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Jacobs University Bremen

Natural Science Laboratory
Electrical Engineering Module I

Fall Semester 2021

Lab Experiment 1 – Usage of Multimeters

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Place of execution	: Teaching Lab EE Room 1, Bench 1 and 2
Date of execution	: Sept. 9, 2021

1. Introduction

This experiment consists of an outlook about the usage of the multimeter being one of the most important tools in electrical engineering and the different type of errors that can be caused during experiments and measurements.
The objectives of this experiment are:

- Understanding the usage of multimeters TENMA and ELABO as voltmeters and ammeters,
- To learn about the best practice dealing with changing and adjusting the range of measurement of Voltage and current that yields the most accurate results,
- Classifying errors into systematical and methodical and consider when they should be accounted for and when they should be neglected.

ELABO and TENMA multimeter were used for the experiment. They both make measurements according to different ranges, where in the ELABO we have to set the range manually, while the TENMA offers some automatic ranges and some selectable ones, respectively for high and small values.

This experiment consists of analysis of measurements using Ohm's Law and Kirchoff's Law. The Voltmeter should be connected in parallel to the circuit, while the Ammeter should be connected in series.

Theoretically, it is assumed that the Voltmeter and the Ammeter has no effect on the circuit but practically, they do have some effect because of their input resistance and since they need some current to operate. Due to this reason, we use the relative and methodical formulas. The absolute error shows the deviation of the measured value from its true value and the relative error is for comparing error values.

2. Execution

Instruments used in this experiment:

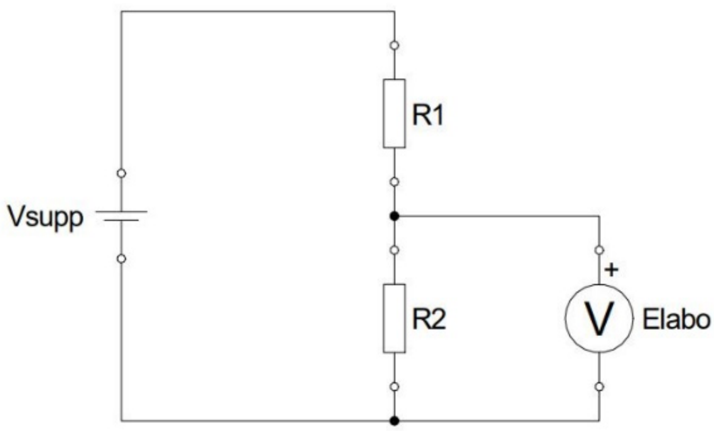
- Power supply
- Breadboard
- Wires and Cables
- Resistor Decade
- ELABO Multimeter
- TENMA Multimeter
- Resistors: 180R Ω and 820R Ω

Part 1A: Voltage Measurement

The SETUP

In this part of the experiment we use the ELABO Multimeter and Voltmeter. We measure a single voltage value and note down the changes it experiences when changing the range of the ELABO. Our goal is to show and determine the influence the multimeter range has on the accuracy of our measurement.
In part 1A of experiment 1, we used the ELABO Multimeter as Voltmeter to measure a single voltage value and recorded the changes in its value with alterations in the range of the ELABO. We did this to determine the influence of the range of multimeter on the accuracy of our results.

We set up the circuit as follows:



The voltage supplied (Vsupp) was 0.9V and the resistances of resistor R1 and R2 were 820RΩ and 120 RΩ respectively. The ELABO multimeter was connected in parallel to the resistor R2 using a breadboard.

Execution and results:

We kept the supplied voltage constant i.e. 0.9V and altered the range of the ELABO from 2000V to 0.2V. The voltage value measurements for all the ranges were recorded and are tabulated below:

Range(V)	Voltage Value(V)
2000.00000	0.20000000
200.00000	0.18000000
20.00000	0.17800000
2.00000	0.17270000
0.20000	0.17298000

The unit for the values in both first and columns are in Volts.

