PHYSICS EXTENDED ESSAY

FACTORS AFFECTING RESISTANCE IN LIQUID CONDUCTORS

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Content

I - ABSTRACT

The aim of this research is to study the relation of resistance with the length and cross sectional area of the liquid conductor. Usually, $V = I \, . R$ and $R = \rho \frac{l}{a}$ formulas are used for metallic materials. The relation of the $R = \rho \frac{l}{a}$ is used to see whether the liquid conductors are ohmic materials or not. Firstly, the potential difference in the conductor is kept constant, and then with this voltage value, the current value is measured by changing the length between two electrodes in five different values which are 5.0, 10.0, 15.0, 20.0, and 25.0 cm at 5.0 cm height of water. After finding current values for five different lengths at 5 cm height of water, the same measurement is applied for five different heights of water which are 10.0, 15.0, 20.0, and 25.0 cm. After changing the unit of the milliampere to ampere unit, the resistance value is observed. With the use of current and resistance values, the resistance versus length, cross sectional area and current graphs are sketched. Using the slope of the graphs and properties of graphs, the appropriateness of hypotheses and the results beyond our hypotheses are discussed. This appropriateness shows the conformity of liquid conductors with Ohm's law and $R = \rho \frac{l}{a}$ formula, which will be the answer to the research question.

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1 – INTRODUCTION

The motion of electric charges creates electric current. According to the Ohm's law, electric current is directly proportional to the potential difference between two points (if the resistance is kept constant). Therefore, Ohm's law is stated as;

$$V = I \,.\, R$$ [1]

Continuum form of this equation will be;

$$R = \frac{V}{I}.$$ [2]

With the help of Ohm's law, different equations are also formed. The best form and also the most useful equation for our investigation is;

$$R = \rho \frac{l}{a}.$$ [3]

This equation shows that resistance is related to electrical resistivity, length and cross-sectional area of the material.

In this study, at different heights of water (5.0, 10.0, 15.0, 20.0, 25.0 cm) electric current is observed at constant potential difference between electrodes with different lengths (25.0, 20.0, 15.0, 10.0, 5.0 cm) between the electrodes. By that way, resistance is calculated with the help of Ohm's law ($R = \frac{V}{I}$) and the electric current is observed at same potential difference. Then, resistance is conformed into the eqution; $R = \rho \frac{l}{a}$. With this two equation, the following continuum form is obtained;

$$\frac{V}{I} = \rho \frac{l}{a}.$$

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[1] *TSOKOS. Kyrgiakos Andreas. Physics for the IB Diploma*. Cambridge. Fifth Edition. 2010 Print.

[2] *TIPLER. Paul Allen. Modern Physics*. Oakland. 4th Revised Edition. 2003 Print.

[3] *RESNICK. Robert. Fundamentals of Physics*. 9th Edition. 2010 Print.

Physicists usually use these formulas for metallic materials (Most common one is copper wire.) because of the high resistivity and stability of metallic materials. However, investigations made under these equations have to be in constant temperature. Most materials obey Ohm's law at low temperatures, but the increase in temperature may cause some problems in this law. Because increase in the temperature results in an increase in resistance.

In conclusion, by this investigation the effect of length and cross-sectional area of liquid conductors to the resistance of the conductor researched.

2- BACKGROUND INFORMATION

2.1- Electric Charge and Current

According to nuclear physics, electrons are particles that carry negative charges, and particles carrying positive charges are called protons. In comparison with electron and nuclei of the atom, electrons are much lighter particles than nuclei and protons. This property gives electrons a chance to move more easily, which means that electrical charge is rustle up with electrons. There may be exceptions for liquids and gases. In liquids and gases, positive particles may also carry electrical charge.

This electrical charge also relates to electric current. By the motion of moving electric charge, electric current is created. *Electric current* is the change of particle that moves from a particular cross-sectional area of a wire per given unit interval of time. By this information, current equation can be written as;

$$I = \frac{\Delta Q}{\Delta t} \quad (\text{Eqn. } 1)$$ [4]

Electric current, I, is a scalar quantity, but there is a direction of current which is taken to be the opposite direction of the actual electron motion.

The most important property of electric charge is that it is conserved. According to the law of conservation, because of the charge conserved the electric current is also conserved. For

[4] *TSOKOS. Kyrgiakos Andreas. Physics for the IB Diploma*. Cambridge. Fifth Edition. 2010 Print.

example, if the circuit is split, then the current given to the circuit is also split through the splitted circuits.

2.2- Ohm's Law

In 1826, the German physicist Georg Simon Ohm stated that the current of a simple circuit is proportional to the potential difference in the circuit, at constant temperature, which can be shown as;

$$I \propto V$$ [5]

Because of being proportional, at constant temperature, graph of I (current) versus V (voltage) gives a straight line, which shows that the material is obeying Ohm's law.

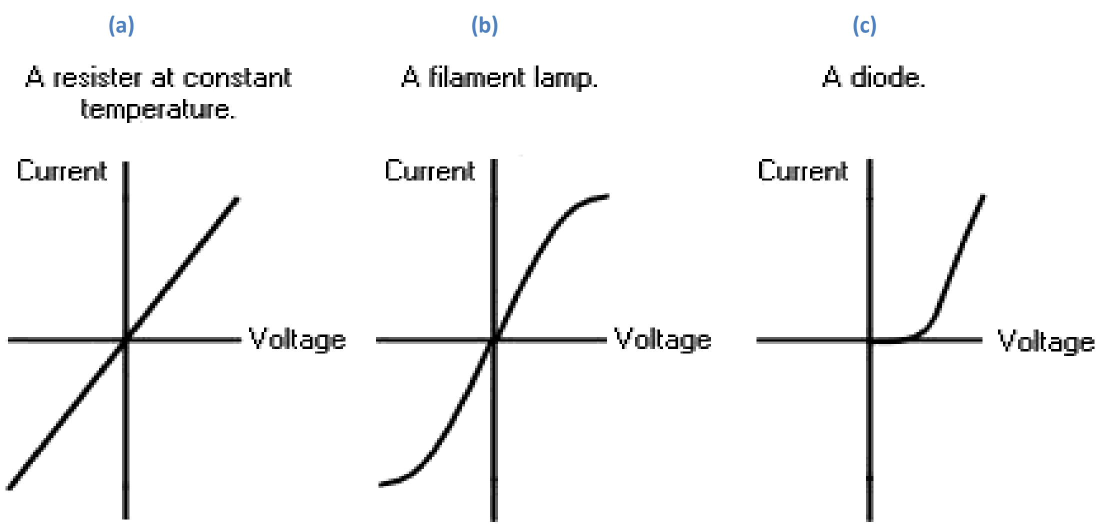


Figure 2.2: Graph (a) shows the proportionality of I (current) and V (voltage) according to Ohm's law, at constant temperature. Graphs (b) and (c) show that filament lamps and diodes do not obey Ohm' Law.

As seen on the graph given above[6], for many conductors, current is directly proportional to voltage. For example, if the current is doubled then the potential difference, will be doubled too. Because of this situation, the following equation can be written;

$$V = I \, . \, R \qquad \text{(Eqn 2)}$$

[5] *TSOKOS. Kyrgiakos Andreas. Physics for the IB Diploma*. Cambridge. Fifth Edition. 2010 Print.

[6] http://lgfl.skoool.co.uk/uploadedImages/coord12.1_graphs.gif

Equation 2 is called Ohm's law. Materials that obey Ohm's law are called Ohmic and materials that do not obey Ohm's law are called nonohmic materials. In Figure 2.2(a), it is seen that the slope of I versus V graph is the same at each point and gives a single value. According to Ohm's law, this value is called *resistance*.

2.3- Resistance

Electrical resistance is the fraction of potential difference of circuit and the electric current flowing through the circuit (which can be seen in Ohm's law). This operation can be shown as;

$$R = \frac{V}{I} \qquad \text{(Eqn. 3)}$$

As seen in Equation 3, the electrical resistance is volt per ampere. This unit is defined as ohm, and its symbol is Ω (Greek letter: "omega").

In materials obeying Ohm's law, the slope of voltage versus current gives a single value, which is the value of resistance. So the resistance of a specific material is constant.

However, temperature is an important factor in the stability of resistance. Most materials obey Ohm's law in low temperatures, but increase in temperature results in deviation in the resistance of materials.

For an example, this situation mostly seen on bulbs. While the bulb is working, the temperature increases are caused by the light energy's conservation into heat energy, so does the resistance increase. Other exceptions, such as lamp filament or diode, also deviate from Ohm's law (Figure 2.2).

2.4- Factors Affecting Resistance

In metallic materials, the increase in temperature also causes increase in resistance, but at constant temperature, three factors affect the resistance.

As stated above (Content 2.3) materials that obey Ohm's law have a specific value of resistance because of the straight line graph of V versus I. This resistance value varies for different types of conductor materials. The cause of this difference can be explained by the value of electrical resistivity with the symbol "ρ" (Greek letter: "rho"). The unit of resistivity is the ohm-meter (Ω.m). Resistivity is also called *proportionality constant*. The reciprocal of the resistivity is the conductivity; σ.

$$\sigma = \frac{1}{\rho}$$ [7]

The second factor that affects the resistance is the length of the material. For ohmic materials, resistance and the length of the conductor is directly proportional. As the length increases, resistance also increases.

The last factor is the cross-sectional area of the conductor. For ohmic materials, resistance and cross-sectional area is inversely proportional. As the cross-sectional area increases, the resistance decreases proportionally to the cross-sectional area.

Such measurements indicate this result;

$$R \; \alpha \; \frac{\mathrm{L}}{\mathrm{A}}$$ [8]

These measurements lead us to a continuum form of the Ohm's law. If resistance depends on the resistivity, length, and cross-sectional area of the material then this equation can be written;

$$R = \rho \frac{l}{a} \qquad \text{(eqn. 4)}$$

[7] *RESNICK. Robert. Fundamentals of Physics*. 9th Edition. 2010 Print.

[8] *RESNICK. Robert. Fundamentals of Physics*. 9th Edition. 2010 Print.

Measurements of these proportionalities shown below in Figure 2.4[9];

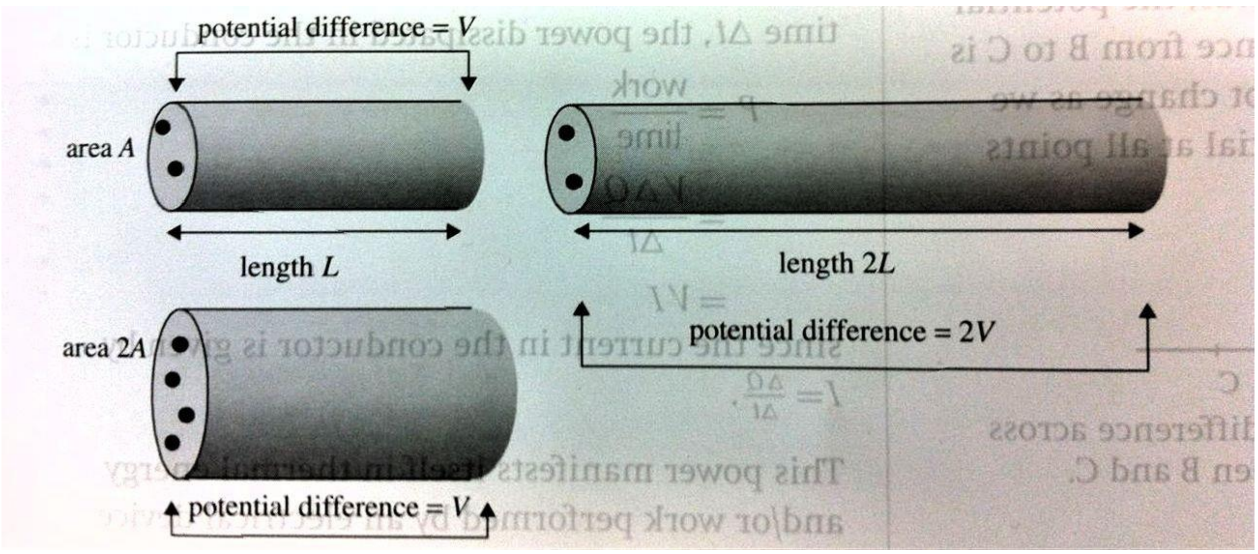


Figure 2.4: **If the cross-sectional area of conductor is doubled at constant potential difference and temperature, resistance will halves and current flowing through the conductor will be doubled. If the length of the conductor doubled, then potential difference will be doubled too while the current stays the same. Hence the resistance doubles.**

[9] Tsokos 313

3- EXPERIMENT

3.1- Research Question

Do the length between the electrodes and the cross sectional area of a liquid conductor affect the resistance as said in Ohm's law ($R = \frac{V}{I}$) and $R = \rho \frac{l}{a}$ formula if five different lengths (5.0, 10.0, 15.0, 20.0 and 25.0 cm) and heights of liquid (5.0, 10.0, 15.0, 20.0 and 25.0 cm) are used in the liquid circuit?

3.2- Hypotheses

According to Ohm's law, the potential difference and the current across the conductor are proportional; from this information, the resistance of a material can be found by using current and voltage values, and both cross-sectional area and length should affect the resistance of the conducting liquid.

Therefore, these are the hypotheses about the relationship of Ohm's law with liquid and the effect of cross-sectional area and length with the liquid conductor:

- Conductor formed by using tap water is obeying the Ohm's law and tap water is an ohmic material.
- If the length of the conductor is increased by changing separation between electrodes, then the resistance of conductor will increase too. In the same potential difference as the length increased, current will decrease proportionally.
- If the cross-sectional area of the conductor is increased by adding water, then the resistance of conductor will decrease. In the same potential difference while the cross-sectional area is increased, current will also increase.

3.3- Key Variables

Two different independent variables were used in the experiment:

Independent Variables:

- Length of the conductor[*]

[*] While the length of the conductor is independent, cross sectional area of the conductor will be controlled.

- Cross-sectional area of the conductor**

Dependent Variables:

- Resistance of the conductor
- Current of the conductor

Controlled Variables:

- Potential difference across the conductors
- Shape of the small water tank
- Same tap water, so that:
  1. Density of water
  2. pH value of water
  3. Viscosity of water
- Type of the electrodes
- Type of multi meter
- Length of the electrode cables
- Volume of the small water tank
- Volume of electrodes
- Salt type
- Type of thermometer
- Type and volume of beher
- Type of digital balance
- Type of metal rulers.

Constant Variables: (These variables are considered as constant.)

- Pressure of air
- Pressure of water
- Gravitational acceleration
- Temperature of water
- Temperature of air

** While the cross-sectional area of the conductor is independent, length of the conductor will be controlled.

4- PROCEDURE AND PREPARATION

4.1- MATERIALS

- Small transparent glass water tank:

  A transparent water tank made of glass with 33.5 cm length, 27 cm height and 16 cm width. Strong made for prevent the water leakage.
- Tap water supplied from school lab
- Two wire electrodes and clips
- A thermometer (an accuracy of 0.1˚C)
- A digital balance (an accuracy of 0.001 g)
- Metal rulers having length of 100.0 cm and 20.0 cm (an accuracy of 0.1 cm)
- A multi meter (measuring current at same potential difference value with an accuracy of 0.001 A)
- Salt
- Board marker
- 600 mL beher (an accuracy of 0.005 mL)

Figure 4.1: Materials used in the experiment.

4.2- PRELIMINARY MEASUREMENTS

Several preliminary measurements were carried out:

- Dimensions of transparent glass water tank were measured with 100.0 cm and 20.0 cm rulers.
- Measurements of the transparent glass water tank were written down on the transparent glass water tank with board marker. The length of the water tank was written down on the bottom of the transparent glass water tank in every 5.0 cm, which looked like a ruler. By that way, the length between electrodes can be measured more easily and abrogate the limitations of the experiment.
- Same measurement and operation were applied on the height on the lateral side of the water tank in order to measure the effect of cross-sectional area of the conductors.

