RESISTANCE & OHM’S LAW

Objectives:
• To understand the relationship between potential and current in a resistor and to verify Ohm’s Law.
• To understand simple parallel and series circuits and to use this understanding to determine the circuit connections of a hidden “black box” resistor network.
• To make the connection between resistance, current, voltage, and power dissipation.

Equipment: Digital multi-meters(2 per group)(DMM for short), variable power supply, breadboard, resistors, LED's of different colors. A multi-meter is a device that can be used as a voltmeter, an ammeter, or an ohmmeter.

Background: Electric resistance, $R$, is defined by:

$$R = \frac{V}{i}, \quad (1)$$

where $V$ is the potential difference across the resistor and $i$ is the current through it. The unit of resistance is the Ohm, 1 $\Omega = 1$ V/A. If $R = 0$ in a circuit, it is called a "short" circuit; if $R = \infty$, it is called an “open” circuit.

The product $P = iV = i^2 R = \frac{V^2}{R}$ is the power dissipated in the resistor.

Ohm's Law: For some devices, such as a light bulb, $R$ increases as the current increases. But for many materials $R$ is a constant, independent of $i$ and $V$. The linear relationship between $V$ and $i$, $V = iR \quad [R = \text{constant}]$ is called Ohm's Law. Materials obeying Ohm’s Law are said to be "ohmic" materials.

Equivalent Resistance: When several resistors are connected together, they can usually be replaced with a single resistor that will have the same potential drop and draw the same current as the combination of resistors. This resistance is called the equivalent resistance of the circuit.

Resistors in Series:

$$R_{eq} = \sum_i R_i \quad (2)$$

When the same current flows through each of a number of resistors, they are said to be in series. The equivalent resistance $R_{eq}$ for resistors connected in series is
Note that $R_{eq}$ is larger than any of the individual resistances.

**Resistors in Parallel**

![Figure 2. Parallel Connections](image)

When the same potential difference appears across each of a number of resistors, they are said to be in parallel. The equivalent resistance $R_{eq}$ for resistors connected in parallel is

$$\frac{1}{R_{eq}} = \sum_{i} \frac{1}{R_i}$$  (3)

Note that $R_{eq}$ is smaller than any of the individual resistances.

**Electrical Measurements:** A voltmeter is a device to measure the potential drop across a circuit. It has a very large resistance so that the current through it is negligible, and it can be assumed that the potential drop across the resistor in Fig. 6a is the same whether or not the voltmeter is attached. A voltmeter is always connected in parallel with the circuit element whose potential difference is to be measured.

An ammeter is a device to measure the current through a circuit element. It has a very small resistance so that the potential drop across is negligible, and it can be assumed that the current through the resistor in Fig. 6b is the same whether or not the ammeter is inserted in the circuit. An ammeter is always connected in series with circuit element whose current is to be measured.
An ohmmeter is a device that measures resistance. It is connected in parallel across the resistance with one of the leads from the resistor to the rest of the circuit unattached.

**Activity 1: Ohms' Law.** You will measure an unknown resistance in two ways and verify that Ohm’s Law applies:

A. Use a ohmmeter to measure the resistance. See if the measured resistance remains the same if the leads to the ohmmeter are reversed.

B. Connect an ammeter in series with the resistor and a voltmeter in parallel with it as shown below, i.e. use two multi-meters in the circuit. Use a variable output power supply to drive the circuit. As the output voltage is increased, measure \( i \) and \( V \). To determine the resistance and verify Ohm’s Law, use CricketGraph to plot \( V \) versus \( i \) for a number of different voltage settings, make a straight line fit to the data and obtain the correlation coefficient. [What is the significance of the slope of the straight line fit?]

![Figure 6a Voltmeter Connection](image)

![Figure 6b Ammeter Connection](image)

**Activity 2: Light emitting diode(LED) - non-Ohmic behavior.** As an example of device which does not obey Ohm's law, you will investigate an LED.

A. Make a circuit by connecting a 100 ~ 200 ohm resistor in series with an LED. The resistor is put in to prevent burning out the LED. Connect a voltmeter across the resistor and measure the voltage across the resistor for several values of supply voltage settings(keep it to be less than 5V). At what value of current does the LED emit light, if it emits light? Now reverse the leads from the power supply and repeat the measurement of current in the same range of voltage setting. Compare your observations with what you would expect for Ohmic behavior.

B. Try another diode with a different color. What do you think determines the color? (you are not expected to know the answer to this question).
Activity 3: Back to Ohmic resistors. For this activity you will use three resistors -- two with the same resistance and one with a different resistance (10 kΩ, 10 kΩ, and 20 kΩ, for example).

A. Determine all possible ways you can connect the resistors in series and/or parallel to give different equivalent resistances. Draw a diagram of each of these combinations, and calculate the theoretical equivalent resistance.

B. Set up two of the circuits in A on the breadboard and measure the actual equivalent resistance with a ohmmeter and compare with your calculation.

C. Calculate the power dissipated by each resistor in the two circuits in B if a 12 V power supply is connected across the circuit.

