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Experiment: Basic Electrical Measurements

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Background

Electronics is the science which studies the behavior of the electrons' mechanics. In fact, it studies the behavior of the flow of charge among different types of materials such as semiconductors, resistors, vacuum, etcetera.

Direct Current is considered to be a constant flow of electrons from low to high potential. As opposite as it happens in *Alternate Current* (AC), the *continuous current* is a constant flow of electrons in the same direction. This flow of electrons is formally known as **electric current**, and it is measured in $Amps$ (SI unit), which is equal to one coulomb of charge per second.

Current is defined as the amount of electric charge flowing through a surface along the time. Thus, from this definition, equation 1 and 2 are obtained.

$$I = \frac{Q}{T} \tag{1}$$

$$i(t) = \frac{\mathrm{d}Q}{\mathrm{d}t} \tag{2}$$

However, in 1827, a physicist named Georg Ohm stated that the current in an ideal resistor could be formulated in function of potential difference (voltage) and internal resistance of the resistor (or ohmic device). Hence, obtaining equation 3.

$$I = \frac{V}{R} \tag{3}$$

The potential difference, commonly called voltage, is the difference of electrical potential energy between two points of an electrical circuit, measured in volts. The potential difference can be calculated by using equation 4.

$$V(r) = \frac{1}{4\pi\epsilon_0}\frac{q}{r} \tag{4}$$

In equation 4, $V(r)$ is the potential difference (measured in volts) respect to a certain distance r away from the charge q. ϵ_0 is the vacuum permittivity, whose value is around $8.85 \cdot 10^{-12}\frac{F}{m}$. However, returning to Ohm's Law, it is stated that, in an electrical circuit, the current passing through a conductor, from one end to another, is directly proportional to the voltage drop across the two terminals and inversely proportional to the resistance of the conductor, as exposed in equation 3.

Thanks to Ohm's Law, calculations are quite logical and solid enough for nowadays electronic measurements. Nevertheless, the is another important law to mention before moving onto the experiments their selves. That law is Kirchhoff's Law.

Kirchhoff's Laws are actually a pair of laws which deal with the conservation of change in energy in electrical circuits. The first law is called **Kirchhoff's Current Law** and it states that at *any point in an electrical circuit where the charge density is not changing in time, the sum of currents flowing towards that point equals the sum of currents flowing away from that point*. Apart from this law, there is a second law called **Kirchhoff's Voltage Law**, which states that *the directed sum of electrical potential differences across a whole circuit must be zero*. Furthermore, as a support evidence for Kirchhoff's Voltage Law, if the sum of potential differences around a whole circuit was not zero, then it would be possible to construct a perpetual motion machine which passed a current in circle around the circuit.

In practice, applying the physics involved in Ohm's Law and Kirchhoff's Laws, very basic calculations may be performed in order to address electrical circuits problems.

Series of the experiments

Ohm's Law Demonstration

According to Ohm's Law, $U = IR$, where U is the potential difference between the ends of the resistor R and I is the current flowing through the resistor. For many resistors, R is fairly constant, meaning that it is more or less independent from the current. The circuit used in this first experiment is shown in figure 1.

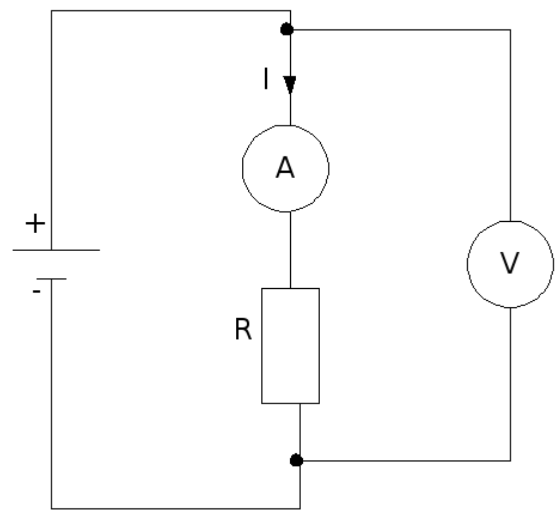

Figure 1: Simple circuit with a resistor connected to a battery.

