TED
ANKARA COLLEGE
FOUNDATION HIGH SCHOOL

DETERMINATION OF THE ELECTRIC FIELD BY DETERMINING THE EQUIPOTENTIAL LINES BY USING A VOLTMETER

Extended Essay (Physics)

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A. ABSTRACT

This essay's aim is to observe the electric field lines between two parallel ring conductors by drawing the equipotential lines of the conductor via voltmeter.

The experiment is done by using a silver pen for creating the conductor. On a carbon sheet two circles which have the same centre but different radius are drawn with silver pen. The equipotential lines between these circles are drawn and the electric field lines are drawn according to equipotential lines. The method is easy to apply. In this experiment, as much data as possible must be collected, because the deviations can be unexpectedly high. So to find the approximate result, the number of data must be very high.

Using 4 different voltage values (40V, 30V, 20V, 10V) about 600 data is collected. The test results show that except some data the values are mostly close to each other. That means proper equipotential lines are drawn. Since the electric field lines are drawn according to equipotential lines, the electric field lines could be drawn. The field lines drawn are almost perfectly same with the theoric field lines between two parallel rings.

(Word count: 186)

B. CONTENTS

1. INTRODUCTION

My brother studies at university in electric electronic engineering section. He always creates different kinds of circuit at home. Though, he has a lot of strange materials and circuit elements. One day, while I was trying to understand what the new circuit that my brother created is used for, I saw a circuit element with a cylindrical shape. I asked about that substance to my brother and he told me that it is called a ‘capacitor’. I knew capacitors but in the level that we learned in high school, maybe it was why capacitor seemed interesting to me. My brother told me how a capacitor works, in detail.

A capacitor consists of two cylindrical conductors. When a current passes from the capacitor, an electric field is obtained between these conductors. I noticed that its working principle was like two parallel plates with a potential difference between them.

I started to search about the capacitors. Every conductor has equipotential lines around it. Equipotential lines represent the lines in which all the voltage values are the same. According to the electric field principle the field lines are perpendicular to the equipotential lines. The two conductors in a capacitor are perfectly parallel to each other so that every electric field line must have been perpendicular to conductors when they are drawn according to equipotential lines.

Then, I thought whether I could make a simple capacitor and map the electric field lines or not. I made a search about electric field mapping and found out that I could make a simple capacitor. By estimating the same voltage values between two conductors I could draw equipotential lines. Then, drawing lines perpendicular to these equipotential lines would give electric field lines. As a result, I did such an experiment to observe electric field between two parallel ring conductors.

2. BACKGROUND INFORMATION

Historically, quantitative relations in electrostatics began with the experiments of Charles Augustin de Coulomb, who formulated in 1785 what is now known as *Coulomb's Law*. Later, Karl F. Gauss developed *Gauss's Law*, and other scientists and engineers contributed various additional important results concerning stationary electric charges.

Electric field is defined as the electric force per unit positive charge. Electric field direction is always the same with the electric force on positive test charge. An electric field occurs from a positively charged object to a negatively charged one. That is also the direction of the electric force. There are many kinds of charged objects (Figure 1) and all of them have different electric field directions. For example, a point charge has the electric field from its center to out. Whereas for a charged conductive sphere for example, the electric field line are always from surface to out and perpendicular to its surface and the electric field inside the sphere is 0.

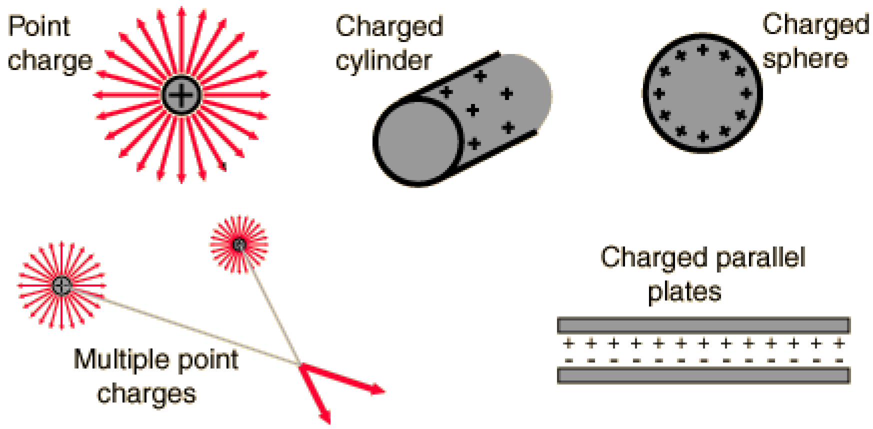


Figure 1: There are many kinds of charged objects.

2.1 ELECTRIC FIELD OF A POINT CHARGE

The electric field of a point charge can be calculated by using the Coulomb's Law. According to Coulomb's Law:

$$E = \frac{F}{q} = \frac{kQ_{source}q}{qr^2} = \frac{kQ_{source}}{r^2}$$

The electric field of a point charge is radially outward from the charge to somewhere in distance 'r'. Q_{source} represents the charge of the point charge.(Figure 2)

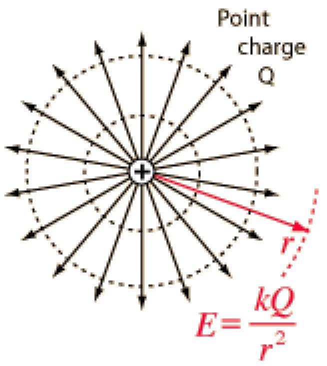


Figure 2: The electric field of a point charge.

