Investigation on the factors that affect the amount of metal coated in an electroplating process

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ABSTRACT

The aim of this investigation is to test the factors that affect electroplating. To narrow down the topic six of these factors were selected: the amount of current, the time that the current is applied, concentration of the electrolyte, temperature, kind of solution and the oxidation state of the metal ion are the factors that were tested.

The hypothesis for each factor were developed as:
- ▲ The relation between the time and the mass of copper coated should be a direct proportion.
- ▲ For a certain time interval, when the current applied to the electroplating cell is increased, the amount of metal that is coated should also increase.
- ▲ With a concentrated electrolyte, the plated metal amount is expected to be greater compared to the one with a diluted electrolyte.
- ▲ The amount of deposited metal is expected to decrease at higher temperatures.
- ▲ The greatest amount of metal will be plated when copper (II) nitrate electrolyte is used.
- ▲ The number of moles of metal plated will have a relation as: silver > copper > aluminum.

After a series of experiments and calculations the following were concluded:
- ▲ Time is directly proportional with the amount of coated metal.
- ▲ If the current applied to the cell is increased, the amount of plated metal also increases in a direct proportion.
- ▲ When the concentration of the electrolyte is increased, the amount of deposited metal decreases.
- ▲ Temperature does not have a valid affect on the electroplating process.
- ▲ Copper (II) nitrate is a more effective electrolyte than copper (II) sulphate.
- ▲ The oxidation state of metal is inversely proportional with the amount of coated metal.

Other than these, some other deductions about the electroplating process were reached and explained in this essay.

INTRODUCTION

Electroplating is the process of coating an electrically conducting surface with a thin layer of metal by using electrolytic deposition. This technique is used in many fields, to increase the value or the quality of a surface. To change the surface's properties such as *abrasion and wear resistance, corrosion protection, lubricity and aesthetic qualities,* (Wikipedia, the free encyclopedia) the surface is plated with a metal that has the lacked properties.

In an electroplating process, the cathode is the surface that the metal is coated on. The anode is generally the metal to be plated or it can be an unaffected metal. The anode and the cathode are put in an electrolyte. The electrolyte has the ions that will be reduced to produce metal atoms on the cathode. A power supply is connected to the cell externally with its positive end connected to the anode and the negative end connected to the cathode. For a copper-copper electroplating cell the reactions occur are like these:

At the anode: $\quad\quad Cu(s) \rightarrow 2e^- + Cu^{2+}(aq)$

At the cathode: $\quad\quad Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$
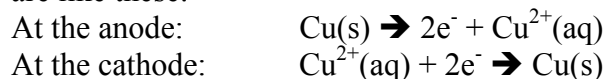
In this way the electrons pumped by the power supply force the ions at the cathode to reduce, and the metal at the anode to oxidize. Electrons flow from the external circuit and ion movement completes the internal circuit. It can be said that the copper from the anode is transferred to the cathode with the use of electricity and this way electroplating occurs.

There are many factors that affect this process. The surface area of the electrodes, the temperature, the kind of metal and the electrolyte, the magnitude of the applied current are some of these factors. In this essay the factors that affect the electroplating process will be investigated. For this essay six of these factors are selected.

The aim of this investigation is to determine how do the amount of current, the time that the current is applied, concentration of the electrolyte, temperature, kind of solution and the oxidation state of the metal ion affect the amount of metal deposited on the cathode in an electroplating process.

The rate of the reaction should not change with time because the current that flows through the circuit, and the potential difference between the anode and the cathode are kept constant throughout the experiment. Also the concentration of the solution is not changing, because the rate of copper metal oxidation and copper ion reduction are equal. All the factors that affect this process are controlled therefore the time versus mass of copper coated graph should be a line. The hypothesis of EXPERIMENT A is developed as: **The relation between the time and the mass of copper coated should be a direct proportion.**

EXPERIMENT B investigates the effect of current in an electroplating cell. According to Faraday's first law of electrolysis, *the amount of a substance produced or consumed in an electrochemical process depends quantitatively on the amount of electricity that flows as the reaction takes place.* (BOOKRAGS STAFF) The amount of electricity is the product of time and the magnitude of current. Using this law the following equation can be written:

$W = Z. I. t$ *where* *W is the mass of the coated substance*
I is the magnitude of current in ampers
t is the time in seconds
Z is the electrochemical equivalent. (TutorVista.com)

According to this equation it can be stated that, **for a certain time interval, when the current applied to the electroplating cell is increased, the amount of metal that is coated should also increase.**

