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Module 200: Non-Ideal Behavior of Instruments

In the core part of Lab 1 you learned how to use the power supply as a source of electrical energy. And you used the multimeters to quantify the behavior of a circuit by measuring the voltage and current associated with each device. You even characterized the resistors used in the circuit you built by measuring the resistance, again, using the multimeter. When using this equipment you did not have to consider how the power was supplied or how the measurements were taken. The assumption was made that these are *ideal devices*.

The plots in Figure 1 illustrate how we think about ideal sources and measuring devices. The ideal power sources maintains a set voltage V_s or current I_s no matter what circuit is connected across the terminals. Even if the terminals are shorted (connected together by a wire) the *ideal* supply maintains the voltage. Ideal measuring devices do not modify the circuit behavior in any way. The ideal voltmeter draws no current into itself but still registers the correct voltage between two points with a circuit. The ideal ammeter accepts any current, creating no voltage drop, and also registers the correct current flowing through the device/circuit tested. The graphs illustrate the ideal behavior as presented in the core lab and in lecture.

In the labs you also measure resistance using the Ohmmeter. Is there such a thing as an ideal ohmmeter? How would you know?

This module explores the limitations of your bench equipment. Experimenting with the limits you will come to a better understanding of how the multimeter and power supply works. Even though you will rarely be aware of the limitations when using the bench equipment these procedures are meant to give you additional understanding so that when you are using non-ideal components like a battery you will be able to work within the limitations of the device.

Let's start by pushing the limits. You will build very simple circuits choosing resistances chosen to make powering the circuit with a quantifiable voltage and current imprecise. You will build other circuits that tax the ability of the multimeter to make precise measurements. Even the bench equipment is really just a circuit – a very well-designed circuit – but a circuit, just like the one you are testing and it must considered as part of the circuit if you want precise measurements.

