which ports they are! Hint: some terminals may be repeated, and we will not use ports A or C.

Multimeter port	HP34401A port
1	B
2	D
3	
4	
5	
6	

Table 1: Matching game. Match the common multimeter port symbols to the ports on the HP34401A multimeter.

An **ideal measuring device** is a piece of equipment that estimates circuit parameters such as voltage, current, resistance, capacitance without changing the circuit characteristics in any way. This is also very difficult to accomplish for a wide variety of circuits and there will be times in which we must decide if the assumption is appropriate.

Procedures

The DC Power Supply

The power supply, as the name suggests, delivers electrical power (alternately, we say it delivers **energy** when we consider that it delivers *power for some amount of time*). You will be using the HP3631A to maintain a constant voltage for any circuit connected between the terminals. It is up to you to “dial in” the desired voltage level.

We know this is not really an ideal source. If you connect a wire from the positive to the negative terminal what do you think will happen? Poof! The power source delivers more power than the load can absorb without damage (something will melt)! Luckily our devices use fuses. Fuses provide a weak point in the load that is designed to fail first. Always think before you apply the power to your circuit, but don't worry if your TA will have to change the fuses. Mistakes will happen so feel free to get comfortable with the equipment and explore!

Let's set up the power supply to output 5V. The steps are listed below as well as illustrated in **Figure** below.

- ✓ **Turn on the power supply** with nothing attached to it (this way, we will have an opportunity to check our circuit for errors before adding power).
- ✓ Toggle the Output On/Off button to **turn on the Output** (the display reads 'Output Off' when it is off). It will now display two numbers indicating the voltage (on the left) and current (on the right).
- ✓ **Push the button labeled +6V** to allow the device to deliver at most 6 volts but at potentially large currents. You will use the pair of black and red terminals labeled +6V. See Figure 5.
- ✓ Now you can use the knob to **raise the voltage to 5 V**. The arrow buttons and voltage/current button below the knob change which digits on the display the knob controls. Make certain that you are varying the voltage and not the current. The Voltage/Current button toggles between the two options.
- ✓ Do not connect the DMM yet (leave the other ends of the red and black wires unconnected).
- ✓ We call this an **open circuit**. Play with the controls of the power supply until you are comfortable setting the device to any voltage and then return it to 5 volts.

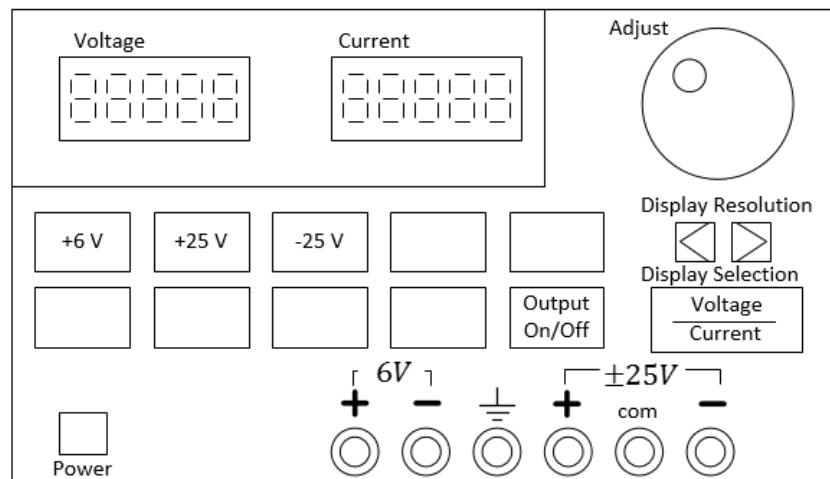


Figure 5: Configuration of the power supply when providing a voltage to a circuit.

