ENED 1020: Circuits Lab (Week 1)

Objectives

1. To learn the definitions, symbols, and units for current, voltage, and resistance.
2. To understand and apply the color code for resistors
3. To practice measuring resistance, voltage, and current
4. To verify Ohm's Law experimentally
5. To explore the properties of resistors connected in series
6. To verify experimentally Kirchhoff's Voltage Law and the Voltage Divider Rule for series circuits

A. About the Board:

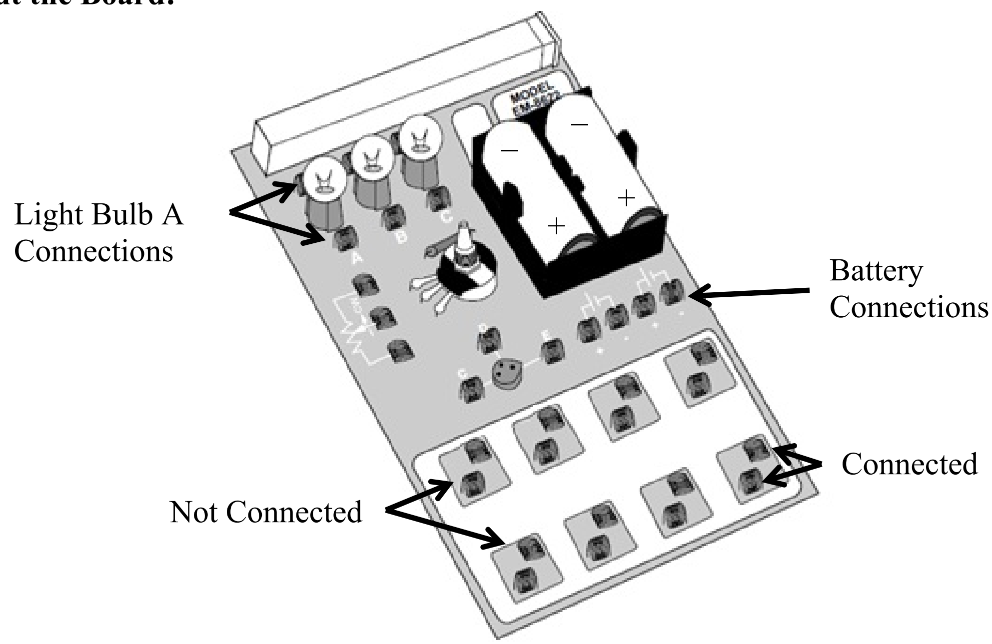


Figure 1: Basic Electricity Experiment Board

The board you will be using to conduct the basic electricity experiments is shown above. There are a few things you should know about the board as you are getting started.

1) While most of the diagrams throughout the these activity documents show two batteries, you will only need one. Make sure you insert the batter with the positive and negative sides in the position indicated above. You can access the positive and negative sides of the batter using the + and – springs just below the battery housing.
2) The pairs of springs at the bottom of the board can be used to construct the circuits described in the activities. The springs in each square are connected, so it does not matter which you use to create your circuit (this allows for different orientations of your components). Springs in different squares are not connected, and so you should place components between the squares.
3) The springs on either side of the light bulbs give you access to the two leads (i.e. + and – side) of the bulb.

B. Current, Voltage, and Resistance

Current

Current (I) is a measure of the flow rate of electrons through a circuit. Current is measured in amperes (A). A current of 1A corresponds to $6.242*10^{18}$ e^{-} flowing through a point in the circuit every second. Except in high power applications, currents are typically much smaller than 1 A and often measured in mA ($1*10^{-3}$ A) or µA ($1*10^{-6}$ A).

Voltage

Voltage (V) is a measure of the potential difference between two points in a circuit. A voltage of 1V means that 1 Joule (J) of energy is required to move 1 Coulomb (C) of charge between the two points in the circuit. Voltage is measured in volts (V).

Resistance

Resistance (R) is a measure of the opposition to the flow of current through a device or circuit. Resistance is measured in ohms (Ω). Oftentimes, resistance is large enough to be measured in kΩ ($1*10^{3}$ Ω) or even MΩ ($1*10^{6}$ Ω).

