HAW HAMBURG

Laboratory for Basics of Electrical Engineering

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Non-linear characteristics and Wheatstone Bridge

Report history – Please leave all original papers in the report

		Date	Remarks
Report	received		
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Final decision:

☐ passed

☐ not passed Prof. ....

Lab report 2

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Contents

1 Introduction

This lab focuses on exploring the principles and practical applications of nonlinear current characteristics and the Wheatstone Bridge. Through a series of experiments, we aim to analyze the behavior of nonlinear resistances and investigate the sensitivity and balance conditions of Wheatstone Bridge configurations. The study emphasizes comparing theoretical concepts with experimental data to deepen understanding of electrical circuit behavior under various conditions.

The experiments include measuring the differential resistance of a nonlinear component, such as a light bulb, and plotting its characteristic curves using both linear and logarithmic scales. Additionally, the Wheatstone Bridge is studied in both quarter and full-bridge setups, highlighting its applications in precise resistance measurements and strain gauge analysis. By integrating theoretical principles with hands-on experimentation, this lab enhances comprehension of core electrical engineering concepts and their real-world implications.

2 Objectives

- Explore the behavior of non-linear resistances and analyze their differential resistance at the operating point.
- Practice presenting data using both linear and logarithmic scales.
- Use the Wheatstone bridge to understand balanced and unbalanced conditions, focusing on sensitivity and linearity.
- Compare experimental data with theoretical values and analyze any differences.

3 Theory

3.1 Ohm's law

Ohm's law describes the relationship between voltage, current, and resistance. it states that the electric current (I) flowing through a conductor between two points is directly proportional to the voltage (U) across those points and inversely proportional to the resistance (R) of the conductor. Mathematically:

$$I = \frac{U}{R}$$

where:

- I is the current flowing through the conductor in amperes (A)
- U is the voltage applied across the conductor in volts (V)
- R is the resistance of the conductor in ohms (Ω)

3.2 Voltage division

It is the result of distributing the input voltage among the components of the divider. A simple example of a voltage divider is two resistors connected in series, with the input voltage applied across the resistor pair and the output voltage emerging from the connection between them.

Basic Concept: When multiple resistors are connected in series, the total voltage applied across the combination is distributed among them in proportion to their individual resistances. This means that a larger resistor will have a larger voltage drop across it compared to a smaller resistor.

- Consider a simple circuit with two resistors, R1 and R2, connected in series. Let's assume:
  - The input voltage applied across the combination is V_{in}.
  - The voltage across resistor R1 is V1.
  - The voltage across resistor R2 is V2.
- According to voltage division, the voltage across each resistor is given by:
  - Voltage across R1 (V1):

$$V1 = V_{in} \cdot \left(\frac{R1}{R1 + R2} \right) \tag{1}$$

  - Voltage across R2 (V2):

$$V2 = V_{in} \cdot \left(\frac{R2}{R1 + R2} \right) \tag{2}$$

3.3 Wheatstone bridge theory

The Wheatstone Bridge is an electrical circuit designed to precisely measure an unknown resistance by comparing it to known resistances. It operates on the principle of null deflection, meaning the bridge is balanced when no current flows through the galvanometer.

A more simplified explanation:

- The circuit consists of four resistors connected in a diamond shape.
- Two resistors are known values (R_1 and R_2), one is adjustable (R_3), and the fourth (R_x) is the unknown resistance.
- A voltage source powers the circuit, and a galvanometer measures the current between two points in the bridge.

The Wheatstone Bridge is a precision measuring instrument widely used in electrical engineering to determine the value of an unknown resistance. It operates on the principle of comparing the unknown resistance with known resistances.

Key Principles:

1. Bridge configuration:The Wheatstone Bridge consists of four resistors arranged in a diamond-shaped configuration.

- Known Resistors: Two of these resistors (R_1 and R_2) have known values.
- Adjustable Resistor: One resistor (R_3) is adjustable.
- Unknown Resistor: The fourth resistor (R_x) is the unknown resistance whose value we wantmine.

