Lab 01: Resistors and LEDs

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1 Abstract

This experiment aims to analyze the current-voltage characteristics of a resistor, a red light-emmitting diode (LED), and a series resistor network. This involved using a Digital Multimeter to measure a resistor's response and graphing it. The resistor's rating was then determined using a linear regression method. The LED was used to display how a load can exhibit a non-linear behavior, and an exponential fit was used to the forward current data. Kirchoff's Voltage Law was then verified a nd tested using a series resistor circuit, and the calculated equivalent resistance (real) was compared to the theoretical expectation (ideal). The results demonstrated an agreement with the theoretical predictions within the acceptable tolerance limits given by the 5% tolerance rating of the resistors.

2 Introduction

This laboratory session was designed as an introductory exploration of several key concepts in electrical engineering, particularly focusing on direct current (DC) circuits. The primary objectives were to validate Ohm's Law and Kirchhoff's Voltage and Current Laws through practical experimentation and to gain hands-on experience with standard electronic components. This lab also aimed to introduce the equipment and methods used for electrical measurements, such as the use of a digital multimeter and the Scopy software tool interfaced with an ADALM2000 unit which served as the power supply and voltmeter.

Understanding the characteristics of resistors and LEDs is crucial for any electrical engineer, as these components are foundational in both educational experiments and industrial applications. The lab was structured to provide a clear demonstration of how theoretical principles are applied in real-world scenarios. By analyzing the color codes on resistors and measuring their response under various voltages, students can directly observe the proportional relationship between current and voltage as postulated by Ohm's Law. Similarly, examining the behavior of LEDs under forward and reverse biases offers insights into semiconductor physics and the special conditions under which non-linear devices operate.

This session was particularly focused on reinforcing circuit analysis techniques, including voltage and current division, to provide students with the tools needed to successfully analyze and build more complex circuits in future labs. The procedures and results from this lab are expected to lay the groundwork for more advanced studies in electronic circuit design and analysis as well as offer an introduction to utilizing the protoboard for circuit layout, the use of voltmeters and current meters, and deciphering an electrical schematic for practical layout.

These expanded sections offer a broader context, detailing the educational and practical implications of the experiments, and setting the stage for a detailed exploration of the experimental results.

3 Theory

3.1 Ohm's Law

A resistor follows **Ohm's Law**, which states that the voltage across a resistor is directly proportional to the current through it:

$$V = IR$$

where:

- V is the voltage across the resistor (volts)
- I is the current through the resistor (amperes)
- R is the resistance (ohms)

By plotting the voltage against current, we can determine the resistance from the slope of the line.

3.2 LED Characteristics

Unlike resistors, LEDs do not obey Ohm's Law. The current through an LED follows the diode equation:

$$I = I_0\left(e^{\frac{qV}{kT}} - 1\right)$$

where:

- I_0 is the reverse saturation current
- q is the charge of an electron (1.6×10^{-19} C)
- k is Boltzmann's constant (1.38×10^{-23} J/K)
- T is the absolute temperature (Kelvin)

The LED requires a threshold voltage to allow significant current flow.

3.3 Kirchhoff's Laws

3.3.1 Kirchhoff's Voltage Law (KVL)

KVL states that the algebraic sum of all voltages around a closed path in a circuit must equal zero:

$$\sum \upsilon_{loop} = \upsilon_1 + ... + \upsilon_p = 0$$

3.3.2 Kirchhoff's Current Law (KCL)

KCL states that the sum of currents entering a node must equal the sum of currents leaving the node.

$$\sum i_{total} = i_1 + ... + i_p = 0$$

3.4 Current and Voltage Division

3.4.1 Current Division

By implementing **Ohm's Law** to calculate i which is the current through all resistors in parallel, the equivalent resistance, R_{eq} can be calculated. Then, Ohm's Law is applied further to produce the current division formula which can be utilized to calculate the current flowing through a particular branch or *junction* of a parallel system. Here, i_j is that junctions current we solve for.

$$i_j = \frac{\upsilon}{R_j} = \frac{R_e q}{R_j} i$$

3.4.2 Voltage Division

Similarly, **Ohm's Law** can be implemented down the chain for calculating the voltage drop through a network for series resistors. As the electromotive force travels through the network, each series resistor resists some of that force and produces a *voltage drop*. This voltage drop can be solved for utilizing the same nomenclature as the current division formula with v_j being the target.