When multiple point charges are presented in a medium as in Figure 1, the net Electric field is found from a vector sum of the individual electric fields.

2.2 ELECTRIC FIELD BETWEEN TWO PARALLEL PLATES

When two parallel plates are connected to a voltage source, because of the potential difference between them, an electric field is formed. This electric field's direction is from the positively charged plate to the negatively charged one. The electric field between these plates is always constant. The value of electric field (E) is directly proportional with the value of the potential difference (V) that the voltage source creates and inversely proportional with the distance between the two plates (d). Since the electric field value doesn't depend on any other condition the formula is found to be as in Equation 1. Two parallel plates with a potential difference between them form a capacitor.

$$E = \frac{V}{d}$$

Equation 1: Electric field between two parallel plates. 'E' is the value of Electric field, 'V' is the potential difference in volts and 'd' is the distance between the parallel plates.

2.2.1 CAPACITORS

In most of our machines that we use in daily life like the computers, kettles, televisions,… there are capacitors.

A capacitor(or condenser) consists of two conductors(parallel plates) separated by free space or a dielectric medium. When a DC (direct current) voltage source is connected between the conductors, a charge transfer occurs, resulting in a charge +Q on one conductor and –Q on the other. Several electric field lines originating from positive charges and ending on negative charges are shown in Figure 3.

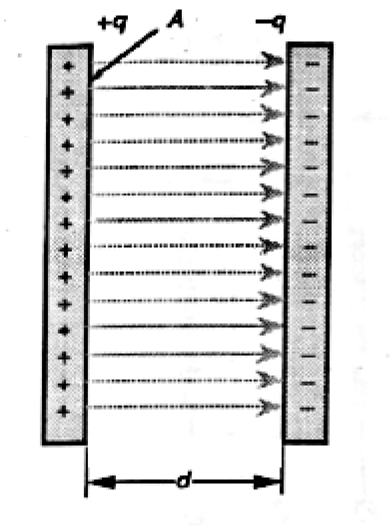


Figure 3: Electric between two parallel plates as in capacitor.

It is observed that the field lines are perpendicular to the conductor surfaces, which are equipotential surfaces. Equation 2 shows the formula of capacitors. For the same capacitor the ratio Q/V remains unchanged so the capacitance of a capacitor is constant.

$$Q = C.V$$

Equation 2: Shows the general formula used for capacitors where 'Q' is the charge, 'C' is the capacitance of the capacitor used and 'V' is the potential difference in volts.

The function of the capacitor is to store electricity, or electrical energy. The capacitor also functions as a filter, passing alternating current (AC), and blocking direct current (DC). The symbol ⊣⊢ is used to indicate a capacitor in a circuit diagram.[1]

An electric charge is stored on each conductor when a DC (direct current) is applied from a voltage source to the capacitor. The current keeps on flowing and at the same time the capacitor charges up. In direct current, the current will stop when the capacitor has fully charged. This is how a capacitor can be used as a filter that blocks direct current.

In my experiment, I made a simple capacitor and examined the voltage between two parallel conductors. Between two parallel plates the voltage value changes with distance. For example, if we consider the voltage at the positive charged conductor as 30V and the voltage in negatively charged part as 0V, and the distance between the conductors are 4mm, then at 2mm away from each conductor (at the middle) the voltage will be approximately 15V. [(30-0)/2]

All conductors have equipotential lines which are formed by the points where the voltage is the same. For a conductive sphere the equipotential lines are also sphere-shaped. (Figure 4) In the Figure 4 all equipotential lines represent different potential values.

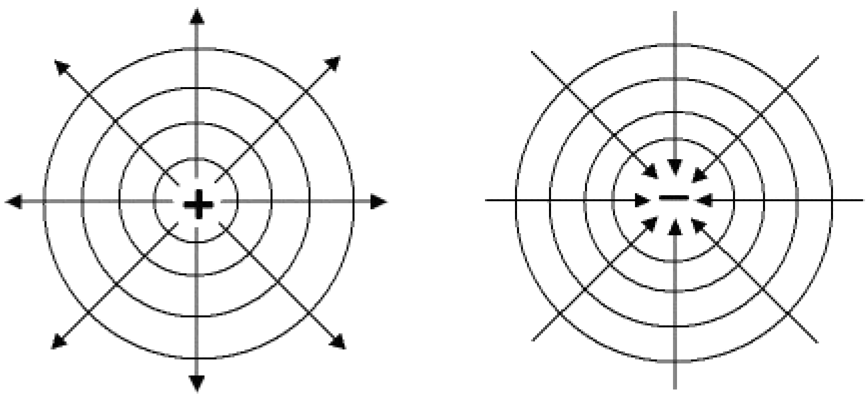


Figure 4: Shows the equipotential lines (circular ones) and the electric field lines (straight ones).