The final look of the transparent glass water tank will be like the *Figure 4.2*:

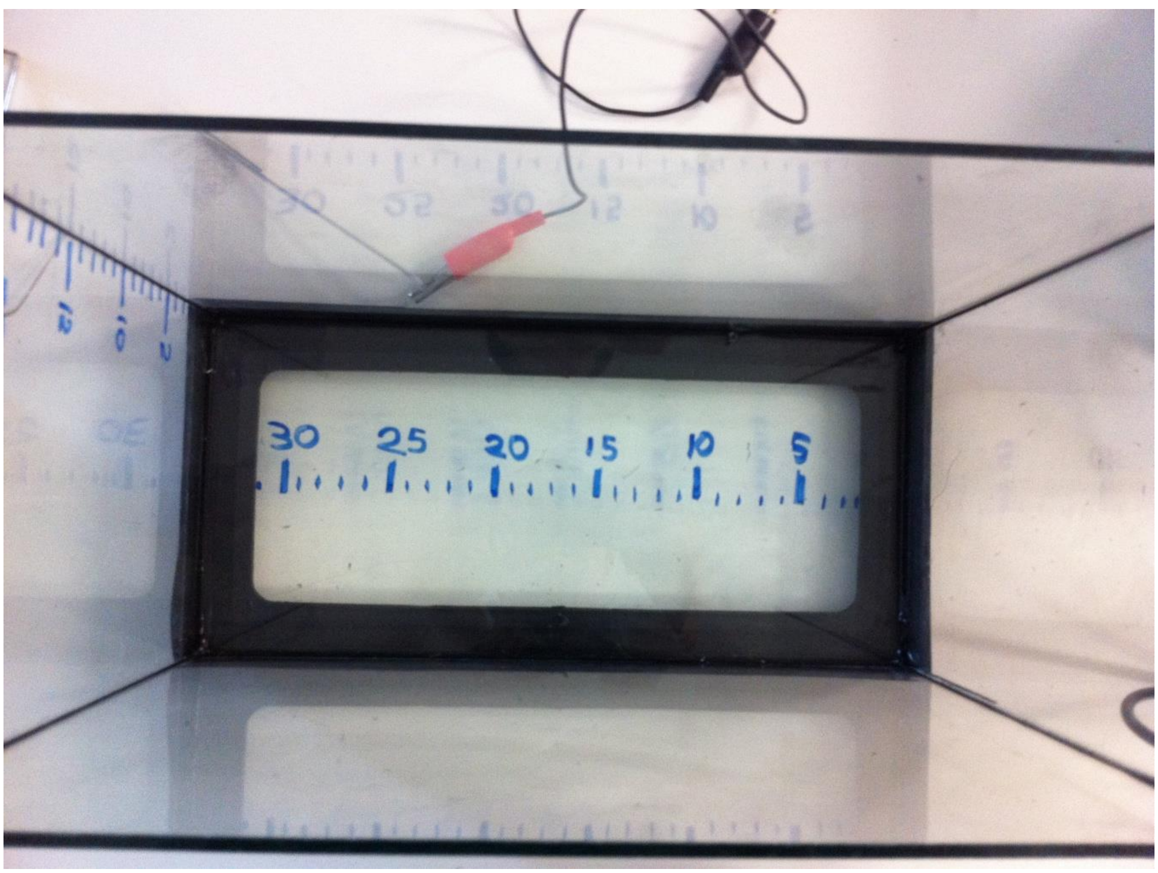


Figure 4.2: Length and height of the transparent glass water tank matriculated with 5 cm intervals (an accuracy of 0.1 cm)

- Water capacity of the transparent glass water tank is measured with the 600 mL beher, and the result of the measurement is matriculated.
- Temperature of water is measured and matriculated.

4.3- METHOD

Have one person in the lab be the electrode holder, one be the recorder.

1. Fill the transparent glass water tank with tap water up to 5 cm height (written down on the lateral side of the glass tank preliminary; see 4.2- preliminary measurements).
2. Measure the temperature of the water with thermometer.
3. Append 2.000 ± 0.001 g of salt into the tap water to make an electric current generating conductor.
4. Place the electrodes with a distance of 25.0 cm.
5. Set the potential difference value to 25.0 voltage.
6. Recorder measures the current value in mA and matriculate.
7. After matriculation, operate the same actions with a distance of 20.0, 15.0, 10.0 and 5.0 cm between electrodes and matriculate the current data obtained from the measurements.
8. While operating these actions, control the temperature of water in order to prevent the temperature increase in water.
9. After measuring the current in 5 different lengths (25.0, 20.0, 15.0, 10.0 and 5.0 cm), disburden the water in glass tank and fill again with tap water up to 5 cm height (see method-bullet 1), and append salt (see method-bullet 2) and measure the current with the same method applied earlier and matriculate the data obtained. (Do these operations in 5 trials)
10. Do all these operations in different heights (10.0, 15.0, 20.0 and 25.0 cm) (Cm values must be written down on the lateral side of the glass tank; see preliminary measurements), but while appending salt into the water, heed to append the salt proportionally with the increase in water. (For example, in 10.0 cm height of water append 4.000 ± 0.001 g, in 15.0 cm height of water, append 6.000 ± 0.001 g of salt).

11. Place the electrodes at the bottom side of the glass tank in every operation in order to see the effect of the cross-sectional area of the conductor.
12. Record the data on the sample data table below;

			CURRENT (± 1 mA)				
		Trials	LENGTH (± 0.1 cm)				
			25	20	15	10	5
HEIGHT (± 0.1 cm)	25	1	.....	....	...	..	.
		2	....				
		3	...				
		4	..				
		5	.				
	20	1					
		2					
		3					
		4					
		5					
	15	1					
		2					
		3					
		4					
		5					
	10	1					
		2					
		3					
		4					
		5					
	5	1					
		2					
		3					
		4					
		5					

Figure 4.3.1: Sample data table for data collection.

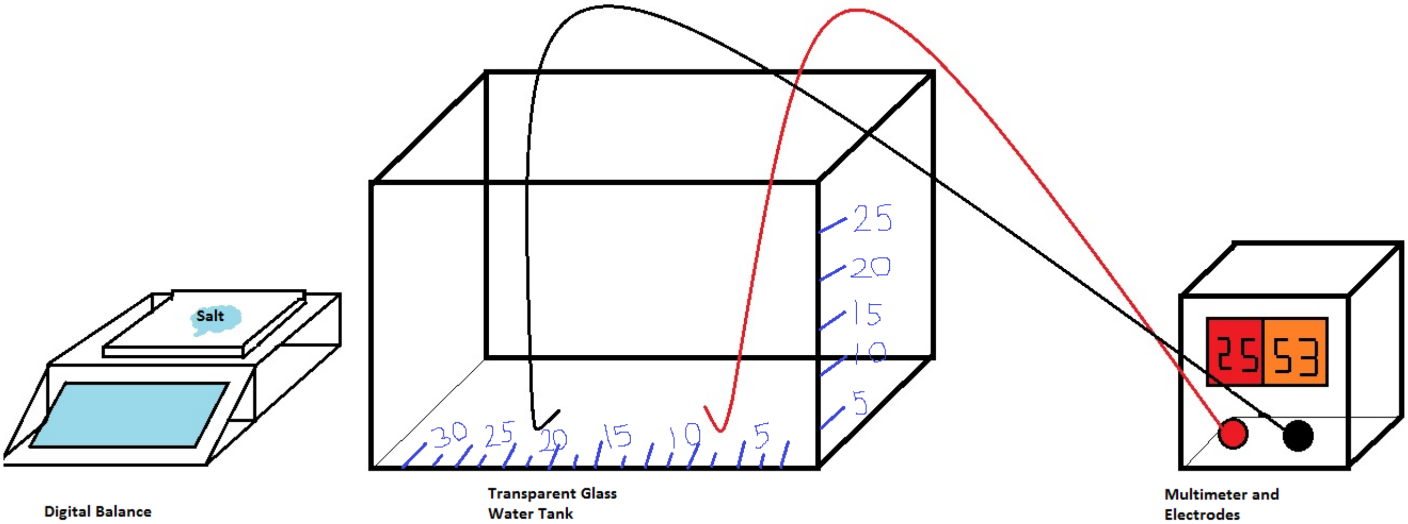


Figure 4.3.2: Diagram for the experiment shown above. Multimeter with electrodes connected and digital balance showed. In the middle transparent glass water tank shown with the length index just like that we used in our experiment.

5- DATA COLLECTION

During the experiments, the following calculations were made with accepting the conformity of water to the Ohm's law;

Temperature increase was observed when the constant value of potential difference (voltage) in multi meter changed to 25.1 V from 25.0. When this alternation was observed, the experiment stopped and waited till the water temperature decreased to its normal value, 21.0˚C. Since then voltage alternation became an indicator of temperature alternation.

All the quantitative data which are controlled variables are given in the table 5.1.1 and for the data observed for current value are given in the table 5.1.2.

Because of the ease of the observation, height values (5.0, 10.0, 15.0, 20.0 and 25.0 cm) were used instead of cross sectional area. However, the cross sectional area of water in different heights is already measured. As it is mentioned in preliminary measurements (see 4.2 preliminary measurements) and method (see 4.3 method), the width of glass water tank was measured as 16.0 cm. With this value, the area of the glass water tank in every height can be measured and with these measurements, the cross sectional area proportional with the height can be observed.

In numerical example;

At 5.0 cm height of water and constant value of 16.0 cm, width of glass water tank, the cross-sectional area was measured as 80.0 cm^2. (See 4.1 Materials, first bullet) So if the height of water is doubled, hypothetically cross-sectional area of glass water tank should be double, too. Fortunately, in our measurements, the cross sectional area of glass water tank was calculated as 160.0 cm^2 in 10.0 cm height of water. So the height of water is proportional to the area. That is why the height of water was used instead of cross sectional area, which gives a chance of an easier and better calculation ability.

5.1- RAW DATA

While observing this experiment, some variables needed to be controlled. The amount of salt, the temperature of water and the potential difference in multimeter are kept constant otherwise the use of different values for these variables can cause error and lead to a result that is inappropriate for our research question and hypothesis.

		Trials	HEIGHT (± 0.1 cm)				
			25.0	20.0	15.0	10.0	5.0
CONTROLLED VARIABLES	Amount of Salt (± 0.001 g)	1	10.001	8.004	6.001	4.000	2.004
		2	10.004	8.001	5.996	4.002	1.999
		3	9.999	8.001	5.998	3.998	1.999
		4	10.002	8.002	6.004	4.001	2.003
		5	10.002	7.998	6.000	4.002	2.002
	Temperature of Water (± 0.1˚C)	1	21.0	21.0	21.0	21.0	21.0
		2	21.0	21.0	21.0	21.0	21.0
		3	21.0	21.0	21.0	21.0	21.0
		4	21.0	21.0	21.0	21.0	21.0
		5	21.0	21.0	21.0	21.0	21.0
	Potential Difference (± 0.1 V)	1	25.0	25.0	25.0	25.0	25.0
		2	25.0	25.0	25.0	25.0	25.0
		3	25.0	25.0	25.0	25.0	25.0
		4	25.0	25.0	25.0	25.0	25.0
		5	25.0	25.0	25.0	25.0	25.0

Figure 5.1.1: This table shows the amount and the values of our controlled variables used in our experiment. Reason of the increase in salt amount explained in 4.3 method-bullet 10. Temperature of water kept constant as explained in 5- Data collection and for the aim of our experiment, potential difference value kept constant in order to observe the resistance differentiation with height and length properties of the liquid conductor. All values showed with the relation of height of water because water changed only in different trials and different heights of water.

After that, current values were observed with the multimeter and measured with the unit of milliampere. However, to find resistance value, it is necessary to use the ampere and voltage value, so the milliampere value, which was observed in measurements, was multiplied by 10^{-3}. By this way, the ampere and resistance value were found in further calculations (see 5.3-Calculations).

			CURRENT (± 0.001 A)				
		Trials	LENGTH (± 0.1 cm)				
			25.0	20.0	15.0	10.0	5.0
HEIGHT (± 0.1 cm)	25.0	1	0.122	0.136	0.156	0.170	0.196
		2	0.127	0.137	0.156	0.168	0.198
		3	0.122	0.138	0.152	0.170	0.202
		4	0.123	0.136	0.157	0.170	0.203
		5	0.123	0.138	0.158	0.168	0.203
	20.0	1	0.117	0.123	0.141	0.156	0.180
		2	0.112	0.122	0.138	0.158	0.178
		3	0.112	0.128	0.138	0.152	0.182
		4	0.113	0.123	0.138	0.152	0.183
		5	0.108	0.122	0.142	0.158	0.180
	15.0	1	0.102	0.112	0.126	0.130	0.160
		2	0.097	0.107	0.123	0.133	0.158
		3	0.097	0.108	0.118	0.137	0.162
		4	0.108	0.113	0.118	0.137	0.162
		5	0.098	0.112	0.127	0.143	0.160
	10.0	1	0.073	0.078	0.087	0.092	0.107
		2	0.072	0.077	0.083	0.088	0.103
		3	0.068	0.078	0.088	0.093	0.108
		4	0.073	0.083	0.088	0.098	0.108
		5	0.073	0.078	0.087	0.097	0.097
	5.0	1	0.053	0.058	0.068	0.078	0.097
		2	0.048	0.058	0.068	0.078	0.092
		3	0.048	0.053	0.063	0.073	0.087
		4	0.053	0.058	0.068	0.073	0.088
		5	0.052	0.057	0.062	0.077	0.092

Figure 5.1.2: This table shows the raw current data observed from the experiment in two independent variables; height (use of height instead of cross sectional area explained in 5-Data collection) and length. Data showed in ampere value instead of milliampere in order to find resistance as the unit; ohm.

5.2- DATA PROCCESSING AND PRESENTATION

- The volume of transparent glass water tank was measured to determine and set the interval values that will be held between electrodes and set the volume of water.
- The volume of water was observed with beher. Different heights of water in glass tank and the volume of water were observed proportional. In 5 cm of water, the volume of water is 3.050 ± 0.005 L, so in 10 cm of water, the volume of water is 6.100 ± 0.005 L.
- Mass of salt was calculated with a digital balance. Salt increased proportionally with the increase of volume of water.
- The temperature of water was calculated with thermometer and matriculated. This value was tried to keep constant during the experiment.
- Electrodes were connected to multi meter and set the constant value for voltage to 25.0 V.
- Electrodes were hold with a distance of 25.0, 20.0, 15.0, 10.0, 5.0 cm in a height of 5.0, 10.0, 15.0, 20.0 and 25.0 cm of water and with the constant potential difference value (25.0 V), current in mA (milliampere) was calculated.
- Calculated mA data turned into A (ampere) value by multiplying with 10^{-3}.
- With the data of these calculations, the resistance of water was found with the Ohm's law. (Equation 2 used.)
- With all these calculations, conformity of water with the Ohm's law and equation 4 (see 2.4 Factors Affecting Resistance) will be shown.

5.3 – CALCULATIONS

In order to show an accurate and precise graph, the average values of current were observed in five trials with different independent variables calculated. With these mean values, results were sketched and calculated more easily.

		CURRENT (± 0.001 A)				
		LENGTH (± 0.1 cm)				
		25.0	20.0	15.0	10.0	5.0
HEIGHT (± 0.1 cm)	25.0	0.123	0.137	0.156	0.169	0.200
	20.0	0.112	0.124	0.139	0.155	0.181
	15.0	0.100	0.110	0.122	0.137	0.160
	10.0	0.072	0.079	0.087	0.094	0.107
	5.0	0.051	0.057	0.066	0.076	0.091

Figure 5.3.1: Mean values for current values for five trials which measure with multimeter at constant 25.0 ± 0.1 volt with different length and height values.

After that, in order to result the experiment, the resistance values for every trial must be found. As mentioned before, the potential difference value in multimeter is kept constant at 25.0 ±0.1 V. So the resistance values are found by using the Ohm's Law (see background information 2.3, eqn. 3.) and by using the current values measured in the experiment.

An example calculation for finding the resistance is as follows;

In the first trial of the 5 cm height of water with 25 cm distance between electrode's, observation, current value is: 0.053 ± 0.001 A . (For all current values see table 5.1.2)

Our constant potential difference value is 25.0 ± 0.1 Volt.

