Lab Report for Lab Electricity

Potentiometer

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1 Introduction

A potentiometer is an electrical component that functions both as a variable resistor and as a voltage divider. It allows for the precise adjustment of electrical resistance and the control of output voltage in a circuit. The aim of the experiments detailed in this report is to analyze the behavior and characteristics of the potentiometer in various circuit configurations.

2 Background/Theory

A potentiometer is a resistor that has three terminals. Two of the terminals constitute the full resistance value, while the third one is a sliding contact. Figure 1 displays the different contacts of the potentiometer [1].
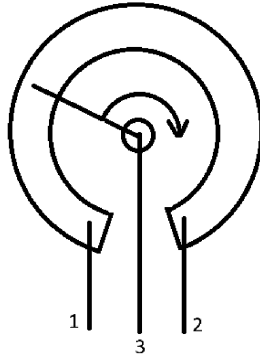

Figure 1: Drawing of a potentiometer
with labeled terminals.

The resistance between terminals 1 and 2 is constant, while the resistance between 1 and 3 is determined by equation 1 [1]:

$$R_{13} = kR \tag{1}$$

Since the potentiometer can be used as a voltage divider, the value of the potential difference between terminals 1 and 3 will be determined using equation 2 [1]:

$$V_{13} = kV_{tot} \tag{2}$$

When adding a load resistor in parallel to terminals 1 and 3, the voltage across them can be calculated using equation 3 [1]:

$$V_{13} = \frac{kR_L}{R_L + k(1-k)R_P}V \tag{3}$$

3 Methods & Materials

All circuits in the experiments were assembled using the provided connection boards. The electrical measurements, including voltage and current, were performed using the AM-520 HVAC multimeter for precision. A 10-turn potentiometer with a total resistance of 1 kΩ and a resolution of $\Delta k = 0.001$ was used to vary resistance and control output voltage. The power supply consisted of two 1.5V batteries connected in series. Fixed resistors of 1 kΩ and 510 kΩ were utilized as load resistors, along with a decade resistor to provide adjustable resistance for certain measurements.

3.1 Experimental Set-Up unloaded potentiometer

An unloaded potentiometer circuit comprises a voltage source and a potentiometer. Measurements are taken for both the voltage supplied by the power source and the potential difference established between terminals 1 and 3. In the unloaded potentiometer circuit, measurements are conducted incrementally by varying the parameter k from 1 to 0.1.

Figures 2(a) and 2(b) display both the electrical diagram, and a picture of the physical set-up of the circuit.
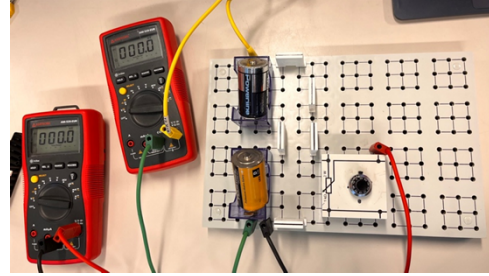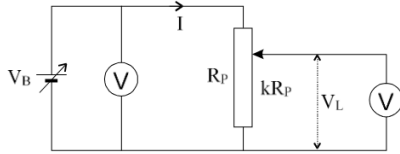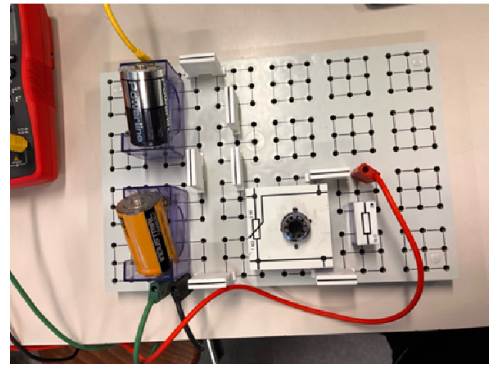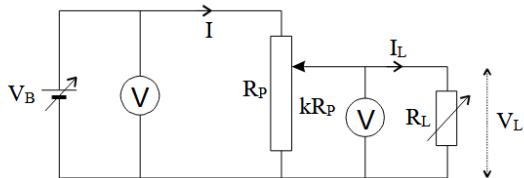

(a) Circuit diagram of unloaded potentiometer circuit [1].   (b) Picture of the unloaded potentiometer circuit.