[1] http://www.piclist.com/images/www/hobby_elec/e_capa.htm

3. PLANNING A

3.1 Aim

An electric field is formed between two parallel conductors when they are connected to a DC voltage source. The aim of this experiment is learning the concepts of electric field lines and equipotential lines and to determine the points having the same potential which form equipotential lines in the electric field between two parallel conductors and using the equipotential lines to draw the electric field lines.

3.2 Research Question

Can the equipotential lines be determined by using a voltmeter, and can the electric field lines be determined by using the equipotential lines?

3.3 Hypothesis

In the machines that we use in daily life like computers, kettles, televisions there are capacitors. These capacitors are made of two parallel conductors. When they are connected to a direct current voltage source an electric field is formed between these conductors.

For any charged object there is the equipotential lines which the points that have the same electric potential form. The electric field lines are always perpendicular to these lines so since the parallel conductors have a charge they will form both the equipotential lines and the electric field lines.

As a result, it can be hypothesized that, if the equipotential lines can be drawn by obtaining the potential values of several points then the electric field lines could be drawn and since the conductors are parallel to each other the electric field lines must be perpendicular to conductors.

3.4 Key Variables

3.4.1 Constants

- Silver Pen (Trace Technologies Conductive Pen)
- Voltmeter (has the accuracy ±0.5%)
- Conductive cables and wires
- Temperature of the medium(19˚C)
- Atmospheric Pressure (assumed to be constant $\approx$1021mbar in Ankara)
- Altitude where the experiment is performed (1218m above the sea level)
- Source of electricity
- Carbon paper

3.4.2 Independent Variables

- Voltage input from voltage source
- The potential of the points chosen

3.4.3 Dependent Variables

- The distance from the inner conductor of the point chosen according to its potential

4. PLANNING B

4.1 Materials

- Conductive silver pen
- A digital multimeter
- Carbon paper (20cm x 30cm)
- Cable sets
- A 40V DC power supply
- A ruler (10cm)
- A pair of compasses

4.2 Method

- Using metal pushpins mount a piece of conductive carbon paper onto the corkboard.
- Using your pair of compasses draw two concentric circles whose radii are 2.5cm and 7.0cm.
- Shake the conductive silver pen several times about 30 seconds when its cap is on, feeling that the metallic ball inside the pen is moving up and down.
- Squeezing the pen from sides, press it against the paper and push its tip to bring the ink out. Go through the circular paths you have drawn before, defining the circles with silver ink. The ink should be continuous. If the line is thin and there exists some discontinuity, go over it again. The silver will dry in about 5 minutes; however it will take 10-15 minutes to achieve full conductivity.
- Set up the circuit where the positive terminal of the power supply is connected to the inner ring and the negative terminal to the outer ring. Plunge metal pushpins to the rings and attach the supply to the pushpins by using cables with crocodiles at the end. Apply different voltages (20, 30, 40) between the inner and outer rings. Then, connect one of the probes of the digital multimeter to a terminal of the power supply. The remaining free probe will serve for tracing and recording the electric potential in the region between the rings.
- Place the free probe of the digital multimeter at some radius between the rings; read the potential and move the probe until you find the exact potential you want to

observe. Measure and record the distance from the inner ring for 15 different voltage values at 10 different points.

- Interpolate a reasonable curve between these points. The locus of points having the same electric potential value should yield a circular equipotential. Draw the equipotential lines according to the data you have obtained.
- Draw the lines which are perpendicular to the equipotential lines to obtain the electric field lines.

5. DATA COLLECTION

TEST NO: 1

	NUMBER OF POINTS OBSERVED									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
VOLTS (±0.1Volts)	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**
10.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.3	0.40	0.42	0.43	0.42	0.41	0.42	0.46	0.46	0.48	0.43
8.6	0.78	0.78	0.75	0.74	0.79	0.76	0.76	0.78	0.71	0.74
7.9	1.33	1.53	1.36	1.34	1.38	1.35	1.34	1.36	1.35	1.35
7.1	1.51	1.53	1.54	1.54	1.50	1.69	1.48	1.55	1.53	1.53
6.4	1.67	1.68	1.69	1.67	1.72	1.64	1.65	1.64	1.67	1.68
5.7	1.84	1.84	1.84	1.84	1.84	1.85	1.84	1.87	1.86	1.84
5.0	2.06	2.04	2.05	2.12	2.07	2.11	2.08	2.12	2.05	2.10
4.2	2.34	2.35	2.34	2.34	2.37	2.38	2.31	2.35	2.34	2.36
3.3	2.63	2.64	2.63	2.63	2.68	2.61	2.68	2.64	2.63	2.61
2.4	2.85	2.86	2.84	2.85	2.88	2.88	2.88	2.89	2.81	2.83
1.8	3.37	3.35	3.17	3.39	3.34	3.35	3.36	3.37	3.37	3.38
0.9	3.69	3.70	3.70	3.71	3.63	3.62	3.65	3.68	3.69	3.70
1.3	4.20	4.25	4.26	4.20	4.21	4.26	4.23	4.27	4.26	4.21
0.0	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50

Table 1: Distance from inner circle related to the changing value of voltage. The table shows ten trials for each voltage value and the voltage value changes between 10volts to 0volts.