So according to Ohm's Law; $R = \frac{V}{I}$

$$\boldsymbol{R = \frac{25.0}{0.053} = 471.7\ \Omega}$$

		RESISTANCE (Ω)				
	Trials	LENGTH (± 0.1 cm)				
		25.0	20.0	15.0	10.0	5.0
HEIGHT (± 0.1 cm) 25.0	1	204.9	183.8	160.3	147.1	127.6
	2	196.9	182.5	160.3	148.8	126.3
	3	204.9	181.2	164.5	147.1	123.8
	4	203.3	183.8	159.2	147.1	123.2
	5	203.3	181.2	158.2	148.8	123.2
20.0	1	213.7	198.4	177.3	160.3	138.9
	2	223.2	204.9	181.2	158.2	140.4
	3	223.2	195.3	181.2	164.5	137.4
	4	221.2	203.3	181.2	164.5	136.6
	5	231.5	204.9	176.1	158.2	138.9
15.0	1	245.1	223.2	198.4	183.8	156.3
	2	257.7	233.6	203.3	188.0	158.2
	3	257.7	231.5	211.9	182.5	154.3
	4	231.5	221.2	211.9	182.5	154.3
	5	255.1	223.2	196.9	174.8	156.3
10.0	1	342.5	320.5	287.4	271.7	233.6
	2	347.2	324.7	301.2	284.1	242.7
	3	367.6	320.5	284.1	268.8	231.5
	4	342.5	321.2	284.1	255.1	231.5
	5	342.5	320.5	287.4	257.7	233.6
5.0	1	471.7	431.0	367.6	320.5	257.7
	2	520.8	431.0	367.6	320.5	271.7
	3	520.8	471.7	396.8	342.5	287.4
	4	471.7	431.0	367.6	342.5	284.1
	5	480.8	438.6	403.2	324.7	271.7

Figure 5.3.2: Resistance values found with using the Ohm's Law (see appendix 2.3, eqn. 3 and for the calculations see appendix 5.3.). Resistance values for different values of height and length are emphasized. For error values for every data see error calculations 7.1 and table 5.5.1.

After finding the resistance values for every trial, it is necessary to find the mean values of resistance for a better conclusion and result.

		RESISTANCE (Ω)				
		LENGTH (± 0.1 cm)				
		25.0	20.0	15.0	10.0	5.0
HEIGHT (± 0.1 cm)	25.0	202.7	182.5	160.5	147.8	124.8
	20.0	222.6	201.4	179.4	161.1	1384
	15.0	249.4	226.5	204.5	182.3	155.9
	10.0	348.5	321.5	288.8	267.5	234.6
	5.0	493.2	440.7	380.6	330.1	274.5

Figure 5.3.3: Mean values for resistance which found from the calculation of current values with using Ohm's Law emphasized for independent values which is different height and length values.

5.4- TABLES AND GRAPHS

In this section, graphs and tables of resistance are shown. Mean values will be used in graphs in order to reach an accurate and precise conclusion. Error bar values for resistance will be used from the data in table 5.5.2 in 5.5 error calculations.

5.4.1- Resistance versus Length

In this section, the resistance with length between two electrodes at constant heights of water collated.

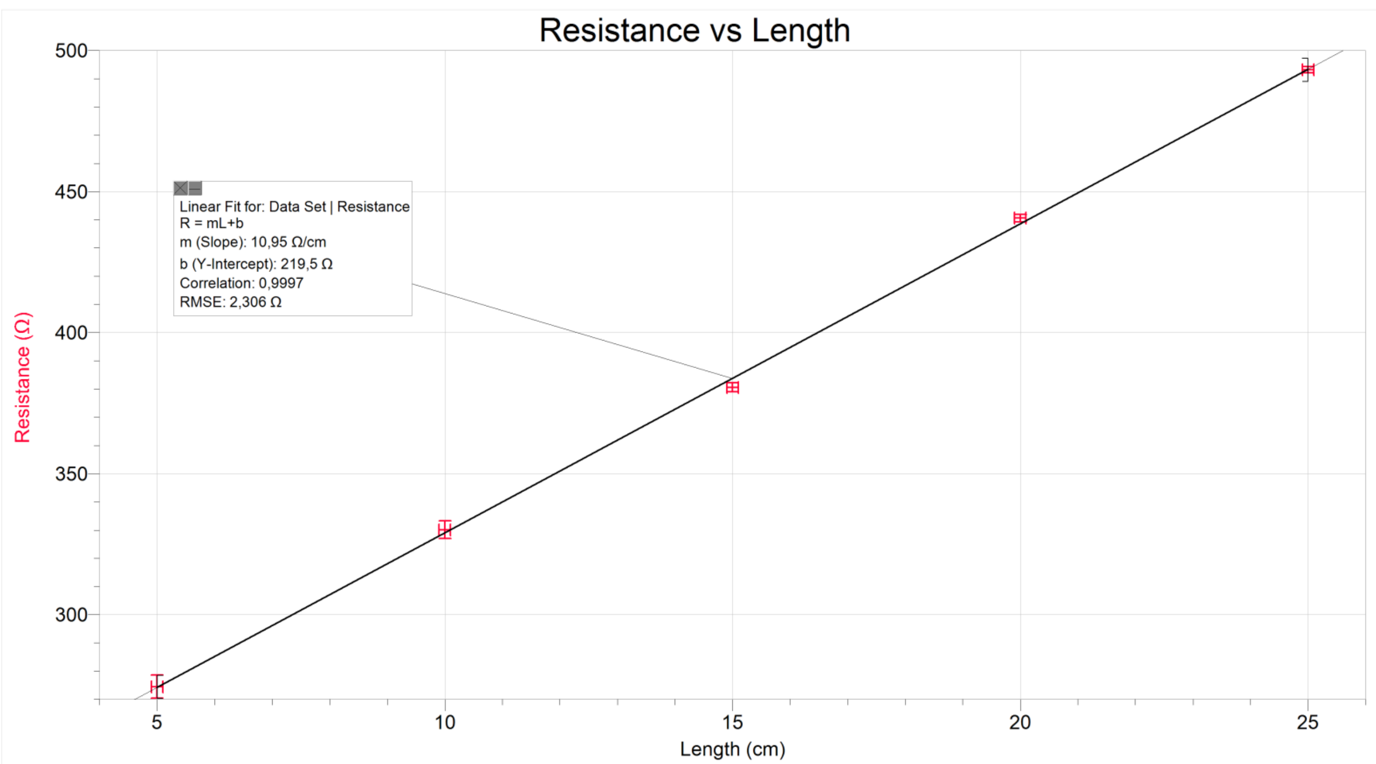
Five different height of water values were considered as constant variable and confront resistance, which is calculated after finding the current value and using the Ohm's Law, to five different lengths and sketch this confrontation's graph.

In these graphs, our independent variable is length and dependent variable is resistance and controlled variable is height of water. And all error bars are used from the data used in table 5.5.2 in 5.5 error calculations.

<u>**5.4.1.a-** *Resistance versus Length at 5 cm constant height of water*</u>

Length (cm) ± 0.1	Resistance (Ω)
5.0	275 ± 4
10.0	330 ± 3
15.0	381 ± 2
20.0	441 ± 1
25.0	493 ± 1

Table 5.4.1.a: This table shows the resistance values relation to length between electrodes at 5 cm constant height of water.

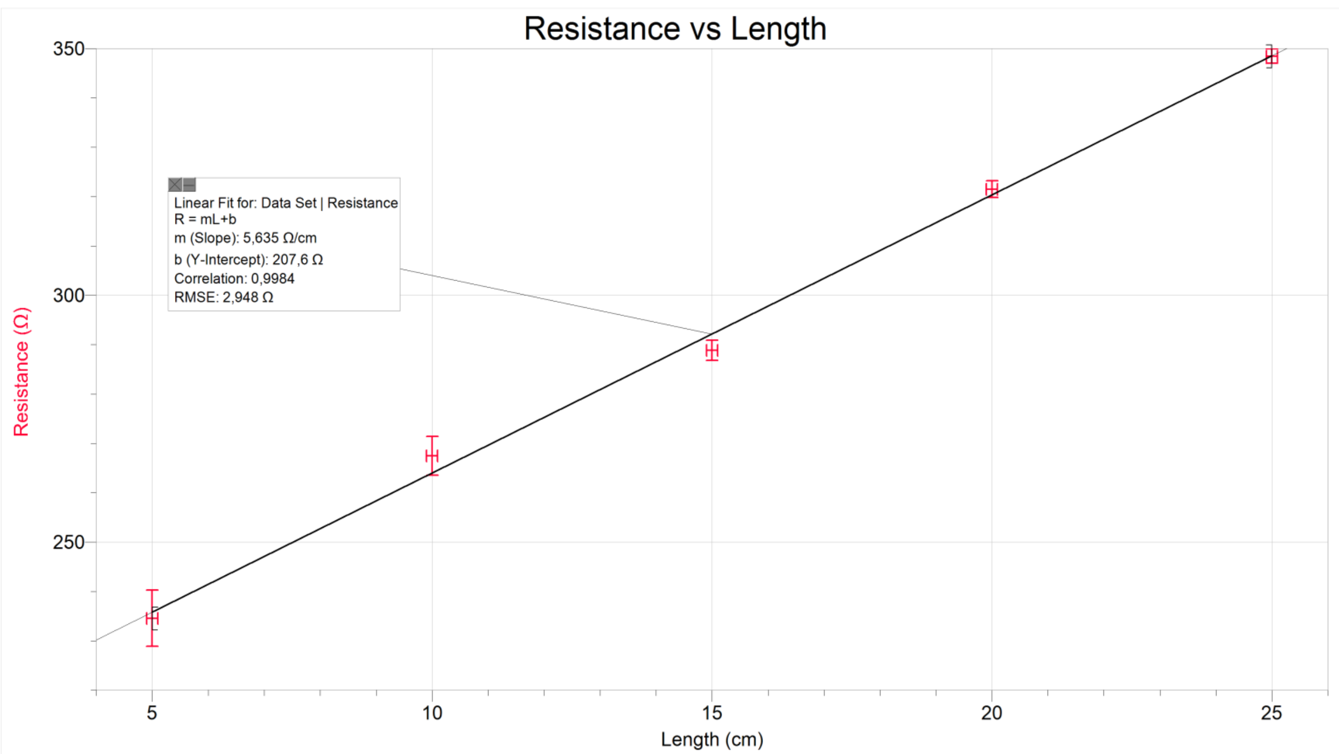


Graph 5.4.1.a: Relation between resistance and length at 5 cm constant height of water graph sketched with data used from the Table 5.4.1.a.

5.4.1.b- *Resistance versus Length at 10 cm constant height of water*

Length (cm) ± 0.1	Resistance (Ω)
5.0	235 ± 6
10.0	208 ± 4
15.0	289 ± 2
20.0	322 ± 2
25.0	349 ± 2

Table 5.4.1.b- This table shows the resistance values according to length between two electrodes at 10 cm constant height of water.

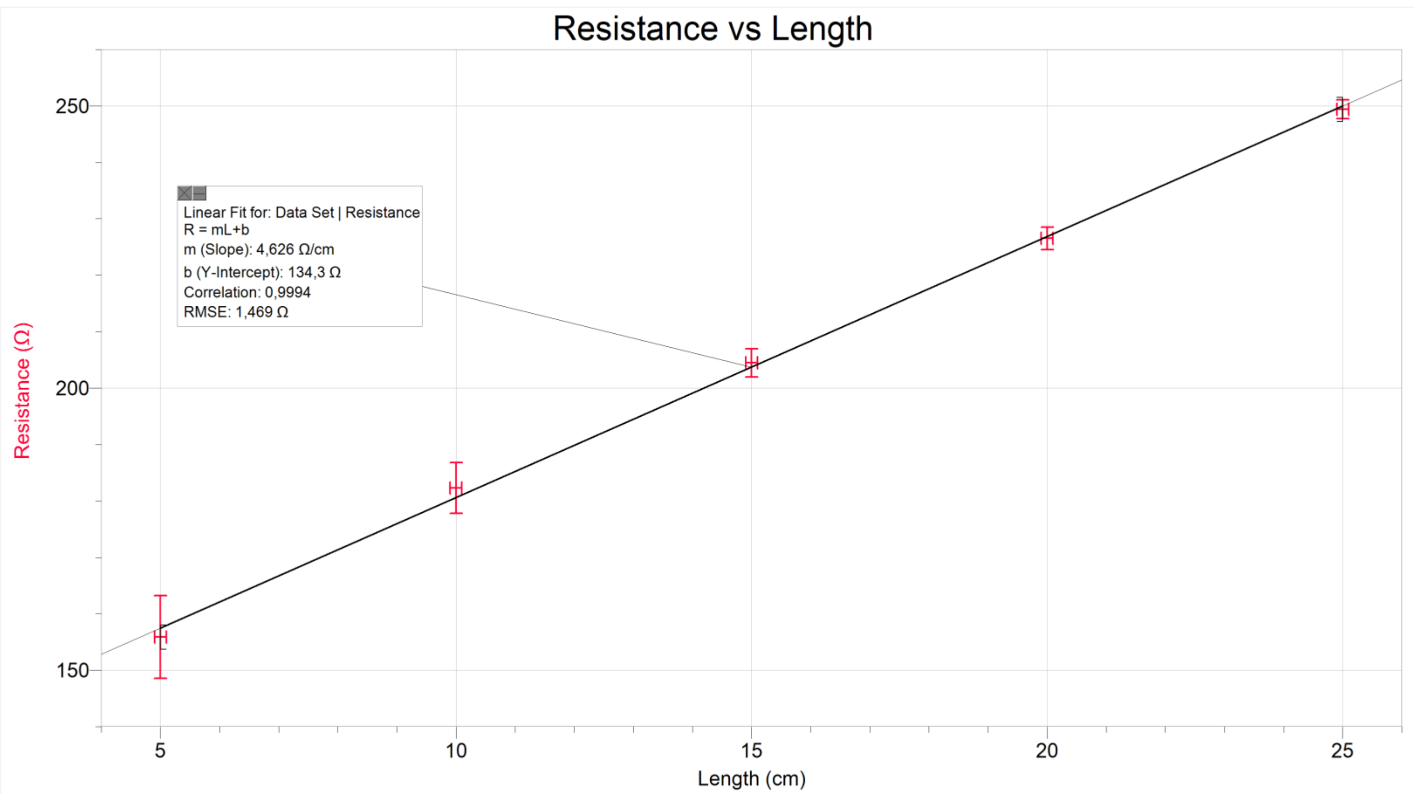


Graph 5.4.1.b: Relation between resistance and length at 10 cm constant height of water graph sketched with data used from the Table 5.4.1.b.

5.4.1.c- *Resistance versus Length at 15 cm constant height of water*

Length (cm) ± 0.1	Resistance (Ω)
5.0	156 ± 7
10.0	182 ± 5
15.0	205 ± 3
20.0	227 ± 2
25.0	249 ± 2

Table 5.4.1.c- This table shows the resistance values according to length between two electrodes at 15 cm constant height of water.