In this experiment, the team proceeded to adjust different voltages, measuring both the voltage over the resistor and the current through it. Hence, by tabulating the obtained data and plotting I versus V, there should be achieved a straight line, since Ohm's Law states that the resistance should remain constant.

For the measurements, the team used a *multimeter*, which is a relatively small device capable of measure different electrical magnitudes, such as resistance, voltage, current, etcetera. Moreover, the team also used a voltage generator with which to adjust the voltage, acting as the battery drawn in figure 1. The results for these first measurements are listed in table 1.

Voltage (V)	**Current (mA)**
1.11	0.74
2.05	1.35
4.24	2.79
7.09	4.66
9.00	5.94

Table 1: Voltage values between $0V$ and $10V$ for a constant resistor.

For highly depicting purposes, the team chose values which were fairly distributed in the table. By the analysis of the data fitted in table 1, if the Ohm's Law was true, then there should be an straight line by plotting the current I versus the voltage V. The graph achieved with the *Logger Pro 3.4.5* software is shown in figure 2.

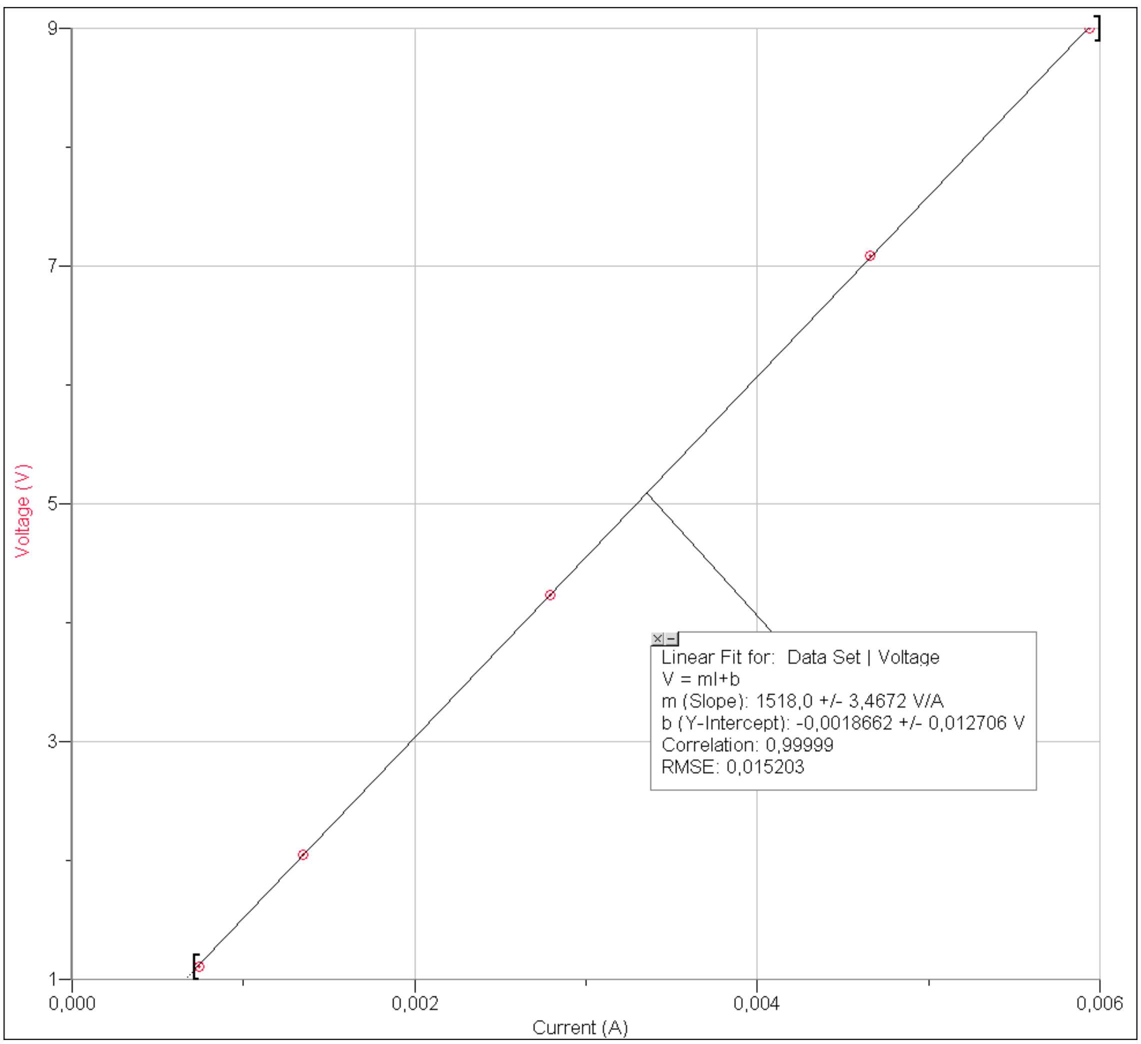

Figure 2: Current I versus the voltage V, depicting the value for a constant resistor R.

As can be noticed from figure 2, the value for the resistor is $(1518.0 \pm 3.5)k\Omega$. However, the team made this calculation by using the theory of the Ohm's Law and the precise value turned out to be $1.502k\Omega$. Hence, there must be an explanation for this difference between the theoretical value and the real value. This is due to the fact that the measuring devices posses certain amount of load (internal resistance), since they are not ideal conductors. Hence, the measurements are accurate, but not accurate enough, given a fairly good precision with a little margin of error.

