85%

Constructor University Bremen

Natural Science Laboratory

Electrical Engineering I

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Lab Experiment 2- Ohm's Law

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Place of execution: Teaching Lab EE

Rotation III, Bench 8

Data of execution: 02 November, 2023

1.INTRODUCTION

In this experiment, we embarked on a systematic exploration of Ohm's Law by subjecting diverse resistive components to rigorous testing. Through a comprehensive analysis of these components, we aimed to vividly illustrate Ohm's Law in action. By scrutinizing the behavior of resistors with distinct properties, we unravel the intricate interplay between voltage, current, and resistance, offering valuable insights into how Ohm's Law governs the electrical characteristics of these components. Ohm's Law states that the current that passes through a conductor between two points is directly proportional to the potential difference across the two points. The constant proportionality of the two is called resistance given that the temperature is constant, meaning that the resistance should be independent of the current. If the temperature is not held constant the resistance will increase as the temperature increases. This will lead to a non ohmic graph, meaning the resistance of the material will be changing based on the current. In this experiment the behavior of the copper wire, metal film resistor, Positive Temperature Coefficient(PTC) and Negative Temperature Resistance(NTC) was experimented, demonstrated- and compared using the ohm's law.

We used the Ohm's Law($I = V/R$) to calculate the current, where I is the current flowing through a given point, V is the potential difference between the given point and R the constant proportionality of I and V called resistance.

We used a copper wire to illustrate Ohm's Law, whose resistance formula is given by $R = \rho\,(l/A)$. 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. For the copper wires in our experiment we used $\rho = 0.0195\Omega mm^2/m$, for the length we measured $l = 1\,m$ long with a cross sectional area of $0.25\,mm^2$. Since the resistance is very low we used the Kelvin (4-wire) resistance measurement method. Using this method eliminated the influence of connecting wires/contacts giving a more accurate result.

Additionally, the PTC (Positive Temperature Coefficient) resistor was used to illustrate Ohm's Law but this time the resistance increases with increase in temperature. This means that a non-ohmic graph is expected. Nickel thin film resistor was used as the PTC.

The equation $R_T = R_{25}(1+\alpha\Delta T)$) with $\Delta T = T - T_{REF}$. Where R is the resistance at temperature T, R_T is the resistance at temperature T, R_{25} is the resistance at the reference temperature (here 1k00 Ω @ 25° C), T is the actual temperature, T_{REF} is the reference temperature of the element. Here 25° C, ΔT is the difference between T and T_{25} and α is the (linear) temperature coefficient. It has the dimension of an inverse temperature (1/K or K^{-1}).

Finally, the NTC (Negative Temperature Coefficient) resistor was used to illustrate Ohm's Law, but this time the resistance decreases with the increase in temperature.

The equation $RT = R25*e^{B(1/T+1/T_0)}$ is the resistance at temperature T. Where R_T is the resistance at temperature T, R_{25} is the resistance at the reference temperature (here R_2 = 1k00 Ω @ 25° C), T is the actual temperature, T_0 is the reference temperature (here 273.15 $^\circ$ + 25 $^\circ$ = 298.15 $^\circ$ K) and B is a constant dependant on the material. In our case B = 3930 K.

2. EXECUTION

Experiment Setup
Workbench No.8

Used tools and instruments:
Breadboard, Tools box from workbench, Multimeters TENMA and ELABO, Copper Wire

Experiment Part 1 – Setup
We assembled the circuit below on the breadboard. Our goal was to measure the resistance of our copper wire using the Kelvin (4-wire) resistance measurement method.