Notes:

Comment: The display on the device shows two numbers. The number on the left indicates the voltage setting and reads 5.00 V because you set the power supply to output 5V, but the number on the right reads 0.00 A - WHY? Because it is presumed to be an open circuit! For an open circuit, $R = \infty$ and Ohm's Law for an *open circuit* implies that current must be zero. Note that voltage is not zero for an open circuit. For example, a 9-V battery has 9 volts across it even as it remains in the package at the store!

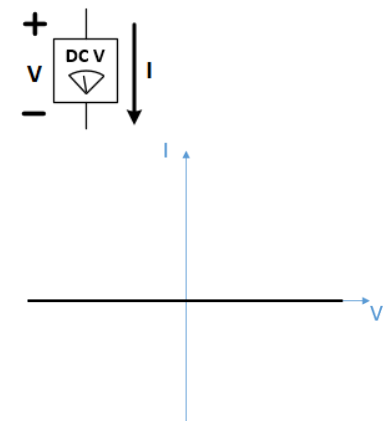
Question 2: Any power supply is power-limited (no matter what the setting, the device has an upper limit to the power it can deliver). Knowing that power is the product of voltage and current ($P = VI$), which voltage setting, +5V or +12V, would you suspect to be capable of delivering a higher current to a load? Explain.

The Digital Multimeter

Voltmeter

Now, setup the DMM to probe the voltage delivered by the power supply. To **probe** means *to take a measurement without disassembling a circuit*. To have minimal effect on the circuit's un-probed characteristics, the probing instrument should have a large resistance to current flow. From the circuit's point of view, a large resistance to current flow is very much like the air around it! The ideal voltmeter should carry no current regardless of how much voltage it measures.

- ✓ Probe the voltage from the power supply with the multimeter configured to measure VOLTAGE using the red and black "banana-plug" cables.
- ✓ Press the leftmost button labeled **DC V** on the DMM to ensure that it will measure voltage.



The ideal voltmeter carries no current regardless of the voltage it measures.

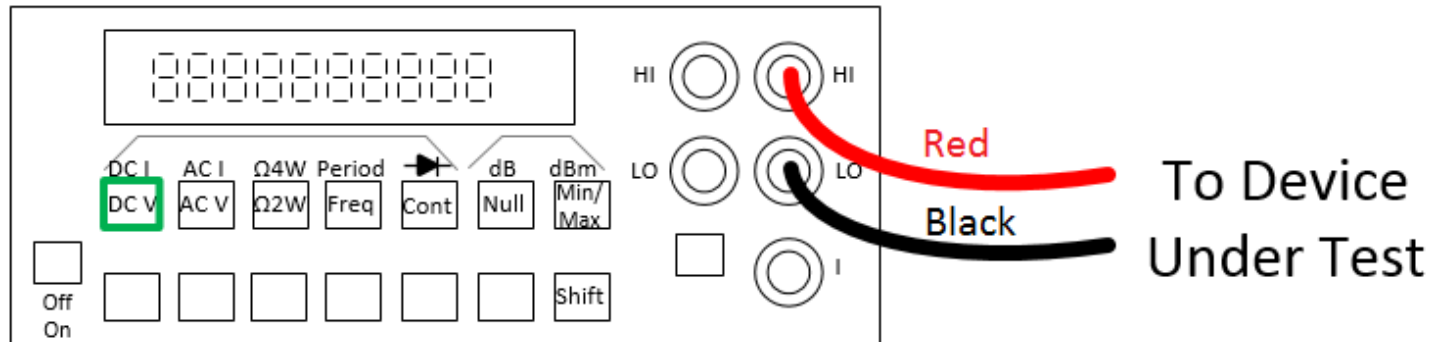


Figure 6: Configuration to measure DC voltage. In this case, the “device under test” is the power supply.

Question 3: With the DMM connected to our “*device under test*” (a.k.a. **DUT**, the power supply in this case) you have now constructed a simple circuit. Let's draw the circuit schematic. It consists of only two components. Use the *circuit symbols* for the ideal voltage source and ideal voltmeter found earlier in this lab and draw them connected with wires labeled “red” and “black” to complete the schematic.

