Chemistry Extended Essay

"Investigation of the effect of magnetism on copper and iron electrolysis"

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ABSTRACT

Electrolysis has various real life applications in many different areas. It is used in the production many active metals, such as aluminum, and in automobile industry to fortify the metal used in the bodies of cars. Electrolysis is also important for space programs and military, where the electrolysis of water is used to produce necessary oxygen for the personnel in some vehicles such as spacecrafts and submarines. Since the rate of electrolysis is very important for these areas, a new method that increases the rate would benefit many areas that use the electrolysis in the process.

This investigation is concerned with the effect of magnetism on the rate of electrolysis. For speeding up electrolysis for the areas mentioned earlier. The aim was to determine the effect of magnetic field with different magnitudes on the rate of electrolysis of copper and iron at a constant voltage, pressure with the same concentration of $CuSO_4$ solution in 3 minutes. Two separate circuit systems were used, one being the electrolysis and other being the electromagnet. The experimentation process of the investigations consists of two parts. First experiment was carried out and the results showed an increase in the rate of electrolysis as the magnetic field increased. The second experiment was carried out to explain the gathered data in the first experiment in the light of Faraday's Laws of Electrolysis, since the raw results from the first experiment needed to be expanded to be applicable to the Faraday's Law. After the necessary calculations from the first experiment and data collection from the second experiment, the results were consistent with the Faraday's Law. The final analysis showed that the increase in the strength of the magnetic field has increased the rate of electrolysis exponentially by changing the current of the electrolysis circuit.

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INTRODUCTION

The aim of this investigation is to identify a relation between the rate of electrolysis and the magnetic field. The chosen fields of study are Chemistry and Physics because the magnetic field and electrolysis are both concerned with the way charged particles' move. The research question can be narrowed down to ***"What is the effect of magnetic field with different magnitudes on the rate of electrolysis of copper and iron at a constant voltage, pressure with the same concentration of $CuSO_4$ solution in 3 minutes?"***

From the core subject High Level Chemistry and Physics in the IB curriculum it is taught that electrochemistry and magnetism play an important role in our lives even though we don't notice them too much. The batteries that we use in daily life are based on redox reactions, which are an evolved version of an electrolytic cell. Also we use electrolysis in industrial process such as electroplating or electrolysis of water to obtain hydrogen and oxygen gases. In addition magnetism, also play an important role in our lives. From Magnetic Resonance Imaging in medicine to headphones magnetism has a great number of real-life applications.

The reason of integration of Chemistry and Physics is that, although their fields of study are the study of matter in different aspects, as Physics is the study of matter and its motion and the Chemistry is the study of the matter in molecular level, they have common elements, such as particle physics and electrochemistry. The way atomic particles behave in particle physics for a certain physical situation is also valid for how particles behave in chemistry in the same circumstances therefore affecting the way the chemical reactions occur.

The magnetic field accelerates charged particles by applying a force on them and since the electrolysis occurs by the movement of ions in a solution, the magnetic field should have an effect on the ions movement in electrolysis. (See Appendix 2 for detailed information.)

If such an effect is discovered, the hypothesis is that the electrolysis process will be easier to carry out in industrial use, which will speed up the production of materials and benefiting the economy.

The investigation of the effect of magnetism on electrolysis required an original experimental setup and procedure because of the fact that there weren't any designated procedures for this kind of investigation. The electrolysis setup and an electromagnet were needed to be combined together in order to gather a proper set of data.

This issue was resolved by placing the electromagnet below the electrolysis setup with the help of a tripod. The chosen place for electromagnet was below the electrolysis setup since the optimum effect of the magnetism could be evenly distributed.(See Figure 1)

Electrolysis

Atoms consist of electrically charged particle, which means that electricity has an important role in all the chemical reactions. Electricity is the name given for the flow of charged particles. The current is carried by electrons moves because of a source of potential difference in a circuit. In solutions of salts, the charge is carried in the circuit by the particles called ions. The substances that release ions when they are melted or dissolved in water are called electrolytes. The substances that are responsible for connecting the electrolytes to the current are called electrodes. There are two main electrochemical systems. The first one is called the electrolytic cell, which consists of two electrodes placed into an electrolyte solution and an outside source that provides potential difference is connected to the system. This kind of cells are capable of decompose elements from the solution, which is known as electrolysis and based on a non-spontaneous reaction. The other type of electrochemical cell is the voltaic cell. In this system, two electrodes made up of different metals are placed in an electrolytic solution, which provide a potential difference that creates a current in the system. This system is based on a spontaneous reaction to provide electricity. Both of these systems rely on oxidation-reduction (redox) reactions. In these systems the electrode in which oxidation occurs is called anode, and the electrode in which reduction occurs is called cathode.

Electrolysis is a chemical process, which derives energy from an outside source of electrical energy to decompose molten salts or solutions to produce pure elements. Electrolysis requires two electrodes that are placed in a molten salt or a solution and any kind of direct current source. Similar to voltaic cells, the electrode where the reduction process occurs is referred as cathode. Other electrode where the oxidation process occurs is referred as anode. To this process to occur correctly, anode should be connected to the negatively charged side of the power source and the cathode should be connected to the positively charged side of the power supply. The negatively charged side repels the electrons and the positively charged side attracts electrons. This incident provides the circle that enables the electrons to transfer from one electrode to another. In other words electric current enables to drive a reaction, which is actually non-spontaneous in standard conditions.

Picture 1: Electrolysis.[1]

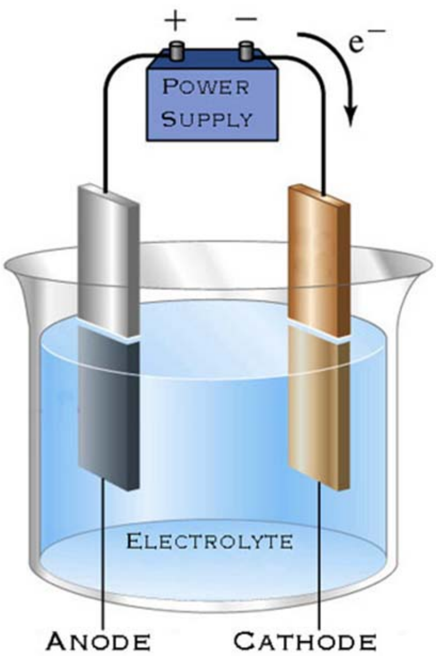

Illustration of a simple electrolysis setup

Electrolysis is a very important industrial process, which is used in the production process of active metals such as magnesium, sodium, and aluminum.[2] There are some customized processes that enable to extract pure metals from rocks such as the Hall-Héroult Process for the production of aluminum.[3] The process dissolves alumina in molten cryolite, which is a natural mineral containing alumina, and electrolyzing the molten salt bath to obtain pure aluminum metal.