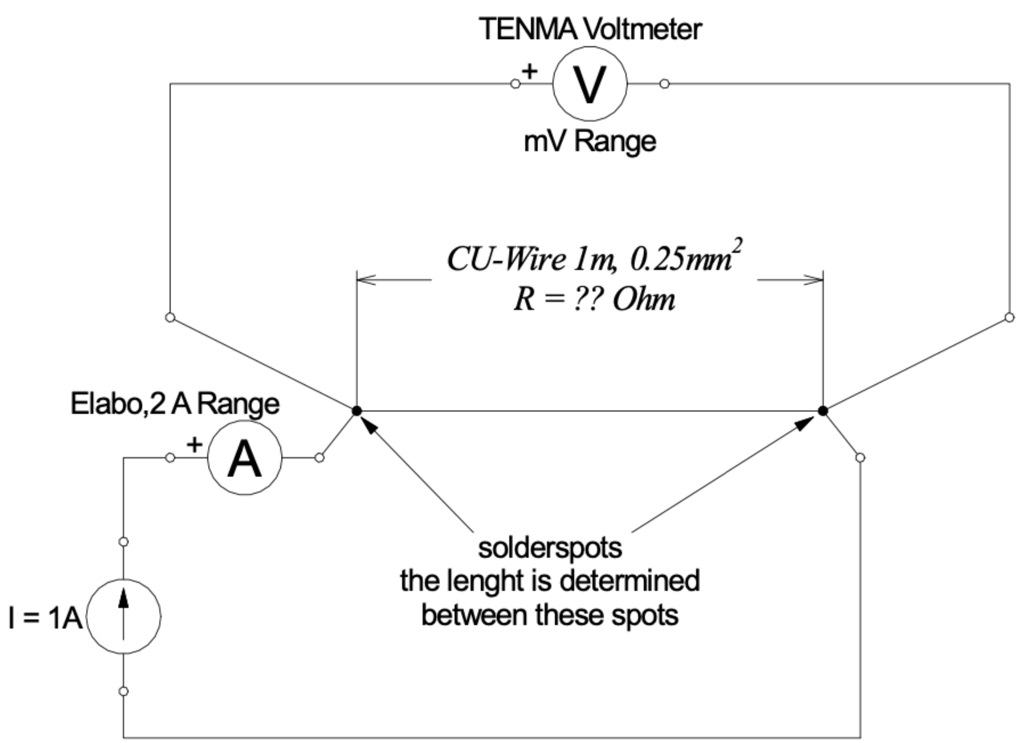


Fig.1: Resistance of a copper wire

No other wires but lab wire to shorten the output terminals were used in setting up our circuit, this was to reduce the total resistance of the whole circuit. We used the TENMA as our voltmeter and the ELABO as our ammeter. We set the voltage to 10 V. In this experiment we used the supply as a constant current source. Switch the internal instrument to current. Set the current to ≈ 1 A. We then measured the resistance using TENMA by changing its range to Ohm(Ω).

Experiment Part 1 – Execution and Results

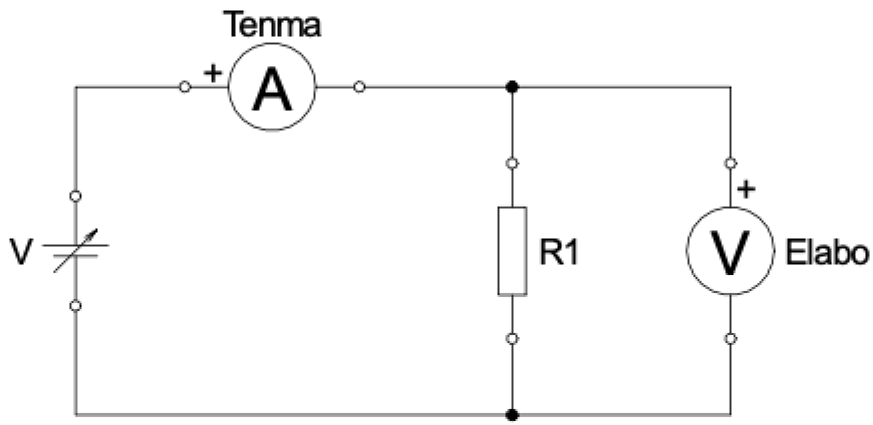
Results:

Voltage (mV)	Current (mA)	Resistance (Ω)
69.05	1013.6	0.37

Table 1: Measured Voltage, Current and Resistance of the copper wire.

