TED ANKARA COLLEGE FOUNDATION PRIVATE HIGH SCHOOL

INTERNATIONAL BACCALAUREATE

EXTENDED ESSAY

"Electrical conductivities of different grade lead pencil graphite"

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ABSTRACT

Graphite is not only a substance that are used in lead pencils, it can also be used as a conductor. In the 21st Century, carbon allotropes and alloys are used in many industrial areas, therefore carbon is an important element to be examined.

The investigation aims to deduce the conductivities of different types of lead pencils. In this extended essay, I investigated the relationship between electrical conductivity and pencil grade in graphite conductors under the research question of "How does the grade of a drawing pencil in HB scale affect the electrical conductivity of the pencil?". To explore this relationship, I used pencils of same brand but different HB grades. I used one sample from each of the seven different pencil grades. I connected each sample to a DC supply in series separately and measured how much current they carry under 2.0V of potential difference.

To outline the process of the investigation after determining the problem, I first designed the experiment mechanism. Then I collected the data and built data tables. After interpreting the data mathematically, I analyzed it and drew conclusions.

I connected each pencil to the DC Power Supply and performed 12 trials for each pencil grade. In the end, there were 12 data for each of the 14 pencil grades. Having a total of 168 data, I calculated the mean current values for each of the pencils. Then I used resistance formulae to calculate the electrical conductivity of the pencils. I built a table to sketch a graph using Logger Pro 3 and drew my conclusions using these two statistical items.

As my conclusion, I deduced that increasing H scale decreases the conductivity of the pencil because of the decreasing amount graphite used while increasing B scale increases the conductivity of the pencil because of the increasing amount of graphite.

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NOTATIONS

A: Area (m^2: meters squared)

σ: Electrical Conductivity ($\Omega^{-1}m^{-1}$)

ρ: Electrical Resistivity (Ωm)

l: Length (m: meters)

i: Electric Current (A: amperes, mA: milliamps; $1A=10^3 mA$)

R: Resistance (Ω: Ohms)

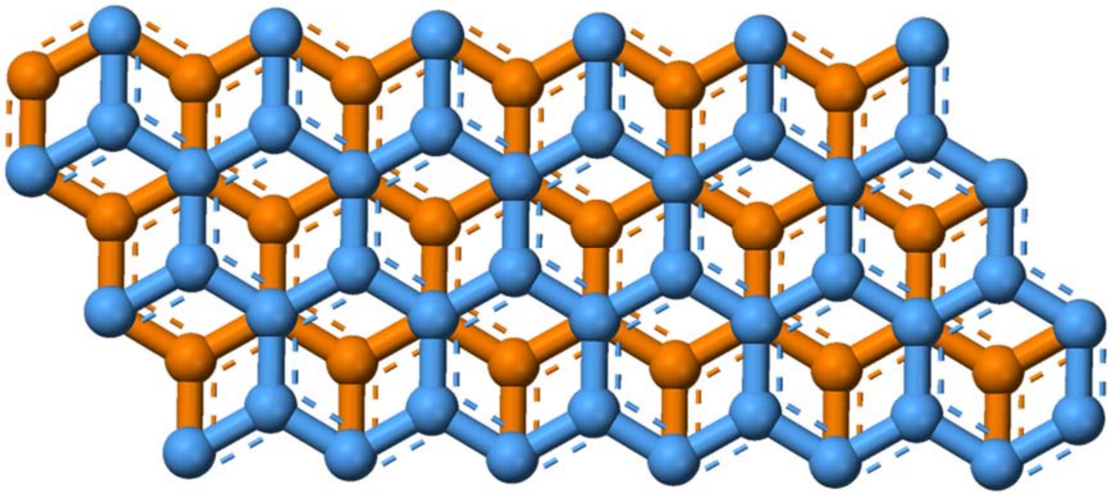
V: Electric Potential (V: Volts)

INTRODUCTION

Research Question: How does the grade of a drawing pencil in HB scale affect the electrical conductivity of the pencil?