[1] http://www.ustudy.in/sites/default/files/electrolysis.jpg
[2] http://en.wikipedia.org/wiki/Electrolysis#Industrial_uses
[3] http://peter-entner.com/E/Theory/PrincHH/PrincHH.aspx

Picture 2: Hall-Héroult Process[4]

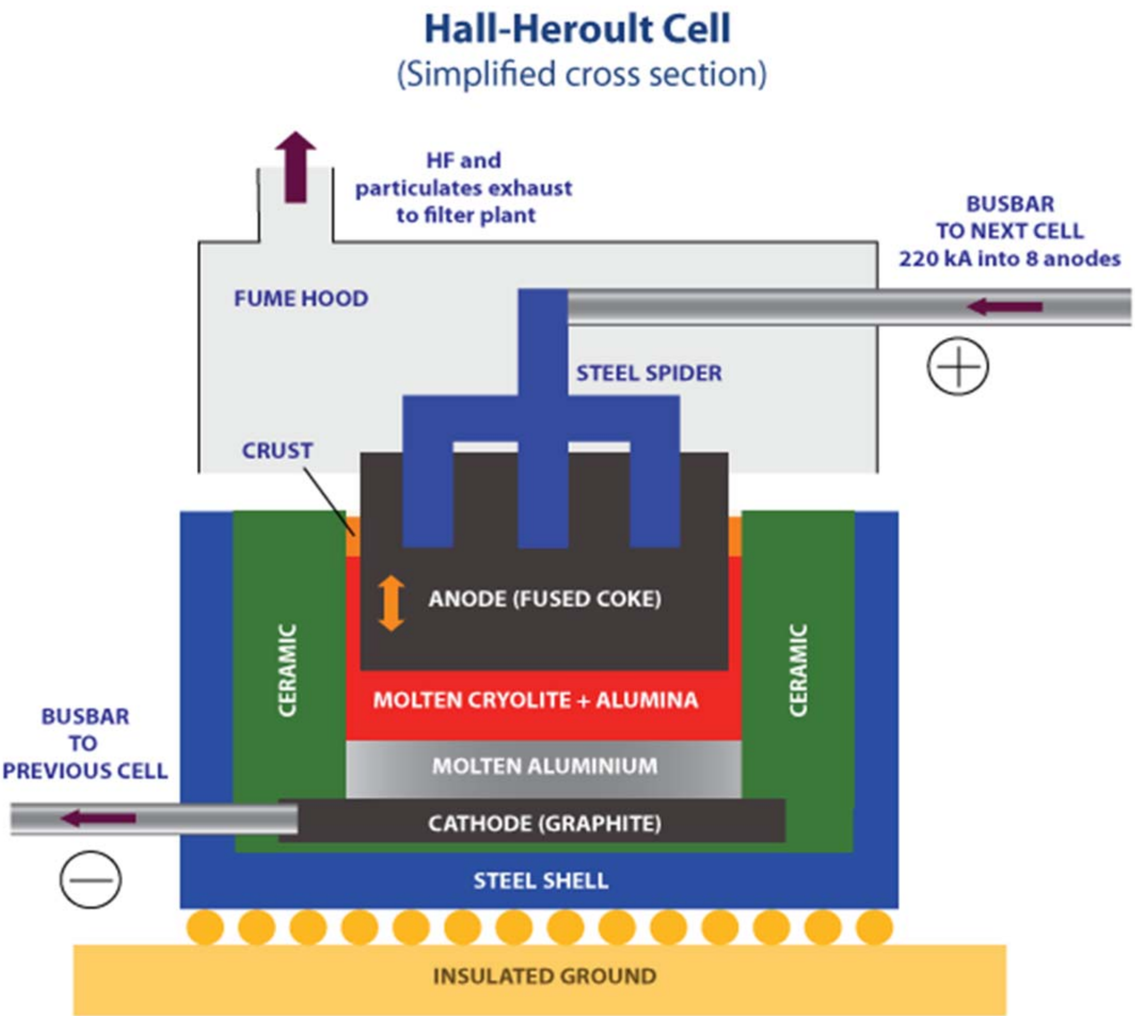

Illustration of Hall- Héroult Process for producing aluminum

Electrolysis is also used in submarines and spacecrafts to provide oxygen to the personnel as a life support, which is known as the electrolysis of water. Electrolysis of water is basically the decomposition of water into oxygen and hydrogen gases with the help of electricity. The methodology is the same with electrolysis, however since the electrodes need to be metal, inert metals such as platinum or stainless steel that are placed into water. Water in itself releases hydronium (H_3O^+) and hydroxide (OH^-) ions at a small amount in standard

[4] http://en.wikipedia.org/wiki/File:Hall-heroult-kk-2008-12-31.png

conditions, which is known as the self-ionization of water.[5] When electricity is given to the water these ions get oxidized and reduced in which the hydrogen is produced at the cathode and the oxygen produced at the anode.

Another way the electrolysis is used in the form of electroplating which is used to fortify metals. Electroplating is the process in which, a thin layer of a metal covers another metal with the help. The metal that is going to be covered is connected to the cathode and the electrolyte solution must contain the metal ions that are responsible of plating.

This method is used tremendously in automobile industry to fortify vehicle bodies and also to prevent them from rusting. Audi, one of the largest automobile companies, uses this method to prevent their aluminum chassis from rusting.[6] Another area that electroplating is used is the electronic components. In this method copper is being used to increase the conductivity in the circuits, which is known as the printed circuit board (PCB).[7] Magnetic field can be used in these areas to increase the speed of production.

Faraday’s Law of electrolysis

Michael Faraday has published a quantitative relationship based on his electrochemical researches. His law states that;

“The amount of a substance consumed or produced at one of the electrodes in an electrolytic cell is directly proportional to the amount of electricity that passes through the cell.”[8]

Q=Ixt

Faraday’s law of electrolysis where;

Q is the electric charge in Coulomb,

I is the value of current in Amperes,

T is the time it took for electrolysis to occur in seconds and,

X is the vector cross product.

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[5] http://chemwiki.ucdavis.edu/Physical_Chemistry/Acids_and_Bases/PH_Scale
[6] http://www.tms.org/pubs/journals/JOM/0108/Kelkar-0108.html
[7] http://en.wikipedia.org/wiki/Printed_circuit_board
[8] http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch20/faraday.php

Any investigation or experiment on the electrolysis must be consistent with the Faraday's Law of Electrolysis. Faraday's Law has an important role in this investigation since it's used to process data and the effects of magnetism are explained in the baseline of this law.