2. Null Deflection: The bridge is said to be balanced when the potential difference between the midpoints of the opposite legs is zero. In other words, no current flows through a galvanometer connected between these midpoints. This balanced condition is crucial for accurate measurement.

3. Balance condition: When the bridge is balanced, the following condition holds:

$$\frac{R_1}{R_2} = \frac{R_3}{R_x} \tag{3}$$

This equation allows us to calculate the value of the unknown resistance (R_x) if the values of the other three resistors are known.

4 Material and equipment

- **Power Supply** - Adjustable DC power supply to supply the required voltage to the circuits.
- **Light Bulb (Non-linear Component)** - 15V / 82mA nominal light bulb to measure nonlinear I-V characteristics.
- **Multimeter** - For measuring voltage and current
- **Precision Resistors**
  - R_1 = 10k potentiometer
  - R_2 = 1000 Ω
  - $R_3 = R_4$ = 1kΩ (Used in the Wheatstone bridge setup)
- **Strain Gauges** - Four strain gauges for the full Wheatstone bridge configuration.
- **Wheatstone Bridge Setup** - A quarter-bridge and full-bridge circuit setup using the above resistors and strain gauges.
- **Bending Beam Setup (for full Wheatstone bridge)** - A setup where the strain gauges are mounted on a bending beam for applying varying loads.

5 Experiment 1:

5.1 Non-linear current characteristics

By using the given formula, $I = a \cdot U^b$ where a is 20, b is 0.5, I is in mA and U is for Voltage measured in V, we calculated the corresponding current as illustrated in the table below.

Voltage (V)	Calculated Current (I/mA)
0.1	6.325
0.2	8.944
0.5	14.142
1	20.000
2	28.284
5	44.721
10	63.246

Table 1: Voltage and corresponding current

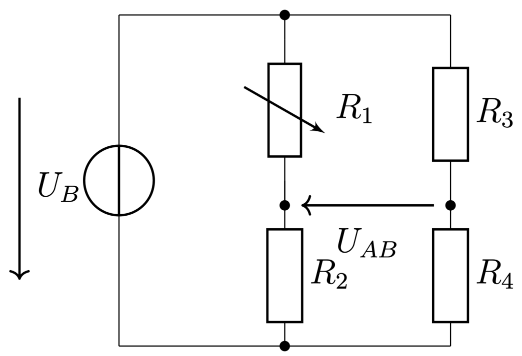

Figure 1: Enter Caption

5.1 Unbalanced bridge

In the circuit below $R_2 = 100\Omega$, $R_3 = R_4 = 1k\Omega$ and $U_B = 6V$. Bridge voltage $U_{AB} = f(R_1)$ was calculated as a preparation before the laboratory experiment for different values of R_1. And then a graph was plotted with the U_B and R_1 values, which was measured in the lab.

R_1 (Ω)	Calculated U_{AB}	Measured U_{AB}
50	-1	-0.9937
70	-0.529	-0.5239
90	-0.158	-0.1529
110	0.143	-0.1471
130	0.391	0.3953
150	0.6	0.6039
170	0.778	0.7815
190	0.931	0.9346
200	1	1.0034

Table 2: Calculated and Measured U_{AB} values

The calculation was done as follows: Given below is the equation we deduced to calculate the U_{AB}

$$U_{AB} = U_{R_4} - U_{R_2}$$

The U_{R_4} value is a constant as the values of R_3 and R_4 remain the same. We can use the voltage divider equation to calculate the values of U_{R_2} and U_{R_4}

First, we calculate U_{R_4}.

$$U_{R_4} = U_B \cdot \left(\frac{R_4}{R_3 + R_4}\right)$$
$$U_{R_4} = 6 \cdot \left(\frac{1000}{1000 + 1000}\right)$$
$$U_{R_4} = 6 \cdot \left(\frac{1}{2}\right) = 3V$$

Then we calculated the U_{R_2} for each R_1 and then the U_{AB} using the above equation.

