Resistance and Resistivity

Name: ___________________________ Partners: ___________________________

Pre-Lab

You are required to finish this section before coming to the lab – it will be checked by one of the lab instructors before the lab begins.

*Use your textbook to develop a quantitative understanding of resistivity and resistance in series and parallel; then answer the following questions. The relevant material in the book is on pages 842-850, from equation 19.13 to the beginning of Section 19.8*

1) Resistance and resistivity both characterize the ability of a material to limit the flow of electrical charge within it. What is the difference between resistance and resistivity? Note that the units of the resistance are “ohms,” which are denoted by Ω and the units of resistivity are “ohm – meter.”

2) Write the equation used to calculate the resistance of a substance based on its resistivity and geometry.

3) A 0.5 m long 20 gauge wire has resistance 0.027 Ω. Of what material might the wire be made? *Hint: use tables for gauge and resistivity in your textbook.*

4) For each of the following resistor networks, (i) identify whether the network in series or in parallel and (ii) find the equivalent resistance for the network.
   a)
   ![Diagram a]
   b)
   ![Diagram b]
   c)
   ![Diagram c]
   d)
   ![Diagram d]

Pre Lab continues on the next page
Steps for determining the equivalent resistance of a complex resistor network:

Step I) Determine the equivalent resistance of all simple parallel parts of the circuit. (Simple parallel resistors are two or more resistors in parallel in which each parallel branch contains only a single resistor.) Then, redraw the circuit using a single equivalent resistor to represent the simple parallel resistors you combined. In the diagram below, resistors A and B are in simple parallel, since each branch contains only one resistor. Resistors C and D are in parallel with A and B, but are not in simple parallel because their branch contains two resistors.

Step II) Determine the equivalent resistance of all simple series parts of the circuit. (Simple series resistors are two or more series resistors with no circuit branches connected between them.) Then, redraw the circuit using a single equivalent resistor to represent the simple series resistors you combined. In the diagram below, resistors D and E are in simple series, since there is no branching between them. Resistors B and C are a parallel branch that is in series with D and E, but not simple series. What about resistor A? A is in simple series with D and E. There would be no change to the equivalent resistance of the circuit if A were moved to the other end of the network (next to E). Remember that since you just add resistors in simple series to get the equivalent resistance, the order of adding has no effect on the result.

III) Keep alternating steps 1 and 2 until you find the single equivalent resistor for the circuit.

5) Calculate the equivalent resistance for the resistor network (right).

End of Pre Lab. To save time during lab, read the lab through, making sure you understand the use of the multimeter, micrometer caliper and how to read resistor codes.
I. Measuring Resistance

You will use a digital multimeter to measure resistance. Resistance settings on the meter are labeled Ω (the symbol for ohms, or the unit of resistance). The multimeter has several resistance sensitivity ranges: for example, the “200” setting will read resistance to a maximum of 200 Ω, while the 20K setting will read to a maximum of 20 KΩ, or 20,000 Ω. The most sensitive setting on your meter is the 200 Ω setting. The setting labeled will not be used for this lab. You obtain the most accurate resistance reading when the meter is set to the most sensitive range (or range with the lowest maximum reading) that will not over-range the meter. To connect the meter to the device whose resistance you want to measure, connect the meter’s probes to the sockets on the meter labeled Ω and COM.

*Internal/probe resistance.* When we use meters to measure resistance, we’d like to assume that they only measure the resistance of the device for which we’re interested in knowing the resistance. In reality, the meter and probes themselves have a small resistance that can’t always be neglected.

1) To measure the internal/probe resistance of your meter, set the meter to the 200 Ω setting and press the tips of the probes together firmly. Record the reading below.

For this lab you can ignore this resistance unless it is greater than 1.0% of the total resistance of the device you are measuring. If it is greater that 1.0%, it should be considered to be a resistance in series with the device you are measuring.

II. Determining Resistivity

You have been provided with three wires that are made of the same material but which have different gauges, or thicknesses. For each of the wires, complete the following, starting with the thickest wire and working to the thinnest. Keep all data in the data table provided on the next page. Try not to bend the wire unnecessarily as you handle it.

1) Measure the diameter of the wire using a micrometer caliper. Be careful not to overtighten the caliper on the wire or you could compress the wire and obtain an inaccurate measurement. Record the data to the nearest micrometer. (For the thickest wire, each group member should measure independently to establish uncertainty). The micrometer scale consists of a rotating dial outside a fixed shaft. The fixed shaft is most commonly graduated in twentieths of a centimeter, as shown in the figure (right). Note that the gradations are laid out so that they can be considered to be millimeters (above the center line) and "half-millimeters" (below the center line).
The rotating dial is most commonly graduated in hundredths of a millimeter (the dial turns once per half-millimeter, and there are 50 graduations per turn, yielding 100 graduations per millimeter.)

To read the micrometer scale, first determine the last visible marking on the fixed shaft. In the figure, the last visible gradation is the "half-millimeter" after 11, so begin with a measurement of 11.5 mm. Add to that the number of hundredths indicated on the rotating dial by the center line. In the figure, the center line points between 17 and 18 hundredths; we can estimate it to be 17.8 hundredths of a millimeter (0.178 mm). So, adding that to the first value yields 11.5 mm + 0.178 mm = 11.678 mm.