Figure 2: Electrical schema and physical set-up of the unloaded potentiometer circuit.

3.2 Experimental Set-Up with fixed resistor

The experimental set-up for the second experiment mirrors that of the first, with the key distinction being the addition of a load resistor connected in parallel across terminals 1 and 3. Specifically, a 510 Ω resistor and a 1 kΩ resistor are incorporated to introduce varying load conditions.

Figures 3(a) and 3(b) display both the electrical diagram and a picture of the physical set-up of the circuit.

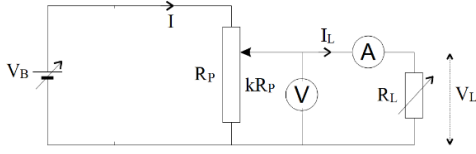(a) Circuit diagram of the loaded potentiometer circuit [1]

(b) Picture of the loaded potentiometer circuit with fixed resistance.

Figure 3: Electrical schema and physical set-up of the loaded potentiometer with fixed resistance.

3.3 Experimental Set-Up with fixed load current

In the third experimental setup, the voltmeter previously used to measure the power source is replaced by an ammeter connected in series with the load resistor. The load resistor is configured as a decade resistor. The experimental process is modified such that, for each change in the k-value, the decade resistor is adjusted to ensure that the current load remains constant. Two specific currents, 2mA and 4mA, are studied in this experiment. For each current, the resistance of the decade resistor and the corresponding voltage drop are measured.

Figures 4(a), and 4(b) display the circuit diagram and picture of this experiment.

(a) Circuit diagram of the constant current load circuit [1]
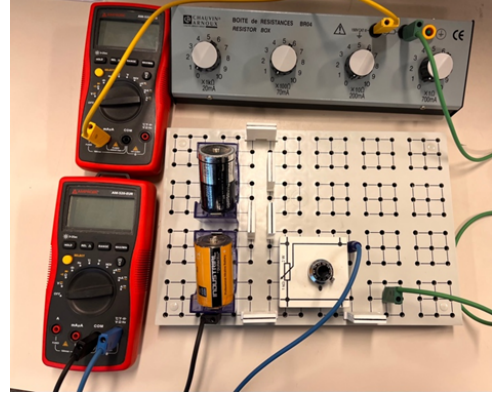
(b) Picture of the constant current load circuit.

Figure 4: Electrical diagram and physical set-up of the constant current load circuit.

4 The Unloaded Potentiometer

4.1 Measurement Results

Table 1 presents the measured voltage values ($V_{unloaded}$) corresponding to the different values of the parameter k, alongside the theoretical voltage values ($V_{expected}$) and the associated measurement error ($\Delta V_{unloaded}$) for the unloaded potentiometer circuit. Additionally, the voltage of the battery was measured and obtained a result of ($V_{cell} = 2.959 \pm 0.028$) V. The calculated error is based on the multimeter's error of reading [2].

Table 1: Measured and expected voltage in terms of the parameter k of the potentiometer.

k	$V_{unloaded}$ (V)	$\Delta V_{unloaded}$ (V)	$V_{expected}$ (V)
0.1	0.302	0.006	0.296
0.2	0.594	0.006	0.592
0.3	0.890	0.009	0.888
0.4	1.184	0.011	1.184
0.5	1.481	0.013	1.480
0.6	1.776	0.015	1.775
0.7	2.076	0.018	2.071
0.8	2.365	0.020	2.367
0.9	2.663	0.024	2.663
1.0	2.957	0.025	2.959

