Physics 313 Lab 1: DC fundamentals

Objectives:
- look at the current-vs.-voltage characteristics of some ohmic and non-ohmic devices
- investigate the effect meters have on a circuit
- begin to develop good breadboarding and troubleshooting technique
- use and design voltage dividers
- see how Thévenin equivalents work
- use the voltage divider technique to determine unknown impedances

1-1. Ohm’s law
You will be given a black box that contains a two-terminal device. Your goal is to determine the current as a function of applied voltage (DC) for the device over a voltage range of about 0-2.5 V. Use a variable DC power supply to apply the voltage, and two digital multimeters (DMM), one used as an ammeter and one as a voltmeter. Note that you have a choice of how to connect the meters; either the voltmeter can measure what you want (V across the device only), or the ammeter can measure what you want (I through the device only), but it’s not possible to have both simultaneously measuring what you want. Therefore, be sure to sketch (schematically) how you have them hooked up. Later, we’ll explore what effect the presence of one meter in the circuit has on the other.

Take a number of measurements between 0 and 2.5 V. Make a rough graph of your data (I vs. V) in your logbook as you go along, so that you know if there are regions where more data would be helpful.

Summarize: Is the component in your black box described well by Ohm’s Law, at least over the range you’ve measured? Why/why not? If it is, what is the resistance of the thing inside the black box?

Discuss the results with me, and then open up the black boxes to see what’s inside.

1-2 Effect of test instruments on measured values
Remember that an ideal ammeter has zero internal resistance and an ideal voltmeter has infinite internal resistance. Because our meters are not ideal, we need to have some idea of how much their internal resistance might affect measurements made with them.

To investigate this question, we’re going to use Ohm’s Law to determine the resistance of a 10k resistor by measuring current and voltage with two different ways of connecting the meters. Before you start, use the appropriate function of one of your DMMs to measure the resistance of your particular 10k resistor directly (use the DMM as an ohmmeter).

First setup: One meter measures voltage across only the resistor, while the other meter measures the current through both the voltmeter and the resistor. Set the output of the variable power supply to about 1 V.

Record the measured current and voltage, as well as the scales the meters are on. Now change the ammeter scale and record the current and voltage values again (did they change significantly?). Change
the ammeter scale back to the original one, and now try a different voltage scale; record the values again. Did they change significantly this time?

Second setup: Repeat with the voltmeter across both the resistor and the ammeter, so that the ammeter is now measuring the current through only the resistor. Again, use several different scales for both meters.

Figure out R in each case (don’t do a formal error analysis, but round your results reasonably). Compare to the resistance value you measured directly using the DMM as an ohmmeter.

**Summarize**: Does the internal resistance of the DMM you used as a voltmeter seem to depend on the scale used? What about the DMM you used as an ammeter?

Why might it be a good idea to record the scale a meter is on when making a careful measurement?

Which way of setting up the meters seems to give more accurate results in this experiment?

### 1-3 Voltage dividers

On the breadboard, construct a voltage divider (p. 56) with $R_1 = 5k$ and $R_2 = 10k$. Use the breadboard +15 V supply to supply $V_{in}$.

Predict what $V_{out}$ should be, then measure it. Comment on the agreement between what you predict and what you measure. Is this agreement reasonable, given the resistor tolerances?

Predict what will happen if you attach a 10k load across the output and measure the output voltage again. Carry out the experiment, and compare the results with what you expect (be quantitative).

What do you predict will happen if a larger load resistance is used? Choose a larger resistor and try it. Do the results agree with what you expect? Why/why not?

**Summarize**: What’s the relationship between $V_{out}$ and $V_{in}$ for a voltage divider with no load? How does $V_{out}$ change when a load is attached? Does a load with resistance large compared to $R_1$ and $R_2$ affect $V_{out}$ more, less, or the same as a load with small resistance?

### 1-4 Thévenin equivalent circuits

Now let’s find the Thévenin equivalent of the circuit in section 1-3 (the unloaded voltage divider). To find the Thévenin equivalent, we need to find $V_{TH}$ and $R_{TH}$ for that circuit. You can save yourself some work if you realize that you know $V_{TH}$ (the open-circuit) voltage already (what is it?).

To find $R_{TH}$, we need the short-circuit output current $I_{sc}$. To find it, start with the unloaded voltage divider and measure the $I_{sc}$ by “shorting” the output to ground through a current meter. This isn’t a true short, but the previous part of the lab should have convinced you that the resistance of a DMM used as a current meter is relatively small. ( Aren’t short circuits always bad?? Why is “shorting” the output ok here?)
From $V_{TH}$ and $I_e$ you can calculate the Thévenin equivalent circuit. Build that equivalent circuit, using a variable power supply or the variable $+V$ supply on the breadboard as the voltage source, and whatever other components you need. Measure the open-circuit voltage and the short-circuit current of the equivalent circuit. Are they the same as those of the original circuit?

Now attach a 10k load and measure the voltage across it. Does the Thévenin equivalent act the same as the original circuit under load (compare to your data from 1-3)?

**Summarize:** In what sense is the Thévenin circuit you built the equivalent of the voltage divider?

**1-5 Impedances of test instruments**
In 1-3, you constructed a voltage divider and used the known resistances to predict $V_{out}$. The same type of circuit can be used to determine an unknown resistance, by making the unknown resistance part of a voltage divider with a known resistance. By measuring $V_{out}$ and knowing one of the resistances in the voltage divider, the other resistance can be determined.

It’s important to realize that this type of measurement will be most accurate if you use a known resistance about equal to the unknown resistance. (Why is this true?)

Use this idea to determine the resistance of the BK meter in voltage mode on a given voltage scale (be sure to explain how you’re doing this, and record the raw data as well as the results). Change scales and repeat.

Repeat for the BK meter in current mode on a couple of different scales.

**Summarize:** Explain why your results for the resistance of the BK meter in voltage or current mode do or do not make sense, given what you know about the properties of ideal meters. Also compare to the values listed in the documentation for the BK meter.

Does the internal resistance of the BK meter used as a voltmeter seem to depend on the scale used? If so, how? What about the BK meter used as an ammeter? Does this make sense, based on what you did in 1-2?

**1-6 Design problem: voltage divider**
Design a voltage divider that will produce 3.5 V from a 15 V supply, and that will maintain that output voltage to within 10% when loads with resistance in the range 10k to 100 k are attached.

Set up your circuit. Before hooking up the power, calculate the power you expect to be dissipated in each resistor and make sure that you won’t exceed the ¼ watt rating for any of the resistors. See me if you think you will.

Test your circuit to make sure it works as you expect. Be sure that you take and record appropriate data to verify that it meets the specifications you were given.