When $R_1 = 50\ \Omega$;

$$U_{R_2} = U_B \cdot \left(\frac{R_2}{R_1 + R_2}\right)$$
$$U_{R_2} = 6 \cdot \left(\frac{100}{100 + 50}\right) = 4$$
$$U_{AB} = 3 - 4 = \underline{-1V}$$

When $R_1 = 70\,\Omega$;

$$\begin{aligned} U_{R_2} &= U_B \cdot \left(\frac{R_2}{R_1 + R_2}\right) \\ &= 6 \cdot \left(\frac{100}{100 + 70}\right) = \frac{60}{17} \end{aligned}$$
$$U_{AB} = 3 - \frac{60}{17} = \underline{-0.529V}$$

When $R_1 = 90\,\Omega$;

$$U_{R_2} = 6 \cdot \left(\frac{100}{100 + 90}\right) = \frac{60}{19}$$
$$U_{AB} = 3 - \frac{60}{19} = \underline{-0.158V}$$

When $R_1 = 110\,\Omega$;

$$U_{R_2} = 6 \cdot \left(\frac{100}{100 + 110}\right) = \frac{20}{7}$$
$$U_{AB} = 3 - \frac{20}{7} = \underline{0.143V}$$

When $R_1 = 130\,\Omega$;

$$U_{R_2} = 6 \cdot \left(\frac{100}{100 + 130}\right) = \frac{60}{23}$$
$$U_{AB} = 3 - \frac{60}{23} = \underline{0.391V}$$

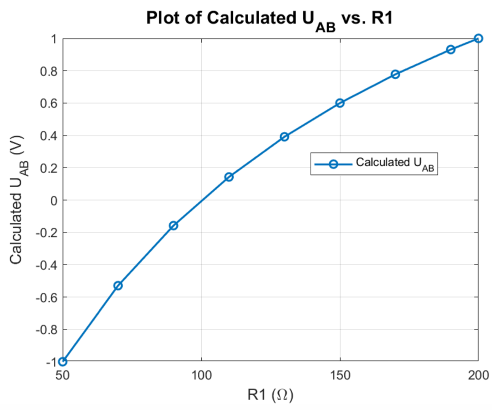

Figure 2: U_{AB} vs. R_1

When $R_1 = 150\,\Omega$;

$$U_{R_2} = 6 \cdot \left(\frac{100}{100+150}\right) = \frac{12}{5}$$
$$U_{AB} = 3 - \frac{12}{5} = \underline{0.6V}$$

$R_1 = 170\ \Omega$;

$$U_{R_2} = 6 \cdot \left(\frac{100}{100+170}\right) = \frac{20}{9}$$
$$U_{AB} = 3 - \frac{20}{9} = \underline{0.778V}$$

When $R_1 = 190\,\Omega$;

$$U_{R_2} = 6 \cdot \left(\frac{100}{100+190}\right) = \frac{60}{29}$$
$$U_{AB} = 3 - \frac{60}{29} = \underline{0.931V}$$

When $R_1 = 200\,\Omega$;

$$U_{R_2} = 6 \cdot \left(\frac{100}{100+200}\right) = \frac{1}{3}$$
$$U_{AB} = 3 - \frac{60}{17} = \underline{0.778V}$$

Conclusion: The gradient of the graph reduces with the increment of the R_1 values. This shows that the current passing through the circuit reduces due to energy dissipation to the surrounding and may be due to temperature changes as well.

6 Experiment 2: Measuring the Characteristic Diagram of Non-Linear Components

6.1 Measuring the Characteristic Diagram of Non-Linear Components

In this experiment, both current and voltage were measured simultaneously in incremental steps to obtain the characteristic diagram of an electrical component. The data were then presented graphically. The nonlinear component used in this experiment was a light bulb with nominal values of 15V/82mA.

6.1.1 a) Measurement of the Cold Light Bulb Resistance

We measured the resistance of the cold light bulb using two multimeters. The recorded data are shown in the table below:

Measurement Device	Measured Resistance (Ω)
Metrahit TRMS	24.58
Metrahit 15S	25.15

Table 3: Resistance of the Cold Light Bulb

6.1.2 b) Measured Voltage and Current

The voltage across the light bulb and the current flowing through it were measured within the range 0.1V to 10V. The table below shows the recorded data. These values were used to draw the lin-lin scaling graph, as depicted below.