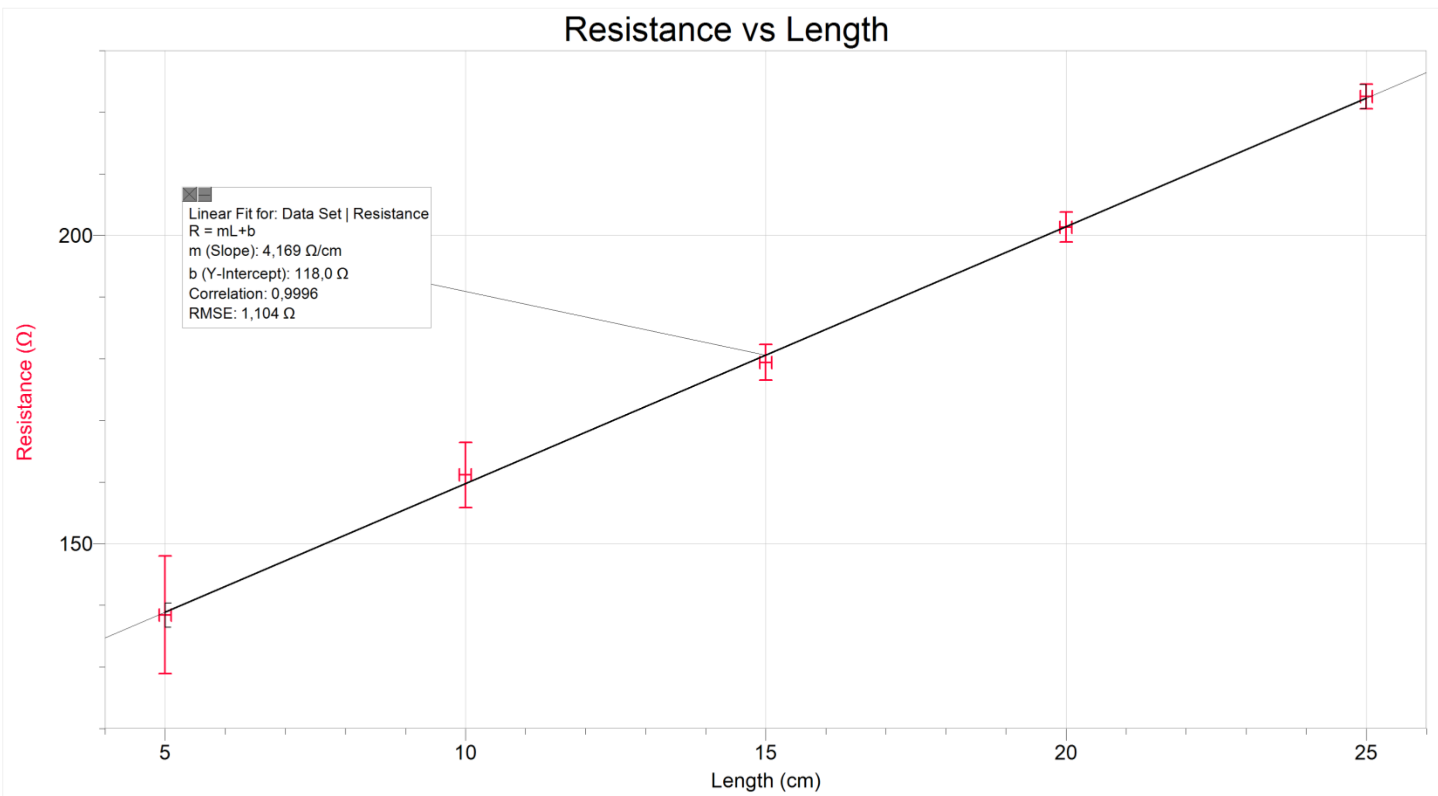


Graph 5.4.1.c: Relation between resistance and length at 15 cm constant height of water graph sketched with data used from the table 5.4.1.c.

5.4.1.d- *Resistance versus Length at 20 cm constant height of water*

Length (cm) ± 0.1	Resistance (Ω)
5.0	138 ± 10
10.0	161 ± 5
15.0	179 ± 3
20.0	201 ± 2
25.0	223 ± 2

Table 5.4.1.d- This table shows the resistance values according to length between two electrodes at 20 cm constant height of water.

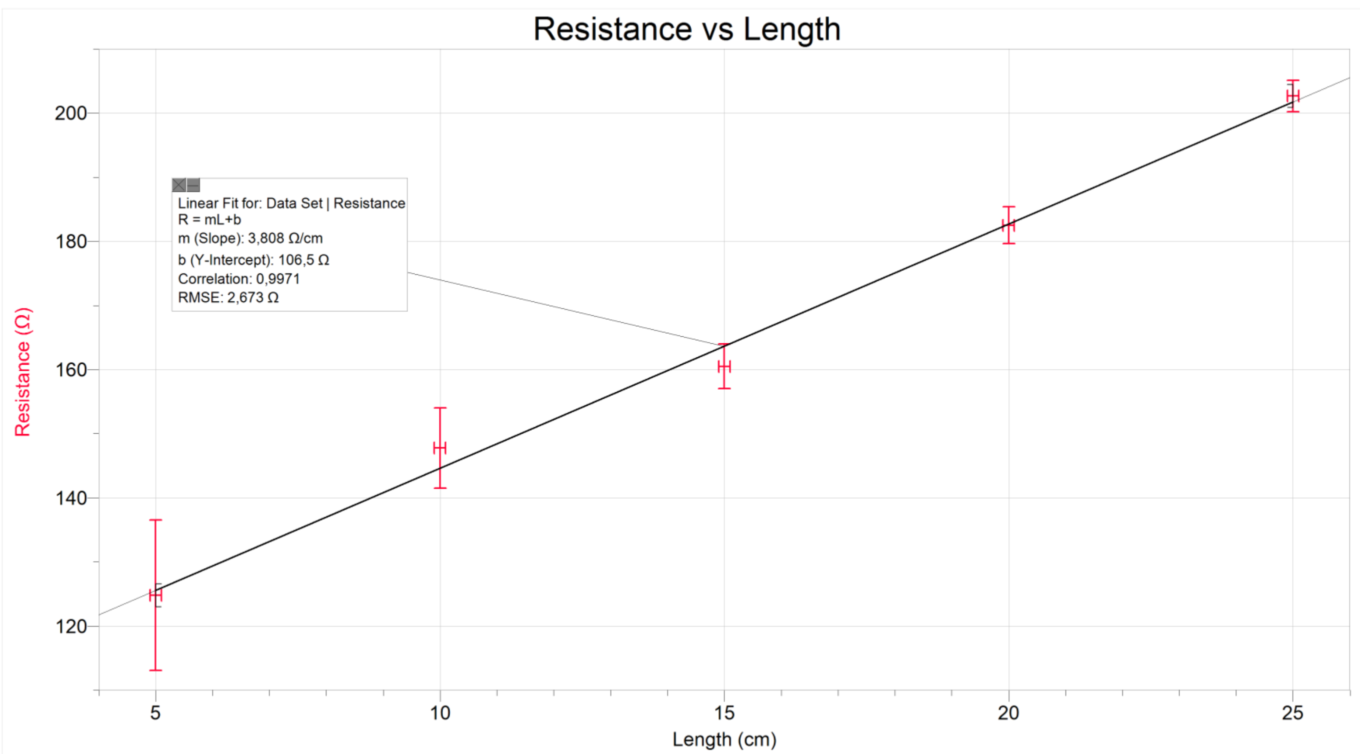


Graph 5.4.1.d: Relation between resistance and length at 20 cm constant height of water graph sketched with data used from the Table 5.4.1.d.

<u>**5.4.1.e-** *Resistance versus Length at 25 cm constant height of water*</u>

Length (cm) ± 0.1	Resistance (Ω)
5.0	125 ± 12
10.0	148 ± 6
15.0	161 ± 3
20.0	183 ± 3
25.0	203 ± 2

<u>Table 5.4.1.e-</u> This table shows the resistance values according to length between two electrodes at 25 cm constant height of water.



Graph 5.4.1.e: Relation between resistance and length at 25 cm constant height of water graph sketched with data used from the Table 5.4.1.e.

5.4.2- Resistance versus Height of Water

In this section, resistance to height of water is confronted. Five different height of water and its current value are used. After finding current, resistance is calculated with the Ohm's Law.

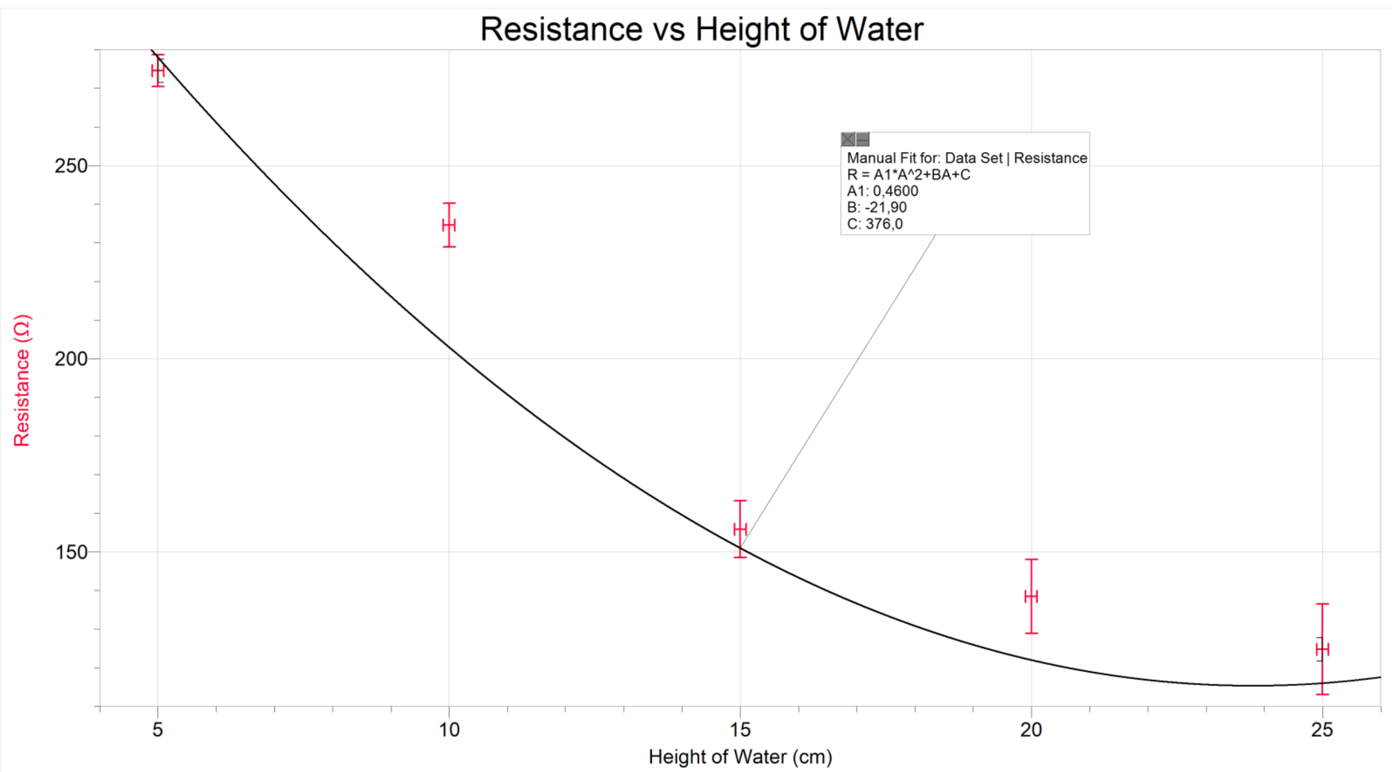
Resistance values are put against the value of height of water, and then our graph is sketched. But to sketch this graph, one independent variable must be considered as constant which will be the length between two electrodes. Our constant variable in this experiment is the length between two electrodes and five graphs for five different length values sketched.

All error bars are used from the data used in table 5.5.2 in 5.5 error calculations.

5.4.2.a- *Resistance versus Height of Water at 5 cm constant Length Between Two Electrodes*

Height of water (cm) ± 0.1	Resistance (Ω)
5.0	275 ± 4
10.0	235 ± 6
15.0	156 ± 7
20.0	138 ± 10
25.0	125 ± 12

Table 5.4.2.a- This table shows the resistance values found from calculation showed in 5.3-calculations and height of water at constant length of 5 cm between electrodes.

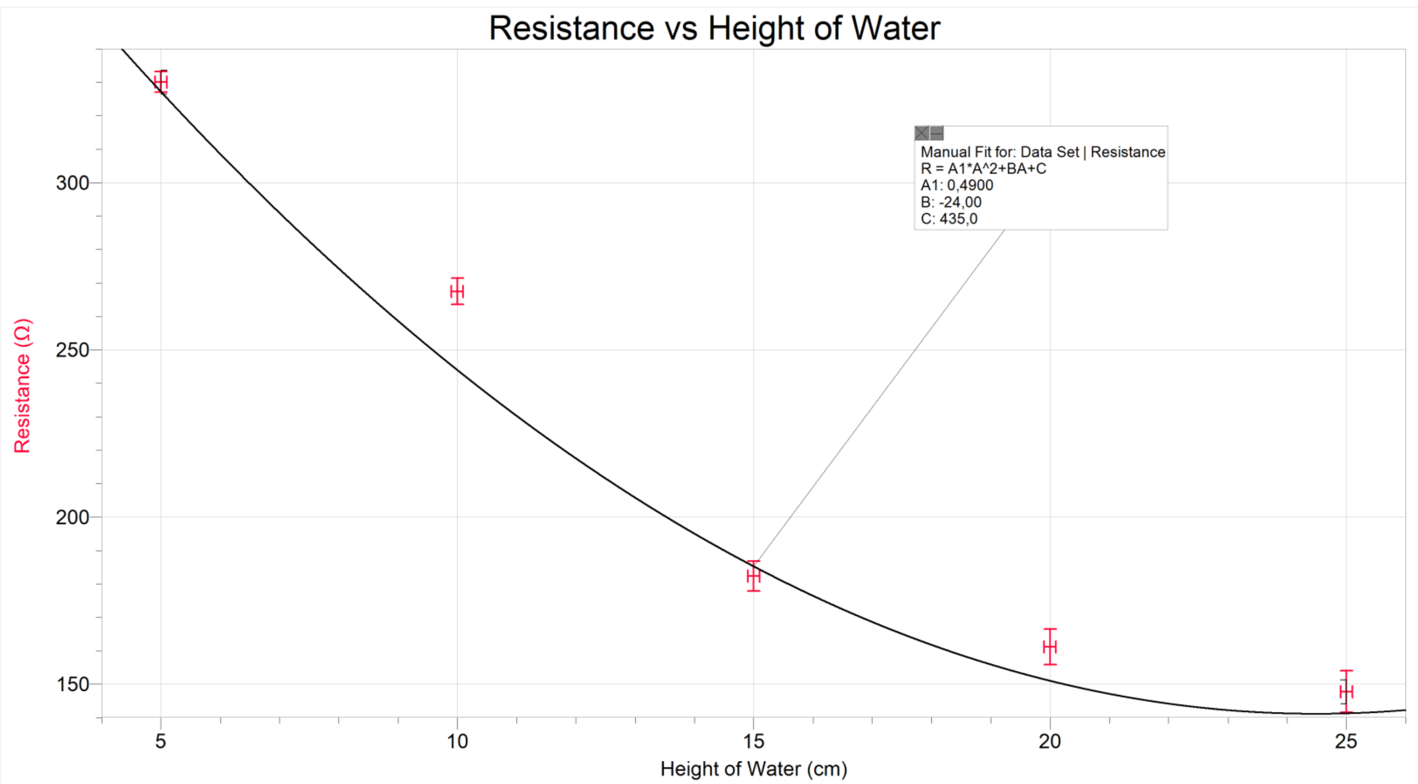


Graph 5.4.2.a: Relation between height of water and resistance at constant 5 cm height of water graph sketched with data used from the table 5.4.2.a

5.4.2.b- *Resistance versus Height of Water at 10 cm constant Length Between Two Electrodes*

Height of water (cm) ± 0.1	Resistance (Ω)
5.0	330 ± 3
10.0	267 ± 4
15.0	182 ± 4
20.0	161 ± 5
25.0	148 ± 6

Table 5.4.2.b- This table shows the resistance values found from calculation showed in 5.3-calculations and height of water at constant length of 10 cm between electrodes.