Experiment Part 2 – Setup

The goal of our second experiment was to see the behavior of a metal film resistor. We then measured the resistance at different voltage values.



$$R_1 = 1\text{k}00\,\Omega$$

Fig 2: Resistance of a metal film resistor

After setting up the above circuit we then varied the voltage at the supply from V = 0 to 24 V in 2 V steps and recorded voltage and current across the 1k00Ω resistor.

Results:

Voltage Supply (V)	Range (V)	Voltage (V)	Current (mA)
0	20	0.009	0.005
2	20	2.079	2.083

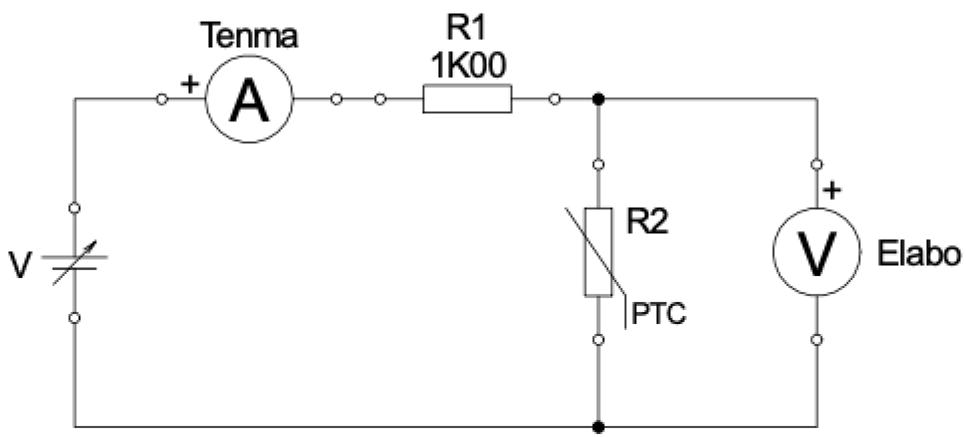
do not split tables..

4	20	4.038	4.05
6	20	6.03	6.048
8	20	8.065	8.094
10	20	10.033	10.062
12	20	12.027	12.062
14	20	13.985	14.028
16	20	15.926	15.975
18	20	17.982	18.04
20	20	19.883	19.949
22	200	21.82	21.932
24	200	23.89	24.007

Table 2: Measured voltage and current across 1k00Ω *in 2 V steps.*

Experiment Part 3 – Setup

The goal of our third experiment was to see the effects of temperature on the PTC (Positive Temperature Coefficient) resistor. With higher temperature the resistance increases.



$$R_2 = 1\text{k}00\,\Omega$$

Fig 3: Resistance of a Positive Temperature Coefficient resistor

Before connecting the power supply, we set the voltage to 0 V. We then varied the voltage at the supply from 0V to 24V in 2V Steps, but this time we waited for about 2 minutes after setting the voltage to record the current and voltage because we wanted the temperature of the resistance to increase in order to see the effects of temperature on the resistor. The circuit was not touched during this period to avoid any heat transfers that can contribute to increase in resistance or temperature adjustments.

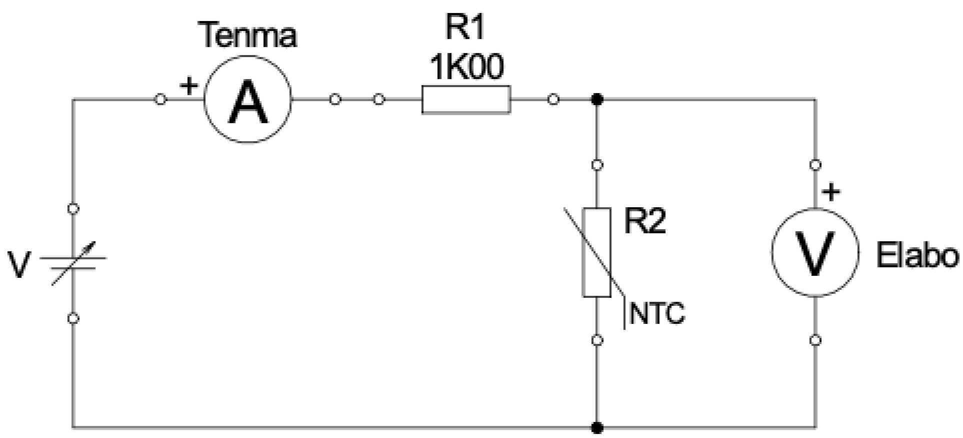
Experiment Part 3 – Execution and Results
We later recorded the voltage and current.