Modeling Devices

But does the DMM really implement an *ideal* voltmeter? Let's try a basic experiment.

Question 4: With the DMM connected to the power supply, turn the knob on the power supply to change the voltage. For the supply voltage range of 0 to 6 V does the current's value remain less than a few milliamps? Why?

Question 5: Does the voltmeter provide a low, a moderate, or a high resistance to current flow? Explain.

Question 6: Do you think that the DMM could be modelled as an ideal voltmeter? Why or why not? Consider that a model is “adequate” if the model does not conflict significantly with the devices operation under “typical” usage.

Comparing Measurement Devices

The DC power supply also displays the voltage it is currently supplying to the user. Let’s now experiment to see if this agrees with the measurement provided by the DMM.

- ✓ Observe the voltage as displayed by the multimeter and power supply.
- ✓ Spin the dial to change the voltage from its minimum value 0 V to the maximum of 6 V.
- ✓ The multimeter measures the voltage delivered by the HP3631A so the voltages should be the same.

Question 7: To how many **significant figures** across the full range of voltages 0-6 V do the two readings match?

Ohmmeter

In your kit you should find several resistors with different values. Let's start with learning how to determine the resistance of these devices.

- ✓ Press the **Cont** button instead of the DC V button you used to measure the voltage. “Cont” stands for **continuity** (a check against an open circuit).
- ✓ Plug a red and black cable into the multimeter in the $V - \Omega$ and LO ports, respectively.

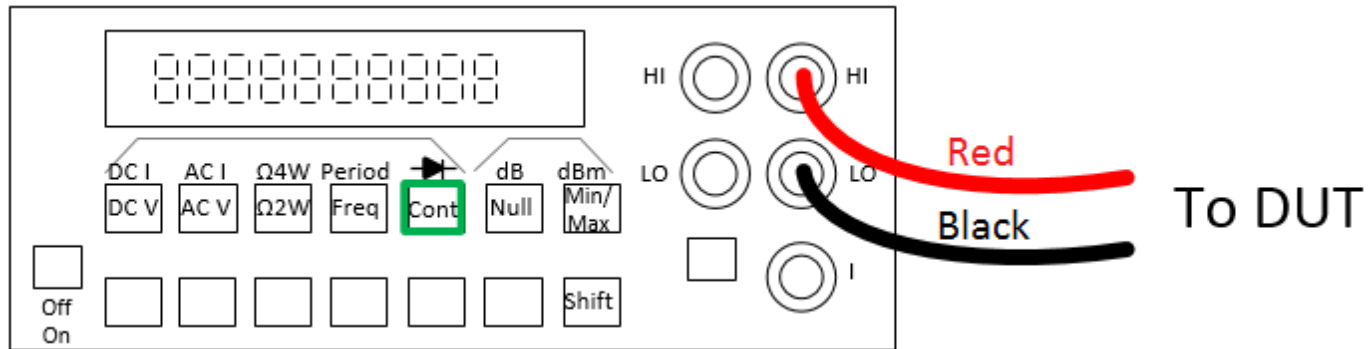


Figure 7: Configuration to measure continuity.

