Voltage, Current, and Resistance

Overview:
In this lab, you will study the relationship between the voltage applied across a conductor and the current flowing through the conductor for various types of conductors. You will also learn the color code for resistors and study series and parallel combinations of resistors.

Physics Principles:
The relationship between voltage and current

New lab skills:
Measuring voltage, current, and resistance
Determining resistance by reading color code

Equipment needed:
Circuit board
DC ammeter (0 – 30 amp)
Digital Multimeter (DMM)
A computer spreadsheet

1. Theory
Whenever a voltage is applied across a conductor a current flows through the conductor. In general, increasing the voltage across the conductor will increase the current flowing through the conductor. A graph relating the current \( I \) through a conductor and the voltage \( V \) across the conductor is called an \( I-V \) plot.

The ratio of the voltage to the current, \( V/I \), is called the resistance \( R \) of the conductor:

\[
R = \frac{V}{I},
\]

where

- \( I \) is the current through the conductor in amperes (A),
- \( V \) is the voltage across the conductor in volts (V),
- \( R \) is the resistance of the conductor in ohms (Ω).

If this ratio is a constant over reasonably wide ranges of voltage and current, the conductor is said to obey Ohm’s law. For the most materials, \( R \) is not a constant. That is, most materials do not obey Ohm’s law.

For some electrical devices, the resistance of the device depends upon which direction the current is flowing. A diode is an example of this. When current is flowing in one direction (the forward direction), the resistance is very low. When current is flowing in the opposite direction (the reverse direction), the resistance is very high (infinite). When an \( I-V \) graph is made for the current through a diode in the forward direction, a sharp break (knee) in
the curve is observed; see Figure 1. If the diode is a germanium diode, the break occurs between 0.2 and 0.3 volts. For silicon diodes, the break occurs between 0.6 and 0.7 volts. As shown in Figure 1, the reciprocal of the resistance (called the *dynamical resistance*, $R_d$) of the diode for a certain value of the current $I$ is the *slope* of the line tangent to the $I$–$V$ curve at that point:

$$\frac{1}{R_d} = \frac{\Delta I}{\Delta V}.$$  \hfill (2)

\begin{figure}[h]
    \centering
    \includegraphics[width=0.5\textwidth]{I-V_diode_graph.png}
    \caption{$I$–$V$ graph for a diode}
\end{figure}

**Color Code for Resistors**

The electrical resistance of resistors is often marked using colored bands painted on the resistor. The color of the bands and their sequence indicate the resistance of the resistor in units of ohms (Ω). As explained in Appendix A, the first and second bands give the first and second significant figures of the resistance. The third band gives the power-of-ten *multiplier*. The fourth band (if present) gives the *percent tolerance* of the resistor.

**Potentiometers**

A potentiometer (often called a *pot*) is a three-terminal resistive device. The center terminal is connected to a movable contact which sweeps across the material out of which the resistor is constructed. One usage of a potentiometer is as a variable resistance. The resistance between the central terminal and either of the other two terminals changes as the contact moves.

**Multimeters**

One of the simplest ways to measure resistance is to use a multimeter. A multimeter is an electrical instrument which is designed to measure volts, ohms, and amps. Which of these is measured at any given time depends upon the settings of the switches located on the front of the meter. To measure resistance the switch is set to the appropriate resistance range, and the element whose resistance is to be measured is placed across the two leads of the multimeter. The meter is then read. The value of the resistance is obtained by multiplying...
the meter reading by an appropriate factor. This factor is indicated by the switch setting on the front of the meter. If there is any question on the usage of the multimeter, ask the instructor.

CAUTION

Never attempt to measure the resistance of any resistor when the resistor is in a circuit which is connected to a voltage source. Attempting to make a resistance measurement under these conditions could burn out and destroy the ohmeter (or multimeter). Furthermore, the reading would not be accurate even if the ohmeter did not burn out. When a resistor is in a circuit, at least one end of it must usually be disconnected from the circuit before its resistance can be measured.