Results:

Voltage Supply (V)	Voltage (V)	Current (mA)	Current (A)
0	0	0	0
2	1.065	1.077	0.001077
4	2.05	2.07	0.00207
6	3.015	3.02	0.00302
8	4.026	3.986	0.003986
10	5.092	4.971	0.004971
12	6.155	5.914	0.005914
14	7.225	6.792	0.006792
16	8.37	7.703	0.007703
18	9.524	8.512	0.008512
20	10.693	9.318	0.009318
22	11.883	10.128	0.010128
24	13.205	10.836	0.010836

Table 3:Measured voltage and current across PTC resistor in 2 V steps.

Experiment Part 4 – Setup
The goal of our fourth experiment was to see the effects of temperature on the NTC (Negative Temperature Coefficient) resistor. In this case with rising temperature the resistance decreases.



$$R_2 = 1\text{k}00\,\Omega$$

Fig 4:Resistance of a Negative Temperature Coefficient resistor

Just like the PTC, Before connecting the power supply, we set the voltage to 0 V. We then varied the voltage at the supply from 0V to 24V in 2V Steps, but this time we waited for about 2 minutes after setting the voltage to record the current and voltage because we wanted the temperature of the resistance to increase in order to see the effects of temperature on the resistor. The circuit was not touched during this period to avoid any heat transfers that can contribute to increase in resistance or temperature adjustments.

Experiment Part 2 – Execution and Results

We later recorded the voltage and current.

Results:

Voltage Supply (V)	Voltage (V)	Current (mA)
0	0.008	0.003
2	1.075	1
4	2.12	1.996
6	3.075	2.979
8	3.879	4.147
10	4.55	5.513
12	5.135	6.943
14	5.592	8.488
16	5.944	10.086
18	6.11	11.913
20	6.249	13.81
22	6.266	15.783
24	6.178	17.833

Table 4:Measured voltage and current across the NTC Resistor in 2 V steps

3.Evaluation

Part 1 : Resistance of a copper wire

1. Calculated resistance of the copper wire using the values in table 1.

$R = V/I$

$R = 69.05E - 3/1013.6E - 3$

$R = 0.068\Omega$

2. Calculated relative error of R using the values in table 1 (error propagation!)

$\Delta V = \pm[(0.05\% rdg + 5dig)/(True\ value)] * 100$

$\Delta V = \pm[((69.05 * 10^\wedge - 3) * (0.05/100) + (5 * 0.00001))/(69.05 * 10^\wedge - 3)] * 100$

$\Delta V = 0.122$

$\Delta I = [(0.15\%\, f.Value + 0.01\%\, f.Range)/(True\ value)] * 100$

$\Delta I = [((1013 * 10^{-3}) * (0.15/100) + (2 * (0.01/100))/(1013 * 10^{-3})] * 100$

$\Delta I = 0.170$

delta is the abs error... you cannot name abs. and rel. error with delta!
so E_I%!! Of course .. same for the values below...

Our error propagation of R in this case is the sum of the current's and voltage's relative error.

$\Delta R = \Delta V + \Delta I$

$\Delta R = 0.122 + 0.170$

units for all calculations??

$\Delta R = 0.292$

E%_R = 0.292%

3. Calculated theoretical resistance of the copper wire.

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

$R = 0.0195\Omega mm^2/m(1m/0.25\,mm^2)$

you are mixing up things!! The 4 wire value is accurate! you showed the prove above. But do you really know the different properties used in the formula????