Voltage (U) [V]	Measured Current (I) [mA]	Measured Voltage V
0.1	3.942	0.105
0.3	7.903	0.294
0.5	10.294	0.491
0.8	12.7	0.782
1	14.65	0.993
3	25.45	2.98
5	33.98	4.97
8	44.57	7.96
10	50.55	9.93

Table 4: Measured Voltage and Current

6.1.3 c) Resistance and Incremental Resistance Calculation

The table below shows the calculated resistance (R) and incremental resistance (r) at the given voltage points.

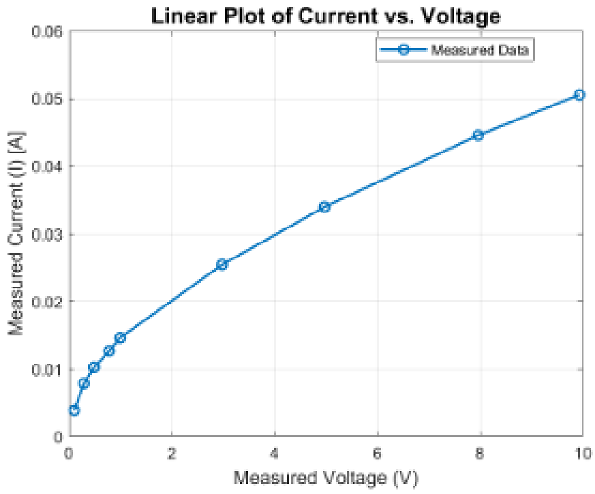

Figure 2: lin-lin scaling graph I = f(U)

Voltage (U) [V]	Measured Current (I) [mA]	R [Ω]	r [Ω]
0.1	3.942	25.36783359	47.71447657
1	14.65	68.25938567	172.3929871
10	50.55	197.8239367	329.4350189

Table 5: Resistance and Incremental Resistance at Given Voltage

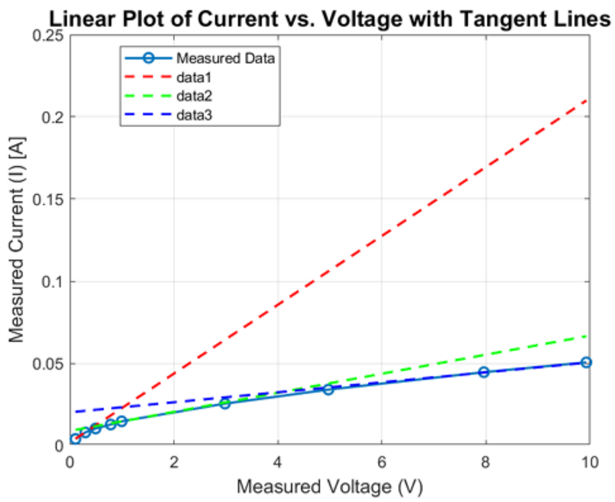

Figure 3: Tangents at 0.1V, 1V, and 10V

6.1.4 d) Log-Log Scaling Graph of I = f(U)

The function $I = f(U)$ was plotted with log-log scaling using Matlab. The table below shows the measured values and their logarithmic values for voltage and current.

Voltage (U) [V]	Measured Current (I) [mA]	log10(U)	log10(I)
0.1	3.942	-1	-1.405
0.3	7.903	-0.522	-0.302
0.5	10.294	-0.301	-0.013
0.8	12.7	-0.097	0.051
1	14.65	0	0.016
3	25.45	0.477	0.406
5	33.98	0.699	0.531
8	44.57	0.903	0.652
10	50.55	1	0.701