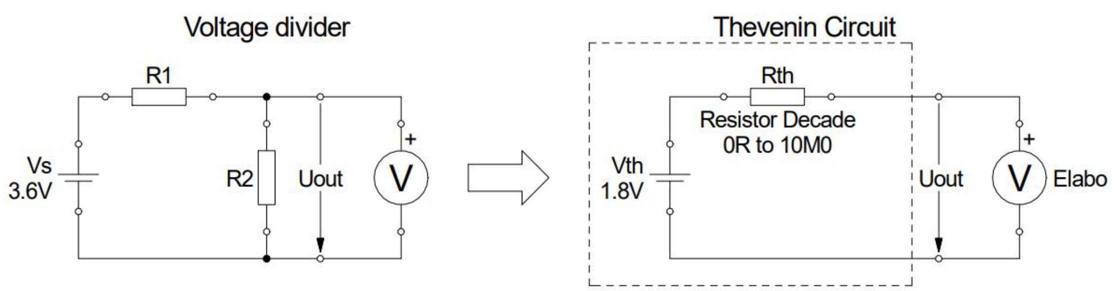
Part 1B: Voltage Measurement Pitfall

The SETUP

In part 1A of this experiment, only the instrumental error was accounted for but for this part, we need to take into consideration the methodical error as well since the Voltmeter is connected in series. The objective of this experiment is to consider the methodical errors while using ELABO as the voltmeter.

We constructed a Thevenin circuit and used a resistor decade to alter the resistances which is set in series with the ELABO multimeter as voltmeter.

The following circuit was set up using the information provided in the Lab Manual:



Execution and results:

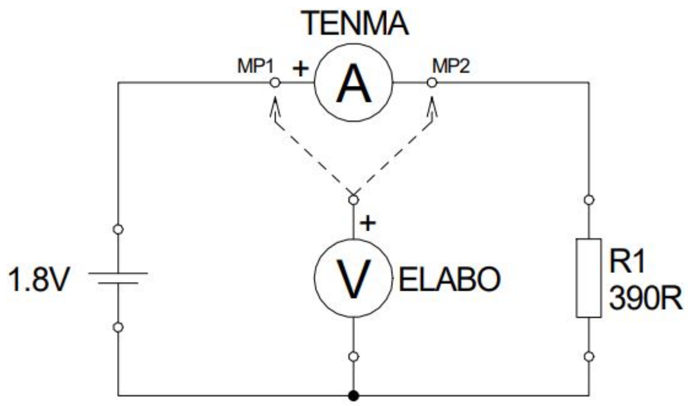
We supplied a constant voltage of 1.8V and altered the resistance of the resistor decade to 0Ω, 10 Ω, 100 Ω,1000 Ω,10000 Ω, 100000 Ω, 1M Ω, and 10M Ω. We measured the voltage values (Uout in the diagram) when the resistances were altered. TO get the most accurate results, we set the ELABO voltmeter to the range of 2V.
The voltage value measurements for all the resistances were recorded and are tabulated below:

Resistance/ [Ω]	Voltage Value/ [V]
0.00000	1.89200000
10.00000	1.89200000
100.00000	1.89200000
1000.00000	1.89190000
10000.00000	1.89020000
100000.00000	1.87330000
1000000.00000	1.72160000
10000000.00000	0.94950000

Part 2: Current Measurement and Pitfalls

The SETUP

In part 2 of experiment 1, we consider the systematical and methodical errors for Tenma as Ammeter just like we did ELABO as voltmeter. We use ELABO as the voltmeter and TENMA as the ammeter. We used a resistor decade as R1 with resistance of 390 Ω in parallel with the ELABO (voltmeter) and in series with TENMA(ammeter). A constant voltage of 1.8V was supplied. The circuit was set up as follows:



Execution and results:

A constant voltage of 1.8V was supplied to the circuit and the range of ELABO was set to 2.0V for the highest accuracy. MP1 and MP2 are the plugs of the TENMA ammeter. The current and voltage at MP1 and MP2 were recorded using the 'A' plug of the TENMA ammeter with the turning knob switched to A and then using the 'µA – mA' plug and switching the turning knob to mA and µA. The current and voltages measured for each of the combinations are tabulated below:

Plug	Switch	Vmp1/ [V]	Vmp2/ [V]	Current/ [A]
A	A	1.85970000	1.859500	0.001000
mAµA	mA	1.85970000	1.830700	0.004663
mAµA	µA	1.85990000	0.850700	0.002017

The results in the columns Vmp1 and Vmp2 are in Volts(V) and those in column Current are in Amperes(A).

3. Evaluation

1.1 Part A: Voltage Measurement

Question 1: Calculate all absolute and relative errors of the values measured with the multimeter from Part 1A. The necessary formulas can be found in the data sheet of the ELABO multimeter!