The electrolyte's concentration's effect on the electroplating process is examined in the stage, EXPERIMENT C. Increased concentration provides more metal ions to be plated in the solution so it is expected to greater the rate of the electroplating. Thus, the hypothesis is like this: **With a concentrated electrolyte, the plated metal amount is expected to be greater compared to the one with a diluted electrolyte.**

In EXPERIMENT D, by using three different electrolytes, the kind of electrolytes affect will be observed. Same concentrations of copper (II) nitrate, copper (II) sulphate and copper (II) chloride will be used. When the solubilities of these salts are compared, it is seen that most and least soluble ones are copper (II) nitrate and copper (II) chloride respectively. In copper (II) nitrate electrolyte and copper (II) chloride electrolyte, there are three ions dissolved in the solution so the conductivities are greater in these electrolytes. Considering these two facts I expect that **the greatest amount of metal will be plated when copper (II) nitrate electrolyte is used.**

The experiments in EXPERIMENT E aim to test the effect of temperature on the electroplating process. Temperature can affect the amount of plated metal because it affects the rate of the reactions at the electrodes. In electroplating processes, there is a very small amount of hydrogen gas production at the cathode, if the electrolyte is an aqueous solution. When the temperature is increased, *the speed of formation of H_2 increases more rapidly than the electrodeposition of metal and at the same time the cathodic efficiency decreases. Also the dissolution rate of the cathode increases and the decrease of over-potential hydrogen with the increase of the temperature produce an increase the H_2 release* (Barbato, Ponce and Jara). Relying on these factors, the hypothesis of EXPERIMENT E is developed as: **The amount of deposited metal is expected to decrease at higher temperatures.**

In the last part, EXPERIMENT F, the oxidation state of the metal ion's affect on the deposited metal's amount is investigated. This factor will be tested using silver, copper and aluminum metals. The oxidation states of the metals, in their nitrate salts are: Ag^+, Cu^{2+} and Al^{3+}. When the same amount of current is applied in a certain time interval, the metal ion that has the least oxidation state will be deposited in the greatest amount. Therefore it can be predicted that **the number of moles of metal plated will have a relation as: silver > copper > aluminum.**

MAIN BODY

IMPROVEMENT OF THE INVESTIGATIVE PROCEDURE

In my electroplating cell, I used a copper strip as the anode. The reason why I used a mesh for the anode is because increasing the surface area increases the rate of the plating process. I used copper electrodes because copper metal is easy to find and many copper salts dissociate completely in water so using different electrolytes is easy. While preparing an electrolyte I had three choices: nitrate, sulphate or chloride salts of the electrodes. Except for EXPERIMENT D I used nitrate salts' solutions as electrolytes, because only silver nitrate was soluble enough. Also the most soluble salts of aluminum and copper are again nitrate ones. I have not changed the electrolyte for every trial because the rate of copper dissociation at the anode and the reduction of copper at the anode is the same; therefore the Cu^{2+} concentration in the electrolyte is kept constant.

When the apparatus is set up I ran the experiment for 1 minute to see whether the plating process is successful. Unfortunately this very first trial failed because the copper metal produced at the cathode was not coated on the mesh, instead it settled at the bottom of the solution as small particles. I thought this might be because of some impurity outside of the mesh so I let it wait in 1M hydrochloric acid solution for a minute. Then I ran the experiment again and this time the copper was plated on the mesh, so before every trial I rinsed the mesh and the strip in acid solution.

I had to mass the mesh both before and after every trial. This seemed like a problem to me because in both situations the mesh is wet therefore I needed a fast method to dry the meshes. Before the experiments there is acid solution on the mesh so wiping it with a tissue is enough to have it dried, but after the experiments wiping the mesh can damage the coated copper layer and affect the results of the experiments. I decided to rinse it with acetone and therefore fasten the drying process. After immerging the mesh into acetone, the acetone became light blue. This indicated a small amount of copper loss but still this is the quickest drying method I could use.

After EXPERIMENT A I decided that running the experiment for 5 minutes plates enough copper to produce reliable data. Therefore while testing other effects I ran the experiment for 5 minutes in every trial.

For EXPERIMENT F, I needed different electrodes with different oxidation states. I decided to use silver, aluminum and copper metals because their oxidation states are different in their nitrate salts and these salts are soluble in water. I had a copper and aluminum mesh but a silver mesh would be so expensive so I had one copper mesh plated with silver. After that I had to find strips with equal surface areas but I was not able to find a silver strip. Then I decided to use another substance at the anode but it would not undergo and oxidation or reduction. I first tried to use a nickel-chromium alloy but it resulted in undesirable changes. The solution's color became dark green and the anode was less in mass, this means that it produced some ions, which may affect the results. I finally decided to use graphite anodes and ran the experiment using pencils. This time the experiment was successful but some smoke came from the wood part of the pencil. To avoid this I used naked lead and this time the experiment went on seamlessly.

