Lab Report 1
Usage of Multimeter

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1 Introduction and Theory

The experiment was designed for two days starting with safety instructions in a laboratory, errors, and error calculations. In this experiment, the usage of multimeters was introduced and demonstrated. The multimeter is an electronic measuring instrument that combines several measuring functions in one unit. A typical multimeter may include features such as the ability to measure voltage, current, and resistance. However, multimeters are not ideal elements to measure. It means that as a non-ideal ammeter, it will have non-zero internal resistance, while as a non-ideal voltmeter, it will have finite internal resistance. During the experiment, methods of using a multimeter and getting accurate values from the multimeter will be clarified. The experiment has two parts: measuring voltage with its errors and measuring current with its errors.

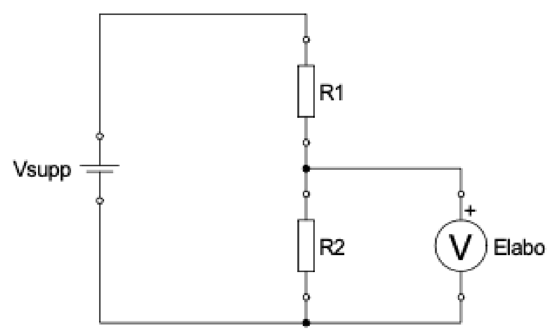
2.1 Voltage Measurement

2.1.1 Objective

In this part of the experiment, the ELABO multimeter was used to measure the voltage in different ranges to show the impact of the multimeter range on the accuracy of results.

2.1.2 Experimental Set-up and Preparation

In Figure 1, the circuit which was used in this part is shown. The circuit consists of two resistors and a voltage supply which are connected in series. The ELABO multimeter is connected to the second resistor. First, ELABO must be set to the voltage DC measure mode and to the highest (2000V) range.



Settings : $V_{SUPP} = 9.0\,\mathrm{V} \quad R_1 = 8K20\,\Omega \quad R_2 = 1K80\,\Omega$

Figure 1

Then, during the experiment, the turn-wheel was changed from 2000V to 200V, 20V, 2V, and 0.2V. All data shown by the ELABO in the different ranges was recorded and given in Table 1.

2.1.3 Results

Voltage Range, V	Reading Voltage, V
2000	1.6
200	1.62
20	1.625
2	1.6258
0.2	overload

Table 1

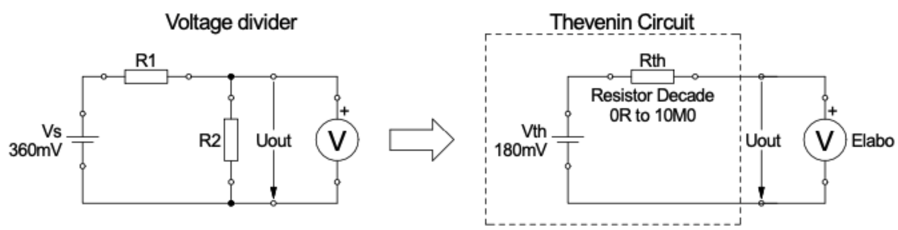
2.2 Voltage Measurement Pitfall

2.2.1 Objective

In the previous experiment, methodical errors were neglected, while instrumental errors were considered. However, in this part of the experiment, the circuit for which methodical and instrumental errors have to be applied was considered.

2.2.2 Experimental Set-up and Preparation

Since any resistive DC circuit can be reduced to a Thevenin circuit, converting the given circuit to a Thevenin circuit makes the process of measuring the voltage $V_{out} = V_{th}$ easier. A value should be independent from the resistors in the circuit and the connected voltmeter. Initially, the resistor decade has to be set to 0R and the range of the voltmeter has to be set to the best resolution. Then, the values at the voltmeter for 0R, 10R, 100R, 1 K00, 10 K0, 100 K, 1 M00, 10 M0 were measured.



$$\text{The voltage divider converts to } \Rightarrow V_{th} = V_S \frac{R_2}{R_1 + R_2} \text{ and } R_{th} = \frac{R_1 + R_2}{R_1 R_2}$$

Figure 2

2.2.3 Results

Resistance, Ohm	Voltage, V
0	0.1888
10	0.1888
100	0.1888
1 K	0.1888
10 K	0.1887
100 K	0.1870
1 M	0.1718
10 M	0.9440

Table 2

3 Current Measurement and Pitfalls

3.1 Objective

As in the case with voltmeter, ammeter has the similar instrumental and methodical errors. In this part of the experiment, these errors were demonstrated.

