LAB REPORT 2

Ohm's Law

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HASEEB AHMED

1. Introduction

The objective of the experiment was to demonstrate ohm's law and demonstrate how the resistance different components changes with the variation of conditions such as temperature. The following resistive component were used in this experiment:

- A wire
- A metal film resistor
- A PTC resistor
- An NTC resistor

Theory:

Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship

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

For a strict fulfillment of the rule the temperature need to be constant and the resistance R must be constant.

Calculating resistance:

The resistance of a copper wire is described by the following formula:

$$R = \rho\, l / A$$

The resistance is dependent on a material constant called resistivity (ρ = Greek letter Rho). It is proportional to the length (l) and inversely proportional to the cross-sectional area (A). ρ is different for every material. For copper you will find a lot of different values. This is due to the different purity of the used copper.

Rho is the constant called resistivity and is different for every material. L is the length of the wire and A is the cross-sectional area of the wire. The above formulas apply to resistive objects who behave linearly. This means that their resistance varies linearly. However, there are resistors whose resistance varies with the change in temperature of the object.

A PTC (Positive Temperature Coefficient) is a resistor whose resistance increases when the temperature increases. For lower temperature ranges (up to ≈ 150◦C) following formula applies:

$$\mathbf{R_T = R_{T0}(1 + \alpha\Delta T) \text{ with } \Delta T = T - T_0}$$

R_T is the resistance at temperature T. T_0 is the reference temperature (in our case 0◦C). ΔT is the difference between T and T_0. α is the (linear) temperature coefficient (in our case 3.85·10-3 °C-1).

The NTC (Negative Temperature Coefficient) resistor also changes the resistance dependent on temperature. For the NTC the resistance decreases with rising temperature. The behavior is dependent by the material and is described by the following formula:

$$R_T = R_0 * e^{B(\frac{1}{T} - \frac{1}{T_0})}$$

R_T is the resistance at temperature T. T_0 is the reference temperature (here 273.15 ◦ + 25 ◦ = 298.15◦K). T is the actual temperature. R_0 is the resistance at the reference temperature. B is a constant dependent on the material. In our case the constants are R_0 = 1500Ω and B = 3480K.

2. Execution

2.1 Experiment Setup

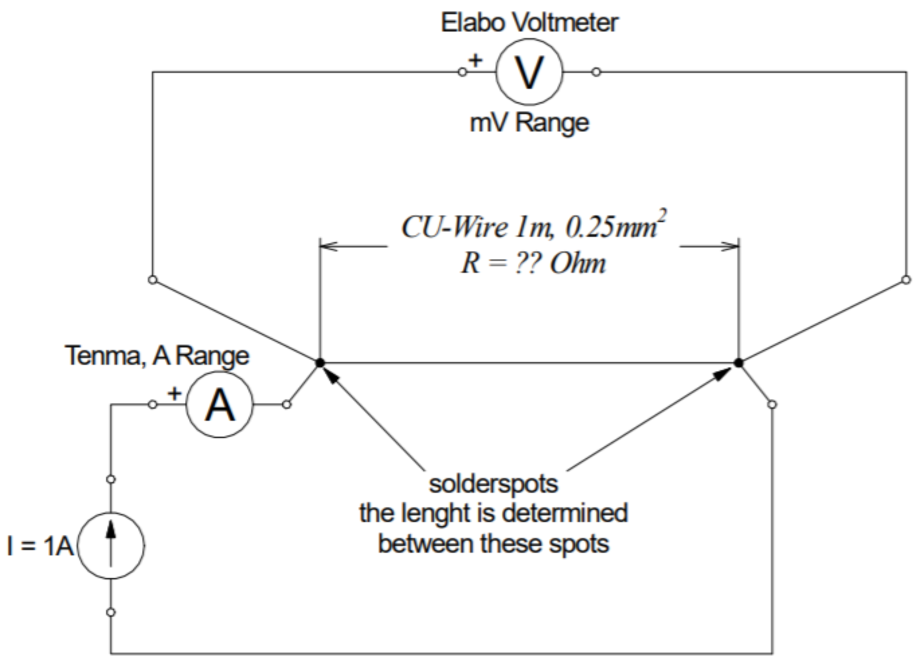
Workbench number 10

Used tools and instruments:

- TENMA multimeter
- ELABO multimeter
- 1m copper wire with 4 terminals
- 1kΩ resistor
- 1kΩ PTC resistor
- 1kΩ NTC resistor
- Breadboard
- Short connecting wires

2.1.1 Experiment Part 1 – Setup

The objective of this experiment was to record the resistance of a 1m long copper wire. The resistance was measured by the Kelvin 4 wire method in order to avoid the methodical error caused by the two-wire method. Two terminals of the wire were connected with ELABO Voltmeter in parallel. The other two terminals were connected with TENMA multimeter and 1 A current source in series. The following circuit was set up:



The values of current through and the voltage across the wire was measured and recorded. Afterwards, the resistance of the wire was measured using the TENMA multimeter directly.

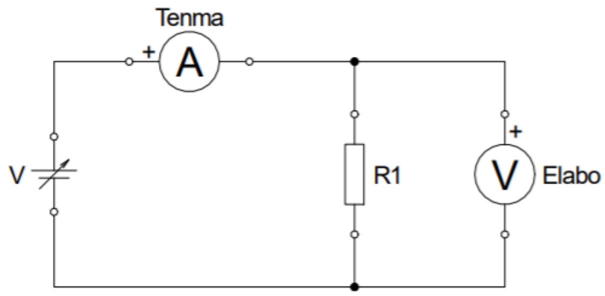
2.1.2 Experiment Part 1 - Execution and Results

The voltage across the wire was measured by ELABO multimeter and the current thorough it was measured by TENMA multimeter. The results are summarized in the following table:

Voltage (V)	Current (A)	Resistance (Ω)
69.89	1.015	70.31

2.2.1 Experiment Part 2 – Setup

The circuit in this experiment was used the study the behavior of an ohmic resistor. A 1k50Ω resistor was attached in series with a variable voltage supply. The current through the resistor and the voltage across it was measured for different voltage supplies. The range of ELABO Voltmeter was set to 200V as the highest voltage supply provided to the resistor was 24V. The circuit was assembled on breadboard. The schematic of the circuit assembled is as follows:



$R_1 = 1k50\,\Omega$

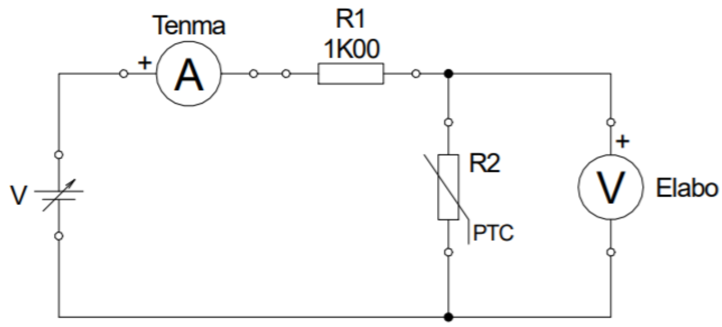
2.2.2 Experiment Part 2 – Execution and Results

The values of voltage and current were recorded with varying voltage source. The results are summarized in the following table:

Vs	Vs/V	I/mA
0	0.008	0.000
2	2.114	1.41
4	4.067	2.71
6	6.038	4.03
8	8.023	5.36
10	10.000	6.68
12	12.055	8.05
14	14.075	9.40
16	15.999	10.69
18	18.013	12.03
20	19.97	13.36
22	21.98	14.71
24	23.95	16.03

2.3.1 Experiment Part 3 – Setup

In this experiment, the behavior of a PTC resistor was studied. A PTC with a resistance of 1k50Ω was attached in series with a voltage supply which was varied from 0V to 24V in 2V steps and the current through the PTC and voltage across it were measured. After each time, the voltage source was changed, we waited for 2 minutes so that the temperature of PTC was stable. The schematic of the circuit assembled is as follows:



$$R_2 = 1k50\,\Omega$$

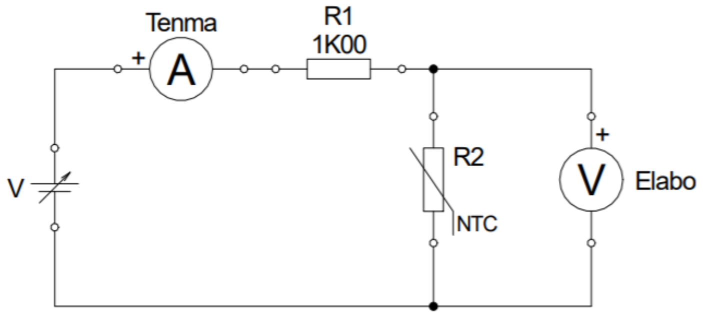
2.3.2 Experiment Part 3 – Execution and Results