Resistors in Series

Theoretically, two resistors connected in series act as a resistor with a resistance equal to the sum of the combined resistors in series, as stated in equation 5.

$$R = R_1 + R_2 + \ldots + R_{n-1} + R_n \tag{5}$$

For this experiment, the team first measured the resistance of the two resistors in series and then each one separately. However, already in this early stage of the experiment, the accuracy of the multimeter was compromised again, as it is noticed from table 2.

R_1	$1.500k\Omega$
R_2	$1.497k\Omega$
R_{total} (theoretically)	$2.997k\Omega$
R_{total} (in practice)	$2.996k\Omega$

Table 2: Different values for the resistors in series.

Besides the tiny error in the measurements, the team proceeded to connect the next circuit, shown in figure 3. In this case, two resistors were connected in series, as well as an ammeter and a voltmeter, in order to find out the voltage drop between the end points (terminals) of the circuit.

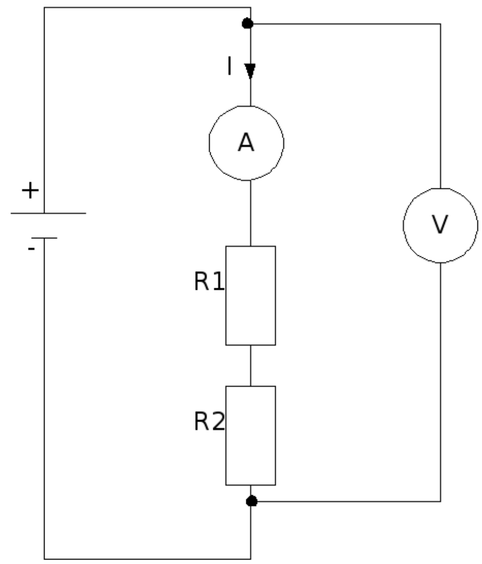

Figure 3: Simple circuit with two resistor of equal resistance connected in series.

Applied to the circuit shown in figure 3, the team used a voltage of $5.00V$ over the circuit. Theoretically, the voltage over the total resistance was proved to be:

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

$$I = \frac{5.00V}{(1.500 + 1.497)k\Omega}$$

$$I = \frac{5.00}{2.996 \cdot 10^3}$$

$$I = 1.6689mA$$

After setting up the circuit and measuring the value in practice with the ammeter, the result was $I = 1.67mA$. This means that there was an error margin of around $\pm 0.01mA$, which is not too bad for this order of magnitude. On the other hand, the voltage read off from the voltmeter turned out to be, in practice, $4.999V$, which compared to the given voltage by the battery, it shows an error margin of $\pm 0.01V$.