$R = 0.078\Omega$

4. We have different R values because the actual value has too many resistors adding up from the wires making the value large. The p= 0.0195-1mm - value from the manufacturers might have been too high to the actual value of the resistivity due to impurities. The resolution used was too high which could have caused calculation errors.

5. The R value from V and I is 0.068Ω and for the multimeter in resistance range is 0.37Ω. Using the multimeter includes methodical errors such as systematic errors due a lot of the wires that were used and were adding up the resistance. These errors can be avoided by using a few wires during the 4-wire method; the 4-wire method has almost no errors because it uses additional sense wires to measure voltage directly at the resistor terminals, eliminating lead resistance from the measurement and enhancing accuracy.

Part 2, 3, 4 : Resistance of different components

1.

Voltage Supply (V)	Voltage (V)	Current (A)	Resistance (Ω)
0	0.009	0.000005	1800
2	2.079	0.002083	998.0796928
4	4.038	0.00405	997.037037
6	6.03	0.006048	997.0238095
8	8.065	0.008094	996.4170991
10	10.033	0.010062	997.1178692
12	12.027	0.012062	997.0983253
14	13.985	0.014028	996.934702
16	15.926	0.015975	996.9327074
18	17.982	0.01804	996.7849224
20	19.883	0.019949	996.6915635
22	21.82	0.021932	994.8933066
24	23.89	0.024007	995.1264215

Table 5: Metal Film Resistor

Voltage Supply (V)	Voltage (V)	Current (A)	Resistance (Ω)

0	0	0	
2	1.065	0.001077	988.8579387
4	2.05	0.00207	990.3381643
6	3.015	0.00302	998.3443709
8	4.026	0.003986	1010.035123
10	5.092	0.004971	1024.341179
12	6.155	0.005914	1040.750761
14	7.225	0.006792	1063.751472
16	8.37	0.007703	1086.58964
18	9.524	0.008512	1118.890977
20	10.693	0.009318	1147.563855
22	11.883	0.010128	1173.281991
24	13.205	0.010836	1218.623108

Table 6:PTC resistor

Voltage Supply (V)	Voltage (V)	Current (A)	Resistance (Ω)
0	0.008	0.000003	2666.666667
2	1.075	0.001	1075
4	2.12	0.001996	1062.124248
6	3.075	0.002979	1032.225579
8	3.879	0.004147	935.3749699
10	4.55	0.005513	825.3219663
12	5.135	0.006943	739.5938355
14	5.592	0.008488	658.8124411
16	5.944	0.010086	589.331747
18	6.11	0.011913	512.8850835
20	6.249	0.01381	452.4981897
22	6.266	0.015783	397.0094405
24	6.178	0.017833	346.436382

Table 7:NTC Resistor.

