Week 1

Experiment 3
Ohm’s Law
The goals of Experiment 3 are:

- To identify resistors based upon their color code.
- To construct a two-resistor circuit using proper wiring techniques.
- To measure the DC voltages and currents in the circuit using a digital multimeter (DMM) with the highest precision possible for each measurement.
- To verify that Ohm’s Law is obeyed.

Modification to Experiment 3 in lab Manual:
- Color code of the “Unknown” resistor is Red Black Brown.
The wire supplied in the parts kit is 22 AWG gauge wire.

- A wire stripper is used to selectively remove (strip) the plastic insulation from the metal core so that you can insert the wire end into the breadboard and make electrical contact with the leaf springs.
> Insert about ¼” of wire into the hole labeled 20-22 on your wire stripper and clamp down on the handles of the stripper.
  > Note that the hole does not completely close.
  > Pull the stripper away from the spool of wire and a short (1/4”) strip of the insulation should be removed.
    * Do not twist the wire while you pull as the wire will either get cold worked and become brittle or be nicked as the insulation is removed.
      * Either way, the bare wire may break off in the breadboard.
      * NEVER try to remove a broken wire from the breadboard with the power cord pulled in.
Cut the desired length of wire needed to run the wire from the spool using the cutter on the stripper.

- Note that the two sides of this part of the stripper do close completely when the handles are clamped together.
- Repeat the previous process to remove $\frac{1}{4}$" of insulation from the newly cut end of the wire.
The first components that we will use in the experiments are (1) a dc voltage source and (2) resistors.

- The voltage source is integrated on the ANDY board.
  - Voltage (V) is the electromotive force that causes a current (I) to flow through a component such as a resistor (R).
- Resistors are discrete components that will be connected to the voltage source using the breadboard and wires.
  - Resistors limit the flow of electrical current from the voltage source.
  - The current that flows through the resistor produces a voltage drop across the resistor.
- This is Ohm’s Law.

\[ V = IR \]
Immediately above the upper left corner of the breadboard on the ANDY board are the power supply connections: +5V, +9V, ground (0V), and –9V.
Wiring Voltage Sources

- We typically wire:
  - +5V or +9V supply to one of the pins in the row labeled with a **red** + using **red** wire.
  - ground to one of the pins in the row labeled with a **blue** – using **black** wire.
    - This provides visual information on where hot (+5 or +9V voltages) and cold (ground) points are in the circuit.
    - This is a safety issue and your use of the appropriate color wires will be graded during each validation.
Resistors

- Each resistor has a power rating, which is the amount of energy per second that can be safely dissipated by the resistor.
  - The resistors that we have purchased for the kits can dissipate one-half watt.

- Resistors have specific values of resistance to current associated with them (nominal values).
  - The nominal value of resistors in our kit are given in a color code standardized by the Electronics Industries Association (EIA).

- They have a tolerance which means how close they are to the desired manufacturing value.
  - The resistors in our parts kit have a tolerance of 5%.
The box of resistors in the kit are called 5% resistors which means each value of resistor is spaced such that there is a spacing of +/- 5% from one nominal value to the next nominal value.

Values that we have are 10, 11, 12, 13, 15, 16, 18, 20, 22, and so on (you can read the full list at the back of the lab manual in Appendix A).

- The two digits are given by the first two colors of the code.
- These two digits are then multiplied by a factor (multiplier).
- The difference between the color code for a 10 ohm resistor and a 10 mega ohm resistor depends on the 3rd color band in the color code.
# 4 Band Color Code

The image shows a 4 band color code table used in electrical engineering, particularly for resistors. The table provides a color code system to indicate the resistance value and tolerance of resistors.

