*University ☺f P☺rtland*
*Sch☺☺l ☺f Engineering*

# EE 271–Electrical Circuits Laboratory
# Fall 2016

# <u>Lab Experiment #1: Ohm's Law and Kirchhoff's Laws</u>

# Ohm's Law and Kirchhoff's Laws

## I. Objective

In this experiment, the student will learn how to read resistor color codes and how to measure voltage, current, and resistance with the digital multimeter (DMM). The student will also build circuits and take measurements to verify Ohm's law, Kirchhoff's laws, and the conservation of energy.

## II. Background: Resistor Color Codes

Standard resistors are labeled with a color code which indicates their resistance values. The value indicated by each color band is listed in Tables 1, 2, and 3, and the resistor's value can be computed by the following equation:

$$R = \left[ \left( \text{1st Digit} \right) \times 10 + \left( \text{2nd Digit} \right) \right] \times \left( \text{Multiplier} \right)$$

Consider a resistor that has the following color bands: brown, green, orange, and silver. We first recognize that the silver band must be the tolerance band since the 1st Digit cannot be silver (see Tables 1 and 2). So the brown band must be the 1st band, which indicates that the value of the 1st Digit equals 1 (see Table 2). The second band, then, is green, which indicates that the value of the 2nd Digit equals 5 (see Table 2). The multiplier band is orange which indicates a value of 1 k (see Table 3). So the value of this resistor is $R = \left[ (1) \times 10 + (5) \right] \times 1\text{k} = 15 \ \text{k}\Omega$. Furthermore, the silver tolerance band indicates that the actual value of the resistance might deviate by $\pm 10\%$ (see Table 1).

A resistor with the bands red, violet, red, gold, would have a value of $R = \left[ (2) \times 10 + (7) \right] \times 100 = 2700 \ \Omega = 2.7 \ \text{k}\Omega$ with a tolerance of $\pm 5\%$.

A resistor with the bands orange, orange, brown, gold, would have a value of $R = \left[ (3) \times 10 + (3) \right] \times 10 = 330 \ \Omega$ with a tolerance of $\pm 5\%$.

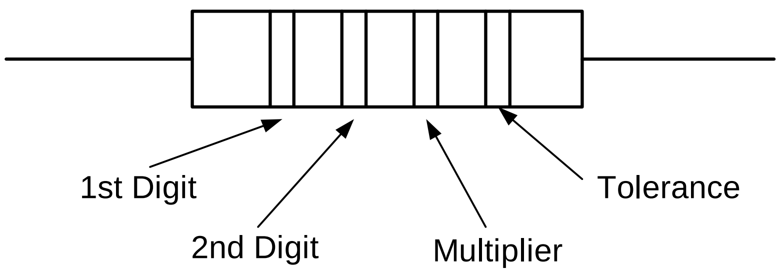


Figure 1. Resistor with 4 color bands.

Table 1. Tolerance band.

| Color | Tolerance |
|---|---|
| Red | 2% |
| Gold | 5% |
| Silver | 10% |
| none | 20% |

Table 2. 1st and 2nd digits.

| Color | Value |
|---|---|
| Black | 0 |
| Brown | 1 |
| Red | 2 |
| Orange | 3 |
| Yellow | 4 |
| Green | 5 |
| Blue | 6 |
| Violet | 7 |
| Gray | 8 |
| White | 9 |

Table 3. Multiplier band.

| Color | Value |
|---|---|
| Silver | 0.01 |
| Gold | 0.1 |
| Black | 1 |
| Brown | 10 |
| Red | 100 |
| Orange | 1 k |
| Yellow | 10 k |
| Green | 100 k |
| Blue | 1 M |
| Violet | 10 M |
| Gray | 100 M |

## III. Procedure

## PART 1: Ohm's Law

**1(a)-Pre-lab Assignment:** Determine the color code for a 10 kΩ resistor with 5% tolerance. For the circuit shown in Figure 2, calculate the theoretical value of the current $I$ (that is, $I_{th}$). Calculate the power absorbed by the resistor ($P_R$) and the power supplied by the voltage source ($P_S$). Show your work. Present all your results in table format using the appropriate tables provided. (You need to provide the following tables in your lab notebook to summarize your pre-lab calculation results.) The resistors we will use in the lab can safely handle 0.25 W. Is it safe to use a 0.25 W resistor for this circuit? State why. Is the conservation of energy satisfied in this circuit? State why.