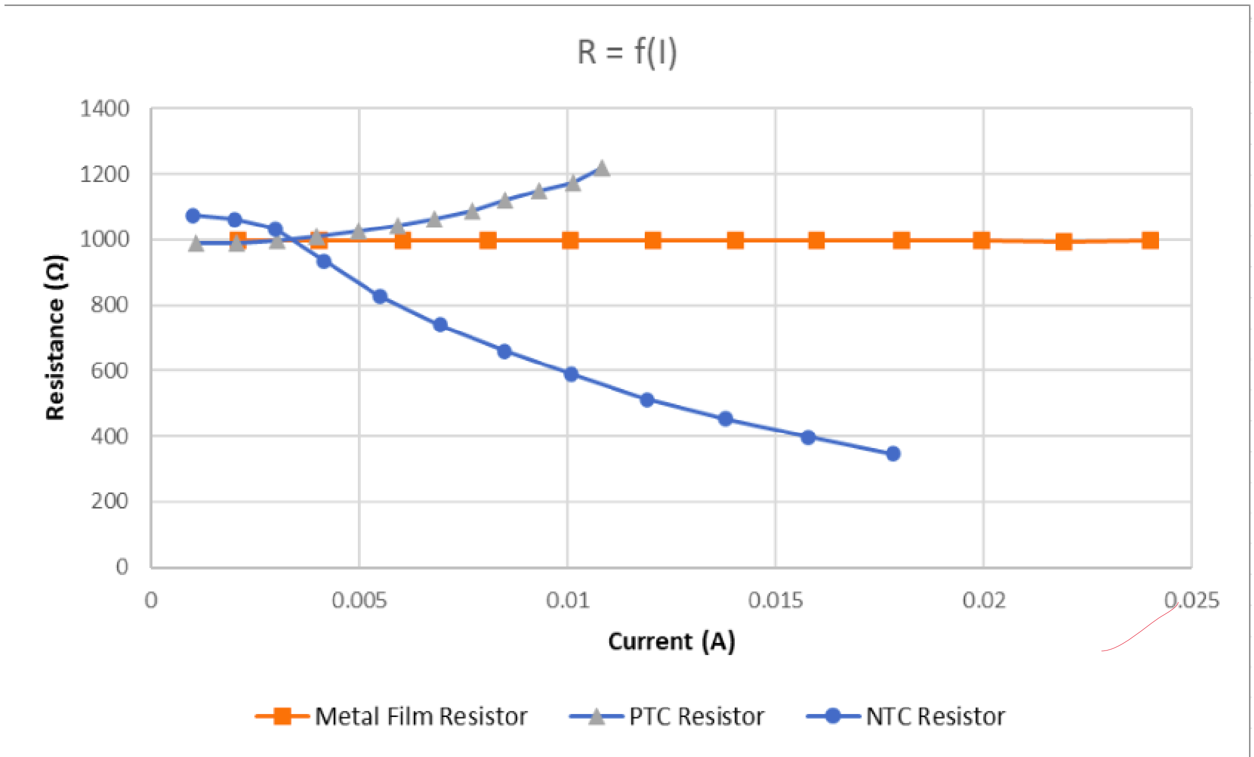


Fig 5:graph R = f(I) for Metal film resistor, PTC resistor and NTC resistor.

Yes, all the three graphs show the expected behavior. The metal film resistor graph shows its behavior which is as the current through the resistor increases, the resistance remains relatively constant. The PTC resistor exhibits a nonlinear behavior because it experiences an increase in resistance as the current or temperature increases. The NTC resistor exhibits a nonlinear behavior because it experiences a decrease in resistance as the current or temperature increases.

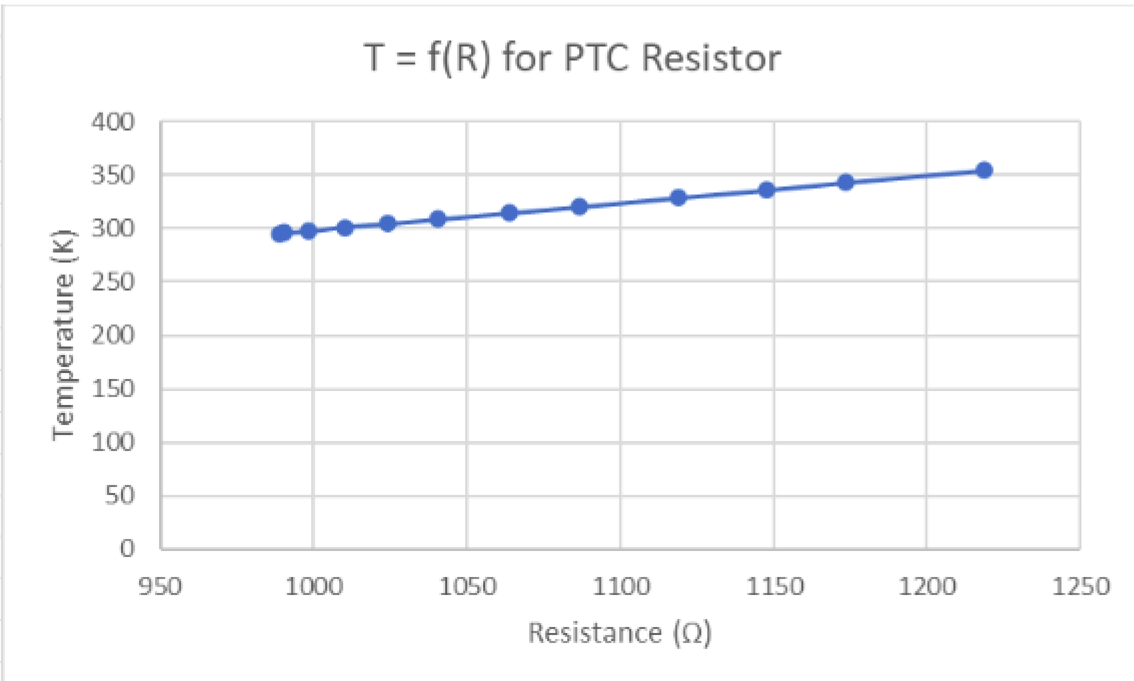
3. $T = \left[\left(\left(R/R_{25}\right) - 1\right)/\alpha\right] + T_{REF}$