Considering the points mentioned, I developed the procedures shown in Appendices for every experiment.

EXPERIMENT A

The aim of this stage was to determine the effect of time on the electroplating process. My expectation was a direct proportion between the time interval and the mass of the coated metal. In the experiment, every trial was processed for different time intervals, keeping other variables constant such as the current applied to the cell, the concentration of the electrolyte, the temperature, the surface area of the electrodes. The results including Table 1 and Graph 1 are shown in EXPERIMENT A part of the Appendix 1. Graph 1 shows the relationship between the mass of the coated copper and the time the experiment was processed. As also seen in this graph the results verify my hypothesis.

EXPERIMENT B

In this part, I tested the effect of current on the electroplating process. According to my hypothesis as the current increases the electroplated metal's mass should also increase. To investigate this effect, I set the power supply for different current values in every trial. The results are shown in Table 2 and Graph 2. Graph 2 predicates that the best fit for the plotted data is a line therefore it can be stated that there is a direct proportion between the magnitude of current and the mass of the plated metal. According to these results, EXPERIMENT B also verifies the hypothesis.

EXPERIMENT C

The factor tested in this stage was the concentration of the electrolyte. As the hypothesis states, my expectation was an increase in the amount of copper plating when the concentration of the electrolyte is increased. To test this factor I prepared 0.1, 0.2 and 0.5M solutions by diluting a 1M copper nitrate solution. I put 100 ml distilled water to 100ml of 1M copper nitrate solution and obtained a 0.5M solution. Mixing 20 ml 1M copper nitrate solution and 180 ml distilled water I had a 0.1M solution and to have a 0.2M solution I added 160ml distilled water to 40 ml of 1M copper nitrate solution. By this way I obtained 200 ml solutions of every concentration. Using these solutions I performed four trials and the data I recorded is shown in Table 3. When I processed the data I saw that the concentration of the electrolyte was not affecting the process the way I predicted. I was surprised to see the inverse proportion. I realized that the potential difference also had a tendency parallel to the mass of coated copper so I added voltage data to Graph 3. The decrease in voltage can be explained by the decrease in resistance as the concentration is increased. As the applied current is constant, the product of the current and the resistance, which is voltage, should decrease. The hypothesis of the EXPERIMENT C was not proved and this can be explained by the relationship between the potential

difference and the rate of the electroplating process. Even though the applied current is kept constant, a decrease in voltage affects the process. The potential difference, forces the ions at the cathode to reduce, and the metal at the anode to oxidize. Therefore decreased voltage provides less amount of copper coation.

EXPERIMENT D

The aim of this stage is to see how the electroplating process is affected when different kinds of electrolytes are used. I used copper (II) nitrate, copper (II) sulphate and copper (II) chloride as different electrolytes. The results of these trials are shown in Table 4. During copper (II) chloride trial, the potential difference constantly increased from 12.0 to 27.0 V although the magnitude of current was constant. This indicates a decrease in concentration. Also the color of the electrolyte changed from blue to dark green (Figure 2). This produced the possibility of the presence of Cu^{1+} ions in the solution. Also a grey solid was plated just the outside of the mesh (Figure 3). This look like a sign of an impurity but the same copper strip was used for every trial so the only possible source of an impurity is the solution. Because of such unexpected results I kept copper (II) chloride trial out of Table 5. When copper (II) sulphate and copper (II) nitrate are compared, copper (II) nitrate plated more copper than copper (II) sulphate. This may be because it produced more potential difference in the cell. This result supports my hypothesis.

EXPERIMENT E

The experiments in this part are made to see the effect of temperature on electroplating process. My expectation was a decrease in the amount of coated metal when the temperature is increased. By using cold and hot baths I ran the experiment in different temperatures and the results of this experiment is plotted in Graph 4. As seen in this graph, the trend of the relationship between temperature and the mass of coated substance is not steady. According to the best line when the temperature is increased, the mass of coated metal is increasing. However the plotted data do not follow this, therefore this result is not reliable enough. This stage's hypothesis was not proved.