Electricity is quite an important part of mankind's life since people mostly rely on electricity to supply their fundamental needs. They cook their meals on electrical stoves, heat their houses by electrical heaters and communicate each other by using the gifts of electronics to mankind: cell phones, computers, televisions and even tablets. In the 20^{th} Century, electrical and electronic industries have propagated significantly in carrying and using the electricity effectively and efficiently. These efforts led up to the substantial lifestyles of people in 21^{st} Century, which depends on electrical energy. To transport electrical energy, electrical conductors are used. Although "All science is either Physics or stamp collecting." (-E. Rutherford), Chemistry significantly contributes to electronics at the point of developing more effective ways of conducting electricity.

Most of the people who have a slight idea about chemistry would say that only metals conduct electricity, thus they will miss a great exception: graphite. A carbon allotrope, graphite stands out as a nonmetal conductor. Graphite has a covalent bond network, in which carbon atoms perform sp^2 hybridization, making 3 σ bonds and 1 π bond. As a result of this hybridization, carbon atoms in graphite form a network which can be seen below:



Ionic compounds conduct electricity in liquid and aqueous state, thanks to the movement of ions; metals conduct electricity because electrons can move freely within the structure; but how does graphite conduct electricity? It is because of the pi (π) bonds (represented with dashed lines in the figure above). The shared electrons in the pi bond are moveable, therefore they make graphite a good conductor.

Industrial conductors stand out as a dynamic area of development in the 21st Century since mankind is looking for more efficient ways to carry electricity over large distances. Graphite might not be the best conductor, however, best conductors may contain it as a substance in an alloy. This investigation works on a system where graphite is not in pure form, therefore the system used in the experiment may create an idea of how the graphite content in a conductor affects its conductivity.

HB scale (where H stands for hardness and B stands for blackness) is a universal pencil scale that is used to express the hardness-blackness of a lead pencil. This is mostly used by painters professionally since they use different pencil grades in different painting techniques and areas. To make different pencil grades, producers use more clay in harder pencils and more graphite in blacker pencils. This HB scale is used as the independent variable of the investigation.

This investigation aims to explore the relationship between the pencil grade and electrical conductivity. Pencil grade determines the lead composition of a pencil, hardness is increased by increasing the clay concentration while blackness is increased by increasing graphite concentration. Electrical conductivity (σ) is the inverse of resistivity (ρ), calculated as:

$$\sigma = \frac{1}{\rho}$$

and its unit is $\Omega^{-1}m^{-1}$. To explore the relationship, pencils of same brand but different HB grades were connected to a DC supply in series separately.

EXPERIMENT DESIGN

To examine the electrical conductivity of different pencil grades, a simple DC circuit consisting of a DC supply and a resistor (pencils in this case) was connected in series. All the measurement was done by the use of the DC Power Supply. The voltage was set to 2.0 Volts manually and when the power supply was connected to the pencil by the use of crocodile cables, the main current shows up on the "current" screen. All the measurement for this experiment was made according to the data displayed on tat screen.

Independent Variable: Pencil grade

Dependent Variable: Electrical Conductivity

Controlled Variables: Pencil brand, potential difference in the power supply, cables used in the circuits, brand and model of the power supply, duration of trials.

Note: Lead lengths could not be controlled since pencil sharpener was used to open both sides of the pencils. Instead, associated lead lengths of each pencil grade are given in the table 1 and calculations for each pencil grade will be done according to the lengths given in the table 1

MATERIALS LIST

1. TT T-ECHNI-C DC Power Supply YH-303 D

2. Copper crocodile cables

3. 14 Faber Castell drawing pencils (One example from each of the following grades: 7 B, 6 B, 5 B, 4 B, 3 B, 2 B, B, H 2 H, 3 H, 4 H, 5 H, 6 H, 7 H (Graphite radius: 1mm)

4. Pencil sharpener

5. 1x 30cm translucent plastic ruler

6. 1x Timer

CONTROLLING THE VARIABLES

Controlling the variables in an experimental academic work is vital since this stage is the insurance of the validity and accuracy of this scientific work. The controlled variables and the method of controlling them is shown below:

Pencil Brand: All the pencils used were the different grades of drawing pencils of Faber Castell

Potential Difference in the Power Supply: The voltage was manually set to 2.0 Volts.