Magnetism

An electromagnet is a type of magnet that produces a magnetic field by the moving particles in its current. These types of magnets aren't permanently magnetized. The magnetic field disappears when the current stops. This characteristic of electromagnets makes them adjustable to required magnetic field. When the current flowing through the electromagnet is increased the magnetic field strength also increases, and when the current decreases the magnetic strength also decreases.

Structure and principles of an electromagnet are shown in the Appendix 2.

PLANNING AND DEVELOPMENT

The specific type of electrolysis used in this experiment is the copper iron electrolysis. This electrolysis in $CuSO_4$ solution is one of the most common and simple electrolysis. Change in the mass of electrodes can be measured easily rather than measuring the gas emission in electrolysis of water. Simplicity of the measurements is important because more complex measurements would result in more error sources, making the collected data in the experiment more unreliable. The measurement of the change can simply be detected by weighing the copper electrode.

The experimentation of the investigation consisted of two parts. First experiment was carried out to determine if there are any changes in the electron transfer with the different strength of magnetism. The results in the first experiment required further investigation of the subject since the results must be consistent with Faraday's Law of Electrolysis, which is mentioned earlier. The results of the first experiment showed that there is an effect of magnetism, which cannot be explained due to the fact that magnetism isn't a variable according to Faraday's Law. Either magnetism changes the variables in electrolysis or an experimental error was present.

With the assumption that magnetic field has an effect on the variables; the current circling in the electrolysis circuit, which is the only remaining variable since the time is fixed, was determined to have changed because of magnetism. The second experiment was carried out with the same procedures to test the hypothesis of the magnetism affecting the value of current in electrolysis, by readapting the experimental setup to collect data for changing current value. The results of the second experiment are then reviewed and with the data taken into consideration from both of the experiments. The analysis was carried out by calculating the current values from Experiment 1 using Faraday's Law, and comparing them to the measured values from the Experiment 2.

Research Question: ***"What is the effect of magnetic field with different magnitudes on the rate of electrolysis of copper and iron at a constant voltage, pressure with the same concentration of $CuSO_4$ solution in 3 minutes?"***

EXPERIMENT 1

Variables and Constants

Constants

Volt given for electrolysis to occur, concentration of $CuSO_4$ solution, kind of electrodes, surface area of electrodes, atmospheric pressure, time, initial temperature.

Volt given to electrolysis circuit was determined to be 12, since the electrolysis will occur faster. The $CuSO_4$ solution was changes for every trial, keeping the concentration constant. The experiment carried out in the same place so a change in the atmospheric pressure wasn't to be discussed. Initial temperature was 22 ^{0}C and was kept constant by waiting the experimental setup to cool down between trials.

Variables

Independent Variable: The magnitude of magnetic field applied on the electrolysis

Dependent Variable: The moles of electrons transferred per unit time (3 minutes.)

Procedure and materials for the experiment are shown in Appendix 3.

Figure 1: Experimental Setup

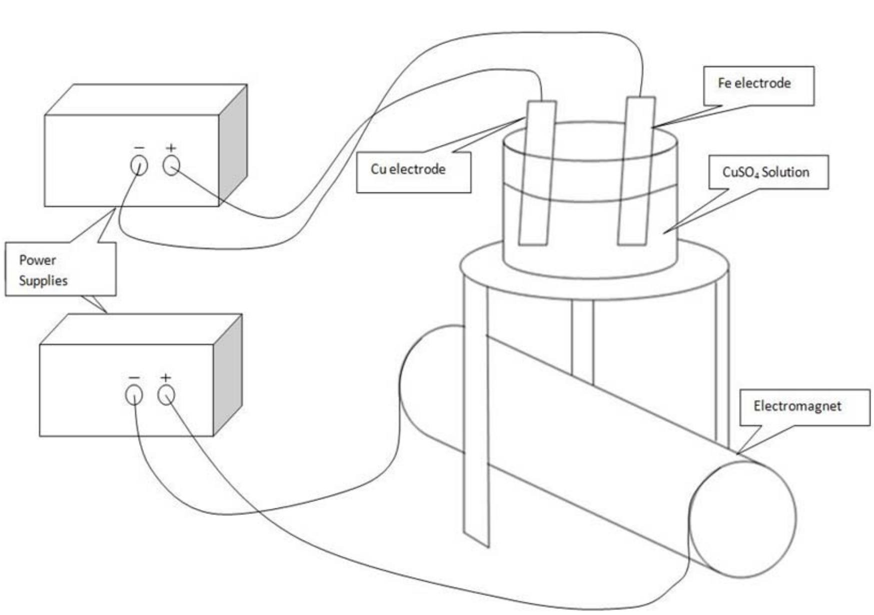


Illustration of the experimental setup consisting all the elements used in the experiment

Data Collection of Experiment 1

After all the data was collected from the experiment, the change in mass in copper electrode was calculated. By doing this, it was possible to determine the moles of copper transferred in electrolysis.

Table 1. Change in mass of the copper

Trial Number	State of the Copper Electrolyte	Mass of copper electrode in grams ± 0.01 (Trial Groups arranged by Amperes given to the Electromagnet)					
		0 A ± (0.01) (control group)	10 A ± (0.01)	12 A ± (0.01)	14 A ± (0.01)	16 A ± (0.01)	18 A ± (0.01)
1	Before	42.10	41.99	41.86	41.70	41.53	41.29
	After	41.99	41.86	41.70	41.53	41.29	40.94
2	Before	40.94	40.83	40.68	40.51	40.28	40.01
	After	40.83	40.68	40.51	40.28	40.01	39.70
3	Before	39.65	39.53	39.39	39.23	39.03	38.78
	After	39.53	39.39	39.23	39.03	38.78	38.43
4	Before	38.43	38.32	38.18	38.01	37.80	37.54
	After	38.32	38.18	38.01	37.80	37.54	37.17
5	Before	37.17	37.05	36.90	36.74	36.54	36.29
	After	37.05	36.90	36.74	36.54	36.29	35.95

Table showing the mass of the copper electrode before and after the electrolysis for each trial group

By subtracting the after values to before the change in mass for copper electrode for each trial was found as shown in Table 2.

Table 2: Change in mass for copper

	Change in mass for each trial and average values in grams ± (0.01) (Trial Groups arranged by Amperes given to the Electromagnet)					
Trial no	0 A ± (0.01) (control group)	10 A ± (0.01)	12 A ± (0.01)	14 A ± (0.01)	16 A ± (0.01)	18 A ± (0.01)
1	0.11	0.13	0.14	0.17	0.24	0.35
2	0.11	0.15	0.17	0.23	0.27	0.36
3	0.12	0.14	0.16	0.20	0.25	0.35
4	0.11	0.14	0.17	0.21	0.26	0.37
5	0.12	0.15	0.16	0.20	0.25	0.34
Average	0.11 (± 0.01)	0.14 (± 0.01)	0.16 (± 0.02)	0.20 (± 0.02)	0.25 (± 0.02)	0.35 (± 0.02)

Table showing the change in mass for copper electrode in every trial and in average with uncertainties

Average Uncertainties are calculated with the formula;

$$Uncertainty = \frac{Highest\ value - Lowest\ value}{2}$$

The values required to be rounded up due to the dependence of the significant figures.