EXPERIMENT F

This part investigates the effect of the oxidation state of the ions on the amount of coated metal. Three experiments were made using silver, copper and aluminum meshes and their nitrate salts' solutions. During the trial with silver, some copper ions were produced in the electrolyte. This was because the mesh was actually plated silver so it had some copper in it. Silver was plated on the mesh but also to the graphite anode unexpectedly. Still I wanted to see how many moles of silver was plated on the mesh but when I took it out of the electrolyte some silver metal fell off and was left in the electrolyte. Therefore I decided not to use silver trial in my calculations. According to the calculations and results of the other trials, there is an inverse proportionality between the oxidation state of metal ion and the mole number of coated metal. This part confirms Faraday's second law of electrolysis and also my hypothesis that was built using this law.

CONCLUSION

Leaning on this investigation the following deductions can be made:

Using the results of EXPERIMENT A it can be said that **time is directly proportional with the amount of coated metal.** This means that at a certain time period, a certain amount of metal is produced at the cathode. Therefore it can be suggested that, **in an electroplating cell, if the same metal is used in both cells, the rate of the electroplating process is constant.** This is because in such cells reverse half-cell reactions occur at the same rate, thus the concentration of the electrolyte is not changing. If other conditions such as temperature, current applied and potential difference applied are controlled, the rate is not changing.

According to EXPERIMENT B **if the current applied to the cell is increased, the amount of plated metal also increases in a direct proportion.** Increased current means more electrons are pumped to the cell and therefore more ions are reduced and oxidized increasing the rate of the electro deposition. Also to increase the magnitude of current more potential difference is applied to the cell and this forces the reactions to take place rapidly.

In EXPERIMENT C I concluded that **when the concentration of the electrolyte is increased, the amount of deposited metal decreases**, just the inverse of my expectation. I observed that the potential difference also decreased and thought that this may be related to resistance of the electrolyte. When the concentration increases the resistance decreases and this decreases the potential difference. And with same amount of current, the cell with the greater potential difference plates more metal. It can be suggested that the potential difference is a more effective factor than the amount of ions in the electrolyte. To test the effect of the concentration of the electrolyte, potential difference should also be a controlled variable.

Copper (II) chloride solution is not a suitable electrolyte for electroplating. In EXPERIMENT D during the trial with copper (II) chloride some undesirable reactions took place. The solution went green and a grey metal was plated. Also the potential difference changed throughout the experiment therefore it is not a suitable trial to test the effect of the kind of electrolyte.

Copper (II) nitrate is a more effective electrolyte than copper (II) sulphate. In EXPERIMENT D, I reached this conclusion and this also verifies my hypothesis. While developing my hypothesis I thought that copper (II) nitrate is a more soluble salt and has more ions therefore its electrolyte would be very conductive. After EXPERIMENT C I have learned that amount of ions in a solution is not a major factor that affects this process. Therefore the reason why copper (II) nitrate electrolyte performed a better electro deposition is not the factor I leaned my hypothesis on. Instead it is because in the trial with copper (II) nitrate the potential difference was greater than the one with copper (II) sulphate. This is the main reason of this deduction.

The potential difference is directly proportional with the amount of coated metal. Although this was not one of the factors I planned to test in this investigation, the results of the parts EXPERIMENT B, C and D show that the amount of metal produced always has the same tendency with the potential difference. Therefore I can suggest that increased magnitude of current increases the amount of metal produced because it increases the potential difference. The same way, the concentration and the kind of electrolyte affect the electroplating process because these affect the potential difference. The potential difference has a major role on the rate of electroplating.

Temperature does not have a valid affect on the electroplating process. When the results of EXPERIMENT E are considered there is no certain relation between the temperature and the amount of metal deposition. This is because the cell was not waited in the baths long enough to have enough temperature change. The temperature data I collected was the temperature of the bath, not the electrolyte. To see the effects of temperature on the electroplating process and for more accurate results the temperature of the electrolyte should be measured and the cell should be waited in the solution for longer periods.

A plated electrode is not useful for electroplating processes. The silver mesh I used in EXPERIMENT F was not pure silver but copper mesh plated silver on. This affected the trial adversely, because during the electroplating process the electrolyte went blue, which indicates presence of copper ions in the solution and some silver was plated on the strip instead of the mesh. Because of these affects I do not suggest using plated electrodes in electroplating processes.

Lead is useful to use as an electrode. To perform the trials in EXPERIMENT F I needed to find the same size copper, aluminum and silver electrodes. I could not find a silver electrode and the other electrodes I found were not the same sized. Therefore I decided to use graphite electrodes and than had the idea of lead for pencils. These electrodes do not undergo any oxidation or reduction and therefore useful for any electroplating cell.