The results are summarized in the following table:

Voltage Source (V)	Voltmeter ELABO (V)	TENMA (mA)
0	0.01	0.000
2	1.30	0.80
4	2.47	01.56
6	3.67	2.42
8	4.73	3.31
10	5.77	4.30
12	6.50	5.60
14	7.14	6.88
16	7.58	8.51
18	8.16	9.89
20	8.27	11.82
22	8.25	13.80
24	8.41	15.58

2.4.1 Experiment Part 4 – Setup

In this experiment, the behavior of a NTC was studied. NTC of 1k50Ω was attached in series with a voltage supply which was varied from 0V to 24V in 2V steps and the current through the NTC and voltage across it were measured. After each time, the voltage source was changed, we waited for 2 minutes so that the temperature of NTC was stable. Another 1K Ω resistor was attached in series with the NTC but it was shorted. The final circuit was as follows:



$$R_2 = 1k50\,\Omega$$

2.4.2 Experiment Part 4 – Execution and Results

The results are summarized in the following table:

Voltage Source (V)	Voltmeter ELABO (V)	TENMA (mA)
2	1.24	0.84
4	2.43	1.64
6	3.64	2.44

8	4.85	3.21
10	6.10	4.00
12	7.31	4.71
14	8.58	5.46
16	9.92	6.15
18	11.23	6.84
20	12.52	7.48
22	13.91	8.12
24	15.31	8.71

3. Evaluation

3.1Evaluation Experiment Part 1

Question: Calculate the resistance of the wire using the values from the 4-wire measurement.

From Ohms law we know:

$$Resistance(\Omega) = \frac{Voltage\ (V)}{Current\ (A)}$$

Hence the resistance using the 4-wire method is:

$$Resistance(\Omega) = \frac{69.89}{1.015} = 68.86\Omega$$

Question: Calculate the relative error of R using the values from the 4-wire measurement.

The formula for absolute error is:

$$Eabs = \pm 0.03\% f.value + 0.01\% f.range.$$

Absolute error for the voltage:

$$Eabs = \frac{0.03}{100} * 69.89 + \frac{0.01}{100} * 200 = 0.040967\%$$

Relative error for the voltage:

$$Erel = \frac{Eabs}{Vmeasured} * 100 = \frac{0.040967}{69.85} * 100 = 0.0586\%$$

The formula for absolute error for the current is:

$$Eabs = \pm 0.2\% rdg + 3 * dig.$$

Absolute error for the current:

$$Eabs = \frac{0.02}{100} * 1.015 + 3 * 0.001 = 0.003203$$

Relative error for the current:

$$Erel = \frac{Eabs}{Vmeasured} * 100 = \frac{0.003203}{1.015} * 100 = 0.3156\%$$

Relative error for the resistance:

$$Erel = Error(voltage) + Error(current) = 0.0586 + 0.3156 = 0.3742\%$$

Question : Calculate the theoretical resistance of the wire (l = 1 m−A = 0.25 mm2). Use the ρ given in the experiment section.

$$R = p\frac{L}{A}$$

$R = 0.0195 \frac{1m}{0.25mm^2} = 0.78\Omega$

Question : The experimental taken R value should be very accurate. Why there are differences to the theoretical value?

As we are measuring a small amount of resistance even the small changes in the circuit might affect the calculated value. The thickness of the wire might not have been uniform with a changing width.

Question:Compare the calculated R value from U and I to the value gotten with the multimeter in resistance range. Using the ohm range of the multimeter includes methodical error. Name these errors. How they are avoided using the 4-wire method?