Cables Used in the Circuit: Two crocodile cables in total exist in the circuit design.

Brand and Model of the Power Supply: TT T-ECHNI-C DC Power Supply YH-303D was used during the whole experiment in order to keep the accuracy and uncertainty of the raw data and data collecting method the same.

Duration of Trials: The timer was set to 10 seconds in each trial. The reason of doing this is to prevent possible errors caused by the heating of the resistors.

EXPERIMENTAL METHOD

To prepare the pencils for being part of a circuit, start with opening both ends of the pencils stated in the third bullet point of the materials list. Then measure each pencil's length using the plastic ruler. Be careful to set the line of sight perpendicular to the table axis to avoid sharp end parallax error. Note down the lengths measured for each pencil. Set the DC Power Supply to 2.0 V and the ammeter unit to milliamps. Connect each pencil to the DC Power Supply and set the timer for 10 seconds countdown. Since pencils heat up quickly under electrical current, it is vital to keep the duration of the trials constant in order to prevent possible errors that may be caused by the increase in resistance as the result of increase in temperature. Note down the readings of the ammeter. Do 12 trials for each pencil grade. In the end, there will be 12 data for each of the 14 pencil grades.

DERIVATION OF ELECTRICAL CONDUCTIVITY

For a resistor connected to a DC supply with a length "l" (m) and cross sectional area A and resistivity ρ, the resistance is given by:

$$R = \frac{\rho \times l}{A}$$

Replacing electrical conductivity (σ) with resistivity (ρ):

$$R = \frac{l}{\sigma \times A}$$

Isolating σ:

$$\sigma = \frac{l}{R \times A}$$

Before calculating the electrical conductivity of pencils, their resistance must be calculated first using the data from the circuit using the formula: $V = i \times R$. The voltage was manually set for 2.0V and current was measured by the ammeter of the power supply. Since the potential difference shown in the display of the power supply is the voltage transferred to the circuit, internal resistance of the DC supply is neglected. Thus replacing R with: $\frac{V}{i}$:

$$\sigma = \frac{i \times l}{V \times A}$$

This formula is used in the calculations. The values for "i" of each graphite grade is accepted as the mean values calculated from 12 trials. For the calculation, "l" is in meters (m), A is in m^2, V will be in Volts (V), and "i" is be in amperes (A).

EXPERIMENTAL DATA

LENGTHS OF THE GRAPHITE RESISTORS

Pencil Grades	Resistor Lengths(±0.2cm)
H	17.7
2H	17.7
3H	17.7
4H	17.8
5H	17.8
6H	17.8
7H	17.8
B	17.7
2B	17.8
3B	17.6
4B	17.8
5B	17.8
6B	17.7
7B	17.7

Table 1: Lengths of the graphite resistors.

Note: Uncertainty of the lengths because of the instrument was normally 0.05 cm, but 0.2 cm was used as the uncertainty because of the sharp end parallax error.

AMMETER READINGS FROM DIFFERENT RESISTORS

The data collected from the experiment system is given in the Appendix, since there are 14 tables each consisting of 12 data from 12 trials and they occupy a huge space, disrupting the integrity of the essay.