The oxidation state of metal is inversely proportional with the amount of coated metal. When the data of the EXPERIMENT F is processed it is seen that aluminum with and oxidation state of 3+, was plated less than copper that has an oxidation state of 2+ under the same conditions. This result verifies my hypothesis and Faraday's second law of electrolysis. According to this law the product of the mass of plated metal and the oxidation state of metal ion should be a constant when the current and the time is the same. In the calculations in the EXPERIMENT F part of the appendix this relation is showed.

In addition to these deductions, there are still some ambiguities that I was unable to explain. The relation between temperature and the electro deposition process is not clear. Also the reactions occurred during the trial with copper (II) chloride are not clarified.

APPENDICES

EXPERIMENT A

Materials: 500ml beaker, stopwatch, power supply, electronic balance, wires, copper strip, copper mesh, a rod, 200ml 0.5M $Cu(NO_3)_2$ solution, 1M HCl solution, acetone.

Precautions: The copper mesh and strip should be waited in the HCl solution for 1 minute, and then wiped.

Procedure:
1. Mass the copper mesh.
2. Fill the beaker with $Cu(NO_3)_2$ solution then place the copper mesh into the beaker.
3. Set the apparatus shown in Figure 1. Be sure that the strip and the mesh do not touch each other.
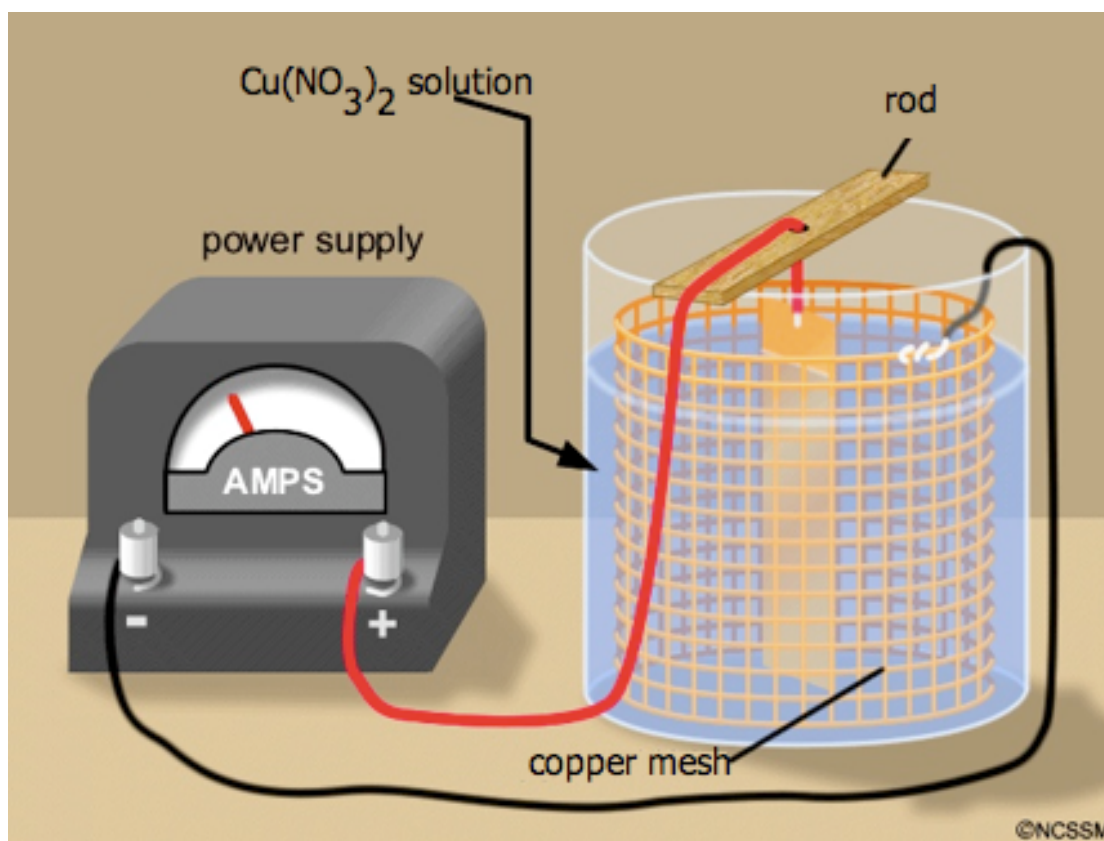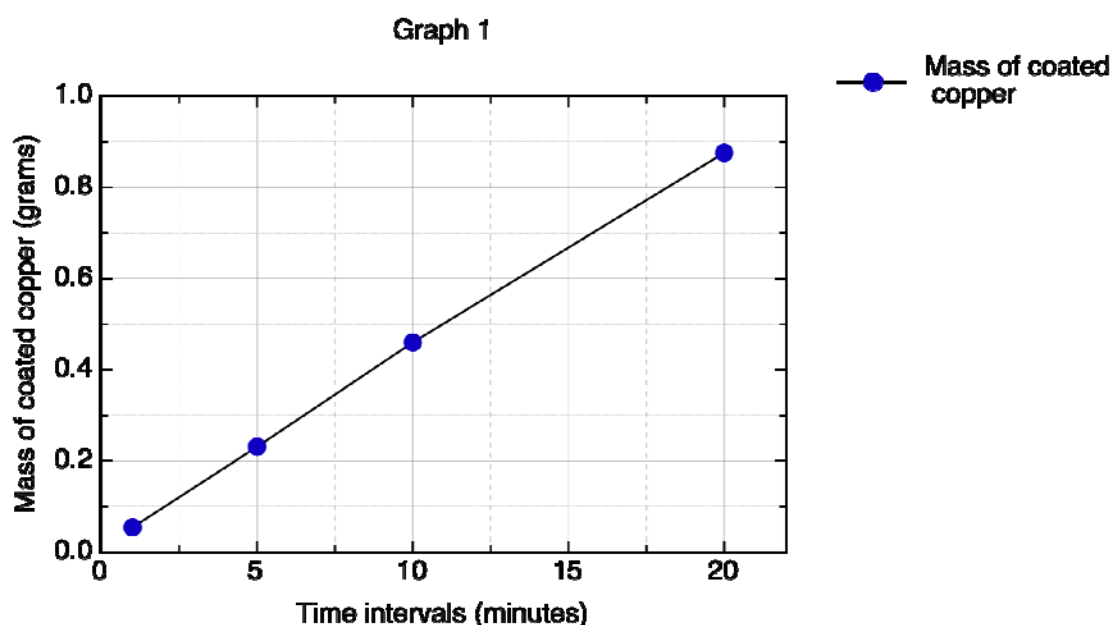