4.2 Graphs

Figure 5 illustrates the relationship between the measured voltage as a function of the parameter k in the unloaded potentiometer circuit, along with a linear best-fit line to further demonstrate the behavior of the data.
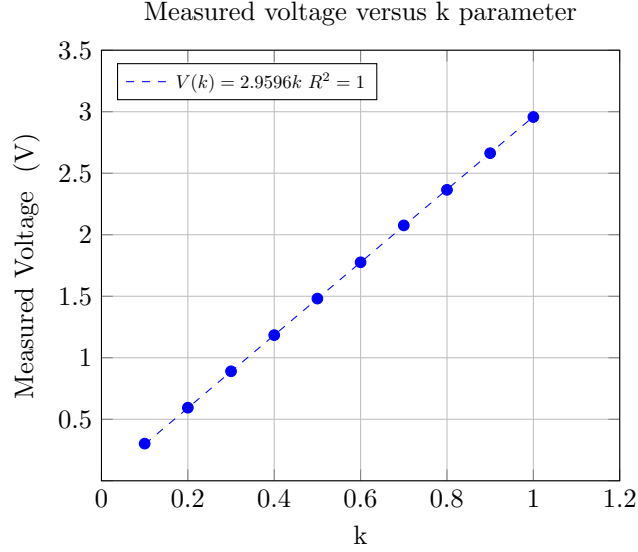

Figure 5: Measured voltage (V) in terms of the potentiometer's k parameter in the unloaded potentiometer circuit.

4.3 Discussion

The goal of this experiment was to determine the effect of modifying the parameter k of the potentiometer on the voltage load. The graphical representation of these values in Figure 5 demonstrates the linear relationship between the k-value and the voltage drop across the potentiometer. This relationship is consistent with the theoretical formula presented in equation 2. The slope of the linear relationship, approximately 2.9596, corresponds to the total voltage supplied by the circuit (approximately 2.960V), reinforcing the expectation that voltage is directly proportional to the k-value in an unloaded potentiometer configuration. The linearity is expected because no current is drawn from the potentiometer's output in the unloaded circuit. This means there is no voltage drop across internal resistances, allowing the simple linear relationship.

Analyzing the difference between measured and expected voltage, the results show strong agreement, with discrepancies falling within the calculated measurement error. These minor deviations can be attributed to potential inaccuracies in measurement or the inherent precision limits of the multimeter. Furthemore, the total voltage supplied by the circuit expected from the theoretical formula is strongly related to the one recorded by measuring the power source ($V_{cell} = 2.959 \pm 0.028$), further confirming the accuracy of the data.

5 Potentiometer loaded with fixed resistor

5.1 Measurement results

Table 2 presents the measurements for k, including the unloaded potentiometer value and the values corresponding to both loads, $1k\Omega$ as load 1 and $510 \,\Omega$ as load 2. The table provides both the measured V_{L1} and V_{L2} values, and theoretical values V_{L1t} and V_{L2t}, along with the calculated percent deviations PD_1 and PD_2.

Table 2: Measured and theoretical voltage for load 1 (1 kΩ) and load 2 (510 Ω.) values in terms of k

k	$V_{unloaded}$ (V)	V_{L1} (V)	V_{L1t} (V)	PD_1 (%)	V_{L2} (V)	V_{L2t} (V)	PD_2 (%)
0.1	0.302	0.274	0.271	9.27	0.253	0.254	16.23
0.2	0.594	0.514	0.510	13.47	0.451	0.457	24.07
0.3	0.890	0.739	0.734	16.97	0.628	0.640	29.44
0.4	1.184	0.957	0.954	19.17	0.809	0.820	31.67
0.5	1.481	1.184	1.183	20.05	0.993	1.012	32.95
0.6	1.776	1.433	1.431	19.31	1.210	1.230	31.87
0.7	2.076	1.717	1.712	17.29	1.470	1.493	29.19
0.8	2.365	2.039	2.040	13.78	1.801	1.828	23.85
0.9	2.663	2.448	2.443	8.07	2.268	2.284	14.83
1.0	2.957	2.952	2.959	0.17	2.948	2.959	0.30

5.2 Graphs

Figure 6 illustrates the relationship between the voltage across the load resistor and the parameter k, comparing the experimental results with the corresponding theoretical values. Additionally, it presents the voltage drop across the unloaded potentiometer for reference. Furthermore, Figure 7 displays the relationship between percentage deviation and the k parameter for both load resistors.