Table 6: Measured and Logarithmic Values of Voltage and Current

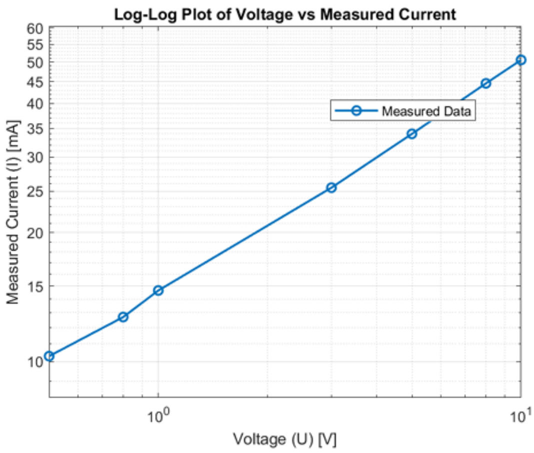

Figure 4: Log-Log Scaling Graph of I = f(U)

6.1.5 e) Log-Log Scaling of Pre-Calculated Values

Within the voltage range $0.5V < U < 10V$, the characteristic function is to be approximated by the expression in Equation 2.1. The pre-calculated values were plotted in the graph below using Matlab.

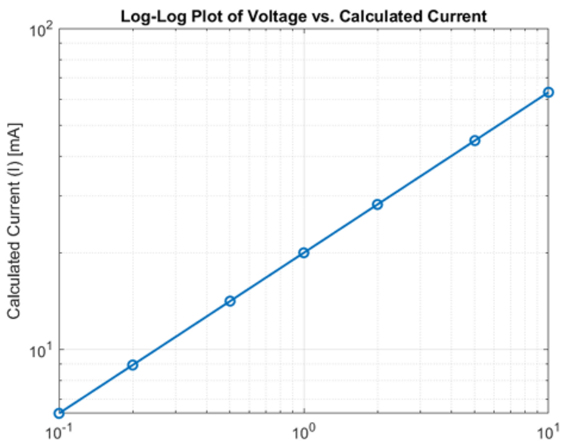

Figure 5: Log-Log Scaling of Pre-Calculated Values

6.1.6 f) Regression Line of the Log-Log Scaling Graph

The graph drawn in part d) was extrapolated to the y-axis to obtain the regression line, which was used to better approximate the measured data in the graph. This regression line is shown below.

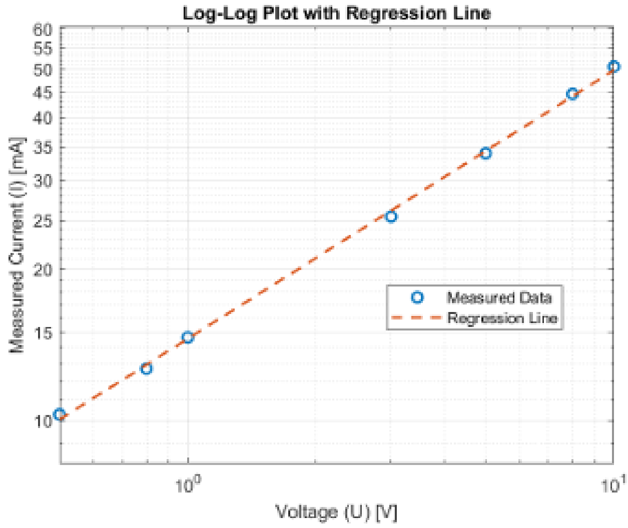

Figure 6: Regression Line for the Log-Log Scaling Graph

6.1.7 g) Equation of the Regression Line

The regression line was plotted using the 'best linear fit' method, and the equation of the regression line was obtained from Matlab. The relationship is given by the following equations:

$$\log\left(\frac{I}{1\,\text{mA}}\right) = \log(a) + b\log\left(\frac{U}{V}\right)$$

From Matlab, we obtained the following values:

$$\log(a) = 1.1632 \quad \Rightarrow \quad a = 10^{1.1632} = 14.56$$

$$b = 0.5333$$

6.1.8 h) Comparison with Linear Relationship

When superimposing the regression line with the linear model, we noticed that while the gradients were similar, the intercept values differed. This shows that the 'a' value had a significant difference, indicating that these are two different non-linear components.