Figure1: The experimental setup.

4. Connect the mesh to the negative end of the power supply and the strip to the positive end of the supply.
5. Turn on the power supply and start the stopwatch spontaneously. Run the experiment for 5 minutes with a current of 2.30 Amp.
6. Disconnect the wires and take the mesh out of the solution.
7. Rinse the mesh with acetone and air dry it for a few minutes.
8. Remass the mesh.

9. Repeat the experiment for 1, 10 and 20 minute intervals. Be sure that the height of the copper strip is the same for every trial.

Results:

Time interval (min)	1	5	10	20
Initial mass of the mesh (g) ± 0.001	102.375	102.341	105.874	104.101
Final mass of the mesh (g) ± 0.001	102.429	102.572	106.334	104.977

Table 1: Measured values of time and the final and initial masses of the copper mesh.

Graph 1

EXPERIMENT B

Materials: 500ml beaker, stopwatch, power supply, electronic balance, wires, copper strip, copper mesh, a rod, 200ml 0.5M $Cu(NO_3)_2$ solution, 1M HCl solution, acetone.

Precautions: The copper mesh and strip should be waited in the HCl solution for 1 minute, and then wiped.
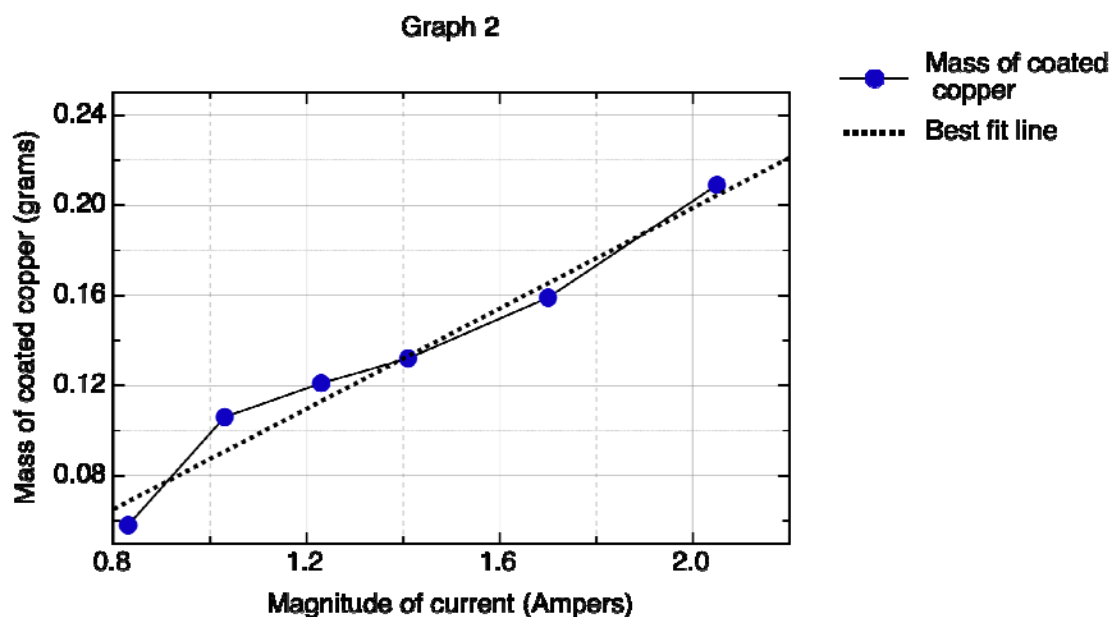
Procedure:
1. Mass the copper mesh.
2. Fill the beaker with $Cu(NO_3)_2$ solution then place the copper mesh into the beaker.
3. Set the apparatus shown in Figure 1. Be sure that the strip and the mesh do not touch each other.