TEST NO: 2

	NUMBER OF POINTS OBSERVED									
	1	2	3	4	5	6	7	8	9	10
VOLTS (±0.1Volts)	Distance from inner circle (±0.01cm)	Distance from inner circle (±0.01cm)	Distance from inner circle (±0.01cm)	Distance from inner circle (±0.01cm)	Distance from inner circle (±0.01cm)	Distance from inner circle (±0.01cm)	Distance from inner circle (±0.01cm)	Distance from inner circle (±0.01cm)	Distance from inner circle (±0.01cm)	Distance from inner circle (±0.01cm)
20.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18.7	0.47	0.51	0.47	0.47	0.48	0.46	0.50	0.46	0.47	0.49
16.9	0.84	0.86	0.84	0.84	0.91	0.85	0.84	0.84	0.85	0.85
14.0	1.00	1.02	1.01	1.01	1.00	1.01	1.04	1.01	0.99	1.00
11.9	1.50	1.47	1.51	1.50	1.53	1.51	1.54	1.51	1.50	1.53
9.8	2.00	2.01	2.00	2.00	2.01	2.00	2.01	2.00	2.00	2.00
7.9	2.50	2.49	2.51	2.50	2.52	2.49	2.54	2.50	2.52	2.50
6.5	2.81	2.81	2.81	2.82	2.81	2.81	2.81	2.83	2.82	2.85
5.2	3.00	3.01	3.00	3.01	3.01	3.00	3.00	3.01	3.00	3.00
3.8	3.50	3.50	3.61	3.63	3.50	3.50	3.51	3.50	3.50	3.51
3.0	3.13	3.17	3.13	3.10	3.13	3.13	3.12	3.72	3.12	3.13
2.1	3.94	3.94	3.94	3.94	3.93	3.95	3.94	3.94	3.94	3.95
0.9	4.00	4.00	4.02	4.01	4.00	4.01	4.35	4.00	4.00	4.01
0.3	4.38	4.41	4.38	4.39	4.38	4.39	4.38	4.38	4.40	4.38
0.0	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50

Table 2: Distance from inner circle related to the changing value of voltage. The table shows ten trials for each voltage value and the voltage value changes between 20volts to 0volts.

TEST NO: 3

	NUMBER OF POINTS OBSERVED									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
VOLTS (±0.1Volts)	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**
30.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27.4	0.46	0.48	0.41	0.49	0.46	0.45	0.42	0.43	0.44	0.46
24.8	0.85	0.89	0.86	0.82	0.84	0.85	0.84	0.84	0.84	0.87
22.2	1.13	1.15	1.13	1.14	1.16	1.10	1.25	1.14	1.13	1.15
19.6	1.48	1.47	1.48	1.48	1.49	1.50	1.47	1.48	1.48	1.46
17.1	1.66	1.65	1.69	1.66	1.64	1.65	1.65	1.66	1.68	1.63
15.0	2.01	2.06	2.03	2.00	2.00	2.01	2.00	1.98	2.45	2.04
13.4	2.21	2.23	2.22	2.21	2.24	2.23	2.27	2.21	2.16	2.24
10.2	2.65	2.64	2.69	2.61	2.60	2.68	2.64	2.65	2.63	2.65
8.4	2.91	2.92	2.94	2.93	2.90	2.92	2.91	2.91	2.94	2.91
6.8	3.31	3.35	3.30	3.52	3.36	3.37	3.31	3.34	3.28	3.30
5.3	3.90	3.90	3.92	3.91	3.92	3.93	3.90	3.91	3.90	4.11
3.2	4.15	4.16	4.15	4.15	4.26	4.14	4.15	4.16	4.17	4.15
1.4	4.41	4.41	4.43	4.42	4.43	4.43	4.44	4.41	4.40	4.43
0.0	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50

Table 3: Distance from inner circle related to the changing value of voltage. The table shows ten trials for each voltage value and the voltage value changes between 30volts to 0volts.

TEST NO: 4

	NUMBER OF POINTS OBSERVED									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
VOLTS (±0.1Volts)	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**	**Distance from inner circle (±0.01cm)**
40.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37.6	0.45	0.48	0.45	0.45	0.43	0.45	0.42	0.47	0.46	0.45
35.0	0.86	0.85	0.85	0.84	0.85	0.89	0.81	0.84	0.86	0.83
32.3	1.26	1.31	1.27	1.25	1.45	1.21	1.23	1.25	1.26	1.26
29.7	1.43	1.42	1.42	1.46	1.43	1.48	1.42	1.40	1.38	1.43
25.3	1.60	1.63	1.64	1.60	1.61	1.58	1.61	1.62	1.60	1.60
23.4	1.83	1.84	1.83	1.84	1.85	1.91	1.80	1.84	1.82	1.85
20.0	2.03	2.04	2.12	2.01	2.13	2.10	2.06	2.04	2.08	2.02
17.4	2.28	2.29	2.24	2.23	2.28	2.26	2.28	2.25	2.29	2.27
15.2	2.59	2.57	2.58	2.59	5.56	2.29	2.54	2.57	2.61	2.59
13.1	2.97	2.94	3.00	2.96	2.97	2.97	2.97	3.01	2.94	2.95
8.2	3.44	3.48	3.50	3.51	3.48	3.51	3.41	3.43	3.50	3.42
5.2	3.72	3.75	3.71	3.74	3.74	3.71	3.72	3.68	3.75	3.71
2.3	4.13	4.15	4.10	4.16	4.17	4.14	4.13	4.12	4.13	4.13
0.0	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50

Table 4: Distance from inner circle related to the changing value of voltage. The table shows ten trials for each voltage value and the voltage value changes between 40volts to 0volts.