DATA PROCESSING

H graded and B graded pencils are processed and analyzed separately. To process the experimental data, mean values for the current in amperes must be calculated first. Then, the formula given in the Derivation of Electrical Conductivity must be used to obtain processed data and to reach to the dependent variable. Since HB pencil grade is not a continuous quantity but is a discrete quantity, processed data will be represented by the use of bar graphs and all of the processes will be made separately for the pencils on H scale and B scale.

CALCULATING UNCERTAINTIES

To calculate the electrical conductivities of pencil grades, arithmetic mean of each of their current readings will be used. Each mean value has its own uncertainty since each of them are calculated from a data set. To express it mathematically, the arithmetic mean is found by:

$$\mu = \frac{x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12}}{12}$$

Uncertainty (u) is found by:

$$u = \pm \frac{x_{max} - x_{min}}{2}$$

H GRADE PENCILS

Grades of Pencils	Pencil length (±0.2cm)	Mean Current Values (A)	Uncertainties (±A)
H	17.7	0.082	0.003
2H	17.7	0.081	0.004
3H	17.7	0.048	0.003
4H	17.8	0.043	0.003
5H	17.8	0.037	0.004
6H	17.8	0.034	0.003
7H	17.8	0.028	0.003

Table 2: H Grade Pencils, their lengths and mean current values with their uncertainties.

The derived formula for electrical conductivity in the Mathematical Interpretation section was:

$$\sigma = \frac{i \times l}{V \times A}$$

This formula involves l in meters, therefore when pencil lengths are converted to meters, all of them can be approximated to 0.18 m. Adding the controlled variables to the formula:

$$\sigma = \frac{i \times 0.18}{2 \times A} = \frac{0.09i}{A}$$

Calculating the common A (cross sectional area) value accepting the cross section of the graphite as a circle and using the graphite radius given in the materials list:

$$A = \pi \times (1 \times 10^{-3})^2 = 3.14 \times 10^{-6} m^2$$

Applying to the formula:

$$\sigma = \frac{0.09i}{3.14 \times 10^{-6}} = 28662i$$

To do demonstrate an example for data processing at this stage, let's find the electrical conductivity of the 2H pencil:

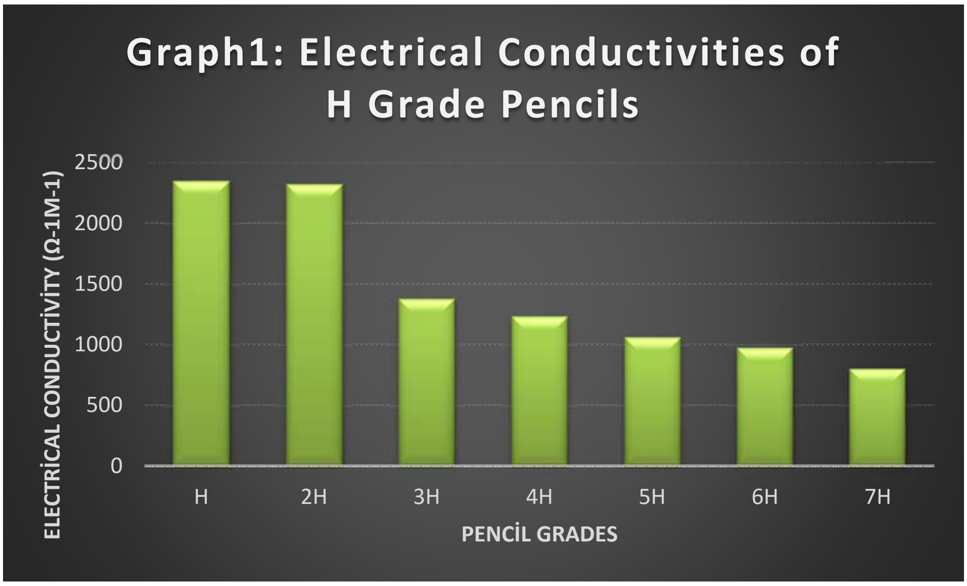
$$\sigma = 28662 \times 0.081 = 2321.622 \cong 2321\ \Omega^{-1} m^{-1}$$

The data in Table 15 is processed by using the formula above and is shown in Table 16:

Grades of Pencils	Electrical Conductivity ($\Omega^{-1}m^{-1}$)	Uncertainty($\pm\Omega^{-1}m^{-1}$)
H	2350	86
2H	2321	115
3H	1375	86
4H	1232	86
5H	1060	115
6H	975	86
7H	803	86

Table 3: Experimental Electrical Conductivities of H Grade Pencils.