$$v_j = iR_j = \frac{R_j}{R_{eq}} v.$$

4 Experimental Procedures

4.1 Resistor I-V Characteristic Measurement

The first experiment utilized the circuit shown in Figure 1

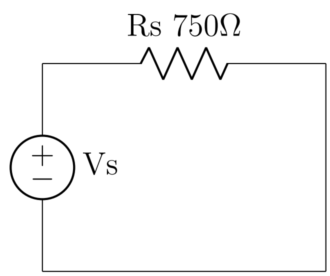
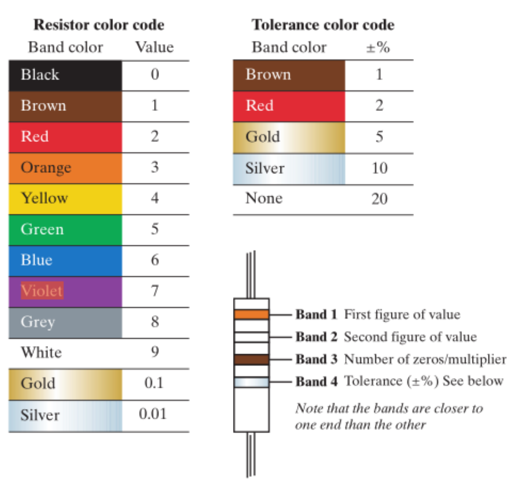


Figure 1: Resistive Circuit 1

1. A resistor with color code Violet, Green, Brown, Gold was tested.

   Utilizing Figure 2, this can be decoded easily as $750\Omega \pm 5\%$.



Resistor color code

Band color	Value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9
Gold	0.1
Silver	0.01

Tolerance color code

Band color	±%
Brown	1
Red	2
Gold	5
Silver	10
None	20

Figure 2: Resistor Color Codes

2. Voltage was varied from -5V to +5V.

   This was recorded utilizing the ADALM 2000 orange leads acting as the voltmeter. For the rest of the experiment, real voltage is measured this way and will require no elaboration.

3. The current was recorded for each voltage step.

   Table 1 contains the data recorded for this first portion. Notice that it exhibits a linear relationship, which is expected.

4.2 LED I-V Characteristic Measurement

1. A red LED was tested.

2. Forward voltage was increased from -3V to 5V.

   Particular care was given to ensuring reverse bias did not exceed 3V to avoid blowing out the LED.

3. The current was recorded for each voltage step in Table 2 and plotted in Figure 6

   Note: If the voltage did not produce enough force to forward bias the LED, no current flows through the circuit.

4.3 Series Resistor Circuit Measurement

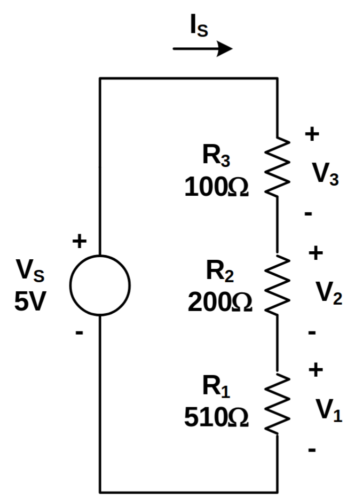


Figure 3: Series Resistive Circuit

1. Measured values of $upsilon_S, upsilon_1, upsilon_2, upsilon_3$ were recorded.

2. Kirchhoff's Voltage Law was tested in conjunction with the Voltage Divider method.

4.4 Parallel Resistive Circuit Measurement

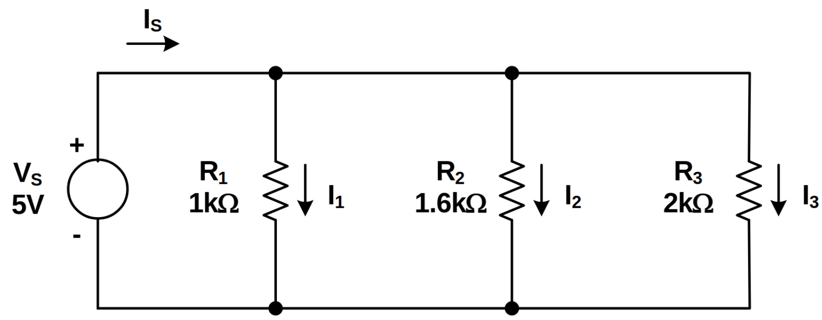


Figure 4: Parallel Resistive Circuit

1. Measured values of I_S, I_1, I_2, I_3 were recorded.
2. Kirchhoff's Current Law was tested in conjunction with the current divider method.