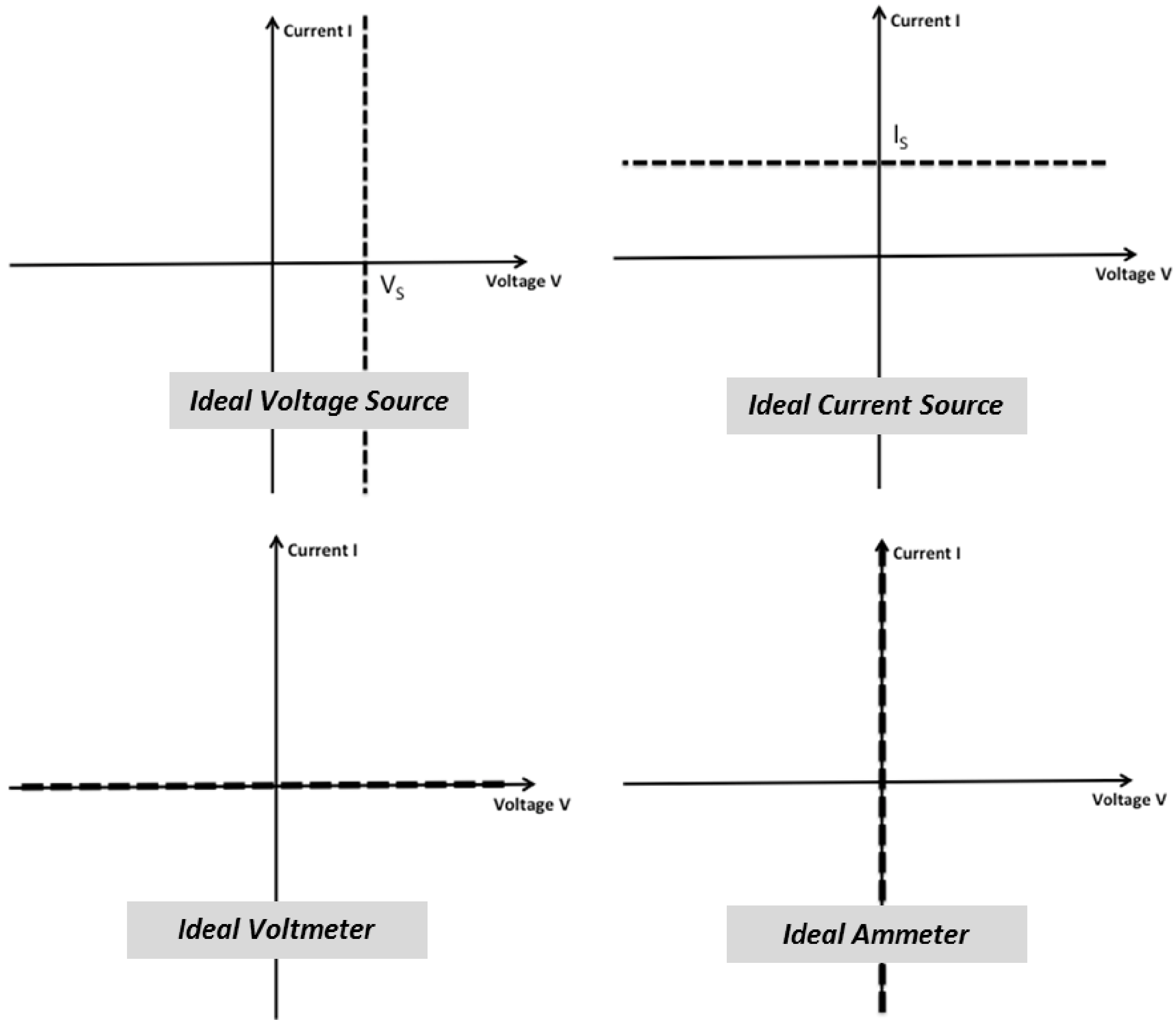


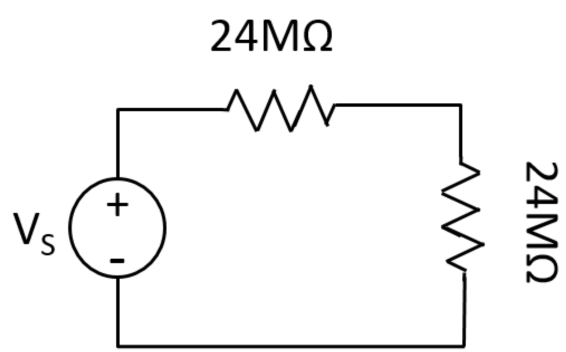
Figure 1: I-V Characteristics of Ideal Sources and Measuring devices

Procedures

Getting the voltmeter to give an Improper Value of the Voltage

Using the simple circuit below, you will cause the voltmeter to provide an incorrect voltage reading. This is a non-invasive procedure and will not hurt the meter and will not damage the circuit components.

- ✓ Build the circuit below consisting of two resistors in series connected to the power supply. The exact value of the two resistors doesn't matter, but the resistors should have a **resistance** $\geq$ $\boldsymbol{1M\Omega}$. The schematic below shows two 24 MΩ resistors connected in series with the power supply.
- ✓ Set the power supply to 5V.
- ✓ Set the multimeter to measure DC voltage.



Answer Question 1.

The measurement does not give the value you have come to expect because our circuit does not see the voltmeter as an infinite resistance. The figure below shows that a *simple* model for the digital multimeter (DMM) ***when measuring DC voltage*** is a parallel connection of a perfect voltage-measuring device that reads the voltage across a resistor with a large (*but not infinite!*) resistance. A small amount of current flows through R_{DMM} across which a voltage appears and is measured by our instrument. For that measured voltage to be the same as the voltage across the $24\ M\Omega$ resistor in the absence of the voltmeter, the current through R_{DMM} must be very small compared to the current through the $24\ M\Omega$ resistor that sits in parallel with it. The value of R_{DMM} is approximately $10\ M\Omega$ for our multimeters. This value that is huge compared to the resistances you *normally* use in the lab and your designs. But the resistances in this particuluar circuit are large. The power supply now sees a single $24\ M\Omega$ resistor in series with a resistance that is the *parallel combination* of $24\ M\Omega$ and $R_{DMM} = 10\ M\Omega$.