***Solution**:*

Formulas used to calculate absolute and relative error percentage:

Absolute Error= 0.03% * f. Value + 0.01% * f. Range

Relative Error %= Absolute value / Voltage value*100

Example:

For range= 2,00 and voltage value= 0,1727V,

Absolute Error= 0.03% * 0.1727+0.01% * 2.00=0.001458

Relative Error %= 0.001458/0.1727*100= 0.1458%

The table below represents the relative error % for each of the data recorded:

Range/ [V]	Voltage Value/ [V]	Absolute Error (ΔE)	Relative Error	Relative Error %
2000.00000	0.20000000	0.20006000	1.000300	100.03
200.00000	0.18000000	0.02005400	0.111411	11.1411111
20.00000	0.17800000	0.00205340	0.011536	1.15359551
2.00000	0.17270000	0.00025181	0.001458	0.14580776
0.20000	0.17298000	0.00007189	0.000416	0.04156203

Question 2: What is your conclusion regarding the usage of the voltmeter ranges? What is the influence of the range to the accuracy?

Solution:

After analyzing the data, it can be confirmed that the accuracy of our results varies along with the change in range. When our range is 2000 V, we get the highest relative error percentage and the lowest relative percentage error at the range 0.2 V, which is because 0.2 V is closest to the real value of the voltage supplied. So, it can be concluded that the range should be adjusted to the most suitable one i.e. the range closest to the actual value to get the most accurate result.

Question 3: Draw a diagram of the relative error E% = f(U) for the 20V range.

Solution:

The absolute error of the ELABO multimeter, as per the ELABO datasheet, is given by:

Absolute Error= 0.03% * f. Value + 0.01% * f. Range

Relative Error %= Absolute value / Voltage value*100

Example:

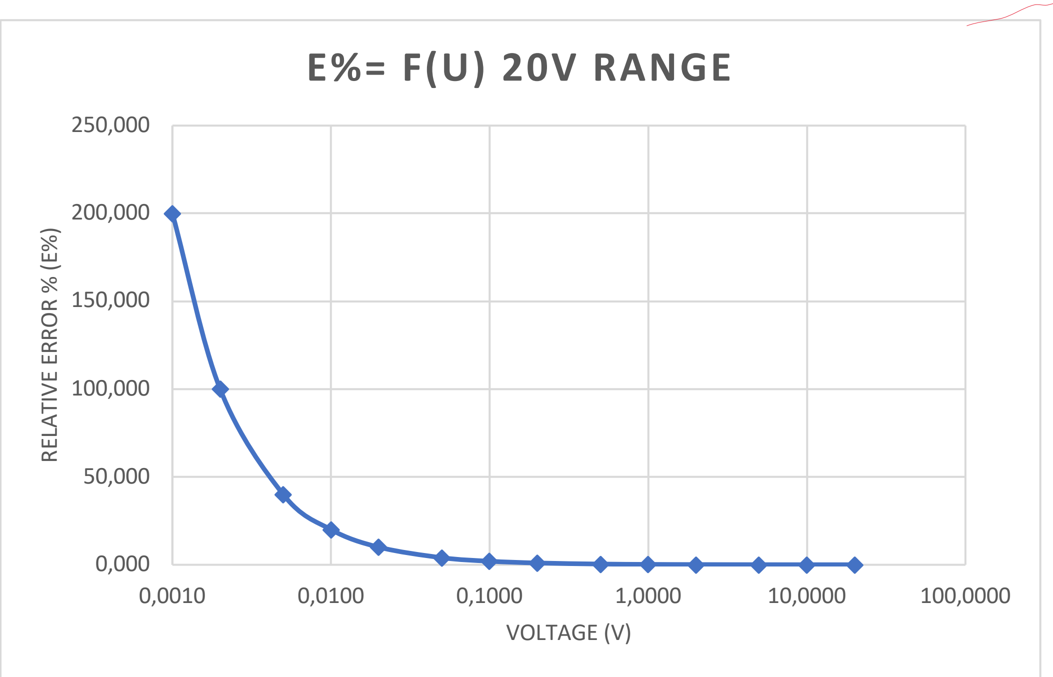
For range= 20,00 and voltage value= 1,00V,