C. Resistor Color Code

Figure 2 shows a picture of a resistor as well as the symbol used for a resistor in a circuit diagram.

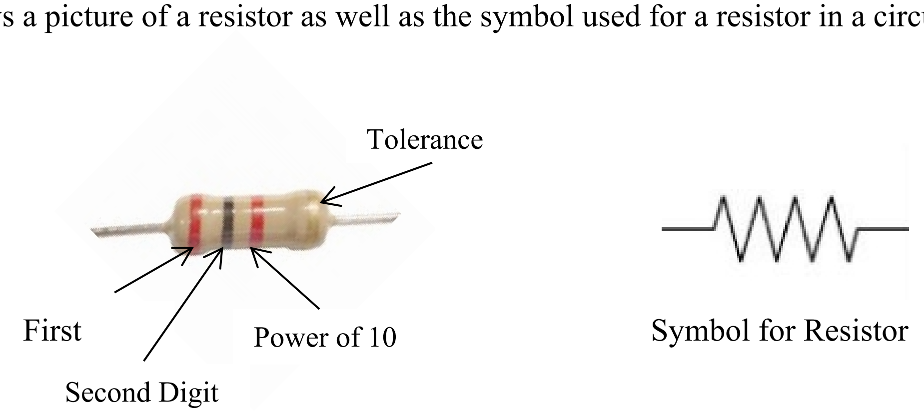


Figure 2: Resistor and Resistor Circuit Symbol

The colored bands on the resistor can be used to identify the resistance. Each color corresponds to a number as shown in Table 1.

Table 1: Resistor Color Code

Color Bands 1-3	Numerical Value		Color for 4th Band	Tolerance
Black	0		Missing	20%
Brown	1		Silver	10%
Red	2		Gold	5%
Orange	3			
Yellow	4			
Green	5			
Blue	6			
Violet	7			
Gray	8			
White	9			

The nominal value of the resistor can be determined from the color bands on the resistor:

$$\textbf{Nominal Value of R} = (\textbf{FirstDigit SecondDigit}) * \mathbf{10}^{\textbf{Power}}$$

The tolerance indicates how much the actual value of resistance can vary from the nominal value. The manufacturer's range for the resistor would then be:

$$\textbf{Range} = \textbf{Nominal Value} \pm \textbf{Tolerance} * \textbf{Nominal Value}$$

Example: Find the nominal value and range for the resistor shown in Figure 1.

Solution: The color bands on the resistors are: RED BLACK RED GOLD

Nominal Value: $(20)*10^2 = 2000\ \Omega = 2\ \mathrm{k}\Omega$.

Range: $2000 \pm 0.05*2000\ \Omega$ or $1900 – 2100\ \Omega$ or $1.9 – 2.1\ \mathrm{k}\Omega$.

Directions:

From your kit, choose three resistors that match the color bands indicated in Table 2. Calculate the nominal value and range for each of these resistors and enter the results into Table 2. Include a sample calculation for one of the three resistors. Measure each resistor and enter the measured values into the table. Indicate whether or not the measured value is in the expected range.

Sample Calculation:

R1:Nominal Value: (33)*10^1 = 330 Ω
Range: 330 ± 0.05*330 Ω
R2:Nominal Value: (56)*10^1 = 560 Ω
Range: 560 ± 0.05*560 Ω
R3:Nominal Value: (10)*10^2 = 1000 Ω
Range: 1000 ± 0.05*1000 Ω

Table 2: Resistor Color Code

	Band 1	Band 2	Band 3	Band 4	Nominal	Range	Measured	In Range?
R1	Orange	Orange	Brown	Gold	330	313.5~346.5	322.0	T
R2	Green	Blue	Brown	Gold	560	532~588	533	T
R3	Brown	Black	Red	Gold	1000	950~1050	985	T

Note: Keep these three resistors for the remainder of this lab.