Voltage Supply (V)	Voltage (V)	Current (A)	Resistance (Ω)	Temperature (K)
0	0			
2	1.065	0.001077	988.8579387	295.2726988
4	2.05	0.00207	990.3381643	295.6549489
6	3.015	0.00302	998.3443709	297.722454
8	4.026	0.003986	1010.035123	300.7414479
10	5.092	0.004971	1024.341179	304.4358121

do not split tables..

12	6.155	0.005914	1040.750761	308.6733862
14	7.225	0.006792	1063.751472	314.613039
16	8.37	0.007703	1086.58964	320.510717
18	9.524	0.008512	1118.890977	328.8521427
20	10.693	0.009318	1147.563855	336.2565631
22	11.883	0.010128	1173.281991	342.8979575
24	13.205	0.010836	1218.623108	354.6067473

Table 8:PTC Resistor's Temperature

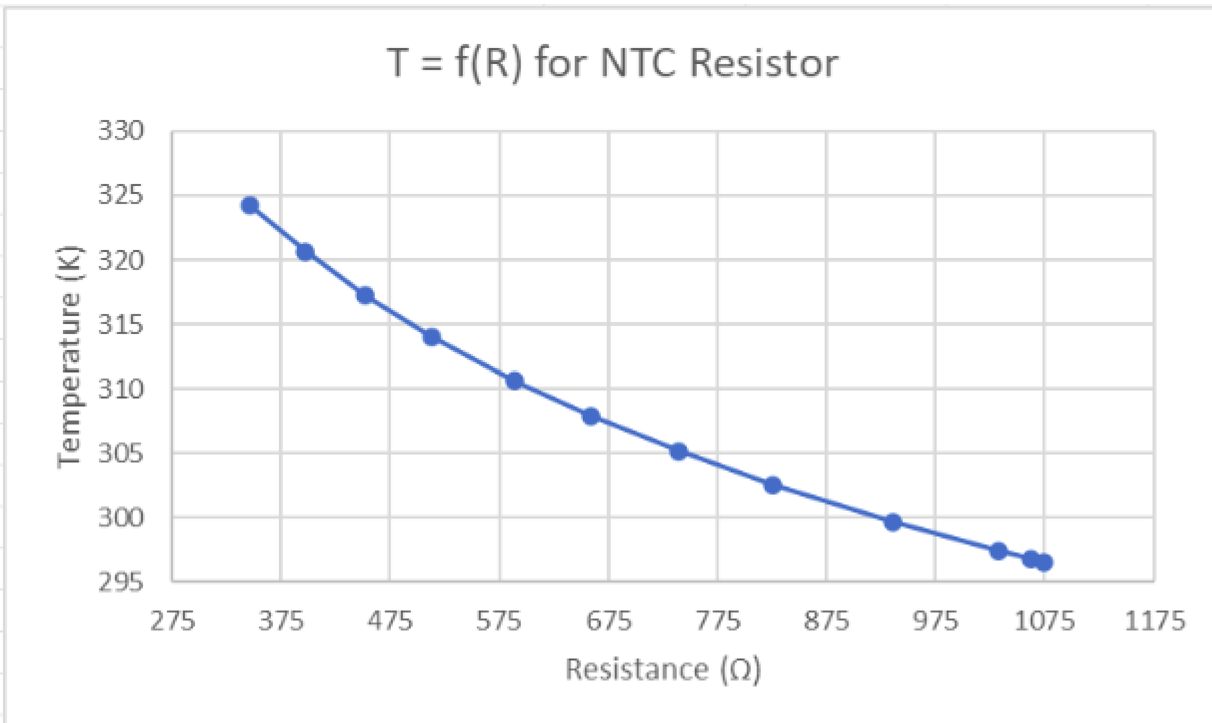


4.$T = 1/[((ln(R_T/R_{25}))/B) + (1/T_0)]$

Voltage Supply (V)	Voltage (V)	Current (A)	Resistance (Ω)	Temperature (K)
0	0.008	0.000003	2666.666667	277.5009468
2	1.075	0.001	1075	296.5230913
4	2.12	0.001996	1062.124248	296.7929259
6	3.075	0.002979	1032.225579	297.4343041
8	3.879	0.004147	935.3749699	299.6688363
10	4.55	0.005513	825.3219663	302.5566526
12	5.135	0.006943	739.5938355	305.1329778
14	5.592	0.008488	658.8124411	307.8979782

16	5.944	0.010086	589.331747	310.6100953
18	6.11	0.011913	512.8850835	314.0587784
20	6.249	0.01381	452.4981897	317.2344755
22	6.266	0.015783	397.0094405	320.6203066
24	6.178	0.017833	346.436382	324.2245616

Table 9:NTC Resistor' Temperature



5. Connecting an NTC resistor to higher voltages is risky because NTC resistors decrease in resistance as temperature rises. This can lead to a feedback loop of increasing current, heat generation, and potential overheating, posing a danger to the resistor and the circuit. Adhering to specified voltage limits is crucial for safe operation.