Once again, in this case, Ohm's Law has been demonstrated in practice. Also it could be stated, though in an inappropriate experiment, that Kirchhoff's First Law (KCL) is accomplished, since the current entering R_1 is the same that the one leaving from it, which is the same entering R_2 and leaving from it. However, the last experiment was the most interesting from the Kirchhoff's Current Law point of view.

Resistors in Parallel

In this experiment, the team had to deal with the value of total resistance when resistors are placed in parallel in an electric circuit. The value of the total resistance is expressed in equation 6. Needless to say, if there are only two resistors in parallel, then the calculations can be simplified by using equation 7.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_{n-1}} + \frac{1}{R_n} \tag{6}$$

$$R = \frac{R_1 \cdot R_2}{R_1 + R_2} \tag{7}$$

By using these formulas, the team first prepared the circuit, which is shown in figure 4, and then calculated the theoretical values before analyzing the circuit itself. In theory, the equivalent value for the whole resistance made by the combination of R_1 and R_2, and the value for the current across the circuit were calculated as follows:

$$R = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

$$R = \frac{1.502k\Omega \cdot 1.4997k\Omega}{2.997k\Omega}$$

$$R = 0.749k\Omega$$

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

$$I = \frac{5.00V}{0.749k\Omega}$$

$$I = 6.67mA$$

After these calculations, which all where theoretical, the team moved onto the next step by analyzing the circuit in figure 4, which contains two resistors in parallel. The voltage was set to $5.00V$, as stated above, and then the theoretical values were compared to the ones read off the circuit with the help of the multimeters.

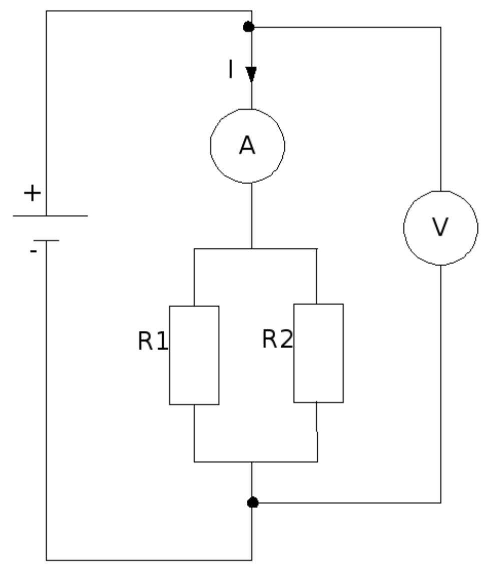

Figure 4: Simple circuit with two resistor of equal resistance connected in parallel.

For this concrete circuit, the measured values were $6.59mA$ from the ammeter and $5.003V$ from the voltmeter. Consequently and admittedly, there was some tiny error margin between the theoretical values and the measured ones. In fact, comparing with the theoretical values, the margin of error was of the order of $0.12mA$ for the current.

Conclusion

First and foremost, this was the most fun experiment the team has performed during the course, by mutual agreement. Obviously, as the team had already some knowledge and skill in dealing with simple circuits, then this set of experiments was not tedious at all and, besides, the team eventually enriched and consolidated its basis about basic electronics.

About the configuration of the experiment and the performing, it was quite easy in general. Actually, the experiment consisted of 6 problems to solve and analyze with different types of circuits. The first three examples were only an introduction to the paper, which already were carried out without problems and put the team ready for the next set of experiments.

Finally, the team decide that all the components should write about this topic since it has been the most liked among all the experiments performed by now. My personal opinion is however that, although this experiment was truly easy, it encouraged us to test, once again, our knowledge in the basics of what it concerns to electric circuits and their associated concepts, such as current, voltage, resistance, etcetera. Also it made me realize that during this time, I have already learn things and assimilated some knowledge that I could not absorb before. For this reason, I enjoyed this experiment in particular and I am already looking forward to further experiments in these laboratory practices.