D. Ohm's Law

Ohm's Law is one of the fundamental laws of circuits and states that voltage is the product of current and resistance:

$$\boldsymbol{V = IR} \qquad \begin{cases} \boldsymbol{V\ is\ voltage\ (volts, V)} \\ \boldsymbol{I\ is\ current\ (amps, A)} \\ \boldsymbol{R\ is\ resistance\ (ohms, \Omega)} \end{cases}$$

In this section of the lab, Ohm's law will be verified experimentally by wiring up a very simple circuit with a battery (voltage source) and a single resistor.

- *You will be using a multi-meter to measure voltage and to measure current.*
- ***Making these measurements incorrectly can cause damage to the multi-meter.***
- *Review the laminated handout included with the kit that provides a procedure for measuring voltage and a procedure for measuring current.*
- *If in doubt, ask your T.A. for assistance*

Directions:

1. Enter the measured values for your three resistors in Table 3. (Include units)
2. Select a D-cell Battery from the kit. Following the directions for measuring voltage, set the multi-meter up to measure voltage and measure the battery voltage (it should be approximately 1.5V). Record the voltage in the space above Table 3.
3. Insert the battery into the battery compartment paying close attention to where the positive and negative terminals go.
4. Applying Ohm's Law, calculate the current expected to flow through each of the three resistors and enter your calculated values into Table 3. (Include units utilizing powers of ten; that is, 2.45 mA is better than 0.00245 A)
   Sample Calculation:

$$\text{Calculated Current 1} = \frac{\text{voltage}}{\textbf{Measured Resistance 1}} = \mathbf{4.360mA}$$

$$\text{Calculated Current 2} = \frac{\text{voltage}}{\textbf{Measured Resistance 2}} = \mathbf{2.636mA}$$

$$\text{Calculated Current 3} = \frac{\text{voltage}}{\textbf{Measured Resistance 3}} = \mathbf{1.426mA}$$

5. Choose one of your three resistors and build the simple circuit shown in Figure 3 leaving the wire from the positive terminal of the battery unconnected from the resistor.
6. Following the directions for measuring current, set the multi-meter up to measure current. Connect the positive lead of the multi-meter to the positive terminal of the battery and the negative lead of the multi-meter to the unconnected side of the resistor.
7. Read the current on the multi-meter and record the measured current in Table 3. (Include units).
8. Calculate the % Error between measured and calculated current as follows:

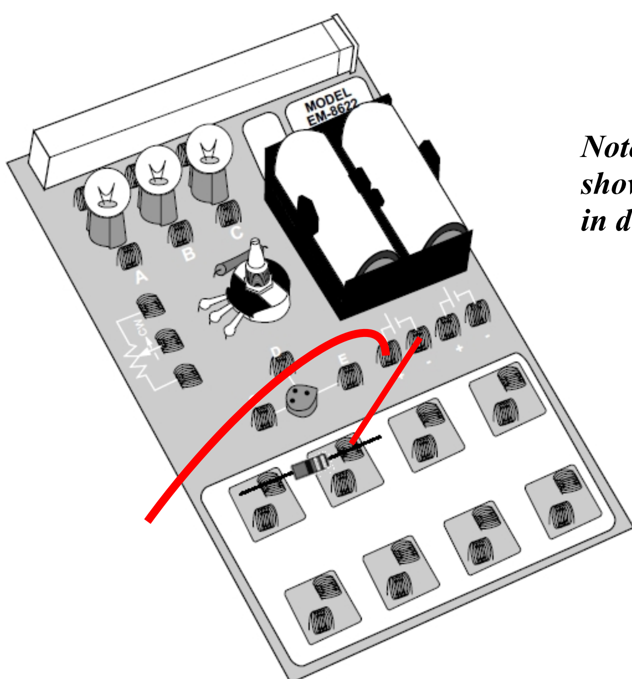
$$\%\ \textbf{Error} = \frac{|\textbf{Calculated Current} - \textbf{Measured Current}|}{\textbf{Calculated Current}} \cdot \mathbf{100\%}$$

Note: the % Error should be pretty small. If your errors are above 2%, re-check your calculations and your measurements.