Measured experimental and theoretical voltages as function of k
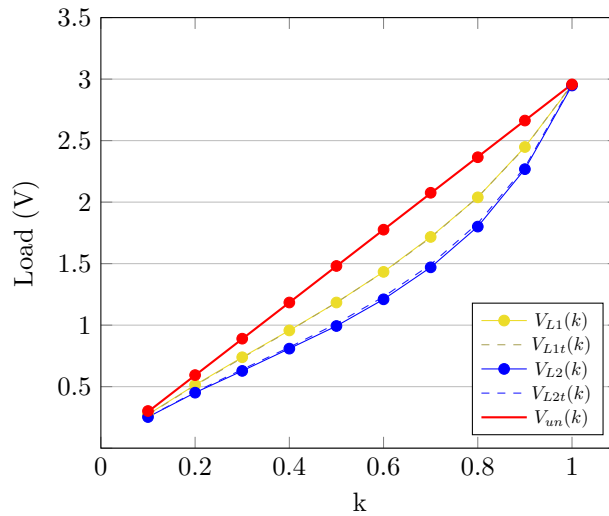

Figure 6: Measured experimental and theoretical voltages in fixed resistor circuit for load 1 (V_{L1}) and load 2 (V_{L2}) as a function of parameter k, including the voltage of unloaded potentiometer (V_{un}).

Percentage deviation as a function of k for load 1 (PD_1) and load 2 (PD_2)

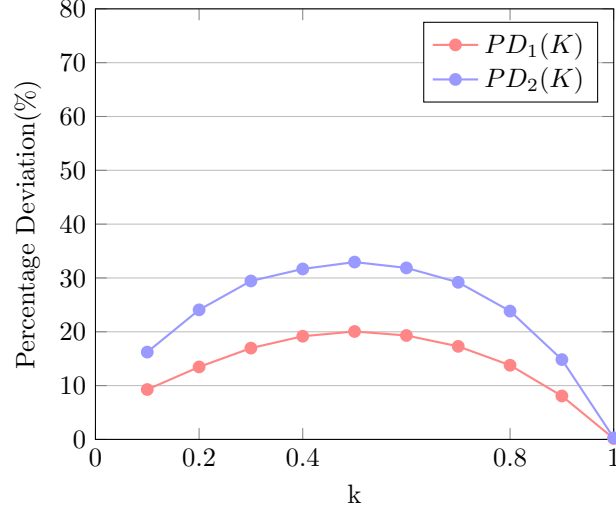

Figure 7: Percentage deviation of the measured voltage for load 1 and load 2 with respect to the unloaded voltage as a function of the parameter k.

5.3 Calculations

To calculate the theoretical load, equation 3 is used. Using k = 0.5 and R_L = 543 Ω, the theoretical voltage across the load resistor is calculated as follows:

$$V_{13} = \frac{kR_L}{R_L + k(1-k)R_P} \cdot V = \frac{0.5 \cdot 543}{543 + 0.5(1-0.5)1001} \cdot 2.959 = 1.012 \text{ V}$$

The error for the voltage across the potentiometer, the load resistor, and the potentiometer itself ΔV, ΔR_L, ΔR_P can be determined using the multimeter's user manual [2]. Equation 4 is used to calculate the error of the resistance, while equation 5 is used to calculate the error of the measured voltage. Example calculation for the error of the load resistors (R_L), the potentiometer resistance (R_p), and the voltage across the potentiometer (V_P) is shown subsequently.