The resistance calculated from the TENMA multimeter is 70.31Ω. the value calculated using the 4-wire method is 68.86Ω. This clearly suggests a methodical error when using the TENMA multimeter. The main reason for this error is the fact that the resistance of the wire is too small and becomes comparable to the resistance of the TENMA multimeter. This is avoided using the four-wire method as we measure the voltage drop across the wire and the current flowing through the wire and indirectly calculate the resistance.

Part 2,3,4:

Question:Draw the graph R = f(I) for all resistors. Put all three graphs in one diagram?

The resistance for all resistors was calculated and presented in the tables below:
Resistance for the Metal Film Resistor:

Vs	Vs/V	I/mA	Resistance(KΩ)
0	0.008	0.000	undefined
2	2.114	1.41	1.499
4	4.067	2.71	1.501
6	6.038	4.03	1.498
8	8.023	5.36	1.497
10	10.000	6.68	1.497
12	12.055	8.05	1.498
14	14.075	9.40	1.497
16	15.999	10.69	1.497
18	18.013	12.03	1.497
20	19.97	13.36	1.495
22	21.98	14.71	1.494
24	23.95	16.03	1.494

Resistance for the PTC:

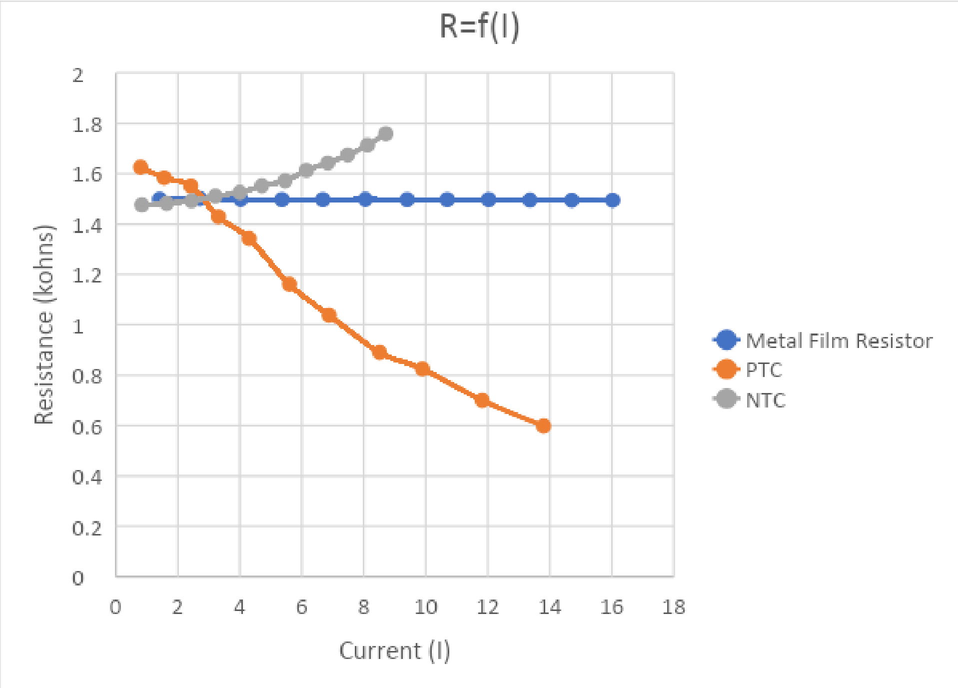
Voltage Source (V)	Voltmeter ELABO	TENMA (mA)	Resistance (KΩ)

	(V)		
0	0.01	0.000	undefined
2	1.30	0.80	1.625
4	2.47	01.56	1.583
6	3.67	2.42	1.551
8	4.73	3.31	1.429
10	5.77	4.30	1.342
12	6.50	5.60	1.161
14	7.14	6.88	1.038
16	7.58	8.51	0.8907
18	8.16	9.89	0.825
20	8.27	11.82	0.700
22	8.25	13.80	0.598
24	8.41	15.58	0.540

Resistance for the NTC:

Voltage Source (V)	Voltmeter ELABO (V)	TENMA (mA)	Resistance (KΩ)
2	1.24	0.84	1.476
4	2.43	1.64	1.482
6	3.64	2.44	1.492
8	4.85	3.21	1.511
10	6.10	4.00	1.525
12	7.31	4.71	1.552
14	8.58	5.46	1.571
16	9.92	6.15	1.613
18	11.23	6.84	1.642
20	12.52	7.48	1.674
22	13.91	8.12	1.713
24	15.31	8.71	1.758

The combined graph is as follows:



Question 2:

Do the graphs show the expected behavior?