The data in Table 16 is plotted in Graph 1 below:



Graph 1: Electrical Conductivities of H Grade Pencils.

B GRADE PENCILS

Grades of Pencils	Pencil length (±0.2cm)	Mean Current Values (A)	Uncertainties (±A)
B	17.7	0.101	0.007
2B	17.8	0.132	0.002
3B	17.6	0.141	0.003
4B	17.8	0.182	0.006
5B	17.8	0.265	0.022
6B	17.7	0.367	0.007
7B	17.7	0.466	0.016

Table 4: B Grade Pencils, their lengths and mean current values with their uncertainties.

Since the same approximation of pencil lengths done on H grade pencils can also be done here ($l \approx 0.18m$), the same formula (reproduced below) can be used for B grade pencils:

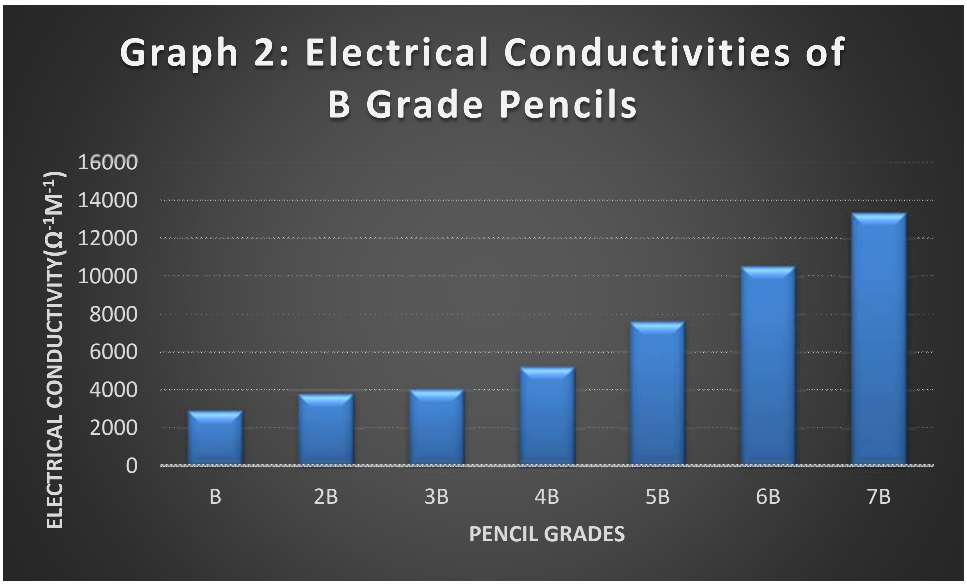
$$\sigma = 28662i$$

Applying the formula to the data in Table 17, electrical conductivities are shown in Table 18:

Grades of Pencils	Electrical Conductivity ($\Omega^{-1}m^{-1}$)	Uncertainty($\pm\Omega^{-1}m^{-1}$)
B	2895	201
2B	3783	57
3B	4041	86
4B	5216	172
5B	7595	631
6B	10519	201
7B	13356	459

Table 5: Experimental Electrical Conductivities of B Grade Pencils.

The data in Table 18 is plotted in Graph 2 below:



Graph 2: Electrical Conductivities of B Grade Pencils.