6. DATA PROCESSING and PRESENTATION

VOLTS (±0.1Volts)	Average Distance from Inner Circle (±0.01cm)
10.0	0.00
9.3	0.43
8.6	0.76
7.9	1.37
7.1	1.54
6.4	1.67
5.7	1.85
5.0	2.08
4.2	2.35
3.3	2.64
2.4	2.86
1.8	3.34
1.3	3.68
0.9	4.24
0.0	4.50

Table 5: Average distance from the inner circle changing with tested electric potentials.

VOLTS (±0.1Volts)	Average Distance from Inner Circle (±0.01cm)
20.0	0.00
18.7	0.48
16.9	0.85
14.0	1.01
11.9	1.51
9.8	2.00
7.9	2.51
6.5	2.82
5.2	3.00
3.8	3.53
3.0	3.19
2.1	3.94
0.9	4.04
0.3	4.39
0.0	4.50

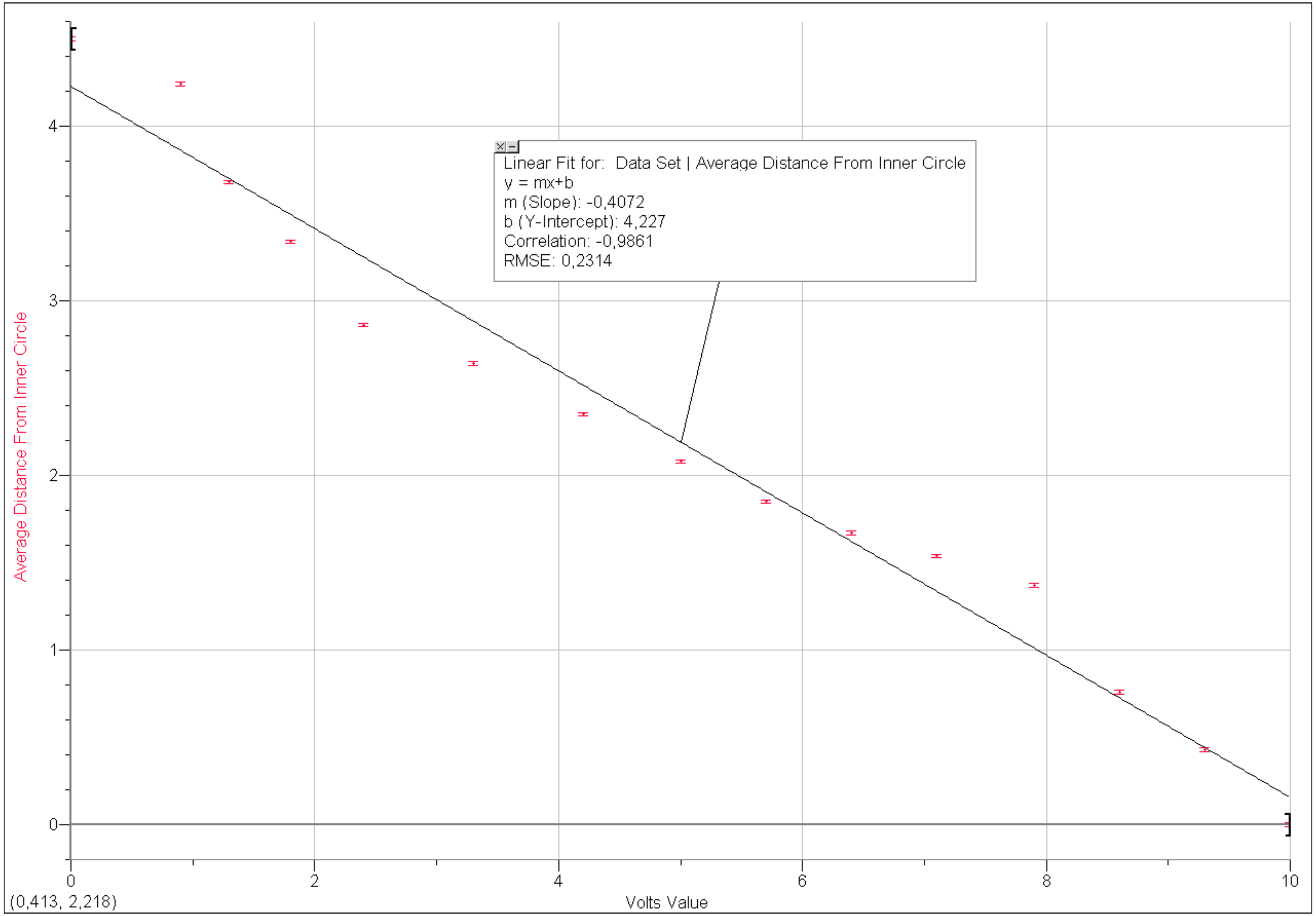
Table 6: Average distance from the inner circle changing with tested electric potentials.