7 Experiment 3: Wheatstone Bridge Measurements

7.1 Relative Unbalance

The relative unbalance r is calculated using the formula:

$$r = \frac{R_1 - R_{1,0}}{R_{1,0}} \tag{4}$$

7.2 Quarter Bridge vs. Full Bridge

The primary distinction between the Quarter Bridge and the Full Bridge is the number of active resistors. In the Quarter Bridge, only one resistor is active, meaning its resistance is dynamic, while the other three resistors remain fixed. In contrast, in the Full Bridge, all four resistors are active. A strain gauge was used in the Full Bridge experiment to achieve the full bridge circuit configuration. Pictures of the built circuits are included in the appendix.

7.1 Quarter Bridge Experiment

1. We used the potentiometer as the active resistor and precision resistors for the other three resistors.
2. The circuit was set up as shown in Figure 4.1.2 (referenced from the experiment setup).
3. The bridge voltage was measured, and the results are recorded in the data table provided below.
4. The $R_{1,0}$ value, for which the bridge is balanced ($U_{AB} = 0$), was determined. The measured value of $R_{1,0}$ during the lab was:

   $$R_{1,0} = 99.7\,\Omega \tag{5}$$

   This value is close to the calculated value. The calculation is shown below.
5. Using the equation for relative unbalance, the r values for the R_1 values were calculated. The data is included in Table 7.

Table 7: Quarter Bridge Data

$R_1\,(\Omega)$	Measured $U_{AB}\,(V)$	Calculated $U_{AB}\,(V)$	Unbalanced (r)
50	-0.9845	-1.008	-0.499
75	-0.4155	-0.430	-0.248
100	0.0114	0.000	0.003
125	0.3433	0.333	0.254
150	0.6091	0.600	0.505
200	1.0079	1.000	1.006

Figure **??** shows the plot of U_{AB} as a function of R_1, with a tangent drawn at the balance point where $R_1 = R_{1,0}$. This tangent line was used to determine the bridge sensitivity E_0.

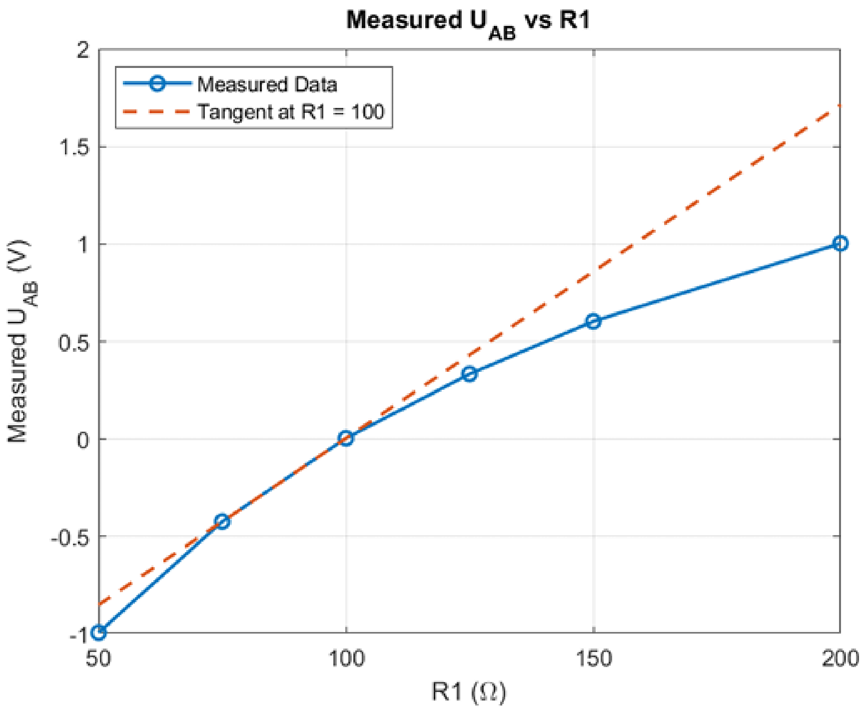

Figure 7: Quarter bridge

The bridge sensitivity was calculated using the following formula:

$$E_0 = k\left(\frac{a}{(1+a)^2}\right) \tag{6}$$

where $a = \frac{R_2}{R_1} = \frac{R_4}{R_3} = 1$ and $k = \frac{U_B}{R_1} = \frac{6}{99.7}$. The calculated value of E_0 was:

$$E_0 = 0.0171\,\mathrm{V}/\Omega \tag{7}$$

The theoretical value determined from the equation was 0.0150 V/Ω. These values were used to compare the bridge sensitivities obtained practically and theoretically.