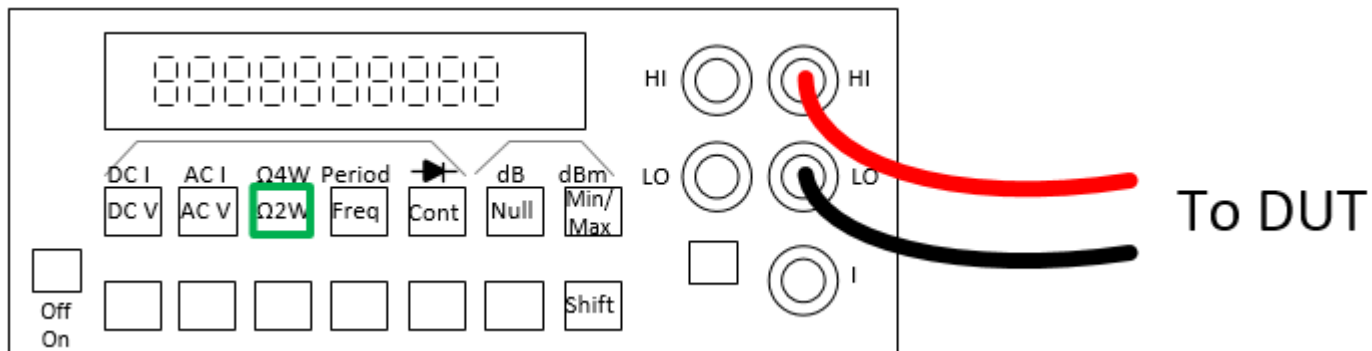


Figure 8: Configuration to measure resistance.

Question 8: Find a pair of “alligator clips” that you should attach on the ends of the banana plugs (your TA will provide them). First connect the ends of the two alligator clips together (without a resistor). What happens? What does the display show? Why?

- ✓ Setup the multimeter in the mode that measures resistance by pressing the Ω **2W** button. The 2W means we are using the **two-wire** sensing. The four-wire method is not used in ECE110, but allows the experimenter to avoid error due to resistive sensing wires for a more accurate measurement.

Question 9: Resistor Tolerance - Use the alligator clips to hold each end of a resistor. How close do the resistances match their marked value? Let’s make some measurements and compare them to the values indicated by the colored bars. Choose four resistors from your package, your choice (larger than 100 Ω) and record the results of your measurements in the table below. Compute the percent error as

$$\% \text{ error} = 100 \times \frac{\text{labeled resistance} - \text{measured resistance}}{\text{labeled resistance}}$$

Labeled Resistance (Ω)	Multimeter reading	% error

Table 2: *Enter your caption here!*



How to read the resistor color code:

http://en.wikipedia.org/wiki/Electronic_color_code

You will want to learn a good mnemonic like the one here:

http://www.orcadxcc.org/resistor_color_codes.html

Question 10: Are all of these resistors within the 5%- or 10%-error limit that is marked with a gold or silver band on the resistor as part of its code? Explain.

Question 11: Consider Ohm's Law. If current can be measured by, say, electro-magnetic deflection of a needle as in a galvanometer, how might the multimeter determine the value of the resistance?

Ammeter

Connect the power source, DMM (as an ammeter), and a resistor as in the following figure. You may trust the reading on the voltage source to be an accurate measure of the voltage supplied to the resistor.