**UNCERTAINTY:** Of course, no measurement is complete without an associated uncertainty! There are two primary causes for uncertainty when reading a micrometer: the uncertainty in estimating the last digit (the 0.008 mm in the example above) and the uncertainty in the position of the instrument with the micrometer scale. The uncertainty in the last digit will be largely based upon how much experience you have reading precision scales - a beginner might claim to be able to have estimated the previous value of 8 ± 3 [yielding a final measurement of (11.678 ± 0.003) mm], while someone with more experience might be able to estimate the final digit to 8 ± 1 [yielding a final measurement of (11.678 ± 0.001) mm].

2) One lab partner should hold the wire against a meter stick, trying to get it as tight as possible and parallel to the edge of the stick. Record the resistance of the wire for 10 different lengths ranging from a few centimeters to almost the full length of the wire. Be sure to turn the multimeter to the most sensitive resistance scale on which you get a reading (you will obtain a non-numerical error indication if you try to use a scale too sensitive for the reading). The meter will only read the resistance of the portion of the wire between the points where you touch with the probes, so gently and firmly press the probes to the points at the points along wire between which you wish to measure the resistance. **This should only take a minute or two per wire:** to work efficiently the person using the micrometer should hold one probe at the same place on the wire and move the other probe. Don’t try to measure using the tip of the probe – just press the probe against the wire somewhere along the side of the probe. **Be sure to press firmly to get a good connection!** For the first wire, each group member should measure the resistance at the shortest length independently to establish uncertainty. Record lengths to the nearest mm. Keep all other conductive materials away from the setup while measuring to avoid the creation of unintended parallel paths.
### Data Table

<table>
<thead>
<tr>
<th>Thickest Wire</th>
<th>Medium Wire</th>
<th>Thinnest Wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (mm):</td>
<td>Thickness (mm):</td>
<td>Thickness (mm):</td>
</tr>
<tr>
<td>Length (m)</td>
<td>Resistance (Ω)</td>
<td>Length (m)</td>
</tr>
</tbody>
</table>

**Information for uncertainty analysis:**

*Check with an instructor before continuing.*
III. Resistors

*Resistance of resistors.* Resistors are commonly found circuit components that are used to control the currents and voltages supplied to different parts of a circuit. Most resistors are still labeled according to an old-fashioned custom of color stripes. In the example, the stripe at the right end of the resistor (red) indicates the first digit of the resistor value. Red indicates the number 2. The next stripe (green) indicates the second digit; green indicates the number 5. The next stripe (brown) indicates the number of zeroes that follow the second digit. Brown = 1 so there is one zero following the second digit. This resistor (red-green-brown) has a resistance of 250 Ω.

Color codes for resistors are as follows

<table>
<thead>
<tr>
<th>Color</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = black</td>
<td>5 = green</td>
</tr>
<tr>
<td>1 = brown</td>
<td>6 = blue</td>
</tr>
<tr>
<td>2 = red</td>
<td>7 = violet</td>
</tr>
<tr>
<td>3 = orange</td>
<td>8 = gray</td>
</tr>
<tr>
<td>4 = yellow</td>
<td>9 = white</td>
</tr>
</tbody>
</table>

The fourth stripe is usually either gold or silver and tells you the *tolerance* of the resistor, or how close to the ideal value the manufacturer guarantees the resistor’s actual resistance will be. We won’t be too concerned with the tolerance right now.

Sometimes all four stripes on a resistor are equally spaced and it looks like the tolerance stripe is the same distance from the end of a resistor as the stripe representing the first digit. In this case, to decide which is the end representing the 1st digit, remember that the tolerance colors, silver or gold, are not colors in the resistor code, so start decoding the resistor on the side with the non-silver or gold stripe.

1) Locate the single resistor at your lab station.
   a) Write the color code colors starting with the 1st digit of the resistor value and identify the resistance value using the resistor code.

   b) Measure the resistance of the resistor: with one hand on each side of the resistor, firmly pinch the resistor lead and probe tip between your index finger and thumb until you obtain a relatively stable resistance reading on the meter. The current used is so low that you will not feel anything, so don’t worry about touching the leads. Make sure to be on the most sensitive scale on which you get a resistance reading! Since the amount of pressure between probe and lead, point of contact between probe and lead, and quality of contact (oxidation of resistor and probe lead, etc) can all affect the measurement, it is likely that different people will get slightly different measurements when measuring the same resistance, so have each group member measure the resistance independently and record all values.
2) Locate the resistor network that contains resistors in simple series.
   a) Draw a circuit diagram showing the network (use the standard circuit symbol for a resistor) and label each resistor with its color code and resistance value using the code.

   b) Calculate the equivalent resistance of the network.

   c) Measure the equivalent resistance of the network, recording the result below. If it is not within 15% of your calculation above, double check the calculation to see if you can spot any error.