CONCLUSION AND EVALUATION

DESCRIPTION AND INTERPRETATION OF THE DATA

In H grade pencils, electrical conductivity decreases as the hardness of the pencil and thus the clay composition increases. Electrical conductivities of the pencils H and 2H are very close, and there is a sudden drop between 2 H and 3 H pencils following a gradual decrease towards 7H. Since 12 trials were made to find the electrical conductivity of each pencil grade and most of the data was close around the mean value in Table 2 while considering the smallness of the uncertainty of the current value of 2 H pencil (± 0.004 Amperes), it would be inaccurate to call this imbalance a random error. This can only show that the percentage of clay and graphite do not gradually change in H grade pencils. The data, in general, shows that increasing clay concentration of the pencil decreases its electrical conductivity.

In B grade pencils, on the other hand, electrical conductivity increases as the blackness of the pencil and thus the graphite composition increases. Unlike in H grade pencils, B grade pencils show a more regular increase. As the pencil grades increase, the increase in electrical conductivity also increases, by which it can be inferred that graphite composition of the pencils increase more and more as the pencil grades in B get higher. This pattern of the electrical conductivities of the B grade pencils shows that increasing graphite composition of the pencil increases its electrical conductivity.

CONCLUSIONS AND EXTENSIONS OF THE INVESTIGATION

The main aim of this investigation was to deduce how graphite and clay composition affect the electrical conductivities of pencils. A possible real life application of this investigation is to use graphite to adjust the electrical conductivities of industrial conductors. To deduce this, a system involving a simple DC circuit was set up for this investigation. 7 different B grade and 7 different H grade pencils were used as independent variables of the experiment. 12 trials were made in order to minimize the effects of random errors. To prevent systematic errors, some variables were controlled and the pencil lengths were adjusted as close to each other as possible.

There are many points to criticize in this investigation. First of all, there is no quantitative data for the graphite compositions of the pencils, which is in fact because of the privacy policies of manufacturers. Since pencil grade is a discrete quantity, it can only plotted on graphs as bar graphs. Therefore it is only possible to make inferences or interpretations about the graphite composition of the pencils. Another shortfall of the investigation was that the tips of the pencils all had different forms which might have caused the data to be more uncertain. Another error caused by the pencils is that the mathematical operations were made assuming that the conductors were cylinders but they all had two sharp ends.

To improve such points, industrial grade graphite alloys could have been used and instead of using a non-systematic and non-scientific parameter as pencil grade as an independent variable, conductors with quantitatively known chemical compositions could have been used. For example, if percentage graphite compositions were known for the conductors, graphs could have been plotted as continuous variables and the quantitative side of the investigation could have been supported by linear or curve fits, resulting in more productive conclusions. Instead of the pencils with sharp ends, the conductors could have been cylinders and could be obtained in same lengths, facilitating to control variables and thus making the data more accurate and trustworthy.

This investigation was conducted under non-industrial conditions and daily materials (drawing pencils) were used as the models of graphite conductors. Although the data could have been more accurate and more useful if professional graphite conductors were used, the conclusions of this investigation can be used to produce useful and efficient conductors. This experiment shows both that graphite is a good and useful conductor although it is an allotrope of carbon ($_6C$), a nonmetal. Even though it does not stand as a handy conductor due to its moderate level electrical conductivity (when compared with metals) and low heat capacity (its swiftness in heating up stands as a problem), it can still be used as an additive in industrial conductor alloys. Carbon has already proven itself as a good additive in steel, increasing the physical endurance of the steel, however, this experiment proves that in graphite form Carbon can be used as an additive in conductor alloys (e.g. in electronics).

To sum up, this investigation was a demonstration of how effective the graphite composition in an electrical conductor is on the electrical conductivity of the conductor.

APPENDIX

H GRADE PENCILS

7H Graphite Pencil	
Trials	**Current (±1)(mA)**
1	29
2	28
3	28
4	29
5	30
6	28
7	29
8	28
9	27
10	27
11	29
12	29

Table 1: Current passing through the 7H graphite pencil under 2.0V potential differences in 12 trials.