### Standard EIA Color Code Table 4 Band: ±2%, ±5%, and ±10%

<table>
<thead>
<tr>
<th>Color</th>
<th>1st Band (1st figure)</th>
<th>2nd Band (2nd figure)</th>
<th>3rd Band (multiplier)</th>
<th>4th Band (tolerance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0</td>
<td>0</td>
<td>10^0</td>
<td>-</td>
</tr>
<tr>
<td>Brown</td>
<td>1</td>
<td>1</td>
<td>10^1</td>
<td>-</td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
<td>2</td>
<td>10^2</td>
<td>±2%</td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
<td>3</td>
<td>10^3</td>
<td>-</td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
<td>4</td>
<td>10^4</td>
<td>-</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
<td>5</td>
<td>10^5</td>
<td>-</td>
</tr>
<tr>
<td>Blue</td>
<td>6</td>
<td>6</td>
<td>10^6</td>
<td>-</td>
</tr>
<tr>
<td>Violet</td>
<td>7</td>
<td>7</td>
<td>10^7</td>
<td>-</td>
</tr>
<tr>
<td>Gray</td>
<td>8</td>
<td>8</td>
<td>10^8</td>
<td>-</td>
</tr>
<tr>
<td>White</td>
<td>9</td>
<td>9</td>
<td>10^9</td>
<td>-</td>
</tr>
<tr>
<td>Gold</td>
<td></td>
<td></td>
<td>10^{-1}</td>
<td>±5%</td>
</tr>
<tr>
<td>Silver</td>
<td></td>
<td></td>
<td>10^{-2}</td>
<td>±10%</td>
</tr>
</tbody>
</table>

The color bands represent the resistance value, and the tolerance is indicated by the last band. The color codes are as follows:

- **Red**: 2
- **Brown**: 1
- **Green**: 5
- **Gold**: 10^{-1}
- **Silver**: 10^{-2}
- **Black**: 0
- **Brown**: 1
- **Orange**: 3
- **Yellow**: 4
- **Green**: 5
- **Blue**: 6
- **Violet**: 7
- **Gray**: 8
- **White**: 9
- **Brown**: 1
- **Orange**: 3
- **Yellow**: 4
- **Green**: 5
- **Blue**: 6
- **Violet**: 7
- **Gray**: 8
- **White**: 9
- **Gold**: 10^{-1}
- **Silver**: 10^{-2}

The tolerance values are ±2%, ±5%, and ±10% respectively for the 4, 3, and 2 band codes.
Note that the color bands are somewhat skewed on the surface of the resistor. So the first band that starts closest to the lead or the end of the resistor, is the first band of the nominal value.

First 2 bands are the two digits for the numeral value of the resistor (10 through 91).

The third band tells you the multiplier and the 4th band on the resistor is the tolerance value.

All of our resistors are 5%, which means that the 4th band will always be gold.
Examples of Color Code

- When you read off the values, the first 2 bands form a number between 10 and 91 and that 10 through 91 is then multiplied by the third band.
- If you happen to have a “orange black orange” for your first through third bands, the value of the resistor is $30 \times 10^3$ ohms or, as is more traditionally written, 30 kΩ.
- If the color were “blue red yellow” for the first through third bands, the resistor would be $62 \times 10^4$ ohm resistor (620 kΩ or 0.62 MΩ).
To Make a Resistance Measurement

- Resistance measurements are made by connecting the DMM probes across the resistor when no voltage is applied to the resistor - the ANDY board power must be off.
  - Either place the tips of your probes at the two ends of the resistor, holding the resistor against the tips with your hands or use either the IC hooks or alligator clip probes to clamp the ends of the probe to the ends of the resistor.
  
  or

  - Place the resistor into the breadboard (select two holes that are not connected by the metal strip under the breadboard), then insert a short length of wire that has been connected to the cables with the probe tips, the IC hooks, or alligator clips into adjacent holes on the breadboard to make the measurement across the component.
    - Again, set the scale to the maximum and then decrease the scale until you have obtained the highest resolution measurement.
    - Resistance measurements should not be made on resistors that are wired into a circuit as the measurement will also include the effect of the other components in the circuit.

The measurement shown on the right may not be correct if the black and red wires are connected to other components.
Setting up the DMM for Voltage Measurements

- The digital multimeter that we have can make AC (alternating current) and DC (direct circuit) measurements of voltage. In Experiment 3, DC measurements are required.
  - Place the banana jacks into the DMM such that the red cable is connected into the V/Ω/T plug and the black cable is connected into the COM plug.
  - Move the dial to V—, which selects a DC voltage measurement.
    - Initially set the scale to the maximum and then reduce it until you obtain the highest resolution measurement (i.e., right before you reach an overflow condition.
    - There are hotlinks in the report template for Experiment 3 with video demonstrations on how to perform the voltage measurements.
Two other types of probe tips
- IC hooks/mini-grabbers, which can be used to attached to wires and the leads on components
  - Shown on the upper right
- Alligator clips, which can clamp onto wires, components, and grounds.
  - However, they have larger uninsulated metal tips that can easily short to other parts of the circuit so use with caution.
  - Shown on the lower right
Voltage measurements are made by connecting the probes to two points in the circuit with the power to the ANDY board on and all components are wired into the circuit including ground.