7.2 Full Bridge Experiment

1. The potentiometer was connected in parallel to one of the four resistors in the strain gauge. The potentiometer was adjusted until $U_{AB} = 0$, with the resistance on the potentiometer recorded as 700 kΩ.

2. The U_{AB} voltage was measured when the bending beam of the strain gauge was loaded with different masses. The recorded data is included in Table 8.

Table 8: Full Bridge Load Data

Load (g)	U_{AB} (V)
0	0.0000
100	0.0009
200	0.0020
300	0.0030
400	0.0038
500	0.0048

To determine the required supply voltage U_B for a bridge voltage change $\Delta U_{AB} = 1\,\mathrm{mV}$, the supply voltage was adjusted proportionally with the weight. The data is included in Table 9.

Table 9: Supply Voltage Data

Weight (g)	Supply Voltage U_B (V)	Multimeter Reading (mV)
0	6.0	0.0
100	6.7	1.0
200	6.7	2.0
300	6.7	3.0
400	6.7	4.0
500	6.7	5.0

A graph of U_{AB} against Load was plotted to compare the Quarter Bridge and Full Bridge setups. The graph is shown in Figure 7.

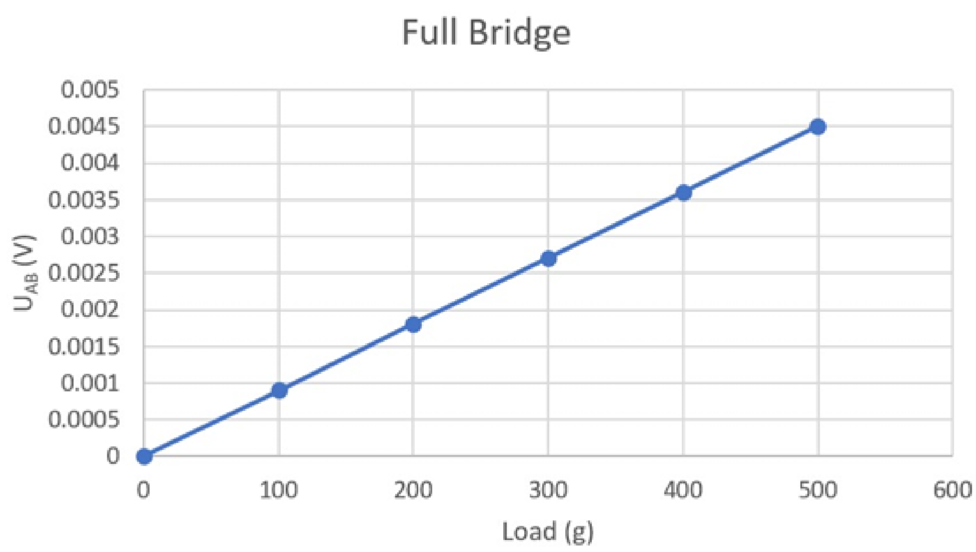

Figure 7: U_{AB} vs. Load

From the graph, the gradient for the Full Bridge is greater than that for the Quarter Bridge, indicating higher bridge sensitivity. This demonstrates that the Full Bridge exhibits a greater change in bridge voltage for a smaller change in resistance.

8 Conclusion

- This experiment provided insights into the behavior of non-linear components like a light bulb and the functioning of the Wheatstone Bridge.
- We measured and analyzed the resistance of the light bulb, observing how it changes with voltage.
- For the Wheatstone Bridge, we learned how to balance the circuit and observed its sensitivity.
- The results aligned with our expectations, enhancing our practical understanding of these concepts.
- During the experiment, the red light on the power supply was observed due to high voltage. This could potentially lead to a short circuit and should be addressed by ensuring proper voltage levels.