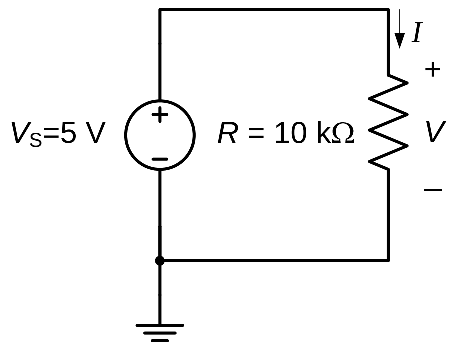


Figure 2. A simple resistive circuit.

Table 4. Color code for the 10 kΩ resistor (Figure 2 circuit).

| First | Second | Third | Fourth |
|---|---|---|---|
| | | | |

Table 5. Theoretical resistor, voltage and current values (Figure 2 circuit).

| $R_{th}$ (kΩ) | $V_{th}$ (V) | $I_{th}$ (mA) |
|---|---|---|
| 10 | | |

Table 6. Power values calculated (Figure 2 circuit).

| $P_R$ (mW) | $P_S$ (mW) | Safe or not? | Energy conserved? |
|---|---|---|---|
| | | | |

**1(a)-Lab Experiment:**

Provide the following table in your lab notebook including the measurements and calculated values related to the circuit shown in Figure 2.

Table 7. Theoretical and measured resistor, voltage and current values (Figure 2 circuit).

| $R_{th}$ (kΩ) | $R_m$ (kΩ) | $V_{th}$ (V) | $V_m$ (V) | $I_{th}$ (mA) | $I_{pr}$ (mA) | $I_m$ (mA) |
|---|---|---|---|---|---|---|
| | | | | | | |

Get a 10 kΩ resistor and measure its actual value by connecting it to the DMM and setting the DMM to DC mode to read resistance. Compute the % error of the resistance value as follows: $\boxed{\%\ \text{error} = \frac{R_{\text{theoretical}} - R_{\text{measured}}}{R_{\text{theoretical}}} \times 100}$ where $R_{\text{theoretical}} = 10\ k\Omega$. Is the % error less than the tolerance specified by the tolerance color band?

Table 8. Percentage error in the actual value of the 10 kΩ resistor (Figure 2 circuit).

| $R_{th}$ (kΩ) | $R_m$ (kΩ) | % error | Less than tolerance value? |
|---|---|---|---|
| 10 | | | |

Construct the circuit shown in Figure 2 using the 5-volt supply in your lab kit (the red terminal). Set the DMM to DC mode and use it to measure the actual values of the voltage $V$ and the current $I$ (represented by $V_m$ and $I_m$). Be very careful to avoid setting your DMM to measure current while it is connected to the power supply or it will short out the power supply and burn up the fuse in the DMM!

Compare the measured value of $I$ to the theoretical value from the pre-lab using percent error as follows: $\boxed{\%\ \text{error} = \frac{I_{\text{theoretical}} - I_{\text{measured}}}{I_{\text{theoretical}}} \times 100}$. If the theoretical and measured values for the current $I$ differ, explain why.

Now calculate the value of the current $I$ predicted by Ohm's law using the **measured** values of the voltage and resistance: $I_{\text{predicted}} = \frac{V_{\text{measured}}}{R_{\text{measured}}}$. Compare the measured value of $I$ to the predicted value as follows: $\boxed{\%\ \text{error} = \frac{I_{\text{predicted}} - I_{\text{measured}}}{I_{\text{predicted}}} \times 100}$. If the predicted and measured values for the current $I$ differ, explain why. Box all your results.

