Lab 08: Ohm's Law

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The objective of this lab was to analyze if a 1000 Ω resistor and an incandescent light bulb obeyed Ohm's law by calculating the resistance of the two objects at various voltages. The calculated resistance of the resistor was:

$$\mathrm{R}_{calculated} = 985.6 \pm 31.9\ \Omega$$

The resistance of the resistor stayed consistent for varying voltages which meant that the resistor obeyed Ohm's laws and thus was a Ohmic device.

On the other hand, the resistance of the light bulb increased as voltage increased due to the heating of the wire filament inside the bulb which meant that the light bulb acted as a non-Ohmic device.

I. INTRODUCTION

Ohm's law is a crucial law to learning the basics of electricity and electrical engineering. It describes the relationship between current (I), voltage (V), and resistance (R) where:

$$V = IR \tag{1}$$

Depending on what voltage and current is passed through a device, the resistance can easily be measured by the relationship given by Ohm's Law.

Ideally, the resistance for a device should remain the same as voltage and current decrease or increase, however that is not always the case. Devices whose resistance stays the same for varying voltages and currents are known as Ohmic devices. Examples include wires and resistors. Non-Ohmic devices such as filament light bulbs, diodes, and transistors do not follow Ohm's law.

A device that does not follow Ohm's law is known as a non-Ohmic device (i.e the resistance is different for different currents passing through it). For both non-Ohmic devices and Ohmic devices, they generate power (P) based upon the relationship:

$$P = \frac{V^2}{R} \tag{2}$$

For an incandescent light bulb, electrical energy is converted into electromagnetic energy in the form of light and heat. This heat then ends up heating up the filament in the light bulb. Since resistance is proportional to temperature, as the filament heats up, the resistance increases which means that the light bulb acts as a non-Ohmic device.

In electrical engineering, equation 2 represents a critical idea in electrical safety. Electrical hazards normally arise due to high power dissipation or current. Generally, touching 30 V isn't inherently dangerous. Assuming a resistance of 1.41 MΩ for a human hand, the power dissipation is merely 0.000638 Watts with a small current of 0.0000213 A. For a wire with a resistance of just 0.1 Ω, the power dissipation is 9,000 Watts as the current has risen to 300 A in the wire. 9,000 Watts is significantly higher than most space heaters which commonly operate at 1,500 Watts. Large power dissipations and currents are the main problem when dealing with electrical safety. Combining equations 1 and 2 yields:

$$P = I^2 R \tag{3}$$

The relationship between current and resistance means that even a small current can result in a high power dissipation. In order to remain safe, precautions must be taken to reduce dangers from high current.

The relationship between current and power was not quantitatively examined during the lab, but rather was qualitatively analyzed when evaluating the resistances for the incandescent light bulb and the resistor. Equation 1 served as the foundation of the lab to determine if the incandescent light bulb and resistor were an Ohmic or non-Ohmic device.

II. PROCEDURE

The procedure of the lab was fairly simple. A simple circuit with a resistor and two multimeters was created as shown in Figure 1. The multimeters allow for the measurement of voltage and current as the voltage on the power supply is varied.

To begin the procedure, the 1000 Ω resistor was connected to the DC power supply with banana cables with alligator clips. The power supply was then turned on and adjusted to 10 V and the current knob was slightly turned to prevent a large current from damaging the components. After calibrating the power supply, the multimeters were connected to the circuit in the configuration shown in Figure 1. The power supply was then set to zero, and then, the voltage and current was recorded for increments of 1 V from 0-9 V. This data can be found