Calculations of the Magnetic Field Strength are shown in the Appendix 1.

Calculation of the Moles of Copper and Electrons

Since copper releases two electrons (reaction shown below) the mole of electrons are found by doubling the moles of copper.

$$CuSO_{4(solid)} \rightarrow Cu^{2+}_{(aqueus)} + SO^{2-}_{4(aqueus)}$$

$$Cu_{(solid)} \rightarrow Cu^{2+}_{(aqueus)} + 2e^{-}$$

Trial Group 0 A

1 mole Cu = 63.5 g

$$Moles\ of\ Cu = \frac{Weight\ of\ transferred\ Cu}{Molecular\ Weight\ of\ Cu}$$

$$Moles\ of\ Cu = \frac{0.11}{63.5} = 1.8x10^{-3}moles$$

Sample uncertainty calculation for moles of copper,

$$Uncertainty = \frac{(Uncertainty\ of\ the\ weight\ copper)x100}{Weight\ of\ copper}$$

This equation was derived from the percentage uncertainty calculation.

Trial Group 0 A

$$Uncertainty = \frac{0.01x100}{0.11} = 9\%$$

Sample Calculation of moles of electrons from moles of copper,

$$Moles\ of\ e^{-} = 2xMoles\ of\ Cu$$

Trial Group 0 A

$$Moles\ of\ e^{-} = 2x1.8x10^{-3} = 3.6x10^{-3}moles$$

The uncertainties of moles of electrons are also double as shown below,

$$Uncertainty = \frac{(Uncertainty\ of\ the\ weight\ copper)x100}{Weight\ of\ copper}x2$$

$$Uncertainty = \frac{0.01x100}{0.11}x2 = 18\%$$

The complete calculations are shown in the Appendix 2.

Table 3: Magnetic field strength in Tesla and average number of moles of copper and electrons

Trial Group	Magnetic Field strength in Tesla with average uncertainties	Average number of moles of copper transferred for each trial group with uncertainties	Average number of moles of electron transferred for each trial group with uncertainties
	(±0.02)	10^{-3}	10^{-3}
0 A	0	1.8 ± 9%	3.6 ± 18%
10 A	0.87	2.2 ± 7%	4.4 ± 14%
12 A	1.04	2.5± 12%	4.9 ± 22%
14 A	1.22	3.1± 10 %	6.3 ± 20%
16 A	1.39	3.9 ± 8%	7.9 ± 16%
18 A	1.56	5.6± 5%	11.2 ± 10%

Table showing the processed data of magnetic field strength in Tesla and average number of moles of copper and electrons with uncertainties.

$$Q = Ixt$$

Faraday's law of electrolysis where;

Q is the electric charge in Coulomb,

I is the value of current in Amperes,

T is the time it took for electrolysis to occur in seconds and,

X is the vector cross product.

As obvious from the equation, the effects of magnetism cannot be explained since the magnetism itself is not a variable. From this point of view since the volt given to the electrolysis is constant, the magnetic field should have changed the resistance of the electrolytic cell therefore increased the current travelling in the circuit. To prove this hypothesis, a follow up experiment needed to be done.

EXPERIMENT 2

The second experiment is carried out by the same setup and procedures as the first one, but in this experiment an ammeter was added to the circuit that electrolysis occurred.

Data Collection of the Experiment 2

Table 4: Measured and average Ampere values for Electrolysis

Trial Number	Measured Ampere Values for Electrolysis (± 0.01) (Trial Groups arranged by Amperes given to the Electromagnet)					
	0 A (± 0.01)	10 A (± 0.01)	12 A (± 0.01)	14 A (± 0.01)	16 A (± 0.01)	18 A (± 0.01)
1	1.93	2.39	2.63	3.37	4.26	5.90
2	1.94	2.40	2.65	3.38	4.29	5.84
3	1.93	2.40	2.64	3.39	4.28	5.93
4	1.91	2.43	2.65	3.38	4.26	5.95
5	1.93	2.41	2.64	3.37	4.28	5.90
Average	1.93	2.4.0	2.64	3.38	4.28	5.92

Table showing the measured and average Ampere values for Electrolysis from Experiment 2 with uncertainties

Calculation of the current from the results of the Experiment 1

These calculations were carried out to compare the results of the Experiment 2 to Experiment 1. Sample calculations are shown below for data processing.

Trial Group 0 A

Conversion of the mole of electrons to Coulomb

1 mole of e = 96500 C

$$0.0036 \times 96.500 = 340(\pm 18\%)\ C$$

Calculation of the current from the Faraday's law of electrolysis

$Q = Ixt \qquad I = \frac{Q}{t}$

t=3 min = 180.0 (± 0.2)sec $\qquad I = \frac{340}{180.0} = 1.910\ (\pm\ 0.080)\ A$

Percentage Error Calculations

Sample calculation for percentage error calculation of current values is shown below.