Yes, the graphs show the expected behavior. An increase in the current means an increase in the power provided to the resistor which results in increased heating of the resistor hence an increase in the current is synonymous to an increase in the temperature. The resistance of a metal film resistor remains the same, the resistance of the PTC decreases with an increase in the current while the resistance of the NTC increases with an increase in the current.

Question 4:

Draw the temperature at the PTC as a function of the resistance of the PTC resistor.

For a PTC the resistance is:

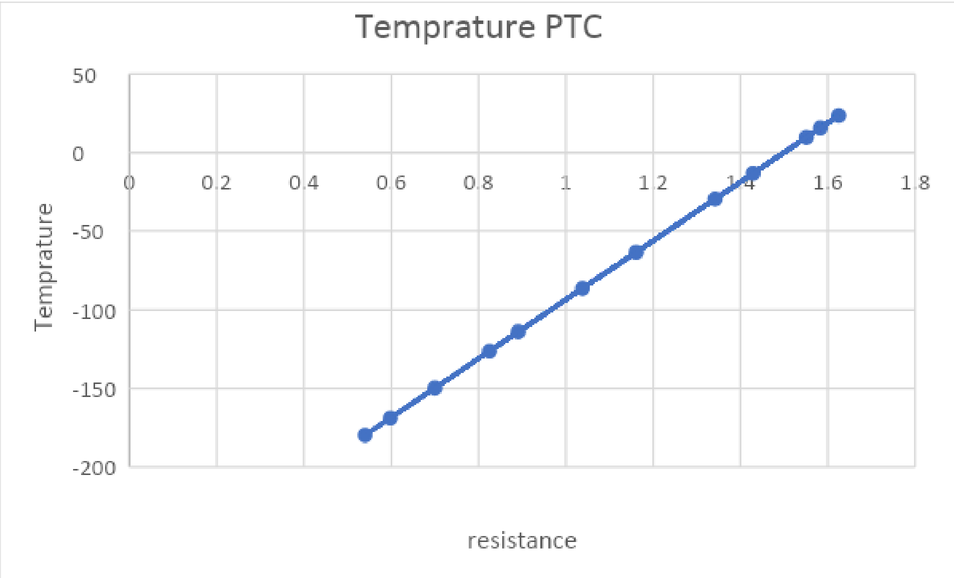
$$R_T = R_{T0}(1 + \alpha\Delta T) \text{ where } R_{T0} = 1000,\ \alpha = 0.0038724$$

Rearranging it to get T as a function of R:

$$(T - 0) = \frac{(\frac{R_T}{R_{T0}} - 1)}{\alpha}$$

Voltage Source (V)	Voltmeter ELABO (V)	TENMA (mA)	Resistance (KΩ)	Temperature (C)
0	0.01	0.000	undefined	
2	1.30	0.80	1.625	175.5618

4	2.47	01.56	1.583	163.764
6	3.67	2.42	1.551	154.7753
8	4.73	3.31	1.429	111.4286
10	5.77	4.30	1.342	120.5056
12	6.50	5.60	1.161	96.06742
14	7.14	6.88	1.038	45.22472
16	7.58	8.51	0.8907	10.67416
18	8.16	9.89	0.825	-30.7022
20	8.27	11.82	0.700	-49.1573
22	8.25	13.80	0.598	-84.2697
24	8.41	15.58	0.540	-112.921



Question 4:

Draw the temperature at the NTC as a function of the resistance of the NTC resistor.