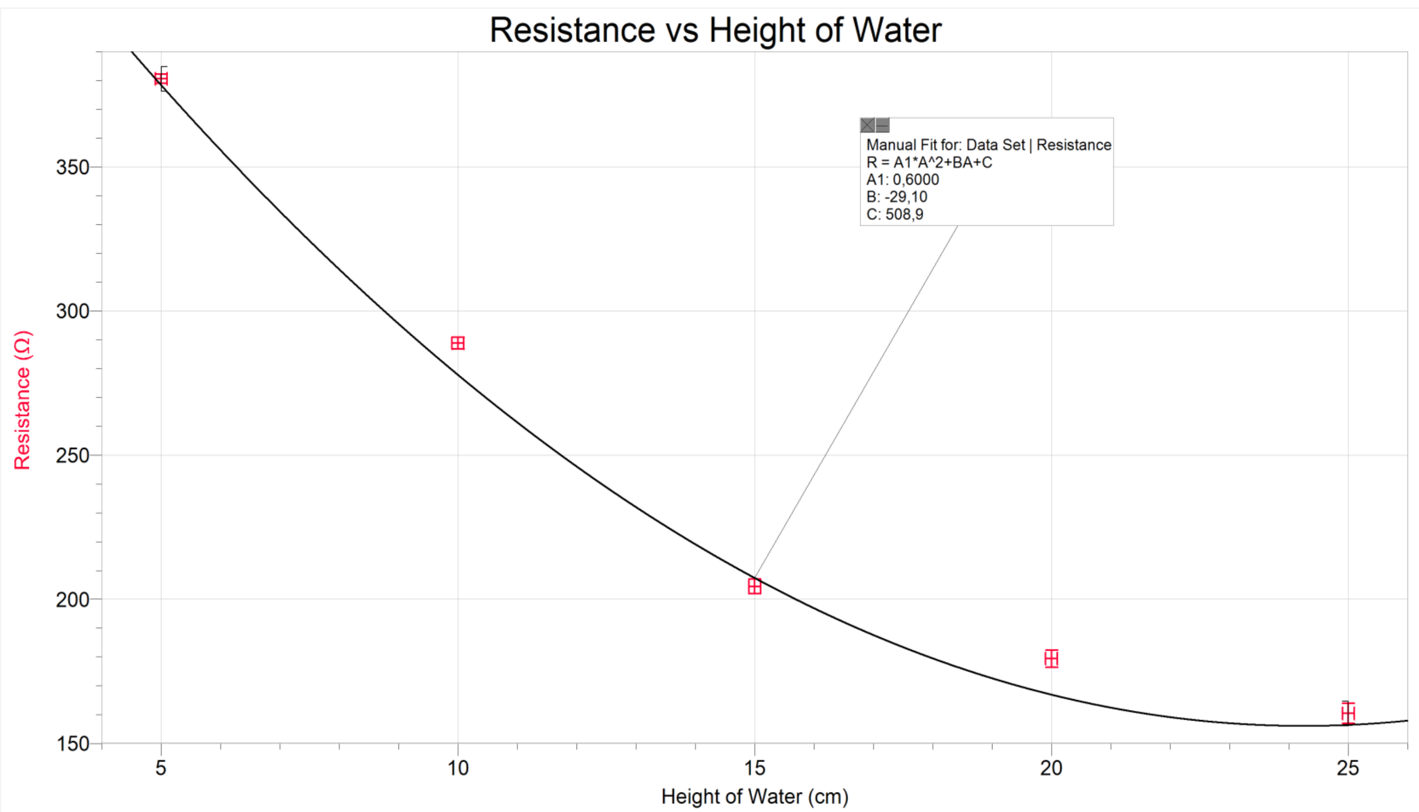


Graph 5.4.2.b: Relation between height of water and resistance at constant 10 cm height of water graph sketched with data used from the table 5.4.2.b.

5.4.2.c- *Resistance versus Height of Water at 15 cm constant Length Between Two Electrodes*

Height of water (cm) ± 0.1	Resistance (Ω)
5.0	381 ± 2
10.0	289 ± 2
15.0	205 ± 3
20.0	179 ± 3
25.0	161 ± 3

Table 5.4.2.c- This table shows the resistance values found from calculation showed in 5.3-calculations and height of water at constant length of 15 cm between electrodes.

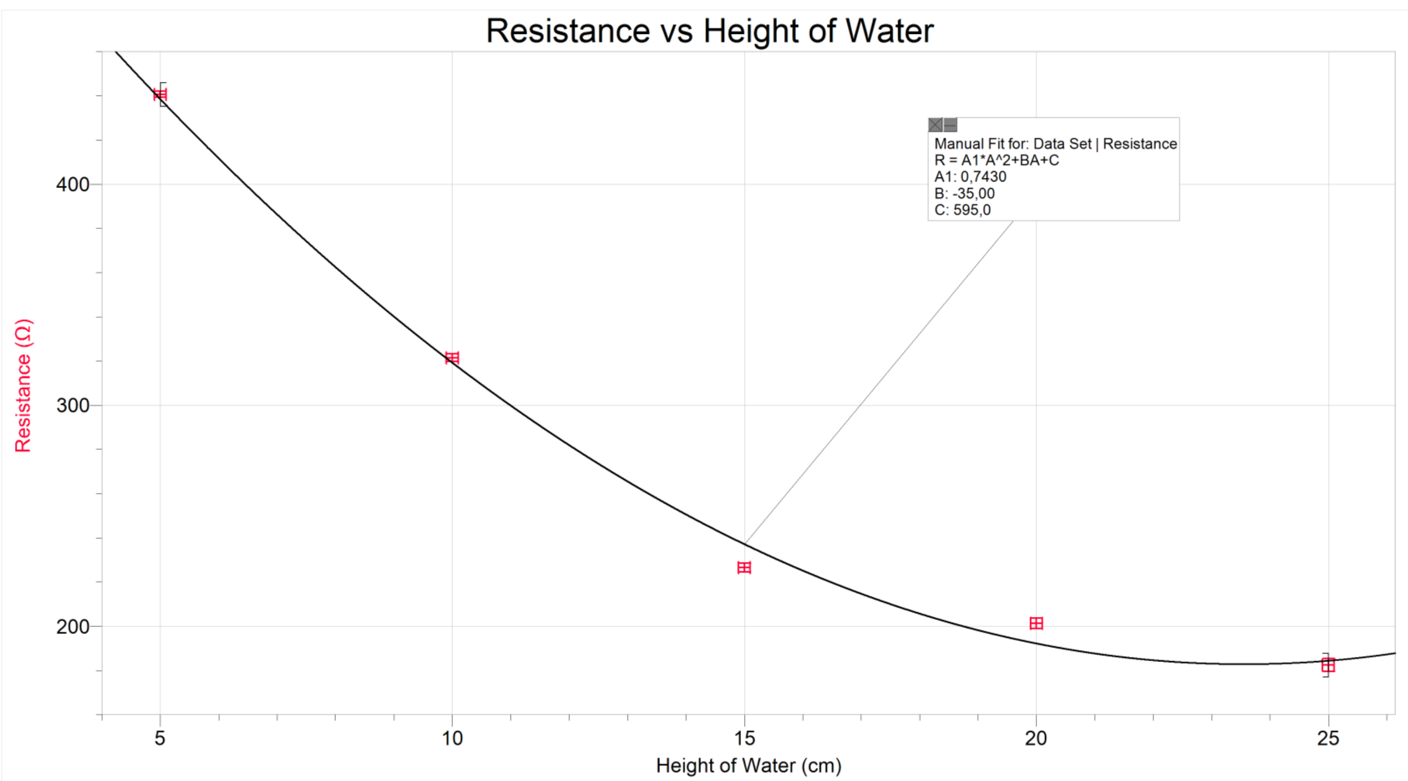


Graph 5.4.2.c: Relation between height of water and resistance at constant 15 cm height of water graph sketched with data used from the table 5.4.2.c.

5.4.2.d- *Resistance versus Height of Water at 20 cm constant Length Between Two Electrodes*

Height of water (cm) ± 0.1	Resistance (Ω)
5.0	441 ± 1
10.0	322 ± 2
15.0	227 ± 2
20.0	201 ± 2
25.0	183 ± 3

Table 5.4.2.d- This table shows the resistance values found from calculation showed in 5.3-calculations and height of water at constant length of 20 cm between electrodes.

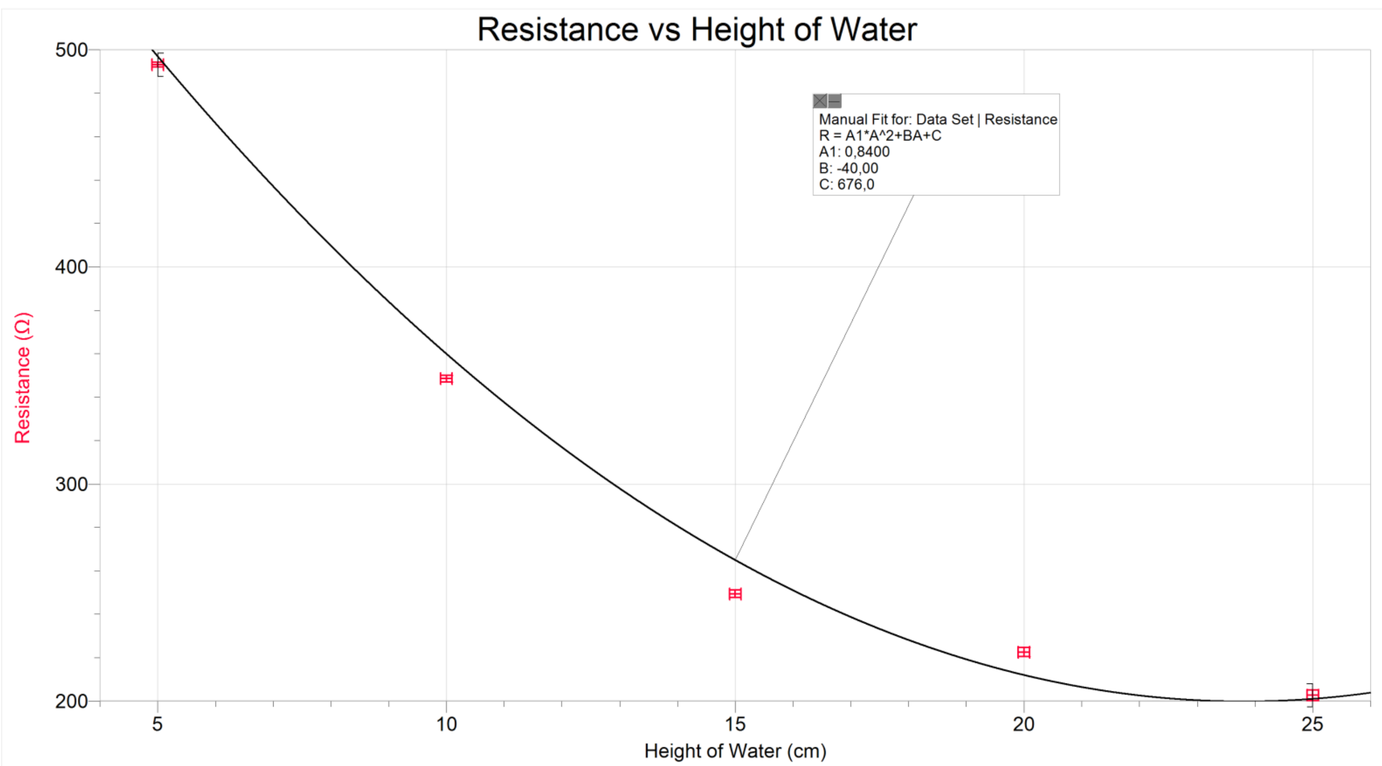


Graph 5.4.2.d: Relation between height of water and resistance at constant 20 cm height of water graph sketched with data used from the table 5.4.2.d.

5.4.2.e- *Resistance versus Height of Water at 25 cm constant Length Between Two Electrodes*

Height of water (cm) ± 0.1	Resistance (Ω)
5.0	493 ± 1
10.0	348 ± 2
15.0	249 ± 2
20.0	223 ± 2
25.0	203 ± 2

Table 5.4.2.e- This table shows the resistance values found from calculation showed in 5.3-calculations and height of water at constant length of 25 cm between electrodes.

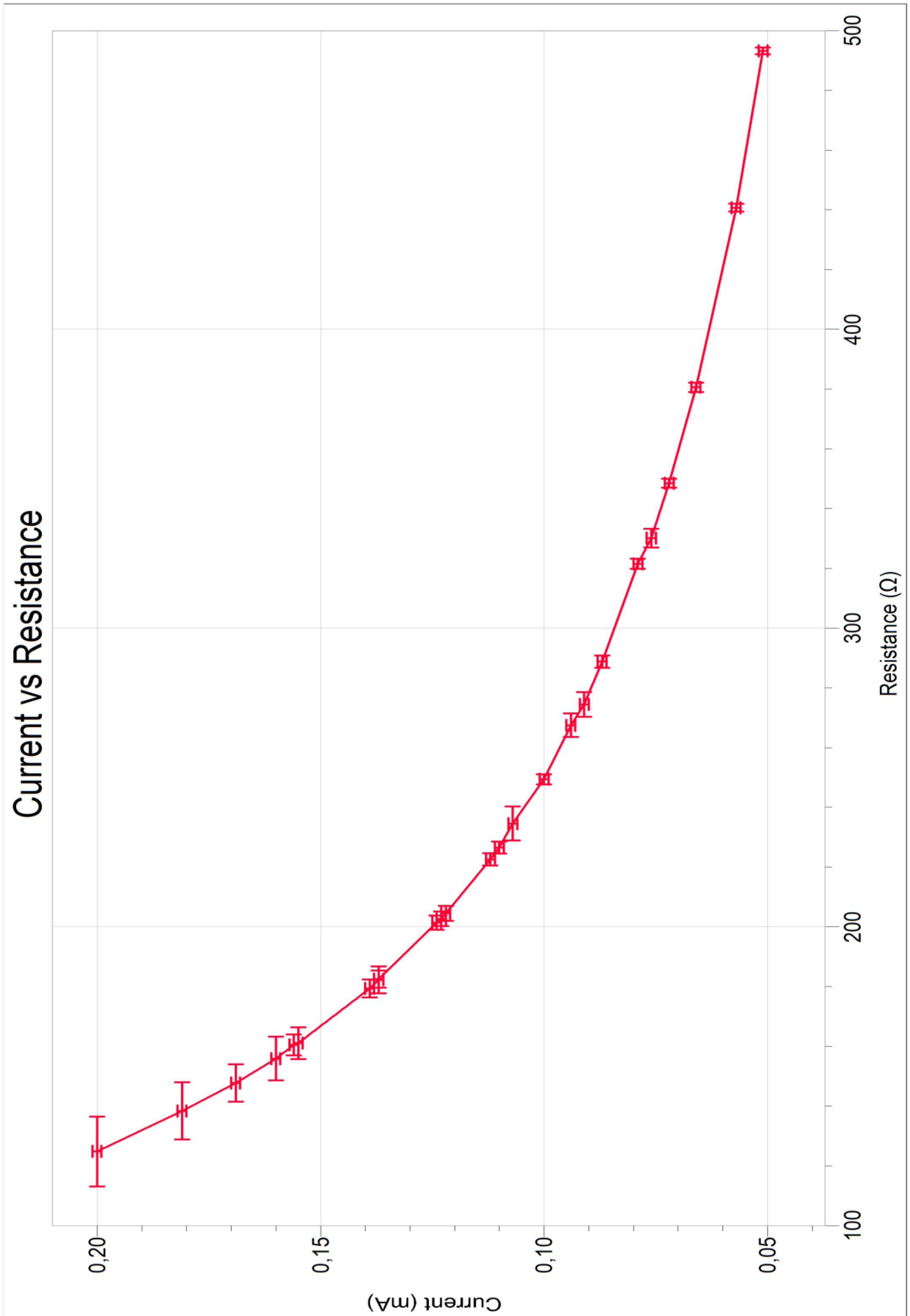


Graph 5.4.2.e: Relation between height of water and resistance at constant 25 cm height of water graph sketched with data used from the table 5.4.2.e.