Trial Group 0 A

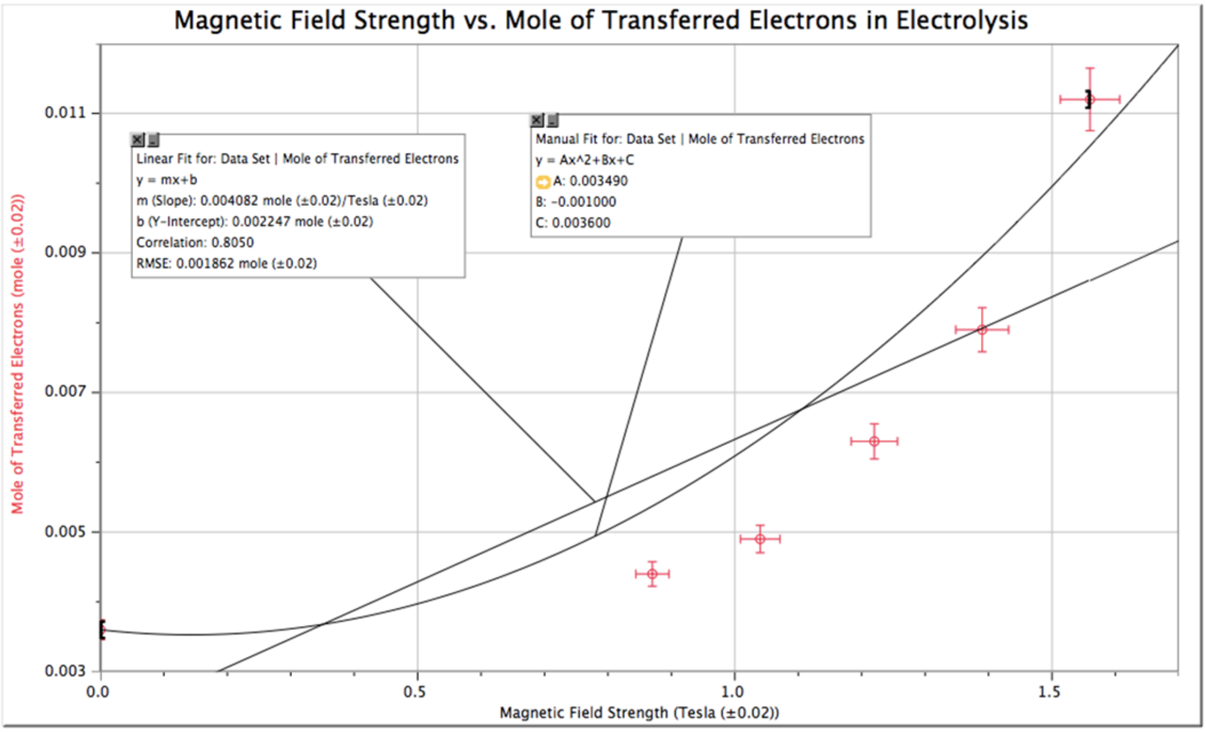
$$\%Error = \frac{(I_{measured} - I_{calculated})}{I_{measured}} \times 100$$

$$\%Error = \frac{1.93 - 1.91}{1.93} \times 100 = 1.03$$

The complete calculations are shown in the Appendix 2.

RESULTS

Graph 1: Graph showing the processed data



Graph showing the processed data of the change in the mole of transferred electrons with the rising magnetic field strengths (manual and linear fit with error values are shown)

The research question was to determine the effects of magnetism on the process of electrolysis. In the first experiment the aim was to identify a change in the rate of electrolysis and if there is an effect of the magnetism on the rate. The results of the first experiment showed a trend in which the moles of copper transferred increased as the magnetic field strength increased. The increase in the moles of transferred electrons is not directly proportional to the magnetic field strength. Since the magnetic field applies a force on ions and the force is proportional with energy where energy is directly the square of the velocity, increase in the rate of electrolysis is exponential. After the data was obtained, the weight of the transferred copper was used to calculate the moles of transferred copper. The copper metal releases two electrons when it dissolves in solutions and creates Cu^{2+} ions.[9] Therefore in order to calculate the moles of electrons transferred the value of moles of copper needed to be

[9] http://en.wikipedia.org/wiki/Copper

doubled. Also the magnetic field strength was calculated. In the Graph 1 this trend is illustrated with best fit and manual fit lines. The linear fit value showed that there is an average $4x10^{-3}$ more transferred electrons per 1 Tesla.

Table 5: Current values

	Trial Groups					
	0(± 0.01) A	10(± 0.01) A	12(± 0.01) A	14(± 0.01) A	16(± 0.01) A	18(± 0.01) A
Calculated current	1.91 (± 0.08)	2.36 (± 0.08)	2.65 (± 0.08)	3.44 (± 0.08)	4.27(± 0.08)	5.96 (± 0.08)
Measured Average Current	1.93 (± 0.01)	2.40 (± 0.01)	2.64 (± 0.01)	3.38 (± 0.01)	4.28 (± 0.01)	5.92 (± 0.01)
Error Percentage	1.03	1.67	1.13	1.74	0.23	0.67

Table showing the calculated and measured current values from both experiments and percentage error values with uncertainties.

In the process of experimentation there were some instances that needed to be noted, however did not have any impacts on the process itself. The first one is the excessive heat emission from both the electrolysis and the electromagnet. Another one is the melting of the plastic cover on the cables due to overheating.

The data obtained in the second experiment showed that the increased strength of the magnetic field resulted in the increase of the current flowing in the circuit that electrolysis occurs. In order to link the data obtained in the two experiments and decide if the results are consistent the value of current was calculated using the data from the first experiment and then two results were compared (See Table 5). This calculation was conducted by using the Faraday's law of electrolysis. The moles of electrons were converted to the units of Coulomb by multiplying them with the Faraday constant. Also the time was converted from minutes to seconds. By doing as such it was possible to use the data to calculate the ampere from the first experiment. The product of division of the Coulomb value to the time, the average Ampere value of the current was calculated.

The calculated and measured Ampere values did not have high percentage difference, which means that the data collected from the two experiments were consistent. However the uncertainty values decrease the reliability of the results.

CONCLUSION

The problem with the experimentation process of this investigation was that the results of the first experiment were not consistent with the Faraday's Law of electrolysis since the variables in electrolysis are determined to be the time and current in the circuit of the electrolysis. Faraday's law state that the mass of a substance altered at an electrode during electrolysis is directly proportional to the quantity of electrical charge transferred at the electrode. However the data clearly showed that there was an increase in the transferred moles of electrons with the increased magnetic strength.

After researching about this issue, it presumed that magnetic field should have affected the resistance of the circuit by accelerating them more therefore, since the volt given for electrolysis to occur is constant, increased the current in electrolysis. To prove this hypothesis a second experiment needed to be done to determine the effects of magnetism to the current and the resistance of the electrolysis. In the second experiment the procedure was the same except, an ammeter was added in the electrolysis circuit to measure the value of current.

The results of the second experiment showed that the increase in the strength of the magnetic field increased the current in the electrolysis circuit. The increase was also consistent with the calculation of the first experiment. The final results show that the increase in magnetic field strength accelerated the rate of electrolysis in unit time by decreasing the current that flows in the circuit.

EVALUATION OF THE EXPERIMENT AND RESULTS

In the calculation process, it was found that the measurements of current in the electrolysis are consistent with calculations of the current by using the Faraday's law of electrolysis. Each data for trial group had less than 2 percent error. However there isn't any literal value for the results of the experiment, which means that the results cannot be compared to any scientific value to calculate errors for the experiment. In addition, the moles electrons also had a high percentile (around 15%) uncertainty.

The increase in the average rate of electrolysis is demonstrated in the Graph 1. However as it can be seen by the graph the rate has increased exponentially in the last two trial groups resulting in the issue of further investigation to find the limit of acceleration of the rate of electrolysis. The acceleration should have a limit because even though the magnetism decreases the resistance, it cannot be less than zero since it would mean a short circuit due to Ohm's law.[10] The experimental setup and resources weren't available to investigate the further effects of the magnetism since the temperature of the electromagnet had increased to dangerous level, resulting in the conclusion of the experiment due to safety reasons.