6H Graphite Pencil	
Trials	**Current (±1)(mA)**
1	34
2	34
3	34
4	32
5	35
6	33
7	34
8	32
9	34
10	33
11	34
12	34

Table 2: Current passing through the 6H graphite pencil under 2.0V potential differences in 12 trials.

5H Graphite Pencil	
Trials	**Current (±1)(mA)**
1	34
2	39
3	39
4	36
5	34
6	34
7	39
8	39
9	37
10	38
11	39
12	39

Table 3: Current passing through the 5H graphite pencil under 2.0V potential differences in 12 trials.

4H Graphite Pencil	
Trials	**Current (±1)(mA)**
1	43
2	44
3	42
4	43
5	45
6	43
7	42
8	43
9	43
10	44
11	43
12	42

Table 4: Current passing through the 4H graphite pencil under 2.0V potential differences in 12 trials.

3H Graphite Pencil	
Trials	**Current (±1)(mA)**
1	48
2	47
3	48
4	48
5	47
6	47
7	48
8	48
9	46
10	49
11	48
12	48

Table 5: Current passing through the 3H graphite pencil under 2.0V potential differences in 12 trials.

2H Graphite Pencil	
Trials	**Current (±1)(mA)**
1	78
2	82
3	80
4	84
5	83
6	82
7	82
8	82
9	81
10	80
11	82
12	81

Table 6: Current passing through the 2H graphite pencil under 2.0V potential differences in 12 trials.

H Graphite Pencil	
Trials	**Current (±1)(mA)**
1	80
2	82
3	81
4	82
5	83
6	84
7	82

8	83
9	84
10	82
11	81
12	80

Table 7: Current passing through the H graphite pencil under 2.0V potential differences in 12 trials.

B GRADE PENCILS

B Graphite Pencil	
Trials	**Current (±1)(mA)**
1	112
2	102
3	100
4	111
5	113
6	112
7	114
8	112
9	112
10	113
11	108
12	110

Table 8: Current passing through the B graphite pencil under 2.0V potential differences in 12 trials.

2B Graphite Pencil	
Trials	**Current (±1)(mA)**
1	130
2	132
3	131
4	134
5	129
6	132
7	134
8	132
9	131
10	134
11	132
12	130

Table 9: Current passing through the 2B graphite pencil under 2.0V potential differences in 12 trials.

3B Graphite Pencil	
Trials	**Current (±1)(mA)**
1	140

2	142
3	139
4	138
5	141
6	143
7	143
8	143
9	142
10	144
11	139
12	141

Table 10: Current passing through the 3B graphite pencil under 2.0V potential differences in 12 trials.

4B Graphite Pencil	
Trials	**Current (±1)(mA)**
1	174
2	172
3	171
4	178
5	180
6	182
7	175
8	177
9	173
10	174
11	176
12	177

Table 11: Current passing through the 4B graphite pencil under 2.0V potential differences in 12 trials.

5B Graphite Pencil	
Trials	**Current (±1)(mA)**
1	256
2	272
3	268
4	262
5	249
6	257
7	264
8	248
9	271
10	274
11	279
12	281

Table 12: Current passing through the 5B graphite pencil under 2.0V potential differences in 12 trials.

6B Graphite Pencil

Trials	**Current (±1)(mA)**
1	365
2	360
3	370
4	363
5	367
6	368
7	366
8	371
9	364
10	372
11	374
12	366

Table 13: Current passing through the 6B graphite pencil under 2.0V potential differences in 12 trials.

7B Graphite Pencil	
Trials	**Current (±1)(mA)**
1	453
2	468
3	473
4	482
5	450
6	451
7	451
8	466
9	474
10	482
11	481
12	464

Table 14: Current passing through the 7B graphite pencil under 2.0V potential differences in 12 trials.