3) Locate the resistor network that contains resistors in simple parallel.
   a) Draw a diagram showing the network and label each resistor with its color code and resistance value using the code.

   b) Calculate the equivalent resistance of the network.
c) Measure the equivalent resistance of the network, recording the result below. If it is not within 15% of your calculation above, double check the calculation to see if you can spot any error.

4) Measure the equivalent resistances of the two “unknown” resistor networks provided. You will use these measurements in the homework section.

5) Locate the resistor network that contains resistors in a combination of series and parallel resistors.
   a) Draw a diagram showing the network and label each resistor with its color code and resistance value using the code.

   b) Measure the equivalent resistance of the network, recording the result below.
III. Sample Calculations

1) Using the steps given in the pre-lab, find the equivalent resistance of the resistor network in question (5). Be sure to draw a separate circuit diagram for each step of the process. Show all work in the space provided below.

2) Estimate the resistivity of the thickest wire using one of the length/resistance combinations you obtained. (Each group member should use a different length.)

*Talk to a lab instructor before you leave the lab.*
Homework

I. Unknown resistor network

1) Each of the two unknown resistor networks you measured during lab contains two resistors. In one of the networks, the resistors are connected in series. In the other the same two resistor values are used, but they are connected in parallel. Using your measurements, find the values of each of the resistors in the networks. Show all calculations.

II. Determining resistivity

1) Using Excel or another graphing utility, plot your data for Resistance vs. Length for your three wire samples. (This means that you put the resistance on the vertical axis and the length on the horizontal axis.) Put the data for all samples on the same graph. Don’t forget to account for the internal/probe resistance if it is greater than 1% of the measured resistance.

2) Plot a best fit line for each of your sets of data. Then, find the equation for each of the lines. You can do this using the graphing utility or by hand. If done by hand, clearly show the slope calculations on separate paper. Be sure to attach the graph and separate paper to your lab before you turn it in.

3) Determine the best value for resistivity of each wire sample using the slope of the best-fit lines.
   a) Using the pre-lab equation for resistivity, write an equation showing the relationship between the best-fit line slope and resistivity.
b) Use your result from (a) to find the resistivity of each wire. Show all calculations.

c) How do the resistivity values for each wire compare? Do the results make sense? Explain based on the definition of resistivity.

4) Prepare a second graph showing only the data for the thickest wire. On this graph, include error flags (see right) showing maximum and minimum values in resistance based on the multiple measurements done at several lengths on this wire. (Additional information about error flags is included at the end of this lab; note, however, that you are only using y-direction error flags and not both x- and y-direction flags as shown in the additional information.) Use the data for the single wire length that produced the greatest uncertainty as the uncertainty for all data points. Then, as shown, draw lines with the maximum and minimum slopes made possible by the range of data represented by the error flags. This can be done on the graph by hand or done in Excel. Don’t forget to attach this graph to your lab before turning it in!

5 a) Determine the maximum and minimum slopes in the graph you prepared in (4). If calculating by hand, be sure to include the calculations below.
b) From your slopes in (a), find your worst-case uncertainty in the resistivity. Don’t forget to include uncertainty in the wire diameter in your calculations! Show all calculations clearly.

6 a) Use the resistivity table in your text (page 843) to determine what substance the wire might be made of. What might the substance be?

b) Determine the gauge of each wire using any information available in your text or online (Wikipedia’s entry on American Wire Gauge, among other sites, might be helpful).
Graphs and Error Flags - Uncertainty in the Slope of a Line

In a typical experiment to determine velocity, the position of an object is recorded every second. Suppose the uncertainty in each position measurement is ± 5 cm, the uncertainty in each time measurement is ± .25 s, and the data for a five-second interval is given by the table to the left of the following figure.

<table>
<thead>
<tr>
<th>t(sec)</th>
<th>x(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
</tr>
<tr>
<td>5</td>
<td>65</td>
</tr>
</tbody>
</table>

In the graph to the right, the uncertainties in each data point are indicated by "error flags", the vertical flags are for uncertainty in distance, horizontal for time. The lengths of this flags correspond to the uncertainty ranges. For example, since the point at \( t = (3.0 ± 0.3) \) seconds corresponds to \( x = (42 ± 5) \) cm, the error flag extends from 37 cm to 47 cm in the vertical direction, and from 2.7 sec to 3.3 sec in the horizontal direction.

The solid line drawn through the data points was estimated by an experimenter to be the "best fit" to this data. The slope of this line, \( V = \frac{dx}{dt} = 11 \text{ cm/sec} \), represents the most probable value of the velocity. But there are many other straight lines which could have been drawn through the error flags, and hence there is a range of possible slopes consistent with the data. To estimate this uncertainty in the slope, we draw the "worst case" lines, i.e.the line of greatest slope and the line of least slope which still pass through most of the error flags. If you think about the slope being given by rise/run, then to get a "max" slope, you will need the "max" rise/"min" run. The worst case lines are shown as dotted lines in the figure, and have slopes of \( V_{\text{max}} = 13 \text{ cm/sec} \) and \( V_{\text{min}} = 9 \text{ cm/sec} \). Given these extremes, it is reasonable to express the final result for the velocity as \( V = (11 ± 2) \text{ cm/sec} \).