EVALUATION OF THE MATERIALS AND METHOD

The preparations for and the development of the experiment were carried out only by myself in the Chemistry Labs at TED Ankara College Foundation High School. No help of any kind was required except getting the lab equipment. The preparation of the experiment was quite challenging. The process of making the electromagnet was really hard since it was handmade and the copper wire had to be rolled around the iron core numerous times. It was also hard to correctly adjust the current given to the electromagnet because of a few failed attempts resulting in short circuit. During the experiment, as it was said earlier, the electromagnet started to overheat after giving it 14 Amperes. Heatproof gloves were put below and above the electromagnet to avoid damaging school property and the risk of fire.

[10] http://www.physics.uoguelph.ca/tutorials/ohm/Q.ohm.intro.html

Yet, it was still not possible to stop it from overheating. These problems can affect the usage of magnetism to speed up the electrolysis since it can cause more harm in industrial use if used in bigger scales. A solution for this problem can be the usage of larger electromagnets, since larger electromagnets don't emit such heat as smaller ones with their lower specific heat values.[11]

Another limitation for this experiment was the kind of electrolysis used for the experiment. Investigation is based on only the copper iron electrolysis, and the results may not be the same if other kind of electrolysis were tried.

The high uncertainty problem can be solved, if the experiment is carried out in a larger scale with excess time for example around an hour. This will decrease the percentage caused by the digital scale and the chronometer.

FURTHER INVESTIGATION

The results show that the magnetic field is a beneficial way to speed up the electrolysis process that can benefit the economy by producing more material in a limited time. However the overall energy consumed by the electromagnet may not cost-beneficial or can have bad effects to the environment due to overconsumption of electricity.

Overheating of the electromagnet was also a major issue in the experimental procedure. In order to decrease the negative effects caused by the overheating, electromagnets with larger sizes can be used since the larger magnets have lower specific heat values.

Another topic is the investigation of the effects of magnetism on other kind of electrolysis. The fact that this investigation was carried out by only one type of electrolysis decreases the reliability of the results gathered in the experiment. In order to prove magnetic field has an exact effect on electrolysis, other investigations should be carried out with different kinds of electrolysis, especially obtaining aluminum from its minerals, since aluminum is used in many chemical reactions as a reductant and used in many areas such as the production of aluminum folio, rocket propellant and explosives.

[11] http://en.wikipedia.org/wiki/Electromagnet

APPENDIX 1

Structure and Principles of an Electromagnet

The structure of an electromagnet is fairly simple. Electromagnets have two main parts, a solenoid, and an iron core. The Lorentz Force provides the explanation of the way the charged particles behave.

- Solenoid

Solenoid is a tightly packed loop of wire that allows the electric current to flow inside it. According to Hans Christian Oersted's discovery about magnetism, which is a current carrying wire creates a magnetic field around it; a solenoid creates a uniform magnetic field when a current is present. This makes solenoids the main part of electromagnet.

- Iron core

Iron core in electromagnets are used to magnify the strength of the magnetic field. Usually, the solenoid is encircled around the iron core to acquire the maximum efficiency from the core. Pure iron core is able to magnify the strength of the magnetic field as much as thousand times. Steels on the other hand usually magnify the strength a hundred times on average.

- Lorenz Force

Lorentz force is the force exerted on an ionic particle by the magnetic field.
$$\mathbf{F} = q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})],$$

Where

F is the force (in Newtons)

E is the electric field (in volts per meter)

B is the magnetic field (in Teslas)

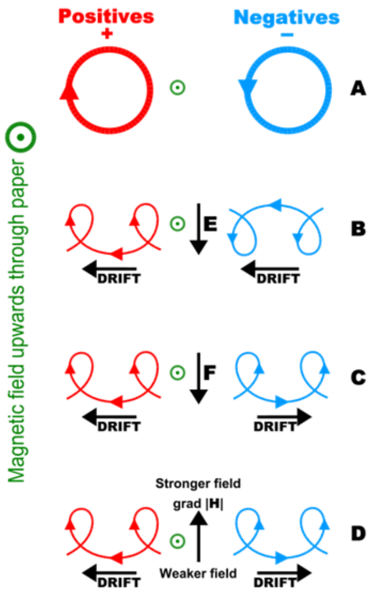
q is the electric charge of the particle (in Coulombs)

v is the instantaneous velocity of the particle (in meters per second)

× is the vector cross product

All the quantities written in boldface are vectors.

This force makes charged particles to gain acceleration and move rapidly when the force is present. However Lorenz force also has an effect on particles that makes them move in circular motion. (See Picture 3.)



Picture 3: Charged particle drifts in magnetic field.[12]

[12] http://en.wikipedia.org/wiki/File:Charged-particle-drifts.svg

Calculations of the Magnetic Field Strength

$B = \frac{kM_0IN}{L}$,

where B is the magnetic field strength in Tesla, k is the relative coefficient of permeability of the stainless steel to $M_{0,}$ $M_{0,}$ is the magnetic permeability of the vacuum, N is the number of turn of the electromagnet and L is the length of the electromagnet.

There cannot be any calculations for Trial Group 0 A since there wasn't any magnetic field exerted on the electrolysis.

The manufacturer of the steel, Ankara Steel Pipe Limited Liability Company, provided the value of k the relative coefficient of permeability.

Trial Group 10 A

$B = \frac{kM_0IN}{L}$ k=105 for stainless steel, M_0=4π10^{-7}, length of the electromagnet L= 0.175m, total turns of the electromagnet N=121

$B = \frac{105\times4\pi10-7\times10\times121}{0.175} = 0.87 \pm 0.01 \ Tesla$

$$Uncertainty = \frac{0.01}{0.001}x10^{-2} = 0.01$$

Trial Group 12 A

$B = \frac{kM_0IN}{L}$ k=105 for stainless steel, M_0=4π10^{-7}, length of the electromagnet L= 0.175m, total turns of the electromagnet N=121

$B = \frac{105\times4\pi10-7\times12\times121}{0.175} = 1.04 \pm 0.01 \ Tesla$

$$Uncertainty = \frac{0.01}{0.001}x10^{-2} = 0.01$$

Trial Group 14 A

$B = \frac{kM_0IN}{L}$ k=105 for stainless steel, $M_0=4\pi10^{-7}$, length of the electromagnet L= 0.175m, total turns of the electromagnet N=121

$B = \frac{105\times4\pi10-7\times14\times121}{0.175} = 1.22 \pm 0.01\ Tesla$

$$Uncertainty = \frac{0.01}{0.001}x10^{-2} = 0.01$$

Trial Group 16 A

$B = \frac{kM_0IN}{L}$ k=105 for stainless steel, $M_0=4\pi10^{-7}$, length of the electromagnet L= 0.175m, total turns of the electromagnet N=121