3.2 Experimental Set-up and Preparation

The following circuit was set with the range of 2V for the ELABO, which can provide the best resolution for voltage measurement.

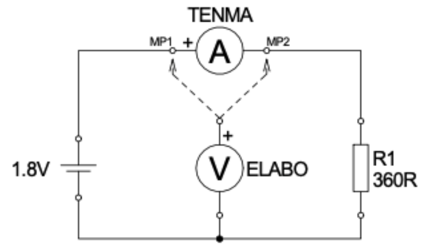


Figure 3

During the experiment the voltmeter was connected to MP1 and MP2 to measure the voltage at MP1 and at MP2. At each connection, three different way of measuring current were used. First, ‘A’ plug and ‘A’ turning knob were set. Then, input terminal was changed from ‘A’ to ‘mAµA’. Turning knob was switched to ‘mA’ and to ‘µA’, and at both cases the data was recorded.

3.3 Results

Plug	Switch	$\boldsymbol{V_{MP1}}$ [V]	$\boldsymbol{V_{MP2}}$ [V]	Current [mA]
A	A	1.8527	1.8524	2.0000
$mA\mu A$	mA	1.8527	1.8215	5.0540
$mA\mu A$	μA	1.8531	0.7741	2.1495

Table 3

4 Evaluation

4.1 Voltage Measurement

Absolute error for the ELABO voltmeter can be calculated by using the following formula:

$$\Delta\text{E} = 0.03\% \times (Reading) + 0.01\% \times (Range)$$

Formula 1

Relative error for all instruments can be calculated by using the following formula:

$$\text{E}_{\text{rel}} = \frac{\Delta E}{Reading} \times 100\%$$

Formula 2

Formula 1 and Formula 2 give the absolute and relative errors for the Table 1. In the next table, all calculated numbers are shown. For the voltage range 0.2, the ELABO was overloaded, therefore, absolute and relative errors cannot be calculated.

Voltage Range, V	Reading Voltage, V	Absolute Error, V	Relative Error, %
2000	1.6	0.200480	12.53%
200	1.62	0.020486	1.26%
20	1.625	0.002488	0.15%
2	1.6258	0.000688	0.04%
0.2	overload		

Table 4

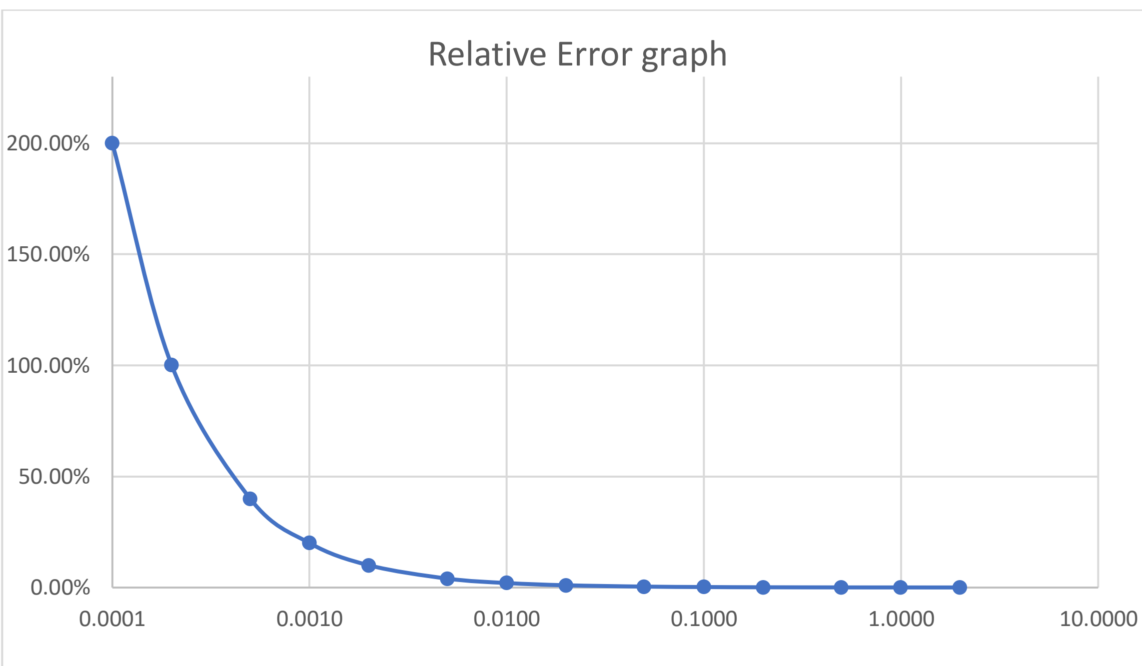
As it can be concluded, the range is directly proportional to the relative error of the ELABO voltmeter. It means that the smaller the range, the more accurate the reading voltage.