The resistance of an NTC is:

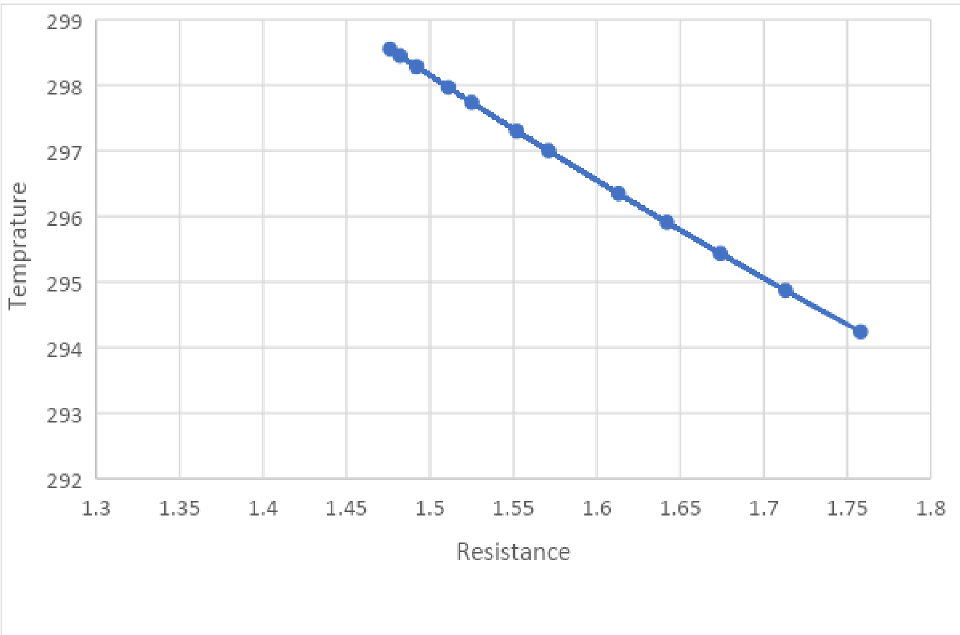
$R_T = R_{25} * e^{B(\frac{1}{T} - \frac{1}{T_0})}$ where $R_{T0} = 1500$, $B = 3560\text{K}$, $T_0 = 298.15\text{K}$

Re-writing the formula for T:

$$T = \frac{B*T_0}{(T_0 * \frac{R_T}{R_{25}}))+B}$$

Voltage Source (V)	Voltmeter ELABO (V)	TENMA (mA)	Resistance (KΩ)	Temperature (C)
2	1.24	0.84	1.476	

				298.553 3
4	2.43	1.64	1.482	298.4518
6	3.64	2.44	1.492	298.2836
8	4.85	3.21	1.511	297.9677
10	6.10	4.00	1.525	297.7378
12	7.31	4.71	1.552	297.3015
14	8.58	5.46	1.571	296.9997
16	9.92	6.15	1.613	296.3474
18	11.23	6.84	1.642	295.9084
20	12.52	7.48	1.674	295.4345
22	13.91	8.12	1.713	294.8709
24	15.31	8.71	1.758	294.2389



Question 5:

Why is it dangerous to connect an NTC resistor to higher voltages?

Subjecting an NTC to high voltages means increasing the temperature for the NTC which leads to a lower resistance of the NTC. This in turn causes the size of the current to increase which might damage other components in the circuit.

Question 6:

What kind of 'resistor' is the copper wire? What are the consequences when using it with high currents or with high temperatures.

The copper wire behaves as a PTC at higher temperatures. At lower temperatures the resistance of the wire remains constant. When connecting the wire to higher currents care must be taken for the wire might over heat and melt or break.

Conclusion:

Ohm's Law is a fundamental law in the field of electricity. Throughout the course of the experiment we find it extremely useful in helping us understand the behavior of various materials. We find that ohm's law applies only to ohmic substances if and only if the condition applied to the substance remain the same. We had seen how the resistance of an NTC or a PTC change with increasing the voltage and indirectly, the temperature and how this change in resistance could lead to damaging of other components connected to the resistor and how careful we must be when using such materials. We also learnt how important these materials can be when used to build temperature dependent circuits such as a heat detector or a thermostat. We can also conclude that using the 4-wire method to calculate a small resistance can prove to be less erroneous as compares to using the 2-wire method.

References
Lab Manual
Data Sheet

https://en.wikipedia.org/wiki/Ohm%27s_law

Appendix:
Part 1:

V_{AB} = 3.339 V , I_{AB}= 15.019 mA

Part 2:

V_{Th} = 7.49 , I_{No}= 58.9mA , R_{Th}=124.8 Ω

Part 3:

I_5 = 59.6, V_5= 3.285

Part 4:

ELABO I = -40.30 mA
TENMA I = -11.68 mA