5 Results and Discussion

5.1 Resistor Data

The experimental data for the resistor's $i-v$ characteristics is summarized in the table below. This data was obtained by systematically varying the input voltage v_{in} and measuring the corresponding voltage across the resistor $v_{measured}$ and the current $i_{measured}$.

$v_{in}(V)$	$v_{measured}(V)$	$i_{measured}(mA)$
5.0	4.994	6.70
3.0	2.940	4.01
2.0	1.992	2.67
1.0	0.993	1.33
0	0.006	0.01
-1	-1.000	-1.34
-2	-2.001	-2.67
-3	-3.057	-4.01
-5	-5.045	-6.69

Table 1: Measured Data for Resistor I-V Characteristics

As depicted in Figure 5, the I-V curve for the resistor demonstrates a linear relationship between the input voltage and the current, which is consistent with Ohm's Law. The slope of the curve, determined from a linear regression analysis of the data points, was found to be approximately 1.338 ohms, which aligns well with the theoretical resistance value calculated based on the color bands of the resistor.

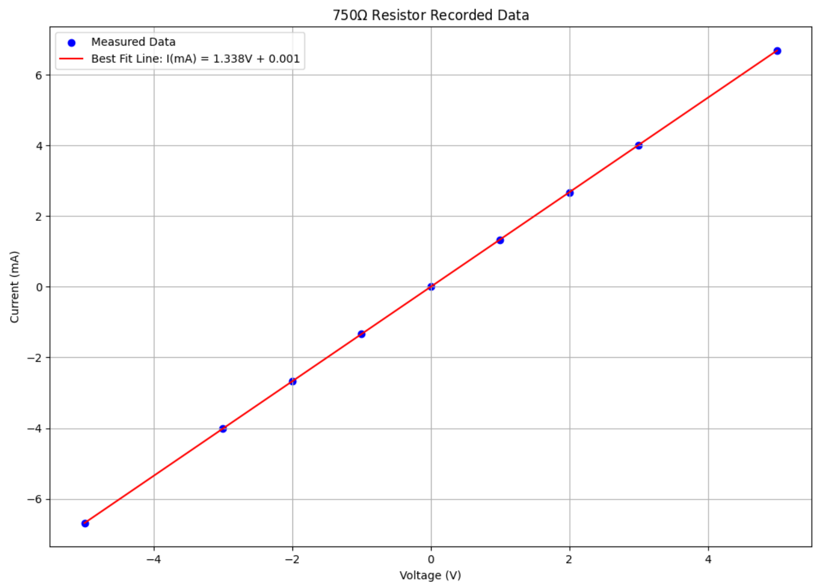


Figure 5: The I-V Curve for the Resistor

- At $v_{in} = 5.0\,V$ and $i_{measured} = 6.70\,mA$, the resistance calculates to approximately $746.27\,\Omega$.
- At $v_{in} = -5.0\,V$ and $v_{measured} = -6.69\,mA$, the resistance calculates to approximately $747.38\,\Omega$.

These values are notably close to 750 ohms. This correspondence within a small margin of error corroborates the reliability of the experimental method and the quality of the instruments used in measuring voltage and current. The slight variations observed can be attributed to the tolerance of the resistor of 5

The linear behavior of the resistor's I-V curve validates the accuracy of Ohm's Law in describing the relationship between voltage and current in a resistive element. The slight deviations observed at higher and lower voltages may be attributed to measurement uncertainties and the non-ideal behavior of the testing setup. The resistor's performance under reverse bias conditions further confirms the symmetric nature of its resistance, underscoring the reliability of passive electronic components in a controlled environment.

5.2 LED Data

The measured I-V characteristics of a red LED are presented in the table below. Unlike resistors, LEDs exhibit non-linear behavior as indicated by the exponential relationship between voltage and current.