To draw a graph of the relative error $E_{\%} = f(U)$ for the 2V range, absolute errors and then relative errors of some values in the range 0 - 2V were calculated. The following table shows it:

Voltage, V	Absolute Error, µV	Relative Error, %
0.0001	200.03	200.03%
0.0002	200.06	100.03%
0.0005	200.15	40.03%
0.0010	200.30	20.03%
0.0020	200.60	10.03%
0.0050	201.50	4.03%
0.0100	203.00	2.03%
0.0200	206.00	1.03%
0.0500	215.00	0.43%
0.1000	230.00	0.23%
0.2000	260.00	0.13%
0.5000	350.00	0.07%
1.0000	500.00	0.05%
2.0000	800.00	0.04%

Table 5

The graph of the relative error $E_{\%} = f(U)$ for the 2V range is:



4.2 Voltage Measurement Pitfall

As in the previous section, by using Formula 1 and Formula 2 with the range of 0.2V, absolute error and relative error can be computed. Table 6 shows absolute and relative errors for this part. In the 4.1 Voltage Measurement section, we concluded that the smallest range gives the most accurate values. However, in Table 6, it can be seen that some values are far away from the expected values. This is due to methodical errors. The methodical errors can be calculated by using the following formula:

$$\text{Methodical Error} = \frac{Reading - True}{True} \times 100\%$$

Formula 3

Resistance, Ohm	Voltage, V	Absolute Error, μV	Relative Error, %	Methodical Error, %
0	0.1888	76.65	0.041%	0.00%
10	0.1888	76.65	0.041%	0.00%
100	0.1888	76.65	0.041%	0.00%
1 K	0.1888	76.64	0.041%	-0.01%
10 K	0.1887	76.60	0.041%	-0.10%
100 K	0.1870	76.09	0.041%	-0.99%
1 M	0.1718	71.53	0.042%	-9.05%
10 M	0.9440	48.31	0.051%	-50.03%

Table 6

In real life, voltmeters have some resistance to measure the voltage. However, usually, their resistance is very high comparing to the resistances used in a circuit. For example, from Table 5, it can be seen that for resistance below 100 K, the methodical error is very small. If the resistance used in this circuit cannot be negligible compared with the internal resistance of the voltmeter, the circuit becomes a potential divider. For the resistance 10 M, reading voltage is half of the expected voltage which means that in this case, the circuit works as a potential divider with almost the same resistors. Therefore, the internal resistance of the ELABO voltmeter has to be about 10 M. It can be verified from the datasheet for the ELABO multimeter.
To avoid methodical error, the resistance of the ELABO voltmeter has to be very high comparing to the resistances used in a circuit. For example, if 10 billion Ohm resistance had been used inside of the ELABO, resistors used in this experiment would be significantly small.

4.3 Current Measurement and Pitfalls

Absolute error of the TENMA ammeter for the range 0-400μA and 400μA-4000μA with the resolution of 0.01μA and 0.1μA respectively can be calculated as:

$$0.1\% \times (Reading) + 15 \times (Resolution)$$

Formula 4

For the range 4000μA-40mA and 40mA-400mA with the resolution 0.001mA and 0.01mA respectively:

$$0.15\% \times (Reading) + 15 \times (Resolution)$$

Formula 5

For the range 40mA-10A with the resolution 0.001A:

$$0.5\% \times (Reading) + 30 \times (Resolution)$$

Formula 6

By using Formula 4, Formula 5, and Formula 6, for the results of this part, absolute and relative errors can be calculated. To calculate the methodical error, Formula 3 was used where 'true value' was calculated by using the following formula with the measured voltage at MP1 and nominal resistor value 360Ω:

$$true\ value = \frac{V_{MP1}}{360\Omega}$$

Formula 7

Plug	Switch	Current, mA	Absolute Error, mA	Relative Error, %	Methodical Error, %
A	A	2.0000	30.0100	1500.50%	-61.14%
$mA\mu A$	mA	5.0540	0.0226	0.45%	-1.80%
$mA\mu A$	μA	2.1495	0.0036	0.17%	-58.24%