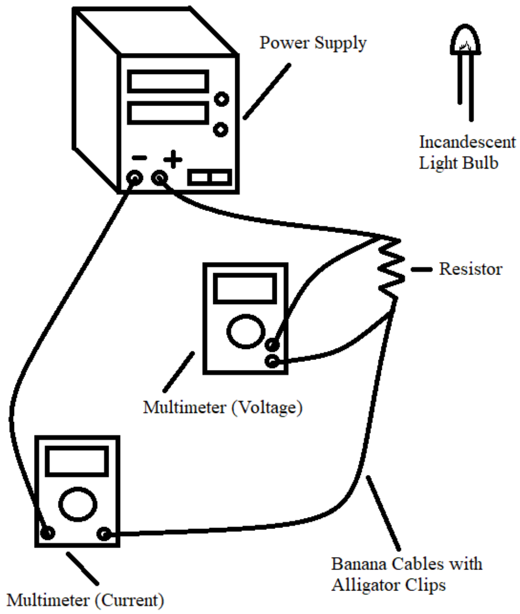

FIG. 1. This is a diagram of the lab circuit set up. The power supply provides a voltage (and therefore a current) to the circuit. The circuit is composed of a power supply and a resistor. The voltage multimeter is connected in parallel to show the voltage drop across the resistor. The current multimeter is connected in series to display the current through the network. The banana cables connect the various parts of the circuit. For Part 2 of the lab, the 1000 Ω resistor will be replaced with the incandescent light bulb with the longer leg attached to the positive side.

in Table I. The uncertainties for voltage and current in Table I were based upon the tolerances given by the manufacture of the multimeters. Equation 1 was also used to calculate the resistance values for the resistor.

For Part 2 of the lab, the resistor was replaced with a mini incandescent light bulb after turning off the power supply and turning down the voltage to zero. After connecting the bulb, the power supply was turned on and the current was measured for increments of 0.5 V from 0-6 V. The current knob on the power supply had to be increased as needed due to the filament of the light bulb. The values for current and voltage can be found be in Table II. Similar to Part 1, the uncertainties for voltage and current were based upon values given by the manufacture and Equation 1 was used to calculate resistance values for the bulb.

III. DATA ANALYSIS

Table I shows that the resistor has a generally constant resistance as the voltage increases which means that the resistor is an Ohmic device.

The resistance of the resistor can also be obtained by plotting the voltage against the current found in Table

Trial #	Voltage (V)	Current (mA)	Resistance (Ω)
1	0.021	0.03	700.000
2	1.001	1.03	971.845
3	1.990	2.04	975.490
4	3.001	3.06	980.719
5	4.035	4.11	981.752
6	4.989	5.08	982.087
7	6.020	6.12	983.660
8	7.020	7.13	984.572
9	8.000	8.14	982.801
10	9.030	9.18	983.660

$\Delta V = 0.09\%$ $\Delta I = 1\%$

TABLE I. As the table shows, the resistance of the resistor was about 980 Ω. The first trial contains a resistance of 700 Ω which is an outlier data point. At lower voltages, small differences in voltage result in a larger impact on experimental resistance values. During the procedure, the voltage reading on the multimeter would slightly go up and down by a few thousandths. The current reading on the multimeter also rounds to the nearest hundredth value, therefore a reading of 0.025 mA would be rounded to 0.03 mA. These two factors led to a resistance value of 700 Ω and therefore this value will be considered an outlier for further analysis. Error in resistance for the resistor will be calculated by taking the upper and lower best fit line shown in Figure 2.

Trial #	Voltage (V)	Current (mA)	Resistance (Ω)
1	0.008	0.86	9.302
2	0.474	16.96	27.948
3	0.990	24.45	40.491
4	1.484	30.35	48.896
5	1.953	35.32	55.295
6	2.469	40.23	61.372
7	3.043	45.23	67.278
8	3.470	48.72	71.223
9	4.010	52.85	75.875
10	4.478	56.24	79.623
11	4.998	59.82	83.551
12	5.498	63.10	87.132
13	5.994	66.40	90.271

$\Delta V = 0.09\%$ $\Delta I = 1\%$

TABLE II. Unlike Table I, the resistances in Table II do not stay consistent, As the voltage rises, the resistance increases as well which means that the incandescent light bulb is not an Ohmic device. Similar to Table I, the first trial data is not included for analysis as the value for the voltage and current may be off.