Absolute Error= 0.03% * 1.00 + 0.01% * 20.00=0.023

Relative Error %= 0.023/1.00 *100= 0.23%

The table below represents the relative error % for each of the data recorded:

Test Voltage/V	Absolute Error(ΔE)	Relative Error % (ΔE/V*100)
0.00100	0.0020003	200.03000000
0.00200	0.0020006	100.03000000
0.00500	0.0020015	40.03000000
0.01000	0.002003	20.03000000
0.02000	0.002006	10.03000000
0.05000	0.002015	4.03000000
0.10000	0.00203	2.03000000
0.20000	0.00206	1.03000000
0.50000	0.00215	0.43000000
1.00000	0.0023	0.23000000
2.00000	0.0026	0.13000000
5.00000	0.0035	0.07000000
10.00000	0.005	0.05000000
20.00000	0.008	0.04000000



From the graph, we can reconfirm that the relative error gets smaller as the voltage value is increased from 0.01 to 20V with the range set to 20V. We get the least relative error % of 0.04% when the voltage is 20.0V. This means the relative error gets smaller as the voltage supplied gets closer to the value in range. We can therefore conclude that in order to get the least error while measuring voltage, the range should be set to the once that’s closest to the voltage we’re supplying.

1.2 Part 1B: Voltage Measurement Pitfall

Question 1: Calculate the relative error of the measured U_{th} value for all R_{th} settings.

Solution:

The absolute error of the Elabo multimeter, as per the Elabo datasheet, is given by:

Absolute Error= 0.03% * f. Value + 0.01% * f. Range

Relative Error %= Absolute value / Voltage value*100

Example:

For range= 2.00 and voltage value= 1.892V,

Absolute Error= 0.03% * 1.892 + 0.01% * 2.00=0.0007676

Relative Error %= 0.0007676 /1.892 *100= 0.04057%

The table below represents the relative error % for each of the data recorded by setting the voltage supply to 1,9V and using a range of 2V:

Resistance/ [Ω]	Voltage Value/ [V]	Absolute Error(ΔE)	Relative Error	Relative Error(%)
0.00000	1.89200000	0.00076760	0.000406	0.04057082
10.00000	1.89200000	0.00076760	0.000406	0.04057082
100.00000	1.89200000	0.00076760	0.000406	0.04057082
1000.00000	1.89190000	0.00076757	0.000406	0.04057138
10000.00000	1.89020000	0.00076706	0.000406	0.04058089
100000.00000	1.87330000	0.00076199	0.000407	0.04067635
1000000.00000	1.72160000	0.00071648	0.000416	0.0416171
10000000.00000	0.94950000	0.00048485	0.000511	0.05106372

Question 2: It should be clearly visible that the accuracy of the displayed values is very good. But some of them are far away from the real values . Here we can see a methodical error. What is the course of this error? Calculate the relative methodical error for all cases.

Solution:

In this experiment, we need to consider the fact that the input resistance of voltmeter, as per stated in the Lab Manual, is 10M ohm. Since the voltmeter was connected in series with the circuit, the resistances of the resistor decade and the voltmeter were almost similar rendering the resistance of the decade insignificant. This is the course of methodical error in this experiment.

To calculate the methodical formula, we use the following formula:

Methodical Error= [(Recorded Value)- (True Value)]/(True Value)*100

The true value for this experiment is the value when the resistance of the Resistor Decade is set to 0 Ω i.e., 1.892V.

Example (When resistance of decade=0Ω):

Methodical Error %= [(1.892-1.892)/ 1.892] = (0/1.892) =0%

The methodical error is calculated and tabulated below:

Resistance of Decade/ [Ω]	Voltage Value/ [V]	Absolute Error[ΔE]	Relative Error[E%]	Relative Error%/ [E%]	Methodical Error %
0.00000	1.89200000	0.00076760	0.000406	0.04057082	0
10.00000	1.89200000	0.00076760	0.000406	0.04057082	0
100.00000	1.89200000	0.00076760	0.000406	0.04057082	0
1000.00000	1.89190000	0.00076757	0.000406	0.04057138	-0.005285412
10000.00000	1.89020000	0.00076706	0.000406	0.04058089	-0.095137421
100000.00000	1.87330000	0.00076199	0.000407	0.04067635	-0.988372093
1000000.00000	1.72160000	0.00071648	0.000416	0.0416171	-9.006342495
10000000.00000	0.94950000	0.00048485	0.000511	0.05106372	-49.81501057

Question 3: What is the internal resistance of the used voltmeter (data sheet!!). What should it be to reduce the methodical error to zero?