Schematic Symbols

In electrical circuit diagrams, electrical components are indicated by symbols. A few electrical symbols are shown in Appendix B. In an electrical drawing (called a schematic diagram), the components which constitute the electrical apparatus are shown connected with lines. The lines represent connecting wires, which have zero resistance.

Series Resistors

When resistors are connected as shown in Figure 2, the same current flows each one and the resistors are said to be connected in series. When resistors are connected in series, the equivalent resistance $R_{eq}$ of the series combination is the sum of the individual resistance:

$$R_{eq} = R_1 + R_2 + R_3 + R_4 + \ldots,$$

where $R_1$, $R_2$, etc. are the resistances of the individual resistors.

In terms of the circuit shown in Figure 2, the resistance between points A and C (indicated by $R_{AC}$) would be:

$$R_{AC} = R_1 + R_2$$
Similarly

\[ R_{BD} = R_2 + R_3 \]  

(5)

and \( R_{AD} \) (the equivalent resistance) is given by

\[ R_{AD} = R_1 + R_2 + R_3. \]  

(6)

**Parallel Resistors**

Resistors connected as shown in Figure 3 all have the same voltage drop, and are said to be connected *in parallel*. The equivalent resistance of the parallel combination, \( R_{eq} \), is given by

\[
\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots
\]

(7)

For the special case of just two resistors, this becomes

\[ R_{eq} = \frac{R_1 R_2}{R_1 + R_2}. \]  

(8)

![Figure 3: Parallel resistors](image)

**2. Instructions**

Start by turning the computer on. Double click on the Excel icon to open the spreadsheet. You will use Excel to analyze and graph your data.

**a. Ohm’s Law**

In this part of the experiment, you will examine the relationship between voltage \((V)\) and current \((I)\) for different circuit elements.

Examine the circuit board. On it are a 10 \( \Omega \) resistor, a light bulb, and a diode with a protective series resistor. Set up the resistor circuit as shown in Figure 4. In this circuit, the ammeter measures the current through the resistor. The voltmeter measures the voltage across the resistor. (*Hint:* First wire the circuit without the voltmeter. Then wire the voltmeter into the circuit.)
Voltage, Current and Resistance

Turn the power supply on. Make a graph of the current through the resistor as a function of the voltage across the resistor. Enter your data (current versus the voltage) into the spreadsheet and use the "Chart Wizard" to graph it. Plot voltage on the horizontal axis and the current on the vertical axis. Call this graph your Figure 1. Don’t print it yet; you will add to it.

Next you will examine the voltage-current relationship for the light bulb. Connect the light bulb circuit shown in Figure 5. Measure the voltage and the current through the light bulb and record your data into the spreadsheet. Plot the data on your Figure 1. This figure now shows the voltage-current relationship for the resistor as well as the light bulb. Answer Question 1.

The same procedure can be applied to examine the voltage-current relationship for the diode on your circuit board. Set up the circuit shown in Figure 6. Note that the positive lead from the power supply is connected to the end of the diode which is marked positive and that the voltmeter is connected across the diode ONLY. The current which flows when the voltage is applied in this direction is called a forward current.

Start at zero volts and increase $V$ in steps of about 0.1 volts to a maximum value of 0.80 volts. Make a graph of the forward current through the diode as a function of the voltage.
b. Resistance Measurements

In this part of the lab, you will determine the resistance of resistors using their color bands, and by a multimeter. All of your data should be recorded in Table 1.

The resistors come in numbered sets. Using the color code, sort the five color-coded resistors into ascending resistance values. Record the number of your set and the resistance values in Table 1. Note: The numbers are engraved on the back of the plastic on which the resistors are mounted. When expressing the values of your resistance use kΩ and MΩ rather than powers of 10.

Using the multimeter, measure the resistance of the same five resistors. Compare the measured values with the color band values, and calculate the deviation and the percent deviation for each resistor. Answer Question 3.

c. Potentiometers

In this part you will measure the resistance of a potentiometer for different settings of the potentiometer knob.