$$\Delta R = \frac{R}{100} + 2LSD \tag{4}$$

$$\Delta V = \frac{0.8V}{100} + 1LSD \tag{5}$$

$$\Delta R_L = \frac{543}{100} + 2LSD = 5.46 \text{ Ω}$$

$$\Delta R_P = \frac{1001}{100} + 2LSD = 10.02 \text{ Ω}$$

$$\Delta V_P = \frac{0.8 \cdot 2.959}{100} + LSD = 0.00616 \text{ V}$$

To calculate the error values of the theoretical values V_t, the formula presented in equation 6 is utilized [3]:

$$\frac{\Delta V_t}{V_t} = \sqrt{\left(\frac{\Delta V_P}{V_P}\right)^2 + \left(\frac{\Delta R_P}{R_P}\right)^2 + \left(\frac{\Delta R_L}{R_L}\right)^2} \tag{6}$$

The example calculation for equation 6 is performed using $k = 0.5$, R_L = 543 Ω as example:

$$\Delta V_{th} = 0.77\sqrt{\left(\frac{0.00616}{2.959}\right)^2 + \left(\frac{10.02}{1001}\right)^2 + \left(\frac{5.46}{543}\right)^2} = 0.011 \text{ V}$$

The error for the measured voltage is calculated using equation 5 as follows:

$$\Delta V = \frac{0.8 \cdot 0.993}{100} + LSD = 0.0109 \text{ V}$$

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Therefore, in standard notation the results for the theoretical voltage (V_T) and the measured voltage (V_L) are listed below:

$$V_T = (1.01 \pm 0.02) \text{ V}$$
$$V_L = (0.99 \pm 0.02) \text{ V}$$

5.4 Discussion

This experiment aimed to analyze the voltage across the potentiometer when loaded with parallel resistors of 1 kΩ and 510 Ω. According to Figure 6, the relationship between the k-value and load voltage follows a non-linear trend, especially at lower k-values. Additionally, Figure 7 highlights that the percentage deviations show a more pronounced variation at lower k-values. For instance, at a k-value of 0.5, the percentage deviation was 20.05% for the 1 kΩ load and 32.95% for the 510 Ω load. When a load resistor is added, the circuit's behavior deviates from ideal conditions. This is due to the internal resistance of the potentiometer forming a voltage divider with the external load resistor.

These deviations are notable but fall within a plausible range given the potential loading effects and measurement uncertainties. As the k-value increased, the percentage deviation decreased, with minimal deviations observed at k = 1.0, where deviations were 0.17% for the 1 kΩ load and 0.30% for the 510 Ω load. As k increases, the overall circuit resistance increases, reducing current and the impact of external resistance (e.g. from the contact or the battery). Despite these discrepancies, the general trend of the measured values aligns with theoretical expectations. The similarity in the overall behaviour of the experimental and theoretical graphs (Figure 6) confirms that the theoretical model accurately represents the system's behavior, particularly at higher k-values where deviations diminish.

6 Potentiometer with fixed load current

6.1 Measurement results

Table 3 presents a detailed comparison of the measured and theoretical voltage values for the potentiometer circuit under fixed load conditions. The table examines two distinct load resistances represented as V_{L1} for the 1 kΩ load and V_{L2} for the 540 Ω load. For each k-value, the table lists the corresponding measured voltages (V_{L1} and V_{L2}), theoretical voltage predictions (V_{L1t} and V_{L2t}), and the calculated percentage deviations (PD_1 and PD_2). In the case of k = 0.1 and k = 0.2, the desired currents could not be achieved by modifying the decade resistor. Thus, the voltage across the load resistor was not measured, labeled as "N/A".