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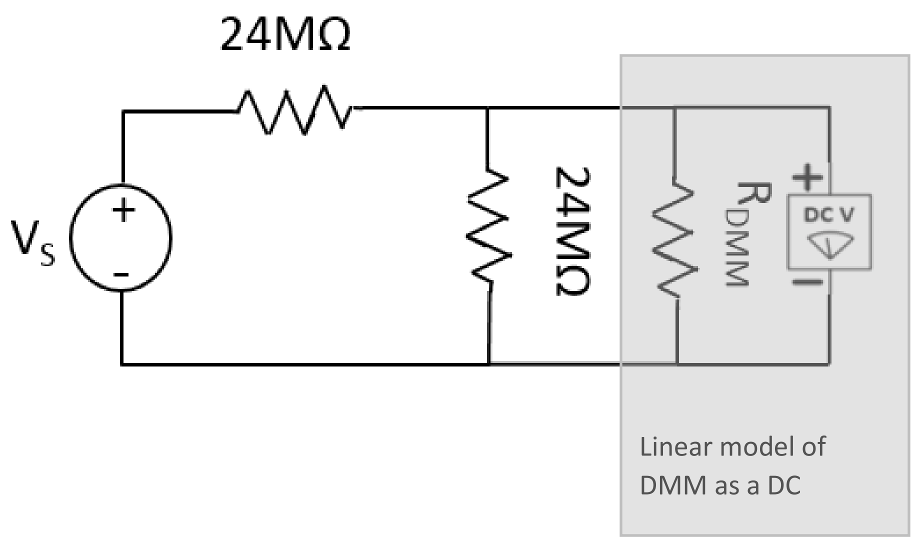
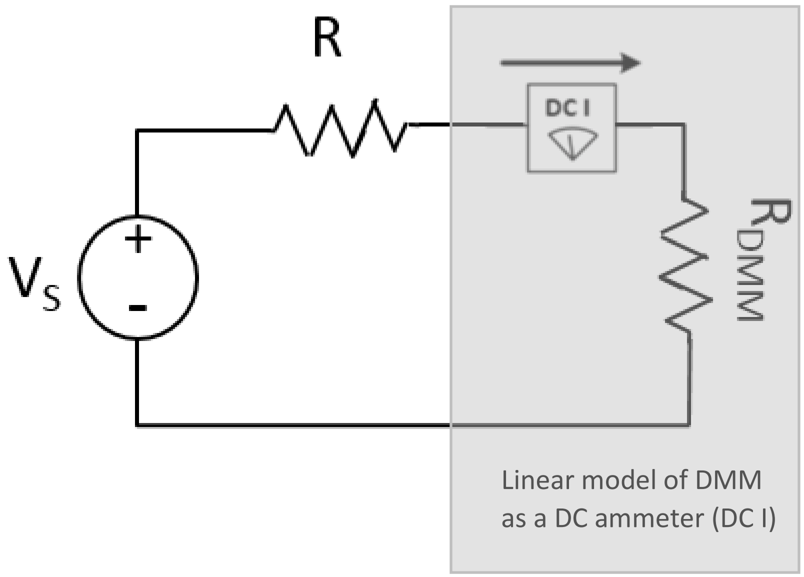


Answer Question 2.

Notes:

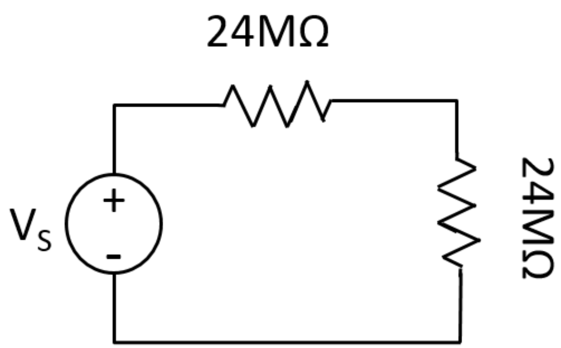
You can get the ammeter to misread the current as well, but that's a bit more risky so let's do a thought experiment. Think about this…when measuring current, you break the circuit and insert the ammeter in series with the "circuitry under test" (the devices for which you want the current to be measured). Below is a schematic of a circuit with a single resistor and the ammeter in DC I mode measuring current. Remember that in the ideal case (ideal ammeter), $R_{DMM} \approx 0\ \Omega$. In reality, for our ammeter, R_{DMM} will be in the range from $0.1\ \Omega$ to $2\ \Omega$.



Answer Question 3.

Getting the Ohmmeter to give an Improper Value of the Resistance

- ✓ Disconnect the Power Supply.
- ✓ Continuing with circuit below.
- ✓ Set the digital multimeter to measure resistance.



Answer Question 4.

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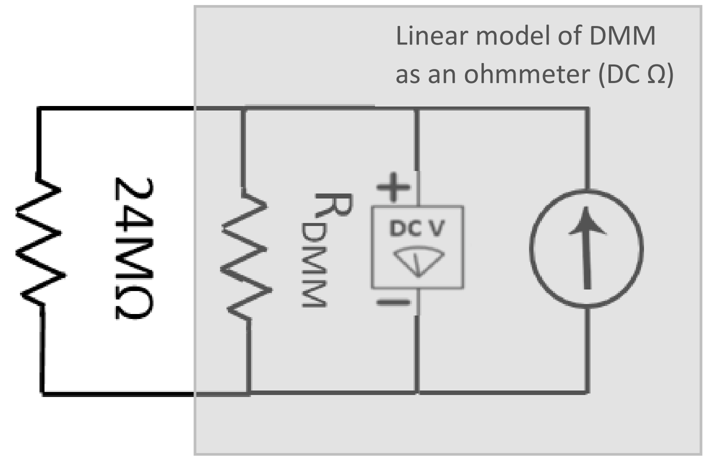
When the multimeter is put into resistance measuring mode, the resistor, or resistive circuit under test must be **disconnected** from the rest of the circuit! How does the Ohmmeter measure resistance?