- The measurements can be:
  - Between the voltage supply and ground to determine the actual value of the voltage supplied to the circuit.
  - Across a single resistor to determine the voltage drop across it.
  - From a node to ground to determine the node voltage, which should match the expected value from PSpice.
  - Across any two nodes to determine the voltage difference between the two node voltages.
Setting up the DMM for Current Measurements

- The red probe on the DMM must be moved from the V/Ω/T plug to the 10A or mA plug.
  - Best practice is to move it first to the 10A plug.
    - However, none of our circuits should ever have more than 100 mA flowing through them at any point in time. Therefore, it is acceptable if you connect the red probe directly into the mA plug.
    - The black probe remains in the COM plug.

- Select the **A** range for DC current measurements.
  - As usual, work your way from the maximum range to the lowest possible to obtain the highest resolution measurement.
To Make a Current Measurement

- Current must flow into the DMM for the measurement to be made. Therefore, you must break the circuit at the point where you want to measure the current and insert your DMM into the circuit.
  - For example, to measure the current flowing through R1, you must break the circuit immediately after R1, before it connects to R2. Insert the current meter into the circuit and then measure the value of the current.
    - Note the black probe on the current meter is connected to R2, which is where you expect the current to be flowing towards as it leaves R1, based upon the position of the arrow head in the upper diagram.
Generally, the red probe is connected to the side of the circuit that has the voltage supply attached and the black probe is connected to the side of the circuit that has the ground connection.

- If the placement of the red and black probes are switched, the magnitude of the current measurement will remain the same, but the sign will be negative.
The DMM can be damaged if:

- **A voltage measurement is made while the red probe at the DMM is connected to either the 10A or mA plug.**
  - Subsequent voltage measurements may be made accurately after the probe is moved, but the current measurements will likely all be 0A.
  - The fuse on the current measurement side of the DMM should be replaced. Instructions on how to do this are posted at [http://www.opel.ece.vt.edu/reference/DMM.html](http://www.opel.ece.vt.edu/reference/DMM.html)

- **AC voltage or current range (V~ or A~) is selected instead of the DC range.**
  - The measurement displayed will be zero.
  - The fuse on the voltage measurement side of the DMM may need to be replace if subsequent measurements are always 0 (doesn’t matter what type of measurement).

- **A resistance measurement is made while the resistor is connected to a circuit with the power on.**
  - The fuse on the voltage measurement side of the DMM may need to be replace if subsequent measurements are always 0 (doesn’t matter what type of measurement).

**Note:** There are 5 replacement fuses in the parts kit. Blowing the fuse on the current measurement side happens frequently. Be careful!!!

If you run out of fuses, Radio Shack, Lowes, Ace Hardware, etc. usually carry the same type of fuse.
Differences

Schematic

Construction
Circuit Construction

- Never make a connection between the voltage supply and ground directly to complete the circuit.
- This is done internally on the ANDY board in the printed circuit board (PCB – the green area with the traces). Therefore, point C and point B shown on the circuit schematic in the lab manual are actually physically the same place; no wire is placed between ground and the +9V supply.
- When you construct the circuit in Experiment 3,
  - Connect a wire from the +9 volt supply from the ANDY board to one of the red rows on the breadboard.
  - Connect a wire from the ground on the ANDY board to one of the blue rows on the breadboard.
  - Wire the resistors, R1 and R2, in series.
  - Use a wire jumper to connect the +9V supply from the red row to one end of R1.
  - Use a wire jumper to connect the ground from the blue row to one end of R2.
  - Plug in the ANDY board to activate the board.

- You are now ready to make the voltage and current measurements described in the Experimental Procedure.