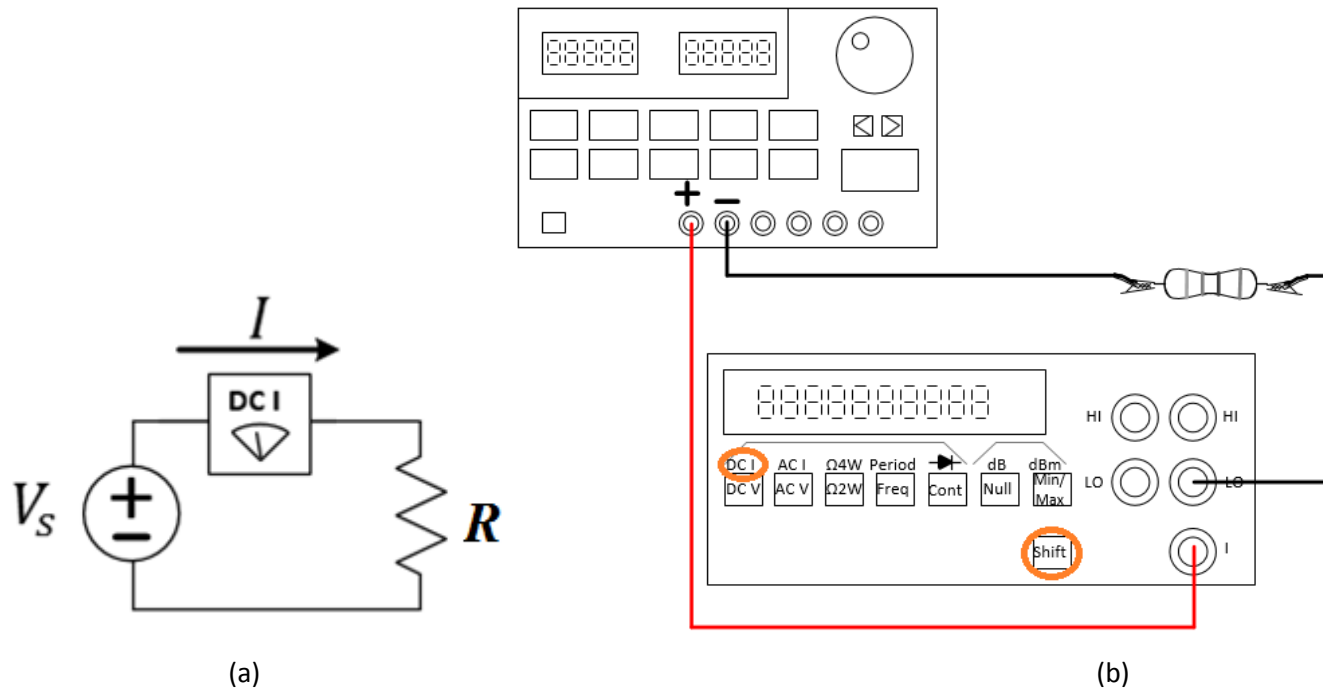
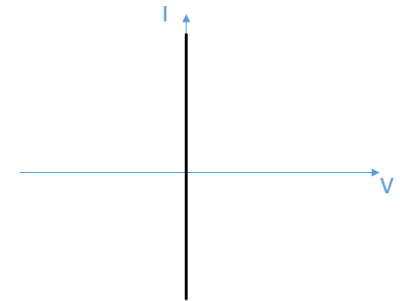


Figure 9: Circuit schematic (a) and physical diagram (b) of a simultaneous DC measurement of current for a resistor.

To measure current you need to put the multimeter in a special mode by pushing the **shift** button followed by the button with **DC I** above it, AND you need to change the position of the red plug entering the multimeter. *Most importantly*, the multimeter must be inserted into the circuit in **series**. Connection of a device in series implies that you **break the circuit and insert the device between the loose ends**. You will break the circuit and connect both wires from the multimeter to the 'loose' wires in the circuit. See the figure below for the correct way to connect the cables to the multimeter and to set the multimeter in the correct mode for measuring current.

Important: please pay attention to the connection to the DMM when you use it to measure current. The current always flows through the lower (I) and middle (LO) ports. To stay consistent with the current polarity indicated by the arrow in the circuit schematic, the I-port looks to the start of the arrow and the LO-port looks to the point of the arrow. To have minimal effect on

Notes:



An ideal ammeter encounters no voltage drop across its terminals regardless of the current flowing through it.

“Break the circuit” means to disrupt the loop that allows electrons to flow through the circuit. It involves removing a wired connection and not physically breaking or destroying anything!

the circuit, the ammeter will have nearly-zero resistance! To measure current, the circuit must be first broken and the instrument is inserted in series. You do not probe the circuit the way that you do for voltage (probing is done without disconnecting any wires).

