Ohm's Law and Resistivity

Apparatus: resistivity apparatus, PASCO Science Workshop 750 Interface & Power Supplies, 2 DMMs per group (handheld & bench top if necessary), DMM red leads, DMM black leads, resistors (100 Ω), micrometers or calipers

Instructor Note: The Pasco power supplies have a 300 mA limit. If you are using them you'll need to have some resistor in series with the long skinny wires or you'll get data affected by the current limit! Also, the bench top DMMs will give good data as long as the appropriate dial setting is used (max out the sig figs without going over limit).

Goals:

1) Build a simple circuit
2) Measure ΔV, I and R in that simple circuit
3) Experimentally verify the relationship between voltage and current by creating an IV-plot
4) Determine resistivity from the slope of an R vs. L plot

For this experiment you will need a long wire with a small cross-section. This skinny wire will act as a resistor. The resistance of the wire is given by

$$R = \frac{\rho L}{A} = \frac{4\rho}{\pi d^2} L$$

where ρ is the resistivity of the wire, d is the diameter of the wire, $A = \pi \left(\frac{d}{2}\right)^2$ is the cross-sectional area of the wire, and L is the length of the wire.

Important comments:
Resistance is a property of an object. Example: The resistor (the object) has resistance 101.4 Ω.
Resistivity is a property of a material. Example: Copper (the material) has a resistivity of 17 nΩ · m.
The units of resistivity are "nano-ohm meters", NOT "nano-ohms per meter".

Part I: Measure the resistance of 1.00 m of skinny wire with the DMM. Hint: try this without the power supply connected AND with the power supply connected. Only one way will give you a good result…

Part II: Now, for the same 1.00 m of wire, do a four-point measurement of the resistance while sweeping the DC voltage. First connect the circuit as shown on the next page. Read about the "four-point" measurement technique.

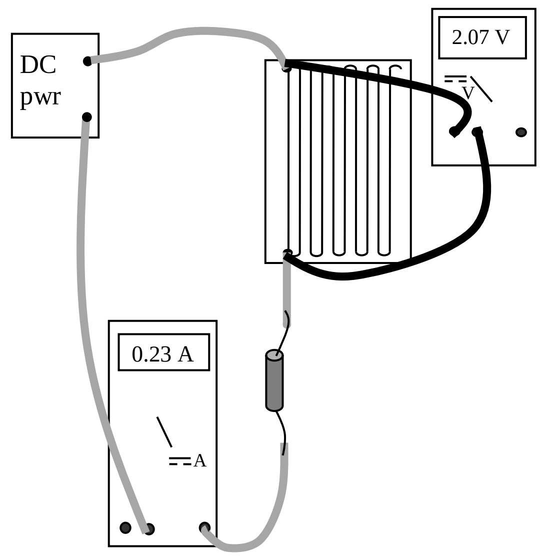
After reading about the four-point technique on the next page, set the power supply at $\Delta V_{source} = 1.00$ V and record both ΔV_{wire} and I_{wire}. Change the power supply to 2.00 V and record both ΔV_{wire} and I_{wire} again. Repeat this procedure for all source voltages between -5.00 V and 5.00V. Hint: to get negative voltages you may need to switch the red and black leads at the power supply!
Be sure to record the ΔV_{wire} across the wire (not the ΔV_{source} of the power supply).

Plot ΔV_{wire} on the x-axis and I_{wire} on the y-axis. This is the standard way because technically the voltage is the independent variable and current is the dependent variable. Get the slope of the graph and use it to determine the resistance of the wire. CAREFUL: the slope is not the resistance but rather… (check the units)!

Part III: Repeat the previous experiment with the following changes. Select a convenient voltage (say 1.00 V). Measure both current and voltage for 1.00 m of wire. Use this information to determine the resistance of 1.00 m of wire. Then repeat this for 2.00 m, 3.00m, etc on up to 10.0 m of wire. A table of R versus L can then be recorded. From this information a plot of R vs. L can be made. The slope of this plot should be given by slope $= \frac{\rho}{?}$. This shows that an experimental value of the resistivity is given by $\rho_{exp} = ?\cdot slope$. Determine your diameter using micrometers so you can calculate ρ_{exp}.

Compare this to the accepted value of some common materials in the table shown at the end of the lab.