Table 9. Percentage error in current values (Figure 2 circuit).

| % error with respect to $I_{th}$ | % error with respect to $I_{pr}$ |
|---|---|
| | |

Using your **measured** values, calculate the power absorbed by the resistor and supplied by the voltage source. Is conservation of energy satisfied in this circuit? State why.

Table 10. Power values calculated (Figure 2 circuit).

| $P_R$ (mW) | $P_S$ (mW) | Energy conserved? |
|---|---|---|
| | | |

**PART 2: Kirchhoff's Voltage Law**

In this part of the experiment, we will add two more resistors (1.8 kΩ and 4.7 kΩ) to the circuit shown in Figure 2 to obtain the circuit shown in Figure 3.

**2(a)-Pre-lab Assignment:**

Determine the color codes for 1.8 kΩ and 4.7 kΩ resistors with 5% tolerance. What condition must always be satisfied by voltages indicated in Figure 3 based on Kirchhoff's voltage law (KVL)? (Box this condition.)

Table 11. Color codes for the 1.8 & 4.7 kΩ resistors (Figure 3 circuit).

| *R* (kΩ) | First | Second | Third | Fourth |
|---|---|---|---|---|
| 1.8 | | | | |
| 4.7 | | | | |

**2(a)-Lab Experiment:**

Provide the following table in your lab notebook to tabulate theoretical and measured resistor values related to the circuit shown in Figure 3.

Table 12. Theoretical and measured values of the resistors (circuit in Figure 3).

| $R_{1,th}$ (kΩ) | $R_{1,m}$ (kΩ) | $R_{2,th}$ (kΩ) | $R_{2,m}$ (kΩ) | $R_{3,th}$ (kΩ) | $R_{3,m}$ (kΩ) |
|---|---|---|---|---|---|
| 10 | | 4.7 | | 1.8 | |

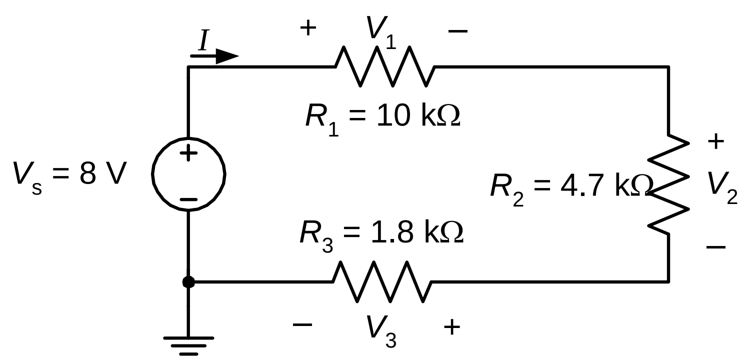


Figure 3. Resistors connected in series.

Measure the actual values of the 1.8 kΩ and 4.7 kΩ resistors in Figure 3 and calculate the % error for each resistor. Are all the % errors less than the tolerance specified by the tolerance color band? Present all your calculation results in table format.

Table 13. Percentage error in the values of 1.8 and 4.7 kΩ resistors (Figure 3 circuit).

| *R* (kΩ) | % error | Less than tolerance value? |
|---|---|---|
| 1.8 | | |
| 4.7 | | |

Provide the following table in your lab notebook to tabulate the measured voltage and current values in the circuit shown in Figure 3.

Table 14. Measured voltage and current values (circuit in Figure 3).

| $V_1$ (V) | $V_2$ (V) | $V_3$ (V) | $I$ (mA) | % KVL error | KVL satisfied? |
|---|---|---|---|---|---|
| | | | | | |

Set the adjustable power supply (the yellow terminal labeled +1.3 to 15V) in your lab kit to 8V. Then construct the circuit shown in Figure 3. Measure the voltages $V_S$, $V_1$, $V_2$, and $V_3$. Also measure the current $I$. Do the measured voltage values in this circuit satisfy KVL? Using the measured values, calculate the percentage error in KVL defined with respect to the source voltage as

$$\%\text{ error in KVL} = \frac{V_S - (V_1 + V_2 + V_3)}{V_S} \times 100$$

For each of the three resistors, calculate the value of the current into each resistor predicted by Ohm's law using the **measured** values of the voltage and resistance: $I_{\text{predicted}} = \frac{V_{\text{measured}}}{R_{\text{measured}}}$. Compare the measured value of $I$ to the predicted value as follows: $\%\ \text{error} = \frac{I_{\text{predicted}} - I_{\text{measured}}}{I_{\text{predicted}}} \times 100$. Present your values in table format. Why do the predicted and measured values for the current $I$ differ, in case they differ?