VOLTS (±0.1Volts)	Average Distance from Inner Circle (±0.01cm)
30.0	0.00
27.4	0.45
24.8	0.85
22.2	1.15
19.6	1.48
17.1	1.66
15.0	2.06
13.4	2.22
10.2	2.64
8.4	2.92
6.8	3.34
5.3	3.93
3.2	4.16
1.4	4.42
0.0	4.50

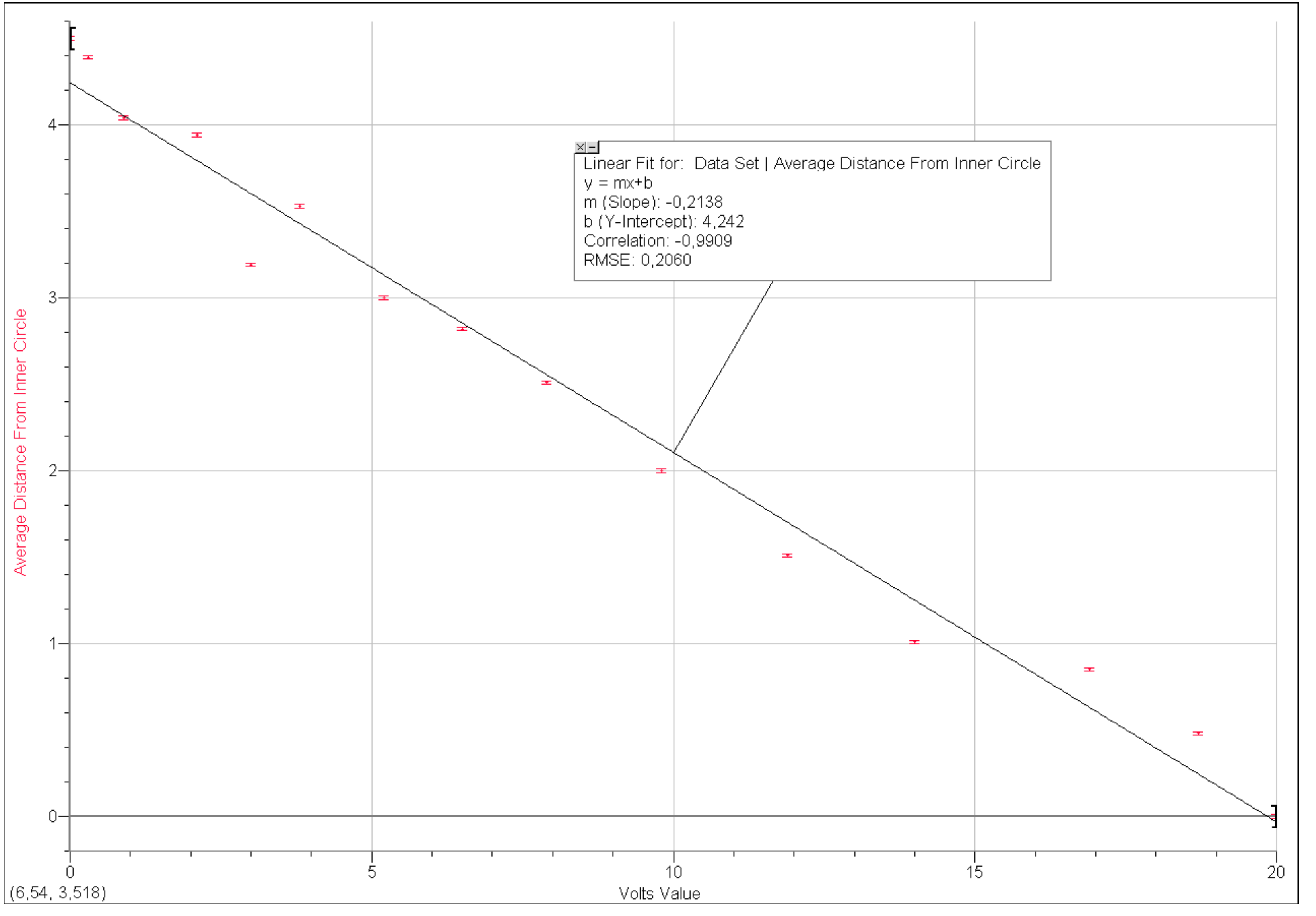
Table 7: Average distance from the inner circle changing with tested electric potentials.