$v_{in}(V)$	$v_{measured}(V)$	$i_{measured}(mA)$
5	2.057	14.67
4	2.019	9.88
3	1.958	5.21
2	1.836	0.86
1.0	1.005	0.00
0	0.008	0.00
-1	-1.009	0.00
-2	-2.016	0.00
-3	-3.073	0.00

Table 2: Measured Data for Red LED I-V Characteristics

The LED emits light when forward biased, typically requiring about 10 mA to emit visible red light. This is evident from the data, where the current surpasses this threshold near voltages of 2V and above. The anode (longer lead) is positive in relation to the cathode (shorter lead), and the conventional current flow is from anode to cathode. The experiment confirmed that negligible current flows when the LED is reverse-biased, adhering to the setup's constraint not to exceed a reverse bias of 3V to prevent damage.

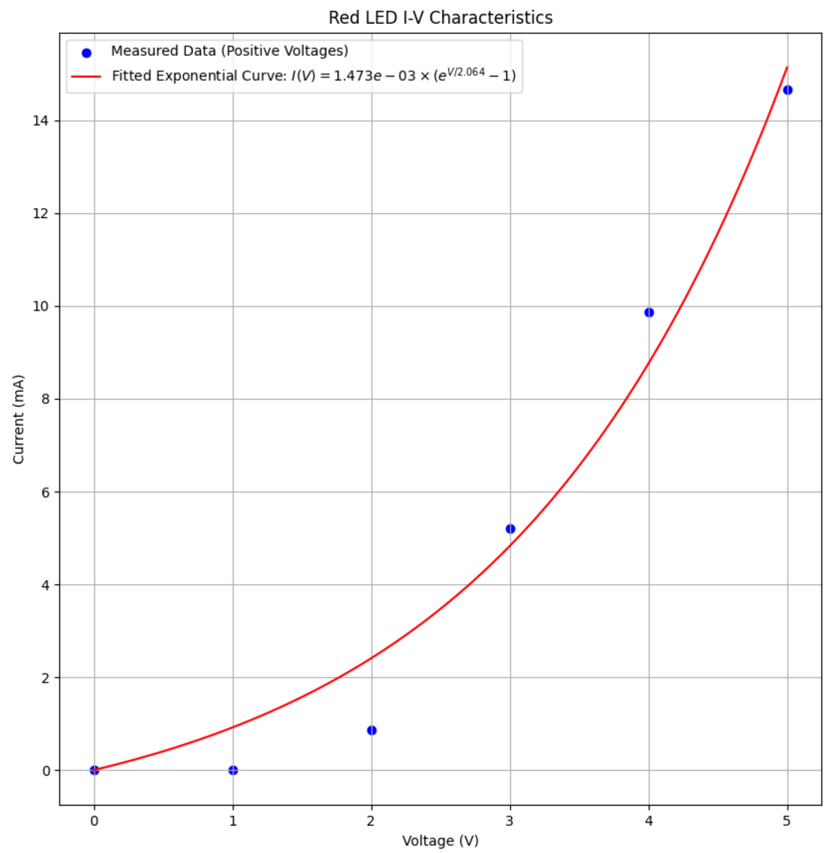


Figure 6: The I-V Curve for the LED

The I-V curve for positive voltages is shown in Figure 6. An exponential function was fitted to this part of the curve, matching the expected behavior for a diode under forward bias:

$$I(V) = 1.473 \times 10^{-3} \times (e^{\frac{V}{2.064}} - 1)$$

5.3 Series Resistor Circuit Measurement

In this part of the experiment, a simple series circuit consisting of three resistors was evaluated under a constant input voltage of 5V. The behavior of the circuit was analyzed based on Kirchhoff's Voltage Law and the voltage divider rule to determine if the observed measurements align with theoretical expectations.

$v_{in}(V)$	$v_{R_1}(V)$	$v_{R_2}(V)$	$v_{R_3}(V)$	$i_{eq}(mA)$
5	0.595	1.217	3.073	6.25

Table 3: Measured Data for Series Resistive Circuit

According to Kirchhoff's Voltage Law, the sum of all voltage drops in a closed loop should equal the total applied voltage. For our setup:

$$0.595V + 1.217V + 3.073V = 4.885V$$

This nearly matches the input voltage of 5V, with a small discrepancy of $0.115V$ likely due to measurement error or inherent resistance in the measurement devices. This demonstrates the practical application of Kirchhoff's Voltage Law in real circuits where slight deviations are expected.