Table 3: Measured and theoretical values for the fixed current circuit with load 1 being the resistance to mantain a 2 mA current and load 2 to mantain a 4 mA current in terms of parameter k.

k	$V_{unloaded}$ (V)	V_{L1} (V)	V_{L1t} (V)	PD_1 (%)	V_{L2} (V)	V_{L2t} (V)	PD_2 (%)
0.1	0.302	0.108	0.116	64.238	N/A	-0.065	N/A
0.2	0.594	0.257	0.271	56.734	N/A	-0.049	N/A
0.3	0.89	0.431	0.467	51.573	0.029	0.046	96.741
0.4	1.184	0.654	0.702	44.764	0.194	0.221	83.615
0.5	**1.481**	**0.968**	**0.979**	**34.639**	0.43	0.478	70.966
0.6	1.776	1.214	1.294	31.644	0.755	0.813	57.489
0.7	2.076	1.554	1.650	25.145	1.156	1.230	44.316
0.8	2.365	1.925	2.047	18.605	1.639	1.726	30.698
0.9	2.663	2.34	2.483	12.129	2.192	2.302	17.689
1.0	2.957	2.786	2.959	5.783	2.838	2.959	4.024

6.2 Graphs

Figure 8 illustrates the relationship between the potentiometer's parameter (k) and the corresponding load voltages under fixed current conditions. The graph compares both measured and theoretical voltage values for two distinct current loads, V_{L1} for 2 mA and V_{L2} for 4 mA. The unloaded potentiometer voltage (V_{un}) is also plotted as a reference. The negative theoretical values for the 4 mA current are not plotted, as they are not physically meaningful for the study of the fixed current relation.
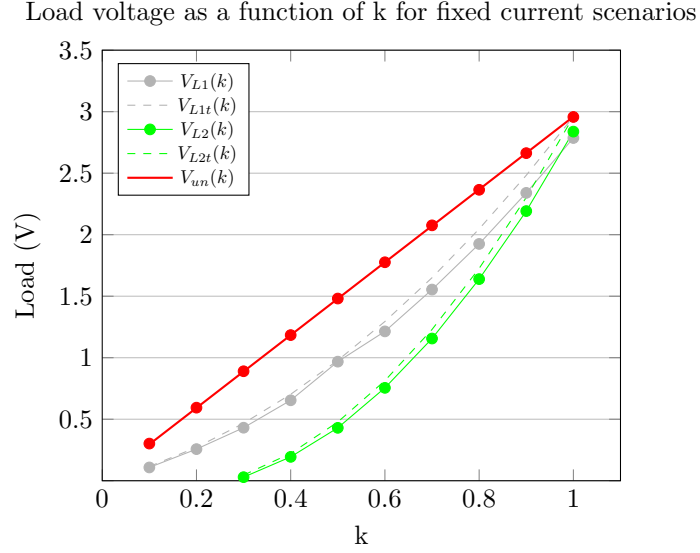
Load voltage as a function of k for fixed current scenarios

Figure 8: Measured and theoretical load voltages (V_{L1}, V_{L2}) as a function of the parameter (k) for fixed current scenarios, 2 mA and 4 mA, respectively.

Furthermore, Figure 9 illustrates the percentage deviation of the measured voltage for both fixed current scenarios, 2 mA and 4 mA as load 1 and load 2 respectively. The deviations for $k = 0.1$ and $k = 0.2$ are not plotted as they can't be calculated due to the lack of measured values.
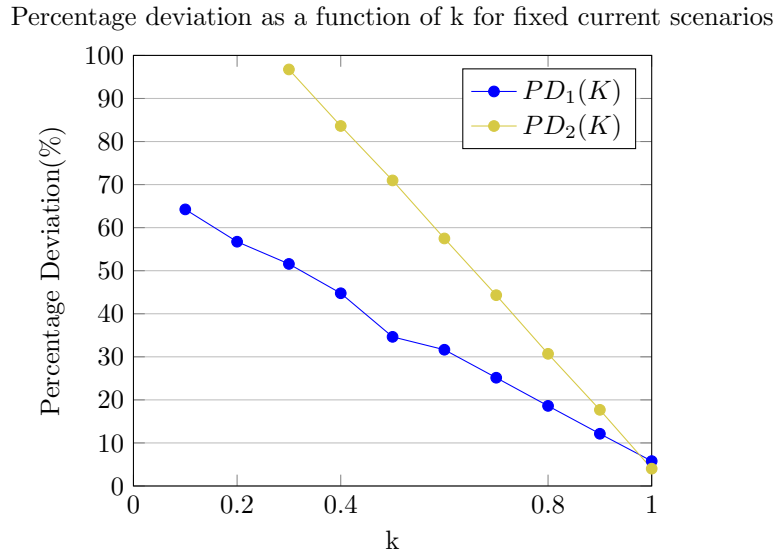
Percentage deviation as a function of k for fixed current scenarios

Figure 9: Percentage deviation in terms of k for load 1 and load 2 in fixed current scenarios, 2 mA and 4 mA, respectively.