What it looks like in real life…
Connect all grey wires first…



Be careful: If you squeeze too hard with the calipers (or micrometer) the wire compresses and gives an incorrect measurement! Use the flat portion of the caliper…not the knife edge. Note: this measurement has only two sig figs AND gets squared in the computation. Squaring implies the error in this measurement is doubled in the final result! Close the caliper until you first begin to feel opposition to your motion in the calipers and this is your measurement.

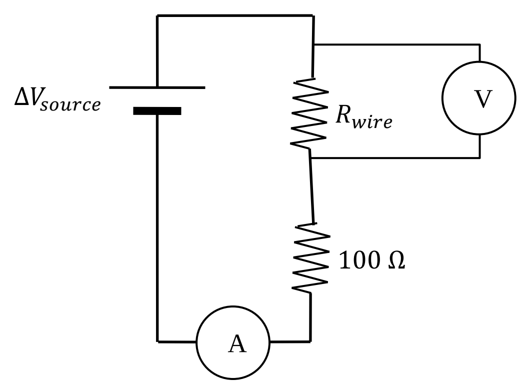
Four-probe measurements: To make a four-probe measurement, connect the circuit as shown in the figure. Notice that there are four "probes" – the two leads from the DMM measuring voltage and the two leads from the DMM measuring current.

The DMM on the right measures the voltage across only the segment of wire. I recommend using the bench top DMM for this measurement. The DMM on bottom measures the current through the circuit.

Note: To change the length of the wire one can connect at the different "taps".

These values of voltage and current can be used to find the resistance for each measured I and ΔV using by Ohm's Law ($\Delta V = IR$).

Schematic



The four point measurement technique is useful for measuring very small resistances that typically are hard to measure with DMM's. Here is a very simple web resource that discusses four-point measurements: http://www.sciencebuddies.org/science-fair-projects/project_ideas/Elec_p025.shtml

When you answer conclusion questions, your answers should be in full sentences.
The sentences used should make clear what question was asked.
You should also provide rationale for your answers as appropriate.

Alternatively, you could re-write the question on your paper then answer however you want.
That said, I think is worthwhile to learn how to answer in full sentences in a manner which makes clear what question was asked.
Engineering uses this same standard for their conclusion question answers.

Conclusions:

1) Suppose you have a connected circuit with some resistors in it. Which method, using a DMM to measure resistance directly (Part I) or using the four-probe measurements (part II), is able to accurately determine the resistance of a single resistor in the circuit while connected to power?
2) Suppose you wanted to measure resistance of only 1.00 cm of wire. Which measurement technique (part I or Part II) should be used in this situation and why?
3) A device is called "ohmic" if it has a linear *IV* plot. Was your long skinny wire ohmic? Note: it is important to plot both positive and negative values for your *IV* plot because some devices could look ohmic for positive voltages but not negative voltages.
4) Suppose you made an *IV* plot of a small length of wire. As the voltage is increased, the current should increase (as well as the temperature of the wire). What should happen to the resistance in the wire? What should happen to the slope of the graph? Sketch a plausible *IV* plot for a small length of wire that gets very hot as 5V is applied. Is this device ohmic? An example of such a device is an incandescent light bulb.
5) Suppose you compared two wires of the same material. Wire 1 is longer than wire 2 while the cross-sectional areas are the same. Which wire (if any) has a larger resistivity? Explain.
6) Suppose you compared two wires of the same material. Wire 1 is a smaller gauge than wire 2 while the lengths are the same. Use a web search to determine how gauge relates to diameter. Which wire (if any) has a larger resistance? Explain.
7) The most common error I have seen in this lab is using inappropriate pressure (either too little or too much) when using the calipers to measure diameter of the wire. If you did squeeze too hard, how would this affect your final result for ρ_{exp}? More specifically, if you squeezed too hard on the calipers do you make your experimental result have a more positive or more negative % difference? Assume you choose the appropriate value for ρ_{th}.

Table of Resistivities (at 20 ℃)

material	ρ_{th} (nΩ · m)
aluminum	26.5
phosphor bronze, grade E	35.92
tungsten	52.8
nickel	69.3
phosphor bronze, grade A	95.79
iron	96.1
phosphor bronze, grade C	132.6
phosphor bronze, grade D	156.7
steel, plain	180
steel, stainless	720
nichrome (80/20)	1090
nichrome (70/30)	1180
nichrome (max)	1500