As the figure below shows, the Ohmmeter uses the same circuitry as the voltmeter including the internal resistance or $R_{DMM} = 10\ M\Omega$. This time, however, the multimeter provides the power (for the voltmeter and ammeter, the power came from the circuit under test). Additional circuitry inside the multimeter injects a known current through the circuit.

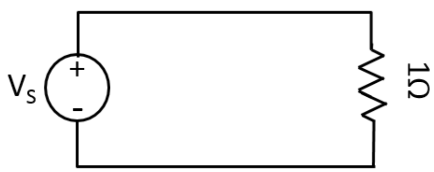


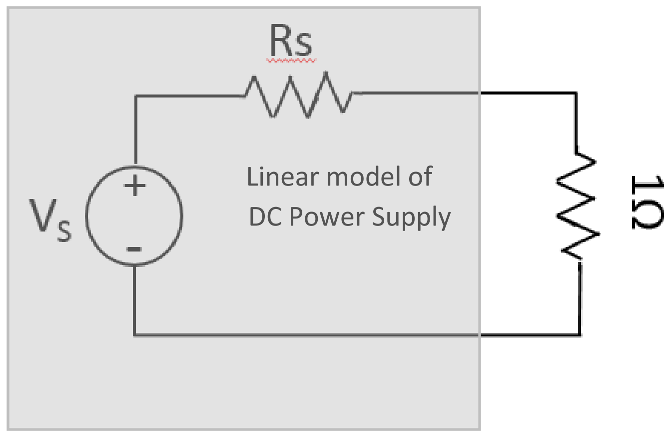
Answer Questions 5 and 6.

Pushing the Power Supply

It is more difficult to drive the power supply into exhibiting non-ideal behavior. The power supplies are very well-designed so that the simplest model is an ideal source with a very small series resistance. For the power supply to fail to deliver the correct voltage the circuit being powered must have a very low resistance. Be certain when doing this portion that the small resistor is up to the task. That is, the resistor must have a high-enough power rating!

- ✓ Build the circuit on the left below. USE A 1Ω RESISTOR THAT IS MADE TO CARRYING A LARGE CURRENT. Your TA can help you find a suitable resistor. **DO NOT USE THE RESISTORS IN YOUR KIT as they are only ¼ Watt**. Be certain that the power supply is not connected until you have set it to 1V.
- ✓ Set the power supply to 1V. When you are ready to answer the next questions, turn it on.





Answer Question 7.

Points awarded: ________

Name: ____________________

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Notes:

Module 200: Non-Ideal Behavior (DC)

Question 1: Probe the voltage across *each* of the resistors. Record the values that you read from the voltmeter. Calculate the expected voltage using KVL or the voltage divider rule. Are the measured values the same as the calculated values?

Question 2: Using the voltage divider rule estimate the voltage you expect to read on the multimeter now that you are considering the internal resistance of the multimeter when it is set in DC V mode. Is this value closer to values you measured?

Question 3: Assuming $R_{DMM} = 0.5\ \Omega$ what value of R will cause the ammeter to measure a current that it is 10% lower than the value predicted by Ohm's Law $= \frac{V_S}{R}$?

Question 4: Measure the resistance of one of $24\ M\Omega$ resistors and record the value.

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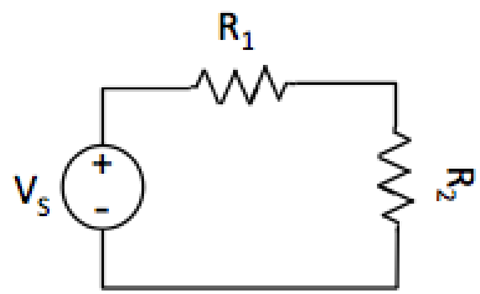
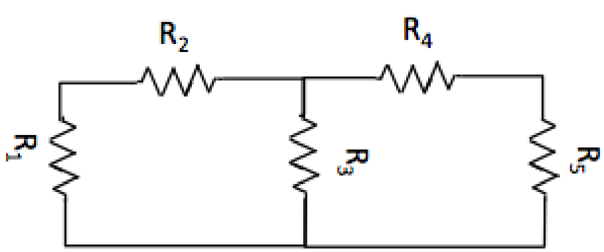
Question 5: Draw the model of the multimeter across the terminals of R_2. Use the diagram to explain why you will not measure the value of R_2 unless you disconnect the resistor being tested from the power source.



Question 6: Again, draw the model of the multimeter across the terminals of R_2. Use the diagram to explain why you must isolate the resistor being tested from the rest of the circuit.



Question 7: Using one of the multimeters, measure the voltage across the 1Ω resistor. Is it 1V? It is probably pretty close, but it has likely changed by some amount. Make an estimate of the value of the internal resistance of the power supply from the voltage you measured.