5.4.3- Resistance versus Current

Resistance (Ω)	Current (A) ± 0.001
493 ± 1	0.051
441 ± 1	0.057
381 ± 2	0.066
349 ± 2	0.072
330 ± 3	0.076
322 ± 2	0.079
289 ± 2	0.087
275 ± 4	0.091
268 ± 4	0.094
249 ± 6	0.100
235 ± 6	0.107
227 ± 2	0.110
223 ± 2	0.112
205 ± 3	0.122
203 ± 3	0.123
201 ± 2	0.124
183 ± 3	0.137
182 ± 5	0.137
179 ± 3	0.139
161 ± 5	0.155
161 ± 4	0.156
156 ± 7	0.160
148 ± 6	0.169
138 ± 10	0.181
125 ± 12	0.200

Table 5.4.3- Mean values of resistance (Ω) and current (A).



Graph 5.4.3: Current versus resistance graph using both mean values of resistance and current value.

5.5- Error Calculations

In this experiment, the resistance values were found by using the Ohm's law ($R = \frac{V}{I}$). Hence, the uncertainty values need to be calculated for every resistance which will be different for every current value is needed to be calculated. These uncertainty values were used for our graphs that were sketched in section 5.4 so, in order to show the error propagation of the resistance values, the formula below was used:

$$\left(\frac{\Delta a}{a} + \frac{\Delta b}{b}\right) x \ \frac{a}{b} = Uncertainty\ Value$$

One example for the uncertainty value of current value at 25 cm length between electrodes and 25 cm height of water in the first trial at constant 25.0 V potential will be like the following:

$\left(\frac{0.1}{25.0} + \frac{0.001}{0.122}\right) x \ \frac{25}{0.122} = Uncertainty\ Value$ **= 2.499**

So that our resistance value will be: **204.9 ± 2.5 Ω**

			RESISTANCE ERRORS (Ω)				
		Trials	LENGTH (± 0.1 cm)				
			25.0	20.0	15.0	10.0	5.0
HEIGHT (± 0.1 cm)	25.0	1	2.50	2.69	3.38	6.06	10.79
		2	2.34	2.88	3.69	6.21	12.93
		3	2.50	2.88	3.69	6.88	12.93
		4	2.46	2.84	3.06	6.06	10.79
		5	2.46	3.06	3.62	6.06	11.17
	20.0	1	2.09	2.37	2.88	5.39	9.16
		2	2.06	2.50	3.12	5.52	9.16
		3	2.04	2.30	3.06	5.39	10.79
		4	2.09	2.46	2.84	4.83	9.16
		5	2.04	2.50	2.88	5.39	9.45
	15.0	1	1.66	1.96	2.37	4.45	6.88
		2	1.66	2.04	2.46	4.83	6.88
		3	1.74	2.04	2.64	4.36	7.89
		4	1.64	2.04	2.64	4.36	6.88
		5	1.63	1.94	2.34	4.45	8.12
	10.0	1	1.45	1.66	2.09	4.04	5.39
		2	1.48	1.63	2.17	4.36	5.39
		3	1.45	1.74	2.06	3.96	6.06
		4	1.45	1.74	2.06	3.62	6.06
		5	1.48	1.63	1.92	3.69	5.52
	5.0	1	1.16	1.33	1.60	3.12	3.69
		2	1.14	1.35	1.63	3.33	4.04
		3	1.10	1.30	1.57	3.06	4.45
		4	1.10	1.29	1.57	3.06	4.36
		5	1.10	1.33	1.60	3.12	4.04

Table 5.5.1: Uncertainty values found for all resistance values and shown in a table for different length between electrodes and height of water. All uncertainty calculations showed in table 7.1 for all resistance values.

		RESISTANCE ERROR AVERAGE (Ω)				
		LENGTH (± 0.1 cm)				
		25.0	20.0	15.0	10.0	50
HEIGHT (± 0.1 cm)	25.0	2.45	2.87	3.49	6.25	12.2
	20.0	2.06	2.43	2.96	5.30	9.54
	15.0	1.67	2.00	2.49	4.49	7.33
	10.0	1.46	1.68	2.06	3.93	5.68
	5.0	1.12	1.32	1.59	3.14	4.12

Table 5.5.2: Average error values found from the error calculations showed in table 5.5.1 emphasized.

6-CONCLUSION & EVALUATION

The aim of this experiment is to investigate the conformity of the Ohm's law ($R = \frac{V}{I}$) and $R = \rho\frac{l}{a}$ in liquid conductors. Usually investigation on Ohm's law and factors affecting the resistance value investigations are applied on metallic materials like copper wire, so that with the curiosity of the conformity on different materials, like liquid conductors, this investigation has been planned and presented. Basic planning of this experiment is based on the observation and measurement of current at constant potential difference with different length between two electrodes and different height of water. With this current value, resistance value was calculated and with the independent variable's relation, the $R = \rho\frac{l}{a}$ formula's conformity was investigated in liquid conductors.

From this investigation significant results were observed. Firstly, the hypothesis said; current will increase as the length decreased between electrodes. Also Ohm's law said that current is indirectly proportional with resistance too. So it is expected that resistance versus length graphs will be ascending functions. With this information when the resistance versus length graph is analyzed, it is seen that the hypothesis is correct because of the resistance versus length graphs which are ascending graphs shown in graphs 5.4.1.

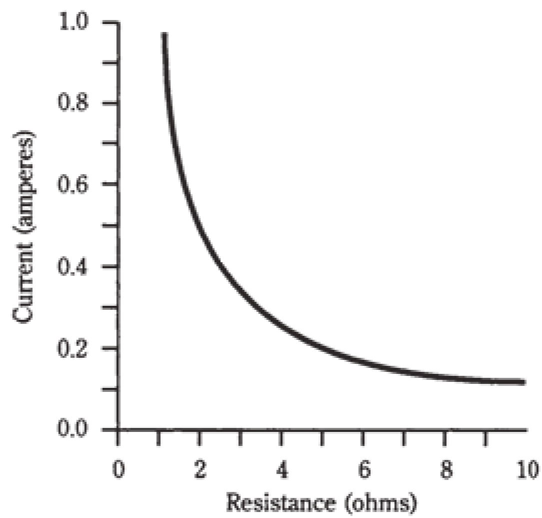
Secondly, for the current, resistance and height of water relations when the graphs and tables shown in 5.5.2 are analyzed, it is determined that current is proportional and resistance is indirectly proportional with the height of water, which is stated in the hypothesis earlier.

By these two results, it is proved that liquid conductor made with tap water is abiding the formula; $R = \rho\frac{l}{a}$.

Beyond these proofs, it is also proved that the relation with using the slopes of graphs.

For an example; in graph 5.5.1.a slope of the graph is 10.95 Ω/cm which is resistance versus length graph at 5.0 cm constant height of water. When the graph at the 5.5.1.b (at 10.0 cm height) and 5.5.1.c graphs are analyzed, slopes are 5.64 Ω/cm and 4.63 Ω/cm. So it is seen that the height of water increase slopes are decreasing, which shows that there is a relation between height of water and resistance, which was proved earlier.

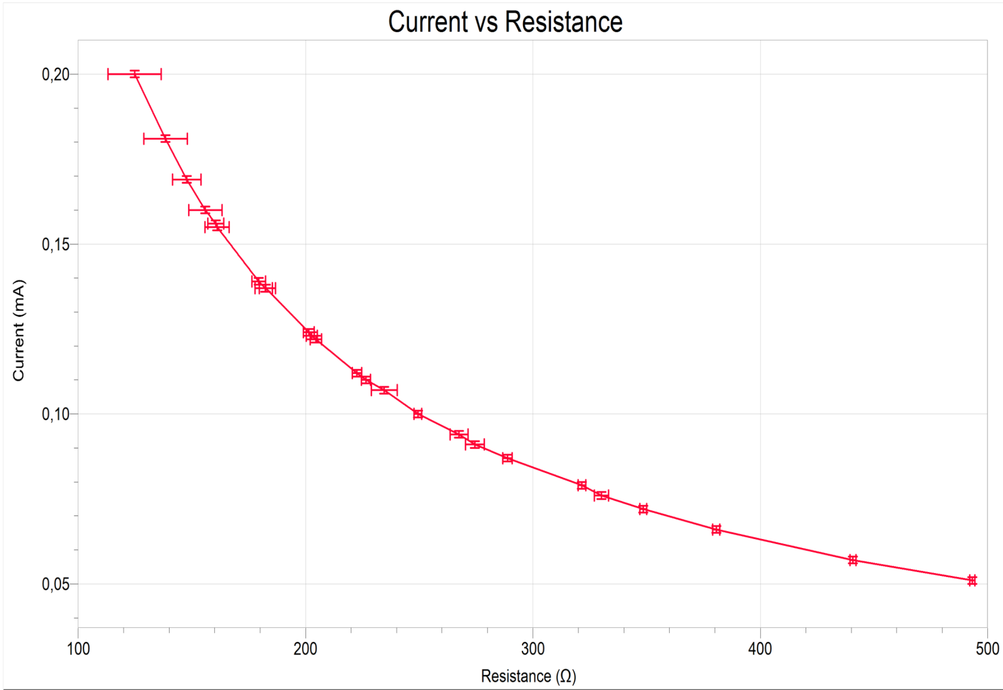
Another observation that is obtained from the experiment is shown in the resistance versus length graph, which is shown in 5.4.3. When voltage is kept constant, the graph is sketched from theoretical values of resistance and current is shown below:



Graph 6.1: In this graph, Current versus Resistance graph with theoretical data used shown above.

As seen in graph 5.4.3, current versus resistance graph is a descending graph just like the theoretical graph shown in graph 6.1.[10] Graph 5.4.3 shown below:

[10] http://technology-electronic.blogspot.com/2010/05/resistance-and-ohm.html



Finally, stated hypotheses proved, and showed that correction and relation of resistance with length and cross sectional area which is stated in formula $R = \rho \frac{l}{a}$ is also abiding in liquid conductors. All of the resistance-length, resistance-cross sectional area and resistance-current graphs proved these hypotheses. Another result that is obtained is electron diversion in liquid conductors. It is known that as the cross sectional area of copper wire increases, there will be some electron diversion, which affects the current. So when uncertainty values shown in tables 5.5.1 and 5.5.2 are analyzed, it is seen that as the height of water increases, uncertainty value also increases. So the increase of cross-sectional area causes electron diversion in liquid conductors, too.

Conclusion reached in this experiment is that the liquid conductors show the same properties with the metallic materials, so liquid conductors are also used as ohmic materials.

7-APPENDIX

7.1- Error Propagation

25 cm length at 25 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.122}\right) x \ \frac{25}{0.122} = Uncertainty\ Value$ **= 2.50**

25 cm length at 25 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.127}\right) x \ \frac{25}{0.127} = Uncertainty\ Value$ **= 2.34**

25 cm length at 25 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.122}\right) x \ \frac{25}{0.122} = Uncertainty\ Value$ **= 2.50**

25 cm length at 25 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.123}\right) x \ \frac{25}{0.123} = Uncertainty\ Value$ **= 2.46**

25 cm length at 25 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.123}\right) x \ \frac{25}{0.123} = Uncertainty\ Value$ **= 2.46**

---

25 cm length at 20 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.136}\right) x \ \frac{25}{0.136} = Uncertainty\ Value$ = **2.09**

25 cm length at 20 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.137}\right) x \ \frac{25}{0.137} = Uncertainty\ Value$ **= 2.06**

25 cm length at 20 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.138}\right) x \ \frac{25}{0.138} = Uncertainty\ Value$ **= 2.04**

25 cm length at 20 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.136}\right) x \ \frac{25}{0.136} = Uncertainty\ Value$ **= 2.09**

25 cm length at 20 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.138}\right) x \ \frac{25}{0.138} = Uncertainty\ Value$ **= 2.04**

---

25 cm length at 15 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.156}\right) x \ \frac{25}{0.156} = Uncertainty\ Value$ **= 1.66**

25 cm length at 15 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.156}\right) x \ \frac{25}{0.156} = Uncertainty\ Value$ **= 1.66**

25 cm length at 15 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.152}\right) x \ \frac{25}{0.152} = Uncertainty\ Value$ **= 1.74**

25 cm length at 15 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.157}\right) x \ \frac{25}{0.157} = Uncertainty\ Value$ **= 1.64**

25 cm length at 15 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.158}\right) x \ \frac{25}{0.158} = Uncertainty\ Value$ **= 1.63**

---

25 cm length at 10 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.170}\right) x \ \frac{25}{0.170} = Uncertainty\ Value$ = **1.45**

25 cm length at 10 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.168}\right) x \ \frac{25}{0.168} = Uncertainty\ Value$ = **1.48**

25 cm length at 10 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.170}\right) x\ \frac{25}{0.170} = Uncertainty\ Value$ = **1.45**

25 cm length at 10 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.170}\right) x\ \frac{25}{0.170} = Uncertainty\ Value$ = **1.45**

25 cm length at 10 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.168}\right) x\ \frac{25}{0.168} = Uncertainty\ Value$ = **1.48**

---

25 cm length at 5 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.196}\right) x\ \frac{25}{0.19} = Uncertainty\ Value$ = **1.16**

25 cm length at 5 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.198}\right) x\ \frac{25}{0.198} = Uncertainty\ Value$ = **1.14**

25 cm length at 5 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.202}\right) x\ \frac{25}{0.202} = Uncertainty\ Value$ = **1.10**

25 cm length at 5 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.203}\right) x\ \frac{25}{0.203} = Uncertainty\ Value$ = **1.10**

25 cm length at 5 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.203}\right) x\ \frac{25}{0.203} = Uncertainty\ Value$ = **1.10**

---

20 cm length at 25 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.117}\right) x\ \frac{25}{0.117} = Uncertainty\ Value$ = **2.69**

20 cm length at 25 cm height of water in second trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.112}\right)x\ \frac{25}{0.112}=Uncertainty\ Value$ = **<u>2.88</u>**

20 cm length at 25 cm height of water in third trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.112}\right)x\ \frac{25}{0.112}=Uncertainty\ Value$ = **<u>2.88</u>**

20 cm length at 25 cm height of water in fourth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.113}\right)x\ \frac{25}{0.113}=Uncertainty\ Value$ = **<u>2.84</u>**

20 cm length at 25 cm height of water in fifth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.108}\right)x\ \frac{25}{0.108}=Uncertainty\ Value$ = **<u>3.06</u>**

---

20 cm length at 20 cm height of water in first trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.126}\right)x\ \frac{25}{0.126}=Uncertainty\ Value$ = **<u>2.37</u>**

20 cm length at 20 cm height of water in second trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.122}\right)x\ \frac{25}{0.122}=Uncertainty\ Value$ **<u>= 2.50</u>**

20 cm length at 20 cm height of water in third trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.128}\right)x\ \frac{25}{0.128}=Uncertainty\ Value$ = **<u>2.30</u>**

20 cm length at 20 cm height of water in fourth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.123}\right)x\ \frac{25}{0.123}=Uncertainty\ Value$ **<u>= 2.46</u>**

20 cm length at 20 cm height of water in fifth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.122}\right)x\ \frac{25}{0.122}=Uncertainty\ Value$ **<u>= 2.50</u>**

---

20 cm length at 15 cm height of water in first trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.141}\right)x\ \frac{25}{0.141}=Uncertainty\ Value$ **= 1.96**

20 cm length at 15 cm height of water in second trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.138}\right)x\ \frac{25}{0.138}=Uncertainty\ Value$ **= 2.04**

20 cm length at 15 cm height of water in third trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.138}\right)x\ \frac{25}{0.138}=Uncertainty\ Value$ **= 2.04**

20 cm length at 15 cm height of water in fourth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.138}\right)x\ \frac{25}{0.138}=Uncertainty\ Value$ **= 2.04**

20 cm length at 15 cm height of water in fifth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.142}\right)x\ \frac{25}{0.142}=Uncertainty\ Value$ **= 1.94**

---

20 cm length at 10 cm height of water in first trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.156}\right)x\ \frac{25}{0.156}=Uncertainty\ Value$ **= 1.66**

20 cm length at 10 cm height of water in second trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.158}\right)x\ \frac{25}{0.158}=Uncertainty\ Value$ **= 1.63**

