In this experiment we will learn about some of the laboratory instruments which will be used during the semester, and gain experience with measuring DC currents and voltages. We will also see that voltmeters and ammeters can sometimes have a non-negligible effect on the behavior of a circuit.

Note that sections (a) and (c) of part 2 involve deriving some simple formulas. This should be done prior to the lab period.

Before you begin, clean the selector switches on the Volt-Ohm-Milliammeter (VOM), the Electrometer, and the resistance boxes by slowly rotating them full circle clockwise and counter-clockwise several times. Also clean the inputs of all meters and resistance boxes and the outputs of the power supply by inserting and removing a snugly fitting banana plug several times. The wiping action helps to remove insulating films from the switches and connectors. This procedure should be followed whenever you encounter a circuit that “drifts” or appears to be noisy or unreliable.

1. First, we will investigate the effect that various DC voltmeters have on a simple voltage divider circuit. Construct the circuit shown at the right. Use the Topward DC power supply for \( V_0 \) (do not ground either terminal), and use a Digital Multimeter (DMM) to set \( V_0 = 8.0 \text{ V} \). Use 10% resistance boxes for \( R_1 \) and \( R_2 \).

   (a) Use one of the Simpson Volt-Ohm-Milliammeters to measure the voltages \( V_1 \), \( V_2 \) and \( V_{12} \) for \( R_1 = R_2 = 100 \Omega \) and \( 10^7 \Omega \). Make a table giving \( R_1 \), \( R_2 \), \( V_1 \), \( V_2 \), \( V_{12} \), and the \( % \) difference between the measured values of \( V_{12} \) and \( V_1 + V_2 \).

   (b) Repeat part (a) using a DMM instead of the VOM.

   (c) Repeat the measurements once more, this time with a Keithley electrometer.

   (d) For an ideal voltmeter you would expect to obtain \( V_{12} = V_1 + V_2 \), but for real voltmeters you see that this is sometimes not the case. Look up the input impedances of the various voltmeters in Appendix C and briefly explain the reason for the discrepancies you observed.
2. Next, we will use a pair of VOM’s (one used as a voltmeter and the other as an ammeter) to measure the resistance of a resistor \( R \). In principle we could use either circuit A or circuit B (shown below) and the resistance would be given by \( R = \frac{V}{I} \), where \( V \) and \( I \) are the voltage and current read on the meters. In practice, however, things are not quite so simple. Note that in circuit A (for example) the ammeter reads the current through \( R \) (as desired), but the voltmeter reads the voltage across both the resistor and the ammeter. Thus, \( R \) should be calculated from \( R = \frac{V_{C}}{I} \), where \( V_{C} = V - V_{A} \) and where \( V_{A} \) is the voltage across the ammeter. In circuit B, \( V \) is just the voltage across \( R \), but \( I \) includes the current through the voltmeter \( (I_{V}) \) as well as the current through \( R \), and thus we want \( I_{C} = I - I_{V} \). Often these corrections are small enough to be ignored, but this is not always the case.

(a) Sketch the two circuits in your notebook. Next, write down the equations needed to correct your measurements for the finite input resistance of the meters. For circuit B, you need a formula that gives \( I_{C} \) in terms of \( I \), \( V \), \( V_{FS} \) (the full scale voltage setting of the voltmeter), and \( S_{V} \) (the sensitivity of the voltmeter). Similarly, for circuit A you want to express \( V_{C} \) in terms of \( I \), \( V \), \( I_{FS} \) and \( S_{A} \) (sensitivity of ammeter). Note that the meter sensitivities are given in Appendix C.

(b) Set up the circuits using the \( \pm 10\% \) resistance boxes for \( R \). Be careful not to connect the ammeter directly across the output of the power supply. Use the DMM to set \( V_{0} \) to the values given in the table below, and then read the values of \( V \) and \( I \). For each circuit, add columns to the table giving \( V \), \( I \), \( V_{C} \) \( (I_{C} \) for circuit B), \( R_{\text{meas}} = \frac{V}{I} \), and \( R_{\text{corr}} = \frac{V_{C}}{I} \) \( (V/I_{C} \) for circuit B).

<table>
<thead>
<tr>
<th>( V_{0} )</th>
<th>( R )</th>
<th>( V_{FS} )</th>
<th>( I_{FS} )</th>
<th>( V )</th>
<th>( I )</th>
<th>( V_{C} ) ( (I_{C} )</th>
<th>( V/I )</th>
<th>( V_{C}/I(V/I_{C}) )</th>
<th>( R_{DMM} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9 V</td>
<td>220 ( \Omega )</td>
<td>2.5 V</td>
<td>10 mA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.9 V</td>
<td>22 k( \Omega )</td>
<td>2.5 V</td>
<td>50 ( \mu A )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(c) Now remove the resistance box from the circuit and use the \( \Omega \) function on the DMM to make a direct, accurate measurement of \( R \) for each resistor used in part (b). Add a column to your tables in B so you can compare the values of \( R \) you obtained with Circuit A, Circuit B, and the DMM. Approximately how close to the correct value did you get by using the VOM’s?
DC MEASUREMENTS

Question: Normally we like to be able to measure R without the need for making any corrections. In particular, suppose we want to keep the corrections below 5%. What condition must hold in order that the correction $V_A$ for circuit A be less than 5% of $V_C$? Use your result from Part 2a to write an equation that involves $R$, $I_{FS}$ and the meter sensitivity. Similarly, find a formula (involving $R$, $V_{FS}$ and $S_V$) that expresses the conditions under which the correction $I_V$ in circuit B is less than 5% of $I_C$. These results will be used in Part 3 below.

3. In this section you are to use VOM’s to check the linearity of a 100 kΩ, 10% resistor, by plotting I as a function of V. Choose the appropriate circuit (A or B) and use the equations you derived above to be sure there is at most a 5% correction to the measured value of R (you may ignore this correction). Make a graph in your notebook with a horizontal axis for V that goes from 0 – 20 volts, and a vertical axis on the left that goes from 0-220 µA. Label a vertical axis on the right for R that goes from 0 to 110 kilo-ohms. Measure the current for a few widely spaced points along the V axis and plot the I values. Also plot $R = V/I$ at the same V value using a different symbol or color and the right axis. Fill in additional points as seem necessary to determine the behavior. Is the resistor linear? (i.e., does it obey Ohm’s law $V=IR$ for a constant value of R? Do you see why this is called “linear” behavior?)

Now do the same for an incandescent light bulb filament. The resistance will be about ten ohms, so choose the appropriate circuit and make sure your errors won’t be over 5%. You can plot your points on the same graph, just use the left scale as mA instead of µA and the right scale as ohms instead of kΩ. Don’t exceed 14 volts or 120 mA. Be sure to fill in extra points where the behavior is changing rapidly. The brightness of the filament is an indication of its temperature. What happens to the resistance of the filament as the temperature increases? (This is a common behavior of nearly pure metals.)

4. (Extra credit) In this section we will measure the input impedance ($R_I$) of a Model 175 DMM. First, connect the DMM across the output of the power supply and measure the output voltage. Then insert a resistance box in series with the DMM and adjust R until the reading of the DMM drops by a factor of two. Since the meter measures the voltage drop across its input terminals and since the power supply produces a constant voltage, we conclude that at this point the voltage drop across R is equal to the voltage drop across the meter, and thus $R_I = R$. Measure $R_I$ for three different scales (2V, 20V, 200V) to determine whether the input impedance depends on the range setting of the DMM. Record in your notebook the model number of the DMM you are using. This method is useful for measuring the input impedance not only of voltmeters but of other circuits as well.