6.3 Calculations

Due to the variable resistance of the decade resistor, R_L at $k = 0.5$ will be 480 Ω.

Firstly, using equation 3, the theoretical load can be calculated as follows:

$$V_L = \frac{0.5 \cdot 480}{480 + 0.5(1 - 0.5)1001} \cdot 3 = 0.979 \text{ V}$$

Using the values highlighted in table 3, the sample error calculations can be determined using equations 4 and 5. An example calculation for ΔR, and ΔV is done for $k = 0.5$:

$$\Delta R_L = \frac{480}{100} + 2LSD = 4.8 \ \Omega$$

$$\Delta R_P = 10.02 \ \Omega$$

$$\Delta V_L = \frac{0.08 \cdot 0.968}{100} + 0.008 = 0.01557 \text{ V}$$

The error for the theoretical value can be found using equation 6 as shown below:

$$\Delta V_{th} = 0.979\sqrt{\left(\frac{0.01557}{0.968}\right)^2 + \left(\frac{10.02}{1001}\right)^2 + \left(\frac{4.8}{480}\right)^2} = 0.021 \text{ V}$$

Therefore, the load values in standard notation for $k = 0.5$ are listed below:

$$V_{Lt} = (0.98 \pm 0.02) \text{ V}$$
$$V_L = (0.97 \pm 0.02) \text{ V}$$

6.4 Discussion

In this experiment, a constant current load was analyzed. Significant deviations from theoretical predictions were observed, especially at lower k-values. Firstly, the values for the fixed 4mA current did not coincide with the theoretical values. This is likely due to the effect of the internal resistance of the batteries on the rest of the circuit. Typical batteries have an internal resistance of around 0.2 Ω at room temperature [4]. Thus, when decreasing both the potentiometer's k-value and the decade resistor, the internal resistance had a greater impact since the external resistances were smaller. Internal resistance is also likely the cause of the discrepancy in the first current load. However, since the external resistances were larger, the overall effect of internal resistance was less pronounced.

Additionally, low k-values correspond to low resistances, increasing the current. Higher current increases the voltage drop across internal resistances and contact resistances, resulting in larger percentage deviations. This explains why deviations like 64.23% at $k = 0.1$ were observed.

Furthermore, the percentage deviation discrepancies could be attributed to the circuit construction method. Since the connections were more exposed compared to a traditional circuit, external interference may have skewed the results. This suggests that ensuring better connections and minimizing external interference would enhance measurement accuracy.

7 Conclusion

This study explored the relationship between the potentiometer's k-value and the resulting voltage in various circuit configurations. The unloaded potentiometer demonstrated a clear linear correlation, aligning well with theoretical expectations. When introducing fixed resistors, deviations were noted, particularly at lower k-values, due to loading effects. In the fixed load current experiment, internal battery resistance and circuit construction impacted measurement accuracy. While theoretical predictions provided a solid foundation, practical factors introduced measurable deviations, emphasizing the importance of considering real-world conditions in experimental analysis.

8 Bibliography

[1] J. Loeckx, "2 potentiometer 21-22."

[2] "AM-500 Multimeter," Dec. 2019. [Online]. Available: https://www.amprobe.com/wp-content/uploads/2019/12/AM-500_DIY-PRO_Digital-Multimeter_Manual.pdf

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[4] E. LLC, "Battery internal resistance," 2005. [Online]. Available: https://data.energizer.com/pdfs/batteryir.pdf