Measured Battery Voltage: 1.405 V

Table 3: Ohm's Law

	Measured Resistance	Calculated Current	Measured Current	% Error
R1	322.0	4.360mA	4.300 mA	1.3%
R2	533.0	2.636 mA	2.600mA	1.4%
R3	985.0	1.426 mA	1.400 mA	1.8%



Note: Wires shown as RED in diagram

A standard incandescent light bulb, like the ones on your circuit board, consist of a thin strand of wire (called the filament) that, when a current is passed through, begins to glow. As more current flows through the filament, the light bulb will glow brighter.

Directions:

1. Choose one of the three light bulbs at the top of your circuit board and build the simple circuit shown in Figure 4, leaving the wire from the positive terminal of the battery unconnected from the light bulb.
2. Following the directions for measuring current, set the multi-meter up to measure current. Connect the positive lead of the multi-meter to the positive terminal of the battery and the negative lead of the multi-meter to the unconnected side of the light bulb.
3. Read the current on the multi-meter and record the measured current below. (Include units).

Measured Current though Light Bulb: _______162.0 mA______

4. Calculate the resistance of the light bulb by applying Ohm's Law:
Sample Calculation:

8.67

Calculated Resistance: _______8.67 Ohm______

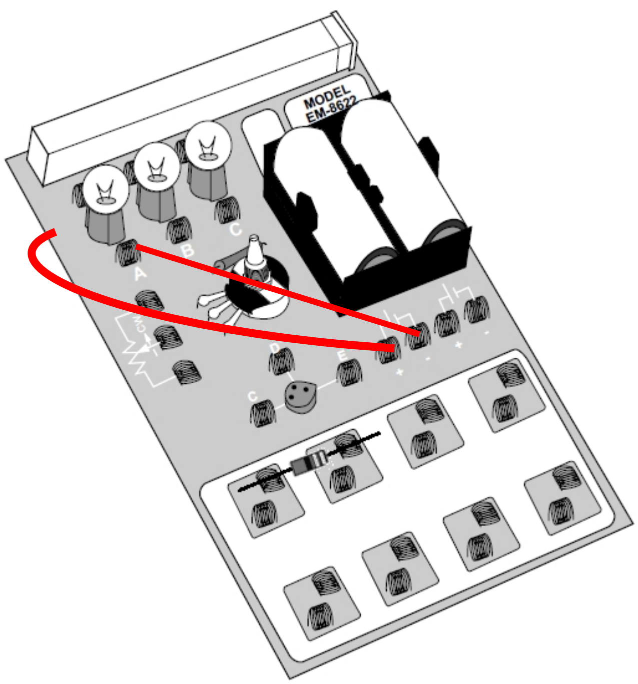


Figure 4: Experimental Set-Up for Light Bulb Test

E. Series Circuits

A circuit diagram with three resistors connected in series in shown in Figure 5.

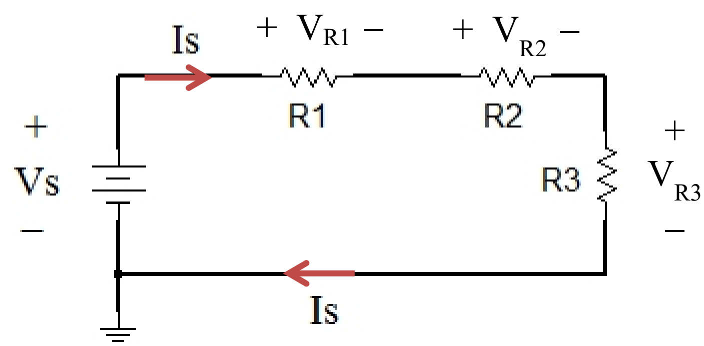


Figure 5: Series Circuit with Three Resistors

When resistors are in series, the current through each resistor must be exactly the same because every electron flowing through one resistor must flow through the next resistor and so on.