Place the potentiometer so that the rotatable shaft is up and the three terminals are toward you. Going from left to right, call the terminals A, B, and C. Using the multimeter, measure the resistance between the terminals for the various conditions shown in Table 2, and record in Table 2.

d. Resistors in Series

Select three resistors from the five, such that $R_1$ is about half $R_2$, and $R_2$ is about equal to $R_3$. Record the values of these resistors in Table 3. Connect the resistors as shown in Figure 2. Fill in Table 3, using the multimeter to make the resistance measurements.
e. Resistors in Parallel

Using the same three resistors you used in series circuit, measure various parallel combinations of the resistors as indicated in Table 4, and record in Table 4. Use the multimeter to make the resistance measurements. In this table, $R_1 \parallel R_2$ means resistor $R_1$ is in parallel with resistor $R_2$.

Answer Questions 5.
Question 1) In part (a), you examined the voltage-current relationship for a resistor and a light bulb. Did the resistor obey Ohm’s law? What about the light bulb? Explain your answers.

Question 2) From your Figure 2, use equation 2 to find the dynamical resistance, $R_d$, of the diode at the following points:

<table>
<thead>
<tr>
<th>$\Delta V$</th>
<th>point $V = 0.55$ V</th>
<th>point $V = 0.65$ V</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta I$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dynamic $R_d$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Question 3) For which resistors was the percent deviation of the measured values of the resistance within the percent tolerance given by the fourth color band?

<table>
<thead>
<tr>
<th>Resistance Measurements</th>
<th>Resistor Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Color of band 1</td>
<td></td>
</tr>
<tr>
<td>Color of band 2</td>
<td></td>
</tr>
<tr>
<td>Color of band 3</td>
<td></td>
</tr>
<tr>
<td>Color of band 4</td>
<td></td>
</tr>
<tr>
<td>Resistance from color code</td>
<td></td>
</tr>
<tr>
<td>Percent tolerance from color code</td>
<td></td>
</tr>
<tr>
<td>Resistance from multimeter</td>
<td></td>
</tr>
<tr>
<td>Deviation</td>
<td></td>
</tr>
<tr>
<td>Percent deviation</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 2

<table>
<thead>
<tr>
<th>Potentiometers</th>
<th>Resistance between terminals</th>
<th>Shaft fully clockwise</th>
<th>Shaft fully counter-clockwise</th>
<th>Result of rotating shaft clockwise (resistance increase, decrease, or same?)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A and C:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A and B:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B and C:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 3

\[
R_1 = \_\_\_\_\_\_\_\_\_\_\_\_\_
\]
\[
R_2 = \_\_\_\_\_\_\_\_\_\_\_\_
\]
\[
R_3 = \_\_\_\_\_\_\_\_\_\_\_\_
\]

<table>
<thead>
<tr>
<th>Resistors in Series</th>
<th>Resistance between points</th>
<th>Measured</th>
<th>Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>A and B:</td>
<td></td>
<td>XXX</td>
<td></td>
</tr>
<tr>
<td>B and C:</td>
<td></td>
<td>XXX</td>
<td></td>
</tr>
<tr>
<td>C and D:</td>
<td></td>
<td>XXX</td>
<td></td>
</tr>
<tr>
<td>A and C:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B and D:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A and D:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## TABLE 4

<table>
<thead>
<tr>
<th>Resistor combination</th>
<th>Measured $R_{eq}$</th>
<th>Calculated $R_{eq}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1 \parallel R_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_2 \parallel R_3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_1 \parallel R_3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_1 \parallel R_2 \parallel R_3$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Question 4) A resistor $R_1 = 50 \, \Omega$ is connected in parallel with resistor $R_2$ as shown below. For each case, what is the percent difference between the resistance $R_1$ and the equivalent resistance of the two parallel resistors? (Note: Divide the difference by 50 $\Omega$ and multiply by 100% to obtain the percent difference.) Show your calculations next to each figure.

What is your conclusion?
Question 5) A student claims: “In any parallel combinations of resistors, the equivalent resistance $R_{eq}$ is always less than the resistance of the smallest resistor in the parallel combination.” Is the student right or wrong? (Hint: Start with equation 8, and consider two resistors $R_1$ and $R_2$. Prove that the equivalent resistance is less than $R_1$. Now use the same proof for resistor $R_2$.)

*Note: A proof for some special case is not adequate!*