I. This gives the value for resistance as the slope of the best fit line where:

$$R = \frac{V}{I} \tag{4}$$

Using Figure 1, the slope of the best fit line was:

$$\text{Slope}_{bestfit} : 985.6$$

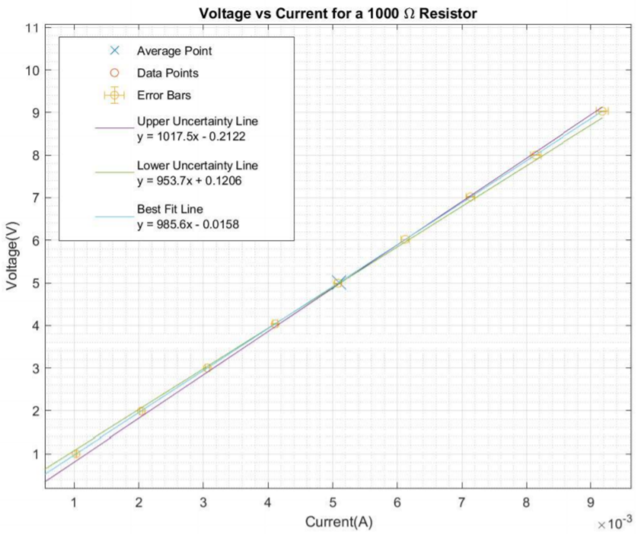

FIG. 2. Figure 2 contains three slope values: the upper and lower uncertainty line and the best fit line. The slope of the best fit line gives the value for the calculated resistance. Rather than calculating the uncertainty of resistance via an error propagation formula, two lines were created to represent the lower and upper uncertainty for the resistance. The slope of the lines of uncertainty were calculated by slightly altering the slope of the best fit line until it hit only about 68% of the error bars. This method can be used to find uncertainty of the resistance as well. Error bars are present for both current and voltage, but may be difficult to see.

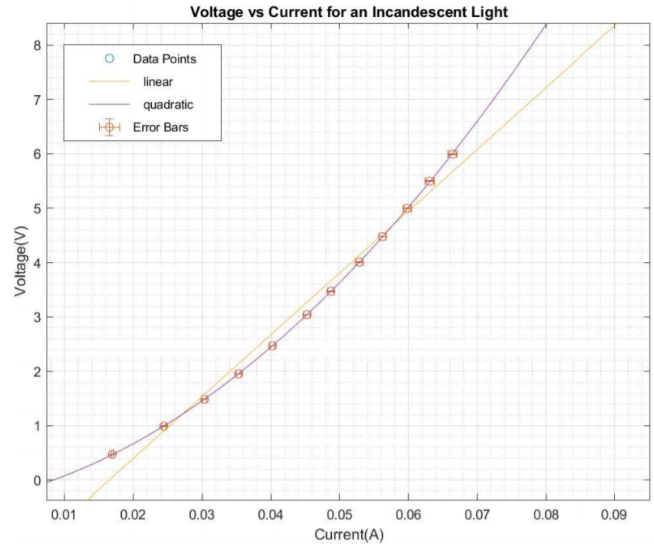

FIG. 3. Figure 3 contains two lines: a quadratic and linear line. An ideal Ohmic device should have the same resistance when voltage is increased, however the resistance increases as the voltage increases. The path of the data points indicate that the voltage and current do not have a linear relationship, but rather a quadratic one. The equations for the lines are not given as the goal of the figure is to highlight a general qualitative relationship. The light bulb is a non-Ohmic device because in order to produce light, the filament of the bulb heats up. By heating up, the resistance of the wire increases as well. Therefore, as the voltage of the bulb increases, the resistance increases as well. Metal wires generally obey Ohm's law, but the filament in the bulb is designed to heat up and produce light which thus represents a non-Ohmic device. The curve of the quadratic shows the path current will take as voltages increases past the collected data points. Error bars for both voltage and current are plotted, but they may be too small to be seen.