Appendix: Resistors are coded with four colored stripes around the body of the resistor that allow easy determination of the resistance. The code is given below:

RESISTOR COLOR CODES

<table>
<thead>
<tr>
<th>COLOR</th>
<th>1ST DIGIT</th>
<th>2ND DIGIT</th>
<th>MULTIPLIER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>0</td>
<td></td>
<td>10^{-2}</td>
</tr>
<tr>
<td>Gold</td>
<td>1</td>
<td></td>
<td>10^{-1}</td>
</tr>
<tr>
<td>Black</td>
<td>2</td>
<td></td>
<td>10^{0}</td>
</tr>
<tr>
<td>Brown</td>
<td>3</td>
<td>1</td>
<td>10^{1}</td>
</tr>
<tr>
<td>Red</td>
<td>4</td>
<td>2</td>
<td>10^{2}</td>
</tr>
<tr>
<td>Orange</td>
<td>5</td>
<td>3</td>
<td>10^{3}</td>
</tr>
<tr>
<td>Yellow</td>
<td>6</td>
<td>4</td>
<td>10^{4}</td>
</tr>
<tr>
<td>Green</td>
<td>7</td>
<td>5</td>
<td>10^{5}</td>
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<tr>
<td>Blue</td>
<td>8</td>
<td>6</td>
<td>10^{6}</td>
</tr>
<tr>
<td>Violet</td>
<td>9</td>
<td>7</td>
<td>10^{7}</td>
</tr>
<tr>
<td>Gray</td>
<td>0</td>
<td>8</td>
<td>10^{8}</td>
</tr>
<tr>
<td>White</td>
<td>1</td>
<td>9</td>
<td>10^{9}</td>
</tr>
</tbody>
</table>

The fourth colored band gives the "tolerance," i.e., the uncertainty in the marked resistance, as follows:
gold: ± 5%   silver: ± 10%   no color: ± 20%

Example:
Helpful Hint: Most people who get incorrect results in this experiment do so because they fail to use the multi-meter correctly. Make sure the multi-meter is reading ohms AND that the gain or sensitivity is at the maximum number of significant digits for that resistance. Change the sensitivity by trial and error the maximum number of digits.
RESISTANCE & OHM’S LAW

Name: _________________________________________________  Section: _______

Preliminary Questions:

You have three identical light bulbs with a constant resistance of 150 Ω. Suppose you connect the circuits to a 12 V battery.

(a) Draw diagrams showing all possible ways they can be connected in series and/or parallel. Rank the circuits as a whole in order of brightness (1 = brightest, 3 = dimmest).

(c) Within each circuit, rank according to the relative brightness. The more power dissipated in the bulb, the brighter it is.

(d) Qualitatively, how is the current passing through each bulb related to the brightness?
RESISTANCE & OHM’S LAW

Name: _________________________________________________ Section: _________
Partners: _______________________________________________ Date: ____________

Activity 1: Measure an unknown resistance and verify Ohm’s Law.

Ohmmeter reading = $R_{\text{unknown}} =$ _______ ______

What is the significance of the slope of the best fit line?

$R_{\text{unknown}} =$ _______ ______ $R^2$ ______

Are your data in agreement with Ohm’s Law? Explain.

Resistance determined from color code = $R_{\text{unknown}} =$ _______ ______ ± ______

How well does this value agree with your measured value?

Activity 2: Light emitting diode(LED) - non-Ohmic behavior.

A. the value of current when LED lights up: _______mA

Describe your observations which show non-ohmic behavior of LED.

B. What do you think determines the color?

Activity 3: Resistance combinations. Use the ohmmeter to measure the resistances of the three resistors you will use. Choose two of the resistances to be as closely the same value as possible and the other resistance to be at least twice as big.

$R_1 =$ _______ ______  $R_2 =$ _______ ______  $R_3 =$ _______ ______
A. Draw diagrams of all possible ways that you can connect these three resistances in series and/or parallel to give different equivalent resistances. For each diagram calculate the theoretical equivalent resistance (show your work) B. Set up two of the circuits and measure the actual value with an ohmmeter. C. Calculate the power dissipated by each resistor in the two circuits in B if a 12 V battery is connected across the circuit. [Not all entries are needed to be filled.]

<table>
<thead>
<tr>
<th>Circuit</th>
<th>$R_{eq}$ (theoretical)</th>
<th>$R_{eq}$ (experimental)</th>
<th>Power dissipated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>________________</td>
<td>________________</td>
<td>________________</td>
</tr>
<tr>
<td></td>
<td>diagram</td>
<td>work</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>________________</td>
<td>________________</td>
<td>________________</td>
</tr>
<tr>
<td></td>
<td>diagram</td>
<td>work</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>________________</td>
<td>________________</td>
<td>________________</td>
</tr>
<tr>
<td></td>
<td>diagram</td>
<td>work</td>
<td></td>
</tr>
</tbody>
</table>
Circuit 4  \( R_{eq} \) (theoretical) = _____________  ___

\( R_{eq} \) (experimental) = _____________  ___

Power dissipated = ______________  ___

diagram        work

Circuit 5  \( R_{eq} \) (theoretical) = _____________  ___

\( R_{eq} \) (experimental) = _____________  ___

Power dissipated = ______________  ___

diagram        work