Solution:

The internal resistance of the used voltmeter is 10M Ω. We had highly accurate results for lower resistances as the voltmeter has a significantly higher resistance the resistor decade. However, when the resistance on the resistor decade is changes to 10MΩ, it is almost the same as the internal resistance of the voltmeter. To reduce the methodical error to zero, it should very high i.e., infinity.

1.3 Part 2 Current Measurement and Pitfalls

Question 1: Calculate the relative error of the measured current for all settings. The necessary formulas can be found in the Tenma 72-7732A Multimeter data sheet!

Solution:

Since we're using Tenma *72-7732A* as the Ammeter for this experiment, the error formulas differ for the A, mA and μA. The error formulas are:

For A: **Absolute Error = 0.5% * rdg+30*0.001**

For mA**: Absolute Error = 0.15% * rdg +15*0.001** (0,001 is the resolution we have here)

For μA**: Absolute Error = 0.1% * rdg) +15*0.001** (0,001 is the resolution we have here)

Relative Error= Absolute Error/rdg *100

Example:

When switch is A,

Absolute Error= 0.5% * 0.0010+30*0.001 = 0.0300050

Relative Error= (0.0300050/0.0010) = 30.00500

Plug	Switch	Vmp1/ [V]	Vmp2/ [V]	Current/ [A]	Absolute Error[ΔE]	Relative Error %
A	A	1.85970000	1.859500	0.0010	0.03000500	3000.500
mAμA	mA	1.85970000	1.830700	0.0047	0,00015699	3.367
mAμA	μA	1.85990000	0.850700	0.0020	0,00000352	0.174

Question 2: Calculate the relative methodical error for all settings.
Hint: To get a 'true value' use the measured voltage V_{MP1} and the nominal resistor value R_1 = 390 Ω!

Solution:

For the calculation of the relative methodical error first we need to have a true initial vale for current. We can find it by using the voltage at MP1 and the nominal resistor value R1= 390 *Ω*.

I true =V/R= Vmp1/R1= 1.8597/390= 4.768 mA

Methodical Error= (Recorded Value-True Value (I true))/True Value(I true)

Example (when switch is A):

Methodical Error= (0.001-0.004768)/0.004768**=** -0.790289

Plug	Switch	Vmp1/ [V]	Vmp2/ [V]	Current/ [A]	Absolute Error[ΔE]	Relative Error %	Methodical Error %
A	A	1.85970000	1.859500	0.001000	0.03000500	3000.500	-0.790289
mAμA	mA	1.85970000	1.830700	0.004663	0.00015699	3.367	-0.022116
mAμA	μA	1.85990000	0.850700	0.002017	0.00000352	0.174	-0.577117

not in %!!

Question 3: How to interpret the results of the systematical and methodical error calculation?

Solution:

explain the subcases from the question. What is methodical error, what is systematical error. Do see error propagation?

It can be observed that the lowest methodical error was recorded when the plug is at mAμA, and the switch is at mA. Therefore, in order to get the most accurate value, the plug and the range of the ammeter can be set according to the true value.

Question 4: If you look at instrument and methodical error which range is best/ most accept- able in our case? What is your conclusion on using an ammeter?

Solution:

In our case, mA is the best acceptable range as it had the lowest methodical error. In order to get the most accurate value, the plug and the range of the ammeter can be set closest to the true value.

Question 5: Calculate the resistance of the ammeter in all three ranges. There are two ways to calculate the resistance:

R_i =(Vmp1-Vmp2)/I(1) and $R_i = {}^{V_{MP1}} - R_1$ (2) II

Calculate the resistance using both formulas. Compile a table with the calcu- lated values.

The resistance for A-Range is ≈ 50mΩ, for the mA-Range it is ≈ 5Ω, and for μA-Range ≈ 500Ω. These values are measured and all approximate values. they may be be different for each instrument. Therefore they are not indicated in the data sheet!!