4. Connect the mesh to the negative end of the power supply and the strip to the positive end of the supply.
5. Turn on the power supply and start the stopwatch spontaneously. Run the experiment for 5 minutes with a current of 0.83 Amp.
6. Disconnect the wires and take the mesh out of the solution.
7. Rinse the mesh with acetone and air dry it for a few minutes.
8. Remass the mesh.
9. Repeat the experiment for different magnitudes of current: 1.03, 1.23, 1.41, 1.70 and 2.05 Amp. Be sure that the height of the copper strip is the same for every trial.

Results:

Magnitude of current (Amp) ± 0.01	The potential difference (V) ± 0.1	Initial mass of the mesh (g) ± 0.001	Final mass of the mesh (g) ± 0.001
0.83	0.7	101.880	101.938
1.03	0.8	105.848	105.954
1.23	1.3	103.951	104.072
1.41	1.4	104.028	104.160
1.70	1.7	104.987	105.146
2.05	2.1	104.977	105.186

Table 2: Measured values of the magnitude of current, the potential difference, and the initial and final masses of the copper mesh.

EXPERIMENT C

Materials: 500ml beaker, stopwatch, power supply, electronic balance, wires, copper strip, copper mesh, a rod, 200ml 0.1M $Cu(NO_3)_2$ solution, 200ml 0.2M $Cu(NO_3)_2$ solution, 200ml 0.5M $Cu(NO_3)_2$ solution, 200ml 1.0M $Cu(NO_3)_2$ solution, 1.0M HCl solution, acetone.

Precautions: The copper mesh and strip should be waited in the HCl solution for 1 minute, and then wiped.
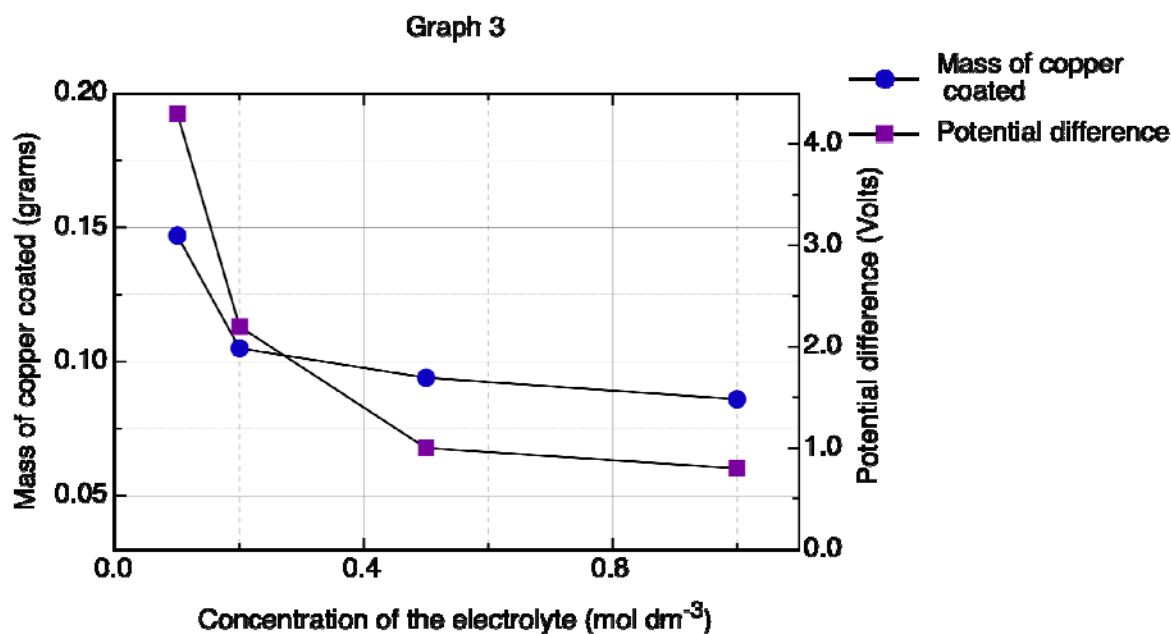
Procedure:
1. Mass the copper mesh.
2. Fill the beaker with 1M $Cu(NO_3)_2$ solution then place the copper mesh into the beaker.
3. Set the apparatus shown in Figure 1. Be sure that the strip and the mesh do not touch each other.
4. Connect the mesh to the negative end of the power supply and the strip to the positive end of the supply.
5. Turn on the power supply and start the stopwatch spontaneously. Run the experiment for 5 minutes with a current of 1.20Amp.
6. Disconnect the wires and take the mesh out of the solution.
7. Rinse the mesh with acetone and air dry it for a few minutes.
8. Remass the mesh.
9. Repeat the experiment for different concentrations of copper nitrate solution: 0.1M, 0.2M and 0.5M. Be sure that the height of the copper strip is the same for every trial.