$B = \frac{105\times4\pi10-7\times16\times121}{0.175} = 1.39 \pm 0.01\ Tesla$

$$Uncertainty = \frac{0.01}{0.001}x10^{-2} = 0.01$$

Trial Group 18 A

$B = \frac{kM_0IN}{L}$ k=105 for stainless steel, $M_0=4\pi10^{-7}$, length of the electromagnet L= 0.175m, total turns of the electromagnet N=121

$B = \frac{105\times4\pi10-7\times18\times121}{0.175} = 1.56 \pm 0.01 Tesla$

$$Uncertainty = \frac{0.01}{0.001}x10^{-2} = 0.01$$

APPENDIX 2

Calculations of the moles of Copper and Electron

Trial Group 10 A

1 mole Cu = 63.5 g

$$Moles\ of\ Cu = \frac{Weight\ of\ transferred\ Cu}{Molecular\ Weight\ of\ Cu}$$

$$Moles\ of\ Cu = \frac{0.14}{63.5} = 2.2x10^{-3} moles$$

Trial Group 12 A

1 mole Cu = 63.5 g

$$Moles\ of\ Cu = \frac{Weight\ of\ transferred\ Cu}{Molecular\ Weight\ of\ Cu}$$

$$Moles\ of\ Cu = \frac{0.15}{63.5} = 2.5x10^{-3} moles$$

Trial Group 14 A

1 mole Cu = 63.5 g

$$Moles\ of\ Cu = \frac{Weight\ of\ transferred\ Cu}{Molecular\ Weight\ of\ Cu}$$

$$Moles\ of\ Cu = \frac{0.16}{63.5} = 3.1x10^{-3} moles$$

Trial Group 16 A

1 mole Cu = 63.5 g

$$Moles\ of\ Cu = \frac{Weight\ of\ transferred\ Cu}{Molecular\ Weight\ of\ Cu}$$

$$Moles\ of\ Cu = \frac{0.20}{63.5} = 3.9x10^{-3}moles$$

Trial Group 18 A

1 mole Cu = 63.5 g

$$Moles\ of\ Cu = \frac{Weight\ of\ transferred\ Cu}{Molecular\ Weight\ of\ Cu}$$

$$Moles\ of\ Cu = \frac{0.35}{63.5} = 5.6x10^{-3}moles$$

Calculations of the value of current from the results of the Experiment 1

Trial Group 0 A

Conversion of the mole of electrons to Coulomb

1 mole of e = 96500 C

$0.0036 \times 96.500 = 343(\pm\ 18\%)\ C$

Calculation of the current from the Faraday's law of electrolysis

$Q = Ixt \qquad I = \frac{Q}{t}$

t=3 min = 180.0(± 0.2) sec $\qquad I = \frac{343}{180.0} = 1.910(\pm\ 0.080)\ A$

Trial Group 10 A

Conversion of the mole of electrons to Coulomb

1 mole of e = 96500C

$0.0044 \times 96500 = 425(\pm 14\%)\ C$

Calculation of the current from the Faraday's law of electrolysis

$Q = Ixt \qquad I = \frac{Q}{t}$

t=3 min = 180.0 (± 0.2) sec $\qquad I = \frac{425}{180.0} = 2.360(\pm 0.080)\ A$

Trial Group 12 A

Conversion of the mole of electrons to Coulomb

1 mole of e = 96500C

$0.0049 \times 96500 = 477(\pm 22\%)\ C$

Calculation of the current from the Faraday's law of electrolysis

$Q = Ixt \qquad I = \frac{Q}{t}$

t=3 min = 180.0 (± 0.2) sec $\qquad I = \frac{476.8}{180.0} = 2.630\ (\pm 0.080) A$

Trial Group 14 A

Conversion of the mole of electrons to Coulomb

1 mole of e = 96500C

$0.0063 \times 96500 = 607\ (\pm 22\%) C$

Calculation of the current from the Faraday's law of electrolysis

$Q = Ixt \qquad I = \frac{Q}{t}$

t=3 min = 180.0 (± 0.2) sec $\qquad I = \frac{607}{180.0} = 3.44\ (\pm 0.080) A$

Trial Group 16 A

Conversion of the mole of electrons to Coulomb

1 mole of e = 96500C

$0.0079 \times 96500 = 768(\pm 16\%)\ C$

Calculation of the current from the Faraday's law of electrolysis

$Q = Ixt \qquad I = \frac{Q}{t}$

t=3 min = 180.0(± 0.2) sec $\quad I = \frac{768}{180.0} = 4.270(\pm 0.080)\ A$

Trial Group 18 A

Conversion of the mole of electrons to Coulomb

1 mole of e = 96500C

$0.0112 \times 96500 = 1072\ (\pm 10\%) C$

Calculation of the current from the Faraday's law of electrolysis

$Q = Ixt \qquad I = \frac{Q}{t}$

t=3 min = 180.0 (± 0.2) sec $\quad I = \frac{1072}{180.0} = 5.900(\pm 0.080)\ A$

Percentage Error Calculations

Trial Group 0 A

$$\%Error = \frac{(I_{measured} - I_{calculated})}{I_{measured}} \times 100$$

$$\%Error = \frac{1.93 - 1.91}{1.93} \times 100 = 1.03$$

Trial Group 10 A

$$\%Error = \frac{(I_{measured} - I_{calculated})}{I_{measured}} \times 100$$

$$\%Error = \frac{2.40 - 2.36}{2.40} \times 100 = 1.67$$

Trial Group 12 A

$$\%Error = \frac{(I_{measured} - I_{calculated})}{I_{measured}} \times 100$$

$$\%Error = \frac{2.65 - 2.63}{2.65} \times 100 = 1.13$$

Trial Group 14 A

$$\%Error = \frac{(I_{measured} - I_{calculated})}{I_{measured}} \times 100$$

$$\%Error = \frac{3.44 - 3.38}{3.44} \times 100 = 1.74$$

Trial Group 16 A

$$\%Error = \frac{(I_{measured} - I_{calculated})}{I_{measured}} \times 100$$

$$\%Error = \frac{4.28 - 4.27}{4.28} \times 100 = 0.235$$

Trial Group 18 A

$$\%Error = \frac{(I_{measured} - I_{calculated})}{I_{measured}} \times 100$$

$$\%Error = \frac{5.96 - 5.92}{5.96} \times 100 = 0.671$$

APPENDIX 3

Materials

- 500.0 (± 0.1) mL beaker
- 5.0 (± 0.1) L 0.5 M $CuSO_4$ solution
- 100.0 (± 0.1) mL acetone
- 2 adjustable direct current supplies (one of them should be adjustable to 18 A)
- 3.00 meter (± 0.01) long copper wire
- Steel cylinder with 175mm (± 1) height and 25mm (± 1) diameter
- Electric tape
- A thermometer (± 0.5)
- A chronometer (± 0.2)
- A lab tripod
- Copper electrode 6.0(± 0.1)cmx10.0(± 0.1)cmx0.2(± 0.1)cm
- Iron electrode 6.0(± 0.1)cmx10.0(± 0.1)cmx0.2(± 0.1)cm
- 4 crocodile clipped cables (standard size)
- Sandpaper
- Tissue papers
- Digital scale (g) (± 0. 01)

Procedure

Preparation of the Electromagnet

Cover the iron cylinder with tissue paper and fix it in a stable position using electric tape. If not done properly, the system may result in short circuit. Encircle the copper wire to the iron cylinder 121 times and fix the ends with the electric tape. Remove the protective skin at the ends of the wire with the sandpaper to be able to connect it to the circuit, therefore enable the current flow.