Table 15. Percentage errors in current values (circuit in Figure 3).

| $I_{1,pr}$ (mA) | $I_{1,m}$ (mA) | % error in $I_1$ | $I_{2,pr}$ (mA) | $I_{2,m}$ (mA) | % error in $I_2$ | $I_{3,pr}$ (mA) | $I_{3,m}$ (mA) | % error in $I_3$ |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

Design and perform an experiment to find out if changing the order in which the series components are connected in Figure 3 will change the voltage across the components or the current through the components. Document the experimental setup, results, and your conclusions.

## PART 3: Kirchhoff's Current Law

In this part of the experiment, we will change the circuit shown in Figure 3 to the circuit shown in Figure 4.

**3(a)-Pre-lab Assignment:** What condition must the currents at node A (see Figure 4) always satisfy according to Kirchhoff's current law (KCL) ? (Box this condition.)

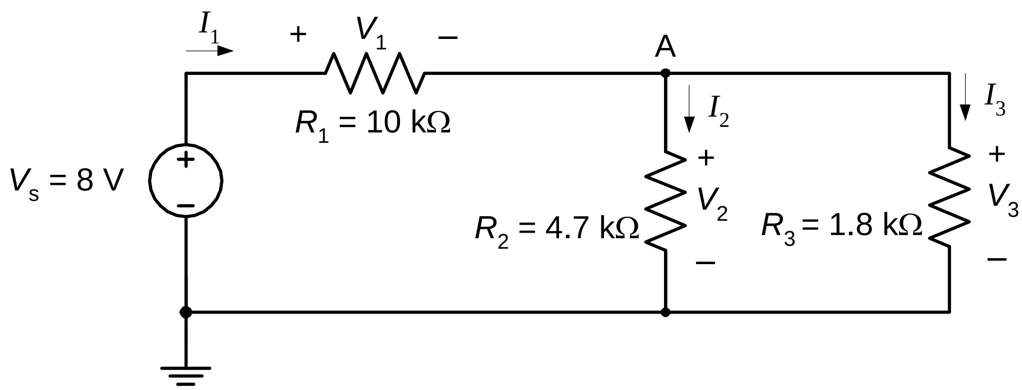


Figure 4. Parallel and series resistors.

**3(a)-Lab Experiment:**

Provide the following table in your lab notebook to tabulate measured current values in Figure 4.

Table 16. Measured current values (circuit in Figure 4).

| $I_1$ (mA) | $I_2$ (mA) | $I_3$ (mA) | % error in $I_1$ |
|---|---|---|---|
| | | | |

Using the same resistors that you used in the last section, construct the circuit shown in Figure 4. Measure the currents $I_1$, $I_2$, and $I_3$. Do the measured currents in this circuit satisfy Kirchhoff's current law at node A? Using the measured values, calculate the percentage error in KCL defined with respect to the current $I_1$ as

$$\text{\% error in KCL} = \frac{I_1 - (I_2 + I_3)}{I_1} \times 100$$

Design and perform an experiment to find out if changing the order in which the parallel components ($R_2$ and $R_3$) are connected in Figure 4 will change the voltage across the components or the current through the components. Document the experimental setup, results, and your conclusion.

**IV. Conclusion**

Write a couple of paragraphs to summarize the following items:

1. What was the objective of this experiment and was the objective achieved?
2. Did your measured values agree with the theoretical values? What was the maximum % error in your calculations?
3. What sources of error may have contributed to the differences between the theoretical values and the measured values?
4. Other comments relevant to this experiment.