Table 7

The ampere range has the biggest relative error. Therefore, any value obtained from it will not have any meaning. For example, the methodical error in the ampere range is very high, but it is expected to below. This is because the reading current is not accurate. However, for the other two ranges, the relative errors are small, making these reading currents very accurate. Moreover, the methodical error for the milliampere range is relatively small which makes it the most accurate for this circuit. Even if the microampere has the smallest relative error, its methodical error is extremely large. Thus, it is not reliable to use ampere and microampere ranges. To find out the reason for the high and low methodical errors, resistances of the ammeters in different rages have to be calculated. There are two formulas to do so:

$$R_i = \frac{V_{MP1} - V_{MP2}}{I}$$

Formula 8

$$R_i = \frac{V_{MP1}}{I} - R_1$$

Formula 9

Where R_1 is the 360Ω resistor used in the circuit. Using these formulas gives two different numbers:

Plug	Switch	$\boldsymbol{V_{MP1}}$ [V]	$\boldsymbol{V_{MP2}}$ [V]	Current, mA	Resistance – 1st formula, Ohm	Resistance – 2nd formula, Ohm
A	A	1.8527	1.8524	2.0000	0.15	566.35
$mA\mu A$	mA	1.8527	1.8215	5.0540	6.17	6.58
$mA\mu A$	μA	1.8531	0.7741	2.1495	501.98	502.11

Table 8

As expected, the results calculated from the ampere range is very different since obtained current for this range is very inaccurate. While for the other two ranges, resistances are very close. Because the microampere has the most accurate values for the current and voltage, its resistances are the closest.

To calculate the error propagation in the microampere range in both formulas, the partial differentiation method was used.

For the first formula:

$$\Delta R = \left|\frac{\partial R}{\partial V_{MP1}} \times \Delta V_{MP1}\right| + \left|\frac{\partial R}{\partial V_{MP2}} \times \Delta V_{MP2}\right| + \left|\frac{\partial R}{\partial I} \times \Delta I\right| = \left|\frac{1}{I} \times \Delta V_{MP1}\right| + \left|\frac{1}{I} \times \Delta V_{MP2}\right| + \left|\frac{V_{MP1} - V_{MP2}}{I^2} \times \Delta I\right|$$

Formula 10

For the second formula:

$$\Delta R = \left|\frac{\partial R}{\partial V_{MP1}} \times \Delta V_{MP1}\right| + \left|\frac{\partial R}{\partial R_1} \times \Delta R_1\right| + \left|\frac{\partial R}{\partial I} \times \Delta I\right| = \left|\frac{1}{I} \times \Delta V_{MP1}\right| + |\Delta R_1| + \left|\frac{V_{MP1}}{I^2} \times \Delta I\right|$$

Formula 11

To use these formulas, absolute errors of the voltmeter are needed. It can be obtained by using Formula 1 since the same voltmeter was used. Using Formula 10 and Formula 11 with $\Delta R_1 = 3.6\Omega$ (given resistor has the relative error of 1%) with obtained values from the experiment and from the calculations, it easy to get the numbers in Table 9 for the microampere range. Moreover, Formula 2 gives the relative error.

Resistance – 1st formula, Ohm	Absolute Error, Ohm	Relative Error, %	Resistance – 2nd formula, Ohm	Absolute Error, Ohm	Relative Error, %
501.98	1.41	0.28%	502.11	5.42	1.08%

Table 9

Both formulas gave very accurate numbers according to the relative errors. However, since the resistor used in the circuit has the relative error of 1%, while others have the relative error of less than 0.5%, the second formula has the larger relative error.

5 Conclusion

This experiment explained how voltmeters and ammeter should be used. During the experiment, relative errors and methodical errors of the voltmeter and ammeter were studied. As it was shown, relative errors depend only on an equipment which was used, while methodical errors depend on elements used in the circuit. For example, in 2.1 Voltage Measurement section it was clearly seen that if a resistor with higher than 100 K resistance had been used, the circuit would be a voltage divider. Moreover, the experiment showed the difference between theoretical and practical circuits. In theory voltmeter should has infinity resistance and ammeter should has zero resistance. However, in real-life, it is impossible to create such instruments.

6 References

Pagel, U., & Joodaki, M. (Fall Semester 2020). *Lab Manual General Electrical Engineering.* Jacobs University Bremen.