This indicates that the calculated resistance was 985.6 Ω. The slope of the uncertainty lines is

$$\text{Slope}_{upper} : 1017.5$$
$$\text{Slope}_{lower} : 953.7$$

The uncertainty lines indicate that the uncertainty for slope (thus the resistance) was ±31.9 Ω. The final value for resistance based on the slope is

$$\text{R}_{calculated} : 985.6 \pm 31.9\ \Omega$$

As shown in Figure 2, the best fit line fits all the data points for Table I data. This means that the current of the resistor follows a linear relationship with the voltage and therefore indicates that the resistor is an Ohmic device.

The resistor has a gold band which indicates a 5% tolerance, and thus, the resistor has a resistance between 950-1050 Ω. The calculated value of the resistance along with the uncertainty of resistance falls within this range which means that the resistance was successfully calculated.

The voltage against current values for the incandescent light bulb from Table II are plotted in Figure 3.

For the bulb, the error in resistance for each trial was calculated by equation 5, derived from equation 4 and the error propagation formula. This data can be found in Table III.

$$\Delta R = R\sqrt{\left(\frac{\Delta V}{V}\right)^2 + \left(\frac{-\Delta I}{I}\right)^2} \tag{5}$$

In conclusion, the data analysis indicates that the resistor follows Ohm's law and acts as an Ohmic device whereas the light bulb acts as a non-Ohmic device due to the heating of the wire filament.

IV. ERROR ANALYSIS

Overall, the error in the lab remained very low as shown by the very small error bars in Figure 2 and 3 as well as the small value for ΔR in Table III. The calculated resistance of the resistor was also well within its tolerance values. The primary source of error in this lab was systematic as all measurements were made by electronic devices (multimeters) rather than a human. As a result, it minimized error that arises when a human measures something such as length or time.

Trial #	Resistance (Ω)	ΔR (Ω)
1	9.302	0.0084
2	27.948	0.2806
3	40.491	0.4065
4	48.896	0.4909
5	55.295	0.5552
6	61.372	0.6162
7	67.278	0.6755
8	71.223	0.7151
9	75.875	0.7618
10	79.623	0.7994
11	83.551	0.8389
12	87.132	0.8748
13	90.271	0.9064

TABLE III. As seen in the table, the uncertainty in the resistance for the light bulb is approximately 1%, therefore the lack of a best fit line that fits all the data points in Figure 3 is due to the nature of a non-Ohmic device and not inaccurate data collection. The low uncertainties in resistance also indicate that the procedure was carried out with accuracy.

These sources of error can be reduced primarily by obtaining better, more precise equipment rather than a change in procedure. The wires also contained a small resistance of 0.1 Ω as described in the lab manual. These wires contribute a small, but insignificant amount of resistance that ultimately impacted the results by a negligible amount.

V. CONCLUSION

Overall, the lab was carried out successfully. Both goals were achieved. One was to calculate the resistance of the resistor where

$$R_{calculated} = 985.6 \pm 31.9\ \Omega$$

This value was within the 5% tolerance of the resistor which means that the procedure for the resistor circuit was done accurately.

The second goal was to determine if the resistor and light bulb followed Ohm's laws. The resistor followed Ohm's laws and thus is an Ohmic device because the resistance stayed consistent for different voltage values. On the other hand, the light bulb did not perfectly adhere to Ohm's laws as the resistance of the circuit increased as the small filament in the light heated up which means that the bulb was a non-Ohmic device. Overall, error was kept low as well which means that analysis of the resistor and light bulb is accurate.

On a practical scale, this lab showed that not all devices adhere to Ohm's laws as light bulbs are purposely made to radiate heat and light which means that the resistance must increase with voltage. Regarding electrical safety in electrical engineering, the main danger is current and high power dissipation rather than just large voltages. A high current or power can damage equipment and potentially put a human life at risk due to electrocution or burns.

[1] Gretarsson, A. M. Callahan, T.K. and Rhoades, E. L. (2020). Lab 8: Ohm's Law. *Laboratory Experiments In Physics for Engineers PS 253, Fall 2020* (Pg. 39-40). Prescott, AZ: Embry-Riddle Aeronautical University.