20 cm length at 10 cm height of water in third trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.152}\right)x\ \frac{25}{0.152}=Uncertainty\ Value$ **= 1.74**

20 cm length at 10 cm height of water in fourth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.152}\right)x\ \frac{25}{0.152}=Uncertainty\ Value$ **= 1.74**

20 cm length at 10 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.158}\right) x \ \frac{25}{0.158} = Uncertainty\ Value$ **<u>= 1.63</u>**

---

20 cm length at 5 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.180}\right) x \ \frac{25}{0.180} = Uncertainty\ Value$ **<u>= 1.33</u>**

20 cm length at 5 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.178}\right) x \ \frac{25}{0.178} = Uncertainty\ Value$ **<u>= 1.35</u>**

20 cm length at 5 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.182}\right) x \ \frac{25}{0.182} = Uncertainty\ Value$ **<u>= 1.30</u>**

20 cm length at 5 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.183}\right) x \ \frac{25}{0.183} = Uncertainty\ Value$ **<u>= 1.29</u>**

20 cm length at 5 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.180}\right) x \ \frac{25}{0.180} = Uncertainty\ Value$ **<u>= 1.33</u>**

---

15 cm length at 25 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.102}\right) x \ \frac{25}{0.102} = Uncertainty\ Value$ **<u>= 3.38</u>**

15 cm length at 25 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.097}\right) x \ \frac{25}{0.097} = Uncertainty\ Value$ **<u>= 3.69</u>**

15 cm length at 25 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.097}\right) x \ \frac{25}{0.097} = Uncertainty\ Value$ **<u>= 3.69</u>**

15 cm length at 25 cm height of water in fourth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.108}\right)x\ \frac{25}{0.108}=Uncertainty\ Value$ **= 3.06**

15 cm length at 25 cm height of water in fifth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.98}\right)x\ \frac{25}{0.98}=Uncertainty\ Value$ **= 3.62**

---

15 cm length at 20 cm height of water in first trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.112}\right)x\ \frac{25}{0.112}=Uncertainty\ Value$ = **2.88**

15 cm length at 20 cm height of water in second trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.107}\right)x\ \frac{25}{0.107}=Uncertainty\ Value$ **= 3.12**

15 cm length at 20 cm height of water in third trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.108}\right)x\ \frac{25}{0.108}=Uncertainty\ Value$ = **3.06**

15 cm length at 20 cm height of water in fourth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.113}\right)x\ \frac{25}{0.113}=Uncertainty\ Value$ = **2.84**

15 cm length at 20 cm height of water in fifth trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.112}\right)x\ \frac{25}{0.112}=Uncertainty\ Value$ = **2.88**

---

15 cm length at 15 cm height of water in first trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.126}\right)x\ \frac{25}{0.126}=Uncertainty\ Value$ = **2.37**

15 cm length at 15 cm height of water in second trial:

$\left(\frac{0.1}{25}+\frac{0.001}{0.123}\right)x\ \frac{25}{0.123}=Uncertainty\ Value$ **= 2.46**

15 cm length at 15 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.118}\right) x \ \frac{25}{0.118} = Uncertainty\ Value$ **= 2.64**

15 cm length at 15 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.118}\right) x \ \frac{25}{0.118} = Uncertainty\ Value$ **= 2.64**

15 cm length at 15 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.127}\right) x \ \frac{25}{0.127} = Uncertainty\ Value$ **= 2.34**

---

15 cm length at 10 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.136}\right) x \ \frac{25}{0.136} = Uncertainty\ Value$ = **2.09**

15 cm length at 10 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.133}\right) x \ \frac{25}{0.133} = Uncertainty\ Value$ **= 2.17**

15 cm length at 10 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.137}\right) x \ \frac{25}{0.137} = Uncertainty\ Value$ **= 2.06**

15 cm length at 10 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.137}\right) x \ \frac{25}{0.137} = Uncertainty\ Value$ **= 2.06**

15 cm length at 10 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.143}\right) x \ \frac{25}{0.143} = Uncertainty\ Value$ **= 1.92**

---

15 cm length at 5 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.160}\right) x \ \frac{25}{0.160} = Uncertainty\ Value$ **= 1.60**

15 cm length at 5 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.158}\right) x \ \frac{25}{0.158} = Uncertainty\ Value$ **= 1.63**

15 cm length at 5 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.162}\right) x \ \frac{25}{0.162} = Uncertainty\ Value$ **= 1.57**

15 cm length at 5 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.162}\right) x \ \frac{25}{0.162} = Uncertainty\ Value$ **= 1.57**

15 cm length at 5 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.160}\right) x \ \frac{25}{0.160} = Uncertainty\ Value$ **= 1.60**

---

10 cm length at 25 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.073}\right) x \ \frac{25}{0.073} = Uncertainty\ Value$ **= 6.06**

10 cm length at 25 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.072}\right) x \ \frac{25}{0.072} = Uncertainty\ Value$ **= 6.21**

10 cm length at 25 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.068}\right) x \ \frac{25}{0.068} = Uncertainty\ Value$ **= 6.88**

10 cm length at 25 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.073}\right) x \ \frac{25}{0.073} = Uncertainty\ Value$ **= 6.06**

10 cm length at 25 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.073}\right) x \ \frac{25}{0.073} = Uncertainty\ Value$ **= 6.06**

---

10 cm length at 20 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.078}\right) x\ \frac{25}{0.078} = Uncertainty\ Value$ **= 5.39**

10 cm length at 20 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.077}\right) x\ \frac{25}{0.077} = Uncertainty\ Value$ **= 5.52**

10 cm length at 20 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.078}\right) x\ \frac{25}{0.078} = Uncertainty\ Value$ **= 5.39**

10 cm length at 20 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.083}\right) x\ \frac{25}{0.083} = Uncertainty\ Value$ **= 4.83**

10 cm length at 20 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.078}\right) x\ \frac{25}{0.078} = Uncertainty\ Value$ **= 5.39**

---

10 cm length at 15 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.087}\right) x\ \frac{25}{0.087} = Uncertainty\ Value$ **= 4.45**

10 cm length at 15 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.083}\right) x\ \frac{25}{0.083} = Uncertainty\ Value$ **= 4.83**

10 cm length at 15 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.088}\right) x\ \frac{25}{0.088} = Uncertainty\ Value$ **= 4.36**

10 cm length at 15 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.088}\right) x\ \frac{25}{0.088} = Uncertainty\ Value$ **= 4.36**

10 cm length at 15 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.087}\right) x \ \frac{25}{0.087} = Uncertainty\ Value$ **= 4.45**

---

10 cm length at 10 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.092}\right) x \ \frac{25}{0.092} = Uncertainty\ Value$ **= 4.04**

10 cm length at 10 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.088}\right) x \ \frac{25}{0.088} = Uncertainty\ Value$ **= 4.36**

10 cm length at 10 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.093}\right) x \ \frac{25}{0.093} = Uncertainty\ Value$ **= 3.96**

10 cm length at 10 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.098}\right) x \ \frac{25}{0.098} = Uncertainty\ Value$ **= 3.62**

10 cm length at 10 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.097}\right) x \ \frac{25}{0.097} = Uncertainty\ Value$ **= 3.69**

---

10 cm length at 5 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.107}\right) x \ \frac{25}{0.107} = Uncertainty\ Value$ **= 3.12**

10 cm length at 5 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.103}\right) x \ \frac{25}{0.103} = Uncertainty\ Value$ = **3.33**

10 cm length at 5 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.108}\right) x \ \frac{25}{0.108} = Uncertainty\ Value$ = **3.06**

10 cm length at 5 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.108}\right) x \ \frac{25}{0.108} = Uncertainty\ Value$ = **3.06**

10 cm length at 5 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.107}\right) x \ \frac{25}{0.107} = Uncertainty\ Value$ **= 3.12**

---

5 cm length at 25 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.053}\right) x \ \frac{25}{0.053} = Uncertainty\ Value$ = **10.79**

5 cm length at 25 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.048}\right) x \ \frac{25}{0.048} = Uncertainty\ Value$ = **12.93**

5 cm length at2 5 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.048}\right) x \ \frac{25}{0.048} = Uncertainty\ Value$ = **12.93**

5 cm length at 25 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.053}\right) x \ \frac{25}{0.053} = Uncertainty\ Value$ = **10.79**

5 cm length at 25 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.052}\right) x \ \frac{25}{0.052} = Uncertainty\ Value$ = **11.17**

---

5 cm length at 20 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.058}\right) x \ \frac{25}{0.058} = Uncertainty\ Value$ = **9.16**

5 cm length at 20 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.058}\right) x \ \frac{25}{0.058} = Uncertainty\ Value$ = **9.16**

5 cm length at 20 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.053}\right) x\ \frac{25}{0.053} = Uncertainty\ Value$ = **10.79**

5 cm length at 20 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.058}\right) x\ \frac{25}{0.058} = Uncertainty\ Value$ = **9.16**

5 cm length at 20 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.057}\right) x\ \frac{25}{0.057} = Uncertainty\ Value$ = **9.45**

---

5 cm length at 15 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.068}\right) x\ \frac{25}{0.068} = Uncertainty\ Value$ **= 6.88**

5 cm length at 15 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.068}\right) x\ \frac{25}{0.068} = Uncertainty\ Value$ **= 6.88**

5 cm length at 15 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.063}\right) x\ \frac{25}{0.063} = Uncertainty\ Value$ **= 7.89**

5 cm length at 15 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.068}\right) x\ \frac{25}{0.068} = Uncertainty\ Value$ **= 6.88**

5 cm length at 15 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.062}\right) x\ \frac{25}{0.062} = Uncertainty\ Value$ **= 8.12**

---

5 cm length at 10 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.078}\right) x\ \frac{25}{0.078} = Uncertainty\ Value$ **= 5.39**

5 cm length at 10 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.078}\right) x \ \frac{25}{0.078} = Uncertainty\ Value$ **= 5.39**

5 cm length at 10 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.073}\right) x \ \frac{25}{0.073} = Uncertainty\ Value$ **= 6.06**

5 cm length at 10 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.073}\right) x \ \frac{25}{0.073} = Uncertainty\ Value$ **= 6.06**

5 cm length at 10 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.077}\right) x \ \frac{25}{0.077} = Uncertainty\ Value$ **= 5.52**

---

5 cm length at 5 cm height of water in first trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.097}\right) x \ \frac{25}{0.097} = Uncertainty\ Value$ **= 3.69**

5 cm length at 5 cm height of water in second trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.092}\right) x \ \frac{25}{0.092} = Uncertainty\ Value$ **= 4.04**

5 cm length at 5 cm height of water in third trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.087}\right) x \ \frac{25}{0.087} = Uncertainty\ Value$ **= 4.45**

5 cm length at 5 cm height of water in fourth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.088}\right) x \ \frac{25}{0.088} = Uncertainty\ Value$ **= 4.36**

5 cm length at 5 cm height of water in fifth trial:

$\left(\frac{0.1}{25} + \frac{0.001}{0.092}\right) x \ \frac{25}{0.092} = Uncertainty\ Value$ **= 4.04**

7.2- Photos

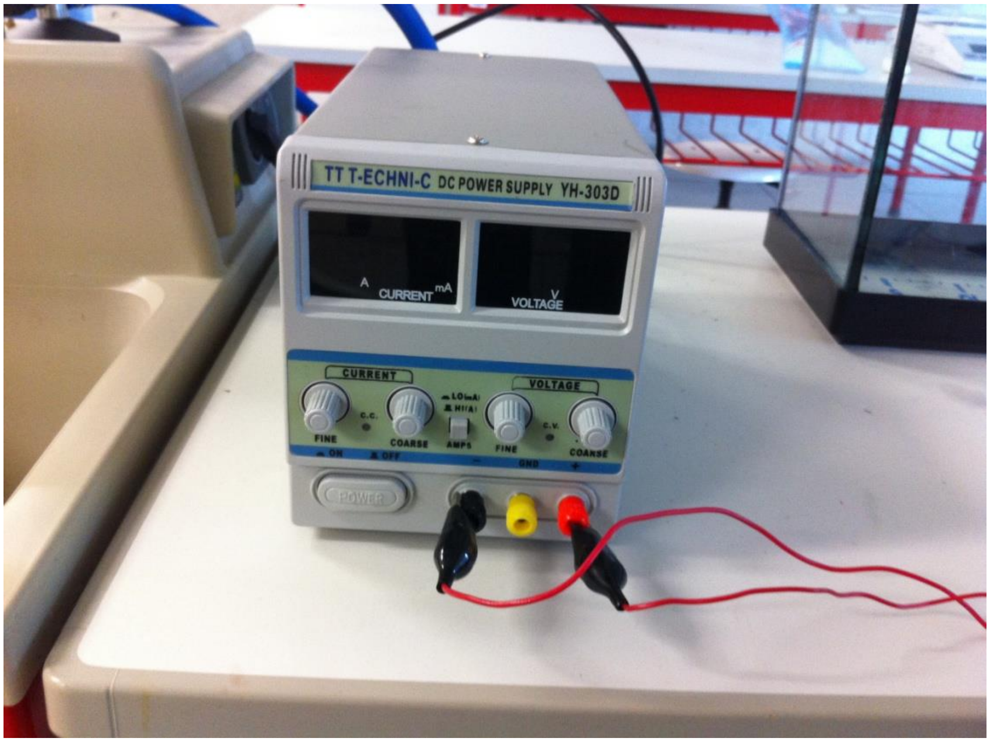


Figure 7.4.1: Multimeter used in the experiment.