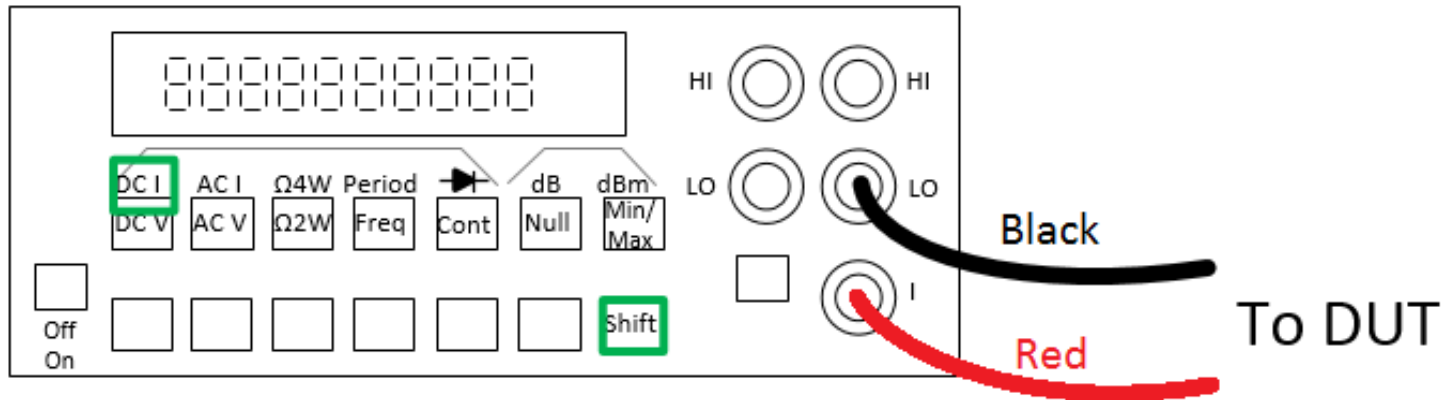


Figure 10: Configuration to measure DC current.

Question 12: Repeat this process and record the current for all the resistors. Apply Ohm's law ($R = V/I$) and *compute* the resistance of each resistor. Compare the results with what you measured directly using the DMM. Are the values the same? Again, do not use resistors smaller than 100Ω .

Labeled Resistance (Ω)	Voltage (V)	Current (A)	Multimeter reading (Ω)	Calculated (Ω)

Table 3: *Enter your caption here!*

Conclusion

Question 13: According to Ohm's law, what would be the internal resistance of an ideal ammeter given that it introduces no voltage drop to a circuit loop?

Question 14: Complete this conclusion by discussing your findings in this lab. Be sure to specifically address the equipment functions, models, and characteristics; schematics and Ohm's Law, and how these things are valuable to us.

What You Learned

In this lab, you learned much about the equipment. You should know how to use a voltmeter, ohmmeter and ammeter properly. You should be able to read circuit schematics and record measurements that are consistent with the indicated polarity of the labeled voltages and currents.

Explore More!

At the end of each regular lab procedure, as time permits, you will be provided with materials to continue to improve your mastery of the materials. The suggested module for this lab is **Explore More! Arduino Blink**. You are to work on these as long as time permits. The modules will be submitted to your TA when finished and a number of them will count in your final grade.

Lab Report Rubric

The following rubric will be provided at the end of each lab procedure. As a final step in preparing your lab report, you will use this rubric to analyze your own performance.

Section	Criterion	Comments:
<i>Experimental Setup and/or Design Description</i>	Circuit Schematics are drawn neatly, accurately, and properly labeled. Decisions regarding experimental setup and design are clearly explained.	
<i>Measurements</i>	Tables include units and proper precision. Any <i>new device</i> introduced should be characterized using measurements!	
<i>Computations</i>	Computations performed on raw data are <i>explicitly</i> described and follow rules for significant figures.	
<i>Analysis</i>	Graphs have title, labels, units, scale, legend; Lines for curve-fitting appear in the graph when needed and parameters like the intercepts and the slope are labeled.	
<i>Modeling</i>	A mathematical model for the curve-fit graph allows for more abstract references to the device's behavior. The expected behavior is explained in the context of the graph.	
<i>Conclusion</i>	Conclusions are drawn from your experimental results to support the reason(s) for completing the experiment. Closes the loop on the Introduction.	
<i>General Formatting</i>	Answers to questions clearly labeled. The overall appearance of the report is professional.	
<i>Self-assessment</i>	This table has been thoughtfully completed.	