6. A copper wire is an ohmic resistor, because its current and voltage are directly proportional to each other. When using a copper wire with high currents or high temperatures, several consequences may arise. The wire's resistance can lead to voltage drops and power dissipation, resulting in energy loss and heat generation. With high currents, the wire may experience increased heating due to its resistance, potentially leading to overheating, melting, or even a fire hazard. It's crucial to consider the wire's gauge, material properties, and current-carrying capacity to ensure safe and efficient operation.

copper is not an Ohmic resistor!!!

4.Conclusion

Throughout the experiment we were illustrating Ohm's law in different settings with different types of resistors. We later observed that the metal film resistor, PTC resistor, and NTC resistor align with Ohm's Law, showcasing the fundamental relationship between voltage, current, and resistance. The metal film resistor demonstrated a linear response, maintaining a relatively constant resistance, in accordance with Ohm's Law. On the other hand, the PTC and NTC resistors exhibited nonlinear behaviors, highlighting variations in resistance with changes in temperature or current—a phenomenon that complements the principles of Ohm's Law while introducing temperature-dependent characteristics crucial for specific applications. From the experiment we can conclude that to avoid methodical and systematic error, the Kelvin 4-wire method is the most efficient method to measure resistance of the wire since it involves no contact of wires or any wires connected. The values may not have been accurate during the calculations of the formula because of the resistivity value from the manufacturer that was too high which could have caused errors in the final calculation.

other generall errors?

5.Reference

1. Pagel Uwe, General Electrical Engineering 1 Lab Manual (2023). Constructor University

6.Appendix

Experiment 3:Thevenin's and Norton's Theorem

Part 1	
Vs =	20
Vab (V) =	12.53
Part 2	
Vth (V) =	16.962
Io (A) =	4.75E-02
Rth&Rn (Ω) =	351.09
Part 3	
ELABO Multimeter	

Range 20 V	
Multimeter	16.966
Vth (V) =	16.9
Ohm Dekade	351
Vab (V) =	12.517
Part 4	
Io (A) =	4.76E-02
Vab (V) =	12.405