The total resistance is the sum of the individual resistances:

Total Resistance in Series Circuit: $$\mathbf{R_{Total} = \sum R_i = R_1 + R_2 + R_3 + \ldots}$$

The current through the series circuit (and through every resistor in the series circuit) can be determined through Ohm's Law:

Current in Series Circuit: $$\mathbf{I_s = I_{R_1} = I_{R_2} = I_{R_3} = \frac{V_s}{R_{Total}}}$$

The voltage drop across each resistor can be determined by applying Ohm's Law to each individual resistor or equivalently by applying the voltage divider rule:

Voltage Drop Across Resistors in Series (Ohm's Law): $$\mathbf{V_{R_i} = I_s \cdot R_i}$$

Voltage Drop Across Resistors in Series (Voltage Divider Rule): $$\mathbf{V_{R_i} = \frac{R_i}{R_{Total}} \cdot V_s}$$

When resistors are in series, the largest resistor will drop the largest voltage. In fact, if resistor R2 is three times the size of resistor R1 in a series circuit, we can conclude that the voltage drop across R2 will be three times the voltage drop across R1.
Kirchhoff's Voltage Law (KVL) is another fundamental law for understanding and analyzing circuits. Kirchhoff's Voltage Law states that the sum of all voltage drops and rises around any closed loop in a circuit must add to zero. Applying Kirchhoff's Voltage Law to the circuit in Figure 3:

KVL for Series Circuit in Figure 3: $$\mathbf{V_s - V_{R1} - V_{R2} - V_{R3} = 0}$$

In this section of the lab, the behavior of series circuits will be explored and Kirchhoff's Voltage Law will be verified experimentally by wiring up a simple series circuit with a battery (voltage source) and three resistors.

- *You will be using a multi-meter to measure voltage and to measure current.*
- ***Making these measurements incorrectly can cause damage to the multi-meter.***
- *Review the laminated handout included with the kit that provides a procedure for measuring voltage and a procedure for measuring current.*
- *If in doubt, ask your T.A. for assistance*

Directions:

1. Using your three resistors, wire the circuit shown in Figure 6 leaving the wire between the positive terminal of the battery and the first resistor disconnected.
2. Using the measured values for each of the resistors, calculate the expected total resistance for the resistors connected in series. Enter your calculated value into Table 4.
3. Now, ***set up the multi-meter to measure resistance*** and measure the total resistance by connecting the multi-meter across all three resistors.
4. Using your measured total resistance and your measured battery voltage, calculate the expected current flow through the series circuit by applying Ohm's Law. Enter the calculated value into Table 4.
5. Now, ***set up the multi-meter to measure current*** and insert the meter into the circuit between the positive terminal of the battery and the unconnected end of the first resistor. Measure the current and record the measured value in Table 4.
6. Remove the multi-meter from the circuit.
7. Using your measured current and measured resistor values, apply Ohm's Law to each of your resistors to determine the expected voltage drop across each resistor. Enter these calculations into Table 4.
   Sample Calculation:

$$\begin{aligned}
\text{expected voltage 1} &= \boldsymbol{meauserd\ current} * \boldsymbol{measured\ R1} = \mathbf{0.248V} \\
\text{expected voltage 2} &= \boldsymbol{meauserd\ current} * \boldsymbol{measured\ R2} = \mathbf{0.410V} \\
\text{expected voltage 3} &= \boldsymbol{meauserd\ current} * \boldsymbol{measured\ R3} = \mathbf{0.758V}
\end{aligned}$$

8. Using your measured value for total resistance, measured values for the resistors, and measured battery voltage, apply the voltage divider rule to calculate the expected voltage drop across each resistor. Enter these calculations into Table 4.
Sample Calculation:

Voltage Divider Rule:
$V1 = \mathbf{measured\ battery\ votage * measured\ R1/measuredtotal = 0.248V}$
$V2 = \mathbf{measured\ battery\ votage * measured\ R2/measuredtotal = 0.411V}$
$V3 = \mathbf{measured\ battery\ votage * measured\ R3/measuredtotal = 0.759V}$