VOLTS (±0.1Volts)	**Average Distance from Inner Circle (±0.01cm)**
40.0	0.00
37.6	0.45
35.0	0.85
32.3	1.28
29.7	1.43
25.3	1.61
23.4	1.84
20.0	2.06
17.4	2.27
15.2	2.85
13.1	2.97
8.2	3.47
5.2	3.72
2.3	4.14
0.0	4.50

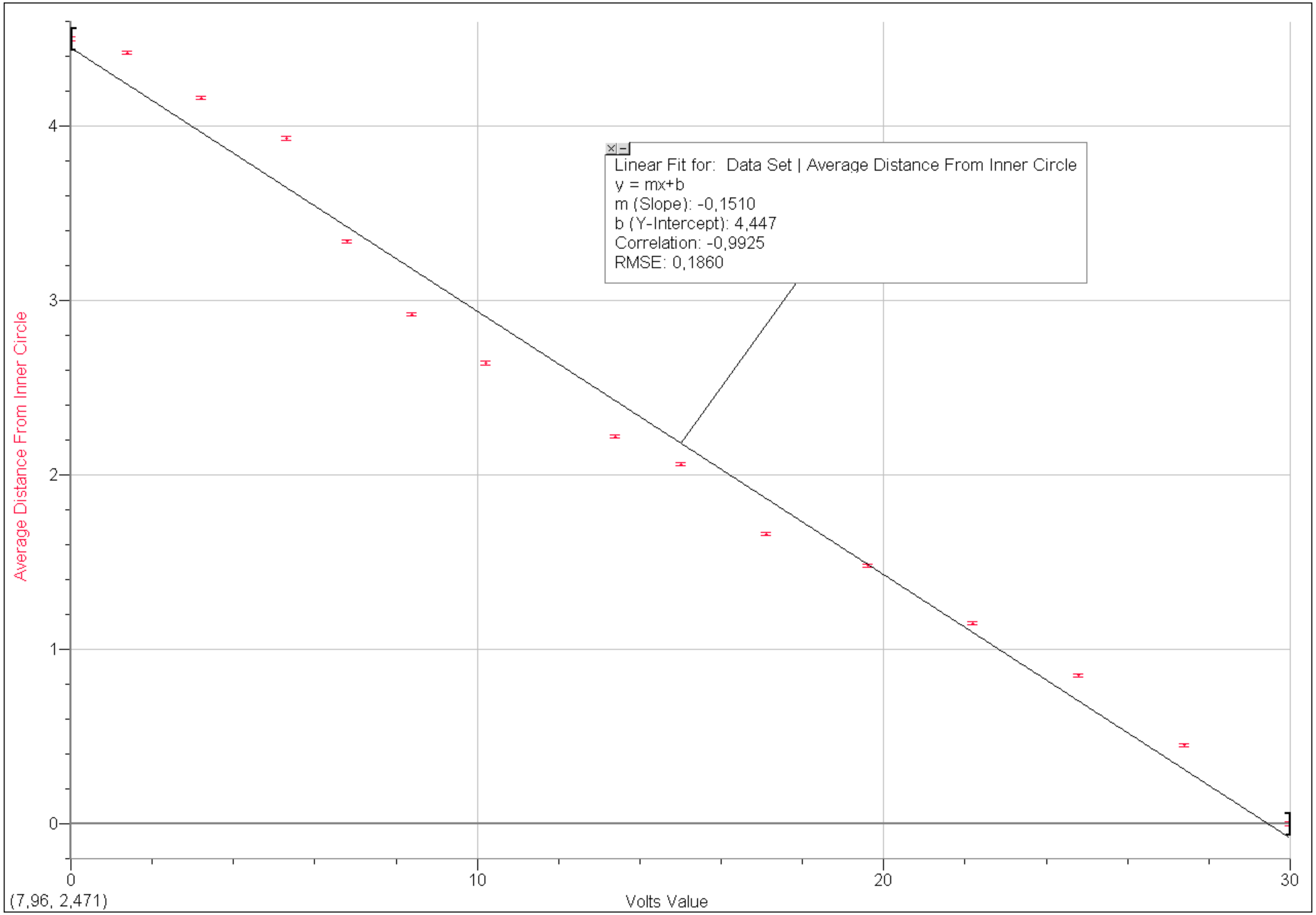
Table 8: Average distance from the inner circle changing with tested electric potentials.