Preparation of Experimental Setup

Connect the electromagnet to the adjustable direct current supply by using two of the crocodile clipped cables. Testing the electromagnet before the real experiment is important make sure there are no safety hazard or sort circuits. Also test the magnet by giving electricity to the circuit and make sure that it can reach the designated Ampere values. (0, 12, 14, 16 and 18). Place the tripod above the magnet, and make sure that the tripod isn't attracted by the electromagnet when it is turned on. Pour 200 ml $CuSO_4$ solution to the 500 ml beaker and place the beaker on the tripod. Clean the electrodes using sandpaper and dry with acetone. Weigh the electrodes and write down the measured values. Place the electrodes in the beaker and make sure that they are not touching (leave 1 cm space between electrodes). Connect the copper electrode to the cathode (positive) side of the second power supply using one of the crocodile clipped cables. Connect the iron electrode to the anode (negative) side of the same supply using the last crocodile clipped cable.

Experimental Procedure

There are five trial groups for this experiment consisting of the trial where the current given to the electromagnet is zero, 10, 12, 14, 16 and 18 Amperes. The first trial group is the control group for this experiment.

Start the electrolysis with 12 Volts for the first trial. Start the chronometer also. Stop the electrolysis when 3 minutes are completed. As soon as the electrolysis stops, remove the copper electrode and dry it with a tissue paper and acetone. Observe heat emission from the electrolysis and the electromagnet. Beware of the high temperature of the electrodes. Use precautions concerning the heat emission where necessary. Weigh the electrolyte and write down the result and record the observations. Repeat the instructions to get five trials for Trial Groups 0, 10, 12, 14, 16 and 18 A.

During the experiment the electromagnet had heated up very fast therefore, since there weren't any heatproof mats in the lab, heatproof gloves are used to protect the school property.

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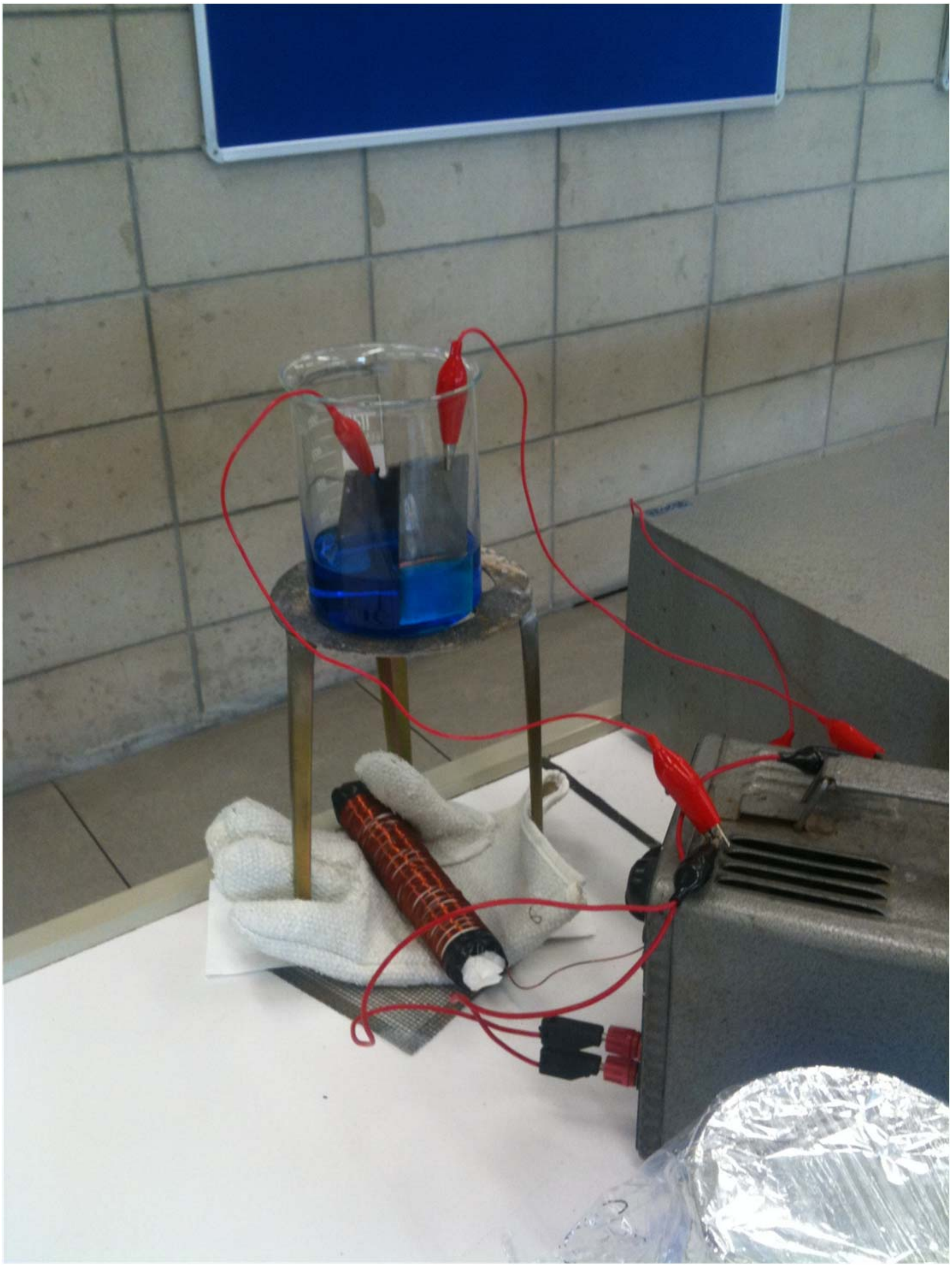
PICTURES FROM THE EXPERIMENT



Picture 4: Photograph of the Experimental Setup

Picture 5: Photograph of the electromagnet while working (Notice the pin attracted by the

magnet)