9. Connect the first resistor to the positive terminal of the battery to establish current flow.
10. ***Set up the multi-meter to measure voltage.***
11. Measure the voltage drop across each resistor and record the values in Table 4.
12. Using your measured voltages, verify Kirchhoff's Voltage Law.
Verification of Kirchhoff's Voltage Law:

$$V_s - V_{R_1} - V_{R_2} - \ldots = 0$$

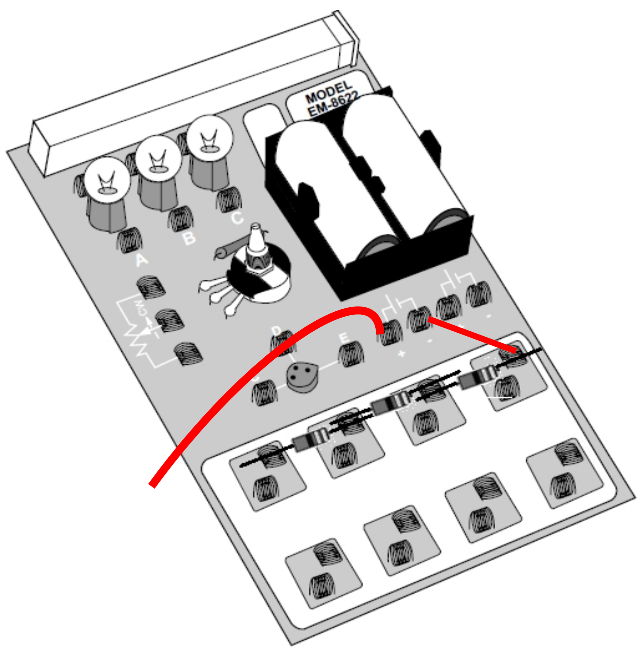


Figure 6: Experimental Set-Up for Series Circuit

Table 4: Series Circuits

Measured Resistances			Calculated Total Resistance	Measured Total Resistance	Calculated Current	Measured Current	% Error
R_1	R_2	R_3					
322	533	985	1840	1824	0.7636	0.77	0.8%

Resistor	Calculated Resistor Voltages (Ohm's Law)	Calculated Resistor Voltages (Voltage Divider Rule)	Measured Resistor Voltages	% Error
R_1	0.248	0.248	0.245	1.2%
R_2	0.410	0.411	0.410	0
R_3	0.758	0.759	0.750	1.05%

Just as we can connect resistors in series, we can also connect other circuit elements, like light bulbs, in series. Follow the directions below to connect two of the light bulbs on the circuit board in series.

Directions:

1. Choose two of the three light bulbs at the top of your circuit board and build the simple circuit shown in Figure 7.
2. Make a note the brightness of the light bulbs compared to how bright the single light bulb was from part C. What do you think causes this?
   Observations:

B is brighter. Because the resistance of B is larger.

3. Disconnect the wire connected to the positive terminal of the battery from the light bulb. Unscrew one of the light bulbs and reconnect the circuit. What happens? Make a note.
   Observations:

B is much brighter than before.

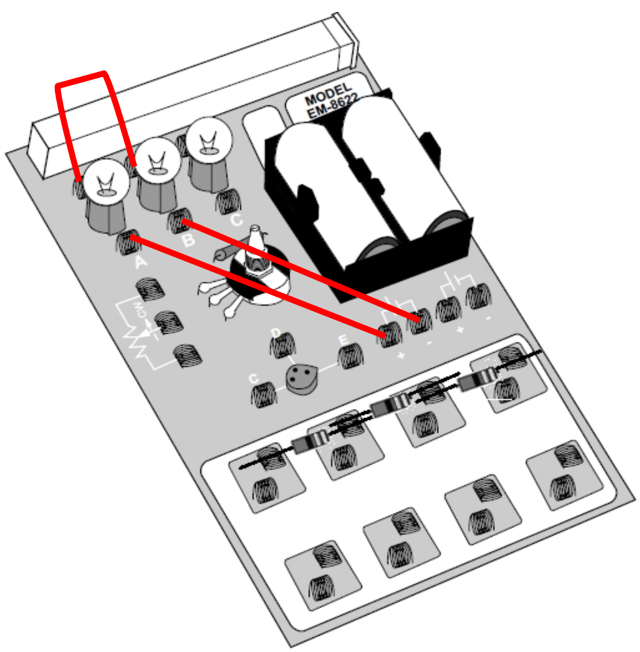


Figure 7: Experimental Set-Up for Series Light Bulb Test