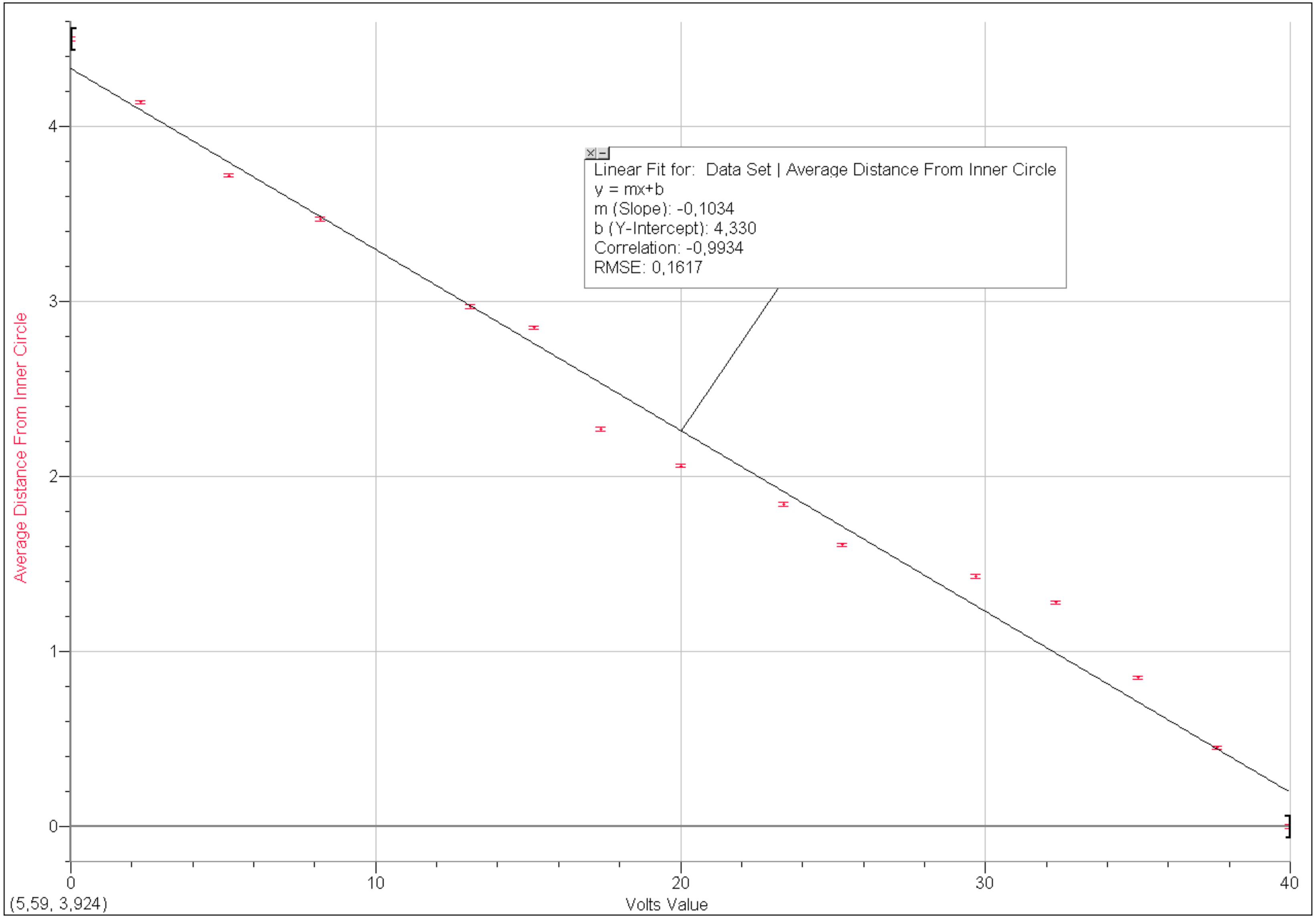
Graph 1: Average distance from inner circle with the changing electric potential (0V - 10V)



Graph 2: Average distance from inner circle with the changing electric potential (0V - 20V)



Graph 3: Average distance from inner circle with the changing electric potential (0V - 30V)



Graph 4: Average distance from inner circle with the changing electric potential (0V - 40V)

6. CONCLUSION and EVALUATION

The hypothesis of the experiment was "If the equipotential lines can be drawn by obtaining the potential values of several points then the electric field lines could be drawn and since the conductors are parallel to each other the electric field lines must be perpendicular to conductors." According to the data collected, when the equipotential lines are drawn, it is seen that they are almost perfect circles. Since the electric field lines are perpendicular to the equipotential lines, then they are almost perpendicular to the conductors, too. This means that the hypothesis is true.

When the data collected is investigated it could be seen that the distance values from the inner circle are not always so close to each other. Indeed, there are some values which are extremely separate and different from the other. While I was preparing the data collection tables, I highlighted these values with yellow. These values have great effect on obtaining the best result. I have drawn some graphs with these data and showed them in Data Processing and Presentation part. The graphs show the change of the average distance from the inner circle according to the changing voltage values. In these graphs there are some sudden changes in the slope. These changes are most probably because of the extremely separate values that are highlighted.

There are some reasons that may have caused these values to appear:

- The values in the tables that are shown in the part 'Data Collection' (Tables 1,2,3,4) are written approximately. Although this makes small changes in the result, it may have caused serious deviations.
- The ring conductors which are drawn with the silver pen could have some points that are wider or thinner than other parts. Because the silver pen's ink may spread more in some places.
- The conductivity of carbon sheet is not 100% reliable; there may have been some places on the surface that conduct worse.
- The temperature of the medium that the experiment is done would affect the conductivity of the wires. For example, if the medium is cold, then the conductivity will decrease.

According to the data collected the equipotential lines are drawn. The lines that are perpendicular to the equipotential lines give us the electric field lines. If the equipotential lines were perfectly obtained, they would be perfect circles that have the same center but in the experiment the equipotential lines are not perfect circles. As a result, the electric field lines that pass perpendicularly from the equipotential lines are not perpendicular to the outer ring conductor. This situation is occurred because of the possible sources of errors that are mentioned before.

8. BIBLIOGRAPHY

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