Solution:

The formulas used to calculate the resistance Ri are as follows:

$R_i = {}^{V_{MP1} - V_{MP2/I}}$ (1) and $R_i = {}^{V_{MP1\,/\,I}} - R_1$ (2) II

Vmp1	Vmp2	Current	Ri1(1st formula)	Ri2(2nd formula)
1.85970000	1.859500	0.0010	0.20000	1859.50000000
1.85970000	1.830700	0.0047	5.80000	393.02050182
1.85990000	0.850700	0.0020	500.42148	421.82773838

Question 6: Why are the results so different? Determine the error propagation in the μA range in both formulas for R_i. What is the conclusion for using measured values in calculations?
(Hint : For the given formulas it is simpler to use partial differentiation instead of the 'simple' rules!!)

Solution:

To find the error propagation for the first formula of resistance, we need to find the absolute errors for Vmp1 and Vmp2. The relative error of the sum of the absolute errors of Vmp1 and Vmp2 should be calculated and should be added with the relative error of Current(I). This is the error for the resistance found using the first formula.

Example(for the µA range) :

Absolute error of Vmp1= 0.0003*1.85990+0.0001*2= 0.0007597

Absolute error of Vmp2=0.0003*0.85070 +0.0001*2= 0.00045521

Sum of the absolute errors =0.0007597+0.00045521= 0.00121491

Finding the error propagation by using this formula:

Ep%= (Sum of the absolute errors /(Vmp1-Vmp2)) *100+Relative error% of current
= (0.00121491 / (1.85990-0.85070)) *100+ 0.174%= 0.294%

To find the error propagation for the second formula of resistance, we need to find the absolute errors for Vmp1. The relative error of Vmp1 should be calculated and should be added with the relative error of Current(I). This is the error for the resistance found using the second formula.

Example (for the µA range):

Absolute error of Vmp1= 0.0003*1.85990+0.0001*2= 0.0007597

Finding the error propagation by using this formula:

Ep%= (Absolute error of Vmp1/(Vmp1)) *100+Relative error% of current
= (0.0007597/1.85990) *100+ 0.174%= 0.214%

you forgot to include
the resistance!!
1% tolerance!!!

Vmp1	Vmp2	Current	Ri1(1st formula)	Ri2(2nd formula)	EP% (1st formula)	EP (2nd formula)
1.85990000	0.850700	0.0020	500.42148	421.82773838	0.294%	0.214%

4. Conclusion

1A:

- In part 1A of Experiment 1, the voltage value for a ranges 2000V, 200V, 20V, 2V, and 0.2 volt was measured and recorded with ELABO.
- The absolute error and relative error were calculated and tabulated.
- It was concluded that 0.2V is the most suitable voltmeter range as it had the least error percentage.
- With this, it was inferred that the closer the value of voltage supply to the range, the accurate the results.

1B:

- For experiment 1B, a Thevenin circuit was constructed, and a resistor decade was used to change the values of the resistance of Thevenin.
- The resistance in the resistor decade was altered for 0 Ω, 10 Ω, 100 Ω, 1 K Ω, 10 K Ω, 100 K Ω, 1 M Ω, 10 M Ω, and the voltmeter values were measured and tabulated after adjusting the range of voltmeter to a suitable range.
- For this experiment, we calculate the absolute error, relative error, and methodical error.
- The accuracy of the measured voltage values was very high except for a few values which deviated from the actual value i.e. when the resistance is 1 million ohms and 10 Million ohms.
- We noticed the big methodical error while calculating for 10 M Ω because of an inefficient method of construction of the circuit in the part where we connected the voltmeter in series with the resistor decade, which in fact should be connected in parallel with the resistor.

The decade resistor is the normally hiden resistor in any voltage source.
so the voltmeter is connected in parallel to an 'unknown' source....

2:

- In part 2 of experiment 1, we used both the ELABO multimeter as a voltmeter and the TENMA multimeter as an ammeter.
- The aim of this experiment was to calculate the values of the voltage and current in different ranges and plugs. We noticed that the resistance of the ammeter is very low and therefore could be ignored.
- The part of the circuit that we want to record the current from should be connected in series with the ammeter, because if it is done differently the results would be away from correct values.
- Mentioning that, in order to make the recording as accurate as possible, the range of the ammeter should fit the value of the measured current, which itself was not ideal to use, because of their large error propagation.

5. References

I. Lab Manual
II. Accuracy sheet for TENMA multimeter
III. Accuracy sheet for ELABO multimeter