Furthermore, the total or equivalent resistance R_{eq} of the circuit was calculated using the measured current:

$$R_{eq} = \frac{v_s}{I_{eq}} = \frac{4.885V}{0.00625A} = 781.6\Omega$$

This calculated resistance is compared against the theoretically expected resistance:

$$R_{ideal} = 100\Omega + 200\Omega + 510\Omega = 810\Omega$$

The percent error in the measured resistance can be calculated as follows:

$$Error = \left(1 - \frac{781.6\Omega}{810\Omega}\right) \times 100 = 3.51\%$$

This error margin is within the typical tolerance range for commercial resistors, which validates the experimental setup and measurement accuracy.

To further validate the results using the voltage divider rule, the expected voltages across each resistor were calculated and compared to the measured values:

$$v_{R_3,Ideal} = 5V\left(\frac{100\Omega}{810\Omega}\right) = 0.617V$$

$$v_{R_2,Ideal} = 5V\left(\frac{200\Omega}{810\Omega}\right) = 1.235V$$

$$v_{R_1,Ideal} = 5V\left(\frac{510\Omega}{810\Omega}\right) = 3.148V$$

The comparison of these ideal voltages with the actual measurements demonstrates good agreement, further confirming the accuracy of the theoretical models used to describe the behavior of series circuits.

5.4 Parallel Resistor Circuit Measurement

In this experiment, a parallel resistor circuit was analyzed to validate Kirchhoff's Current Law and to explore the current divider rule. A constant voltage of 5V was applied, and the currents through individual resistors and the total current were measured.

Current Measurement	**Value (mA)**
Total Current (I_S)	10.60
Current through R_1 (I_1)	4.99
Current through R_2 (I_2)	3.16
Current through R_3 (I_3)	2.53

Table 4: Measured Currents in Parallel Resistive Circuit

According to Kirchhoff's Current Law, the total current entering a node must equal the total current leaving the node. In our circuit:

$$I_S = I_1 + I_2 + I_3$$

$$10.60mA = 4.99mA + 3.16mA + 2.53mA = 10.68mA$$

This small discrepancy of 0.08mA between the measured total current and the sum of the individual current is accounted for in the tolerance of the resistors themselves of ±5%.

Using the current divider rule, the ideal current for each resistor in the parallel circuit is given by:

$$I_{1,Ideal} = I_S\left(\frac{R_{eq,Ideal}}{R_1}\right)$$

$$I_{2,Ideal} = I_S\left(\frac{R_{eq,Ideal}}{R_2}\right)$$

$$I_{3,Ideal} = I_S\left(\frac{R_{eq,Ideal}}{R_3}\right)$$

Where $R_{eq,Ideal}$ is calculated using the parallel resistance formula:

$$\frac{1}{R_{eq,Ideal}} = \frac{1}{1000\Omega} + \frac{1}{1600\Omega} + \frac{1}{2000\Omega}$$

$$R_{eq,Ideal} = \frac{1}{0.002125} \approx 470.6\Omega$$

Plugging $R_{eq,Ideal}$ back into the formulas:

$$I_{1,Ideal} = 10.625mA\left(\frac{470.6\Omega}{1000\Omega}\right) \approx 5.00mA$$

$$I_{2,Ideal} = 10.625mA\left(\frac{470.6\Omega}{1600\Omega}\right) \approx 3.125mA$$

$$I_{3,Ideal} = 10.625mA\left(\frac{470.6\Omega}{2000\Omega}\right) \approx 2.50mA$$

These theoretical values for the currents $I_{1,Ideal}$, $I_{2,Ideal}$, and $I_{3,Ideal}$ closely align with the measured currents, confirming the validity of the current divider rule and the precision of the experimental setup.

This detailed assessment confirms that the parallel circuit adheres to Kirchhoff's Current Law, and the calculations based on the current divider rule provide a valid framework for predicting the behavior of complex resistor networks in electrical engineering applications.

Conclusion

This laboratory exercise successfully demonstrated fundamental electrical principles such as Ohm's Law, Kirchhoff's Voltage and Current Laws, and the behavior of LEDs under different biases. The experiments reinforced theoretical knowledge through practical application, providing a solid foundation for further study in electronic circuit design and analysis.