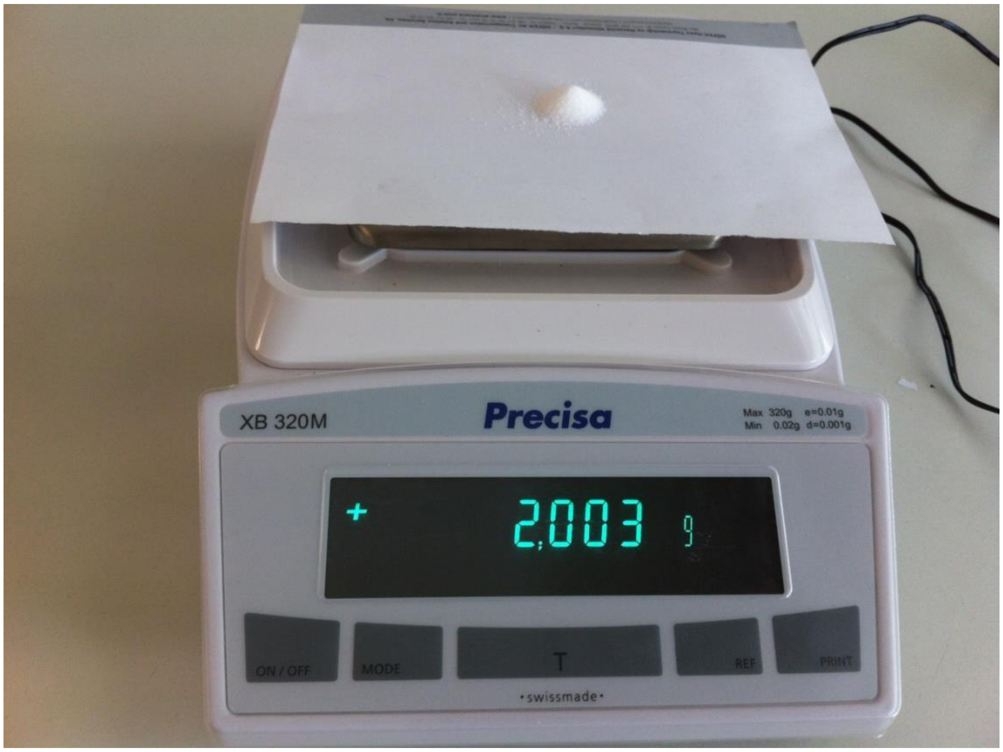


Figure 7.4.2: Digital balance used in the experiment

Figure 7.4.3: Salt used in the experiment

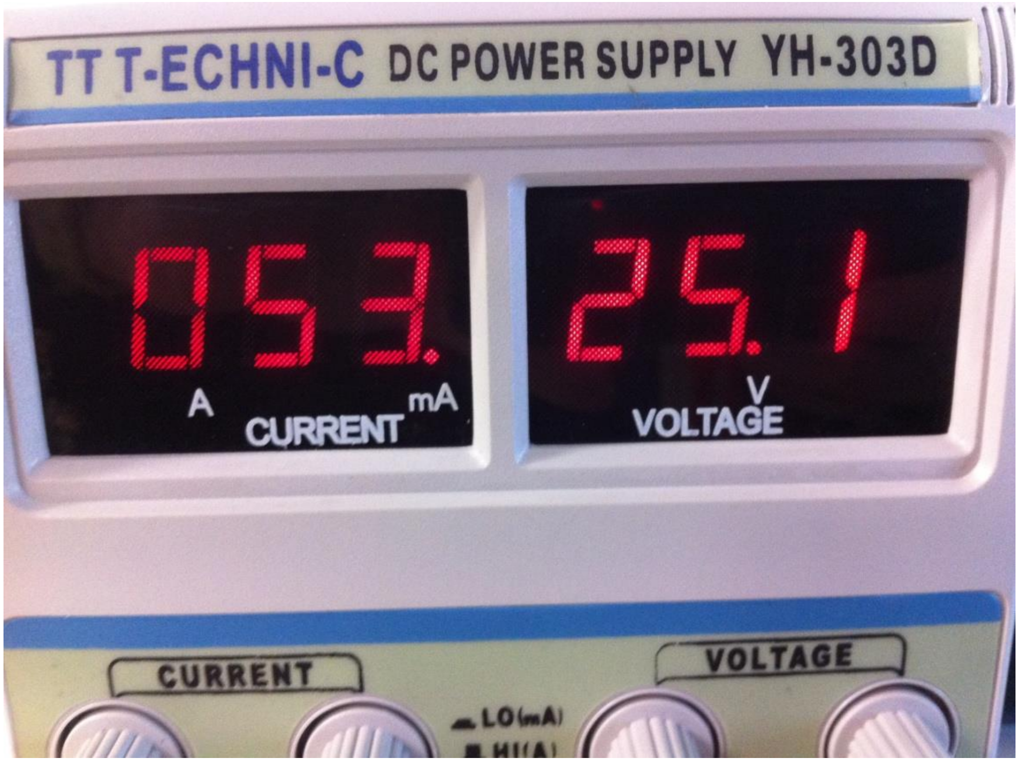


Figure 7.4.4: Example current and voltage value measurement.

Figure 7.4.5: Example salt mass measurement at first trial of 10 cm height of water.

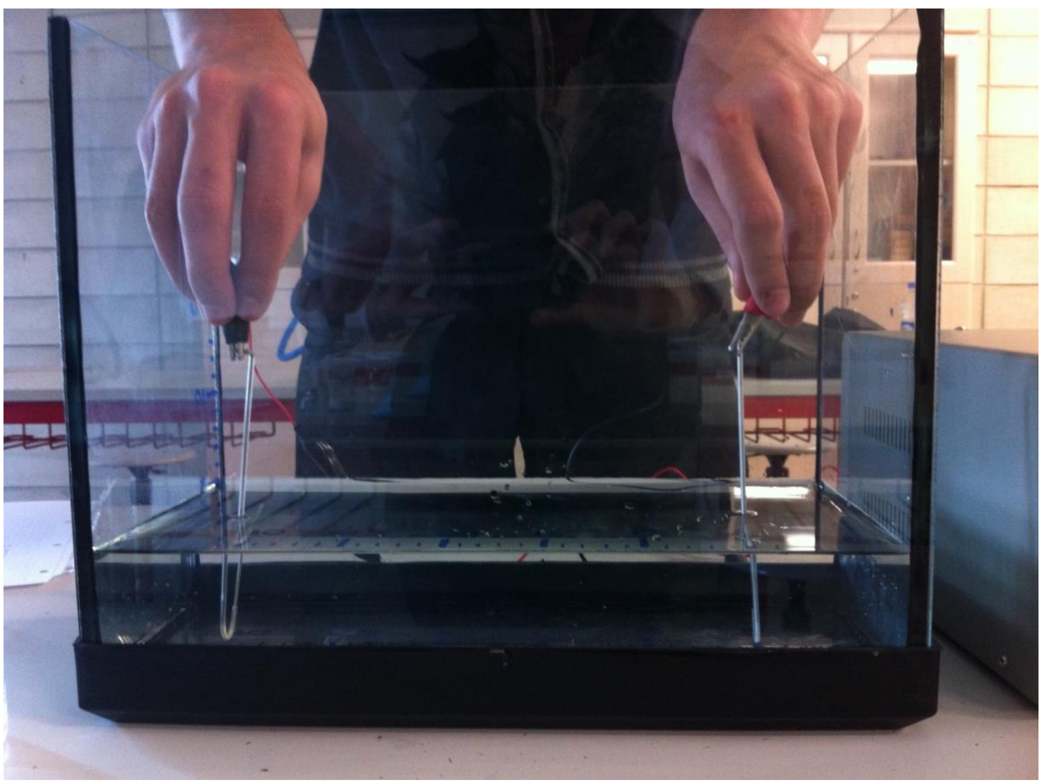


Figure 7.4.6: Method while observing the current value.

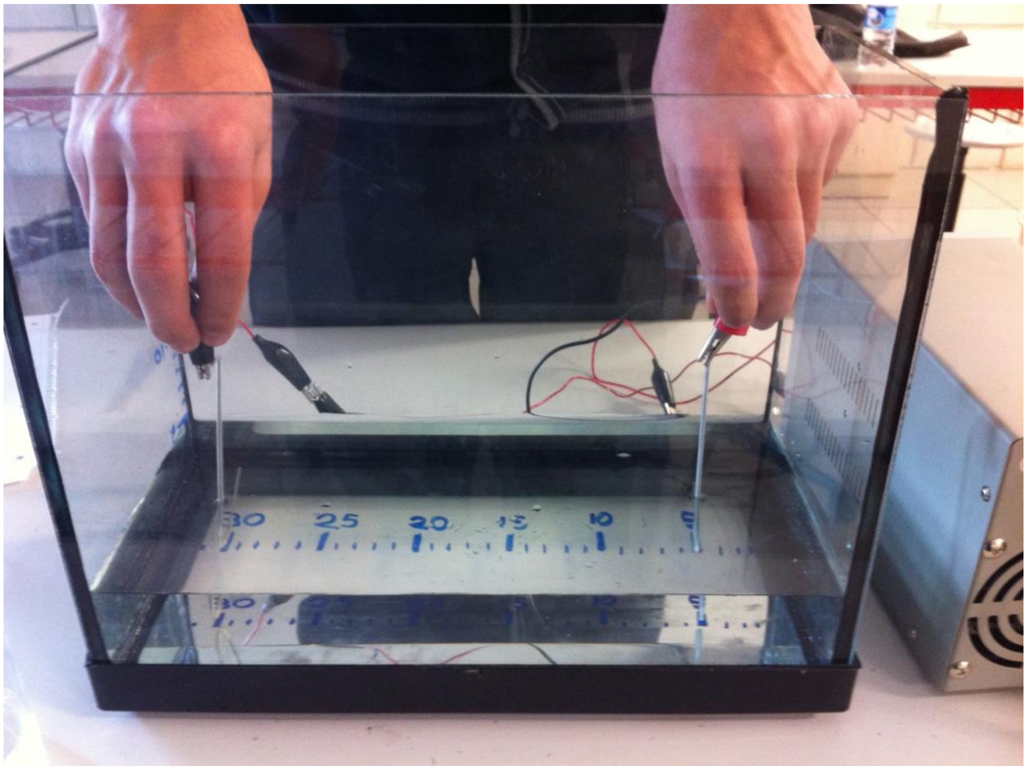


Figure 7.4.7: Placing electrodes in a length of 25 cm at 5 cm height of water and current value observed.

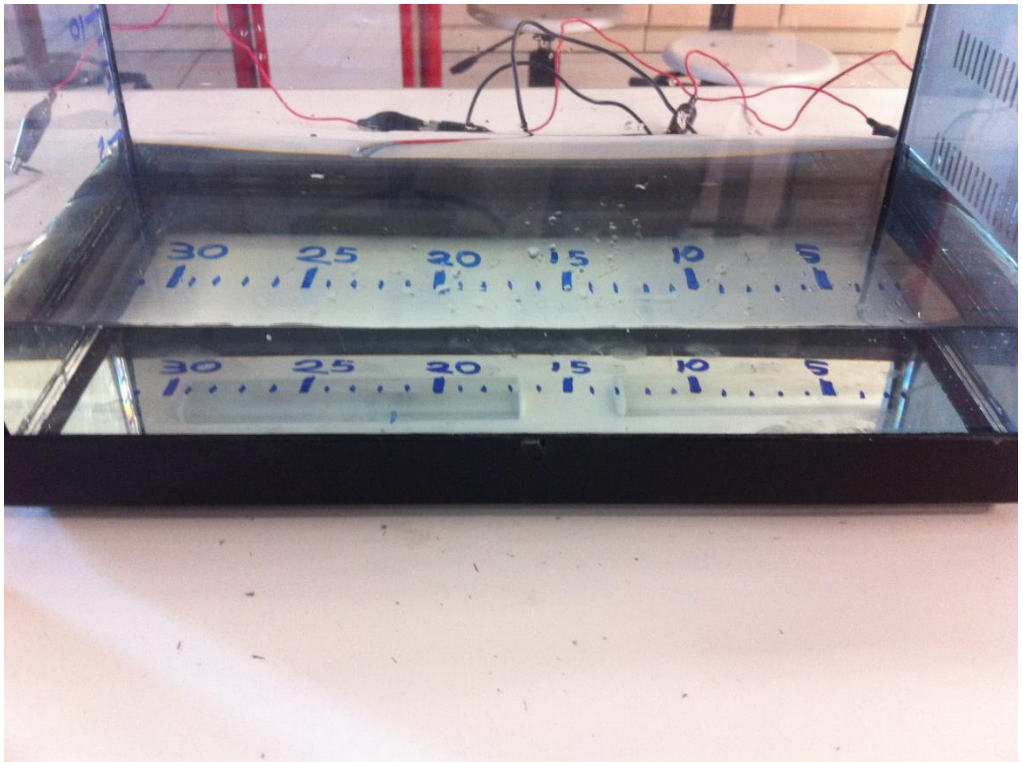


Figure 7.4.8: Length markings and water at 5 cm height.

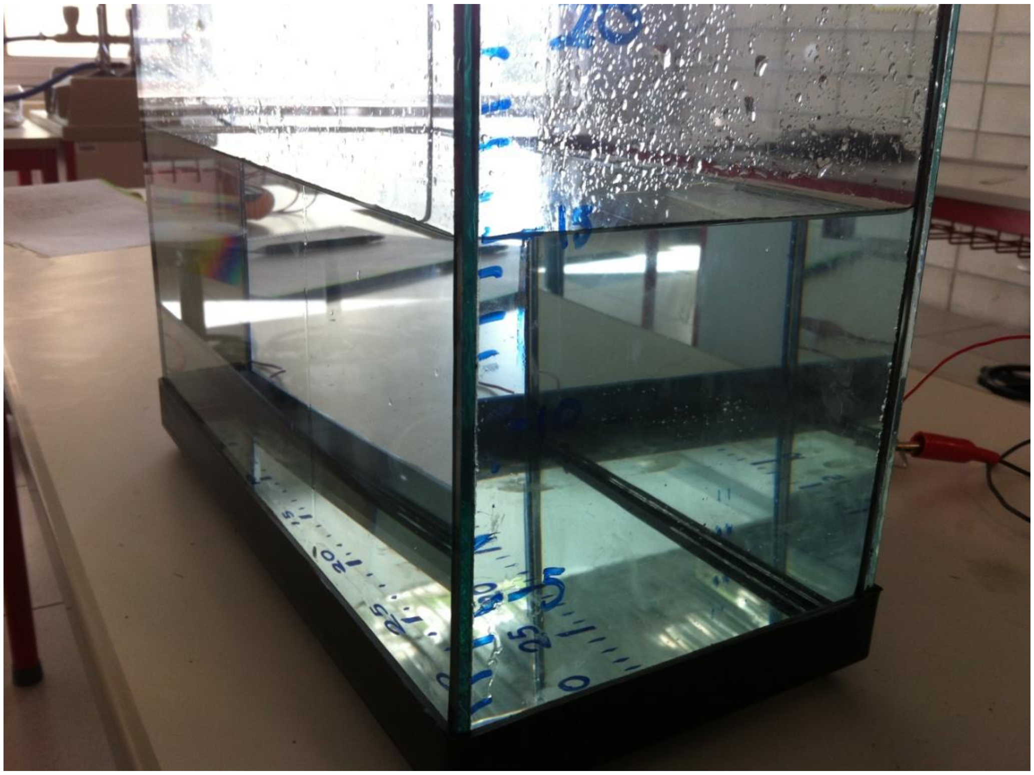


Figure 7.4.9: Water at 15 cm height.

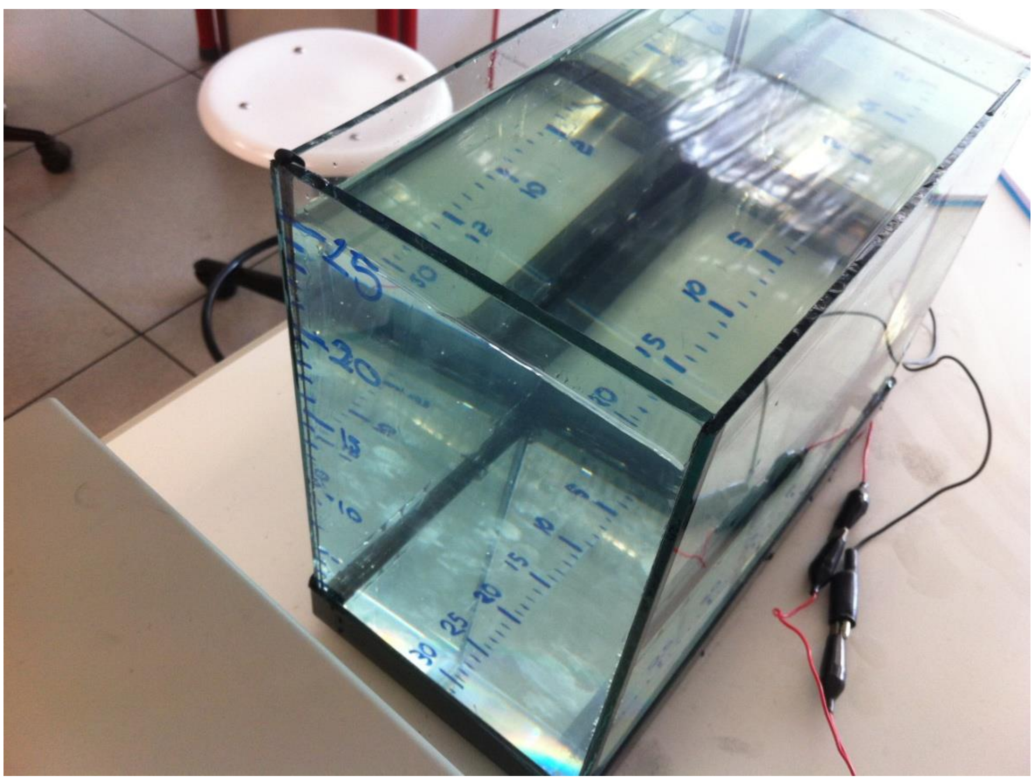


Figure 7.4.10: Water at 25 cm height.

7.3-Bibliography

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- *TSOKOS. Kyrgiakos Andreas. Physics for the IB Diploma*. Cambridge. Fifth Edition. 2010 Print.
- *http://technology-electronic.blogspot.com/2010/05/resistance-and-ohm.html*
- *http://lgfl.skoool.co.uk/uploadedImages/coord12.1_graphs.gif*

All graphs sketched with Logger Pro 3.8 Vernier Software.