Results:

Concentration of the electrolyte (mol dm^{-3})	Magnitude of current (Amp) ± 0.01	The potential difference (V) ± 0.1	Initial mass of the mesh (g) ± 0.001	Final mass of the mesh (g) ± 0.001
0.1	1.20	4.3	100.028	100.175
0.2	1.20	2.2	101.661	101.766
0.5	1.20	1.0	99.948	100.042
1.0	1.20	0.8	105.164	105.250

Table 3: Measured values of the magnitude of current, the potential difference, the initial and the final masses of the mesh for every concentration value.

Graph 3

EXPERIMENT D

Materials: 500ml beaker, stopwatch, power supply, electronic balance, wires, copper strip, copper mesh, a rod, 200ml 1M $Cu(NO_3)_2$ solution, 200ml 1M $CuSO_4$ solution, 200ml 1M $CuCl_2$ solution, 1M HCl solution, acetone.

Precautions: The copper mesh and strip should be waited in the HCl solution for 1 minute, and then wiped.

Procedure:
1. Mass the copper mesh.
2. Fill the beaker with $Cu(NO_3)_2$ solution then place the copper mesh into the beaker.
3. Set the apparatus shown in Figure 1. Be sure that the strip and the mesh do not touch each other.
4. Connect the mesh to the negative end of the power supply and the strip to the positive end of the supply.
5. Turn on the power supply and start the stopwatch spontaneously. Run the experiment for 5 minutes with a current of 1.40 Amp.
6. Disconnect the wires and take the mesh out of the solution.
7. Rinse the mesh with acetone and air dry it for a few minutes.
8. Remass the mesh.
9. Repeat the experiment for different electrolytes: copper (II) sulphate and copper (II) chloride. Be sure that the height of the copper strip is the same for every trial.

Results:

Kind of electolyte	Magnitude of current (Amp) $\pm$ 0.01	Potential difference (V) $\pm$ 0.1	Initial mass of the mesh (g) $\pm$ 0.001	Final mass of the mesh (g) $\pm$ 0.001
$Cu(NO_3)_2$	1.40	2.5	100.144	100.250
$CuSO_4$	1.40	1.0	101.828	101.991
$CuCl_2$	1.40	12.0-27.0	106.008	106.182

Table 4: Measured values of the magnitude of current, potential difference and final and initial masses of the mesh for every electrolyte.

Kind of electrolyte	Potential difference (V) $\pm$ 0.2	Mass of coated copper (g) $\pm$ 0.002
$Cu(NO_3)_2$	2.5	0.163
$CuSO_4$	1.0	0.106

Table 5: Shows the change in the potential difference and the mass of coated copper for different electrolytes.

Figure 2: Shows the electrolyte after the experiment with copper (II) chloride.

Figure 3: Shows the cathode after the experiment with copper (II) chloride.

EXPERIMENT E

Materials: 500ml beaker, a bigger container, stopwatch, power supply, electronic balance, wires, copper strip, copper mesh, a rod, 200ml 0.5M $Cu(NO_3)_2$ solution, 1M HCl solution, acetone, aquarium heater, ice, thermometer.

Precautions: The copper mesh and strip should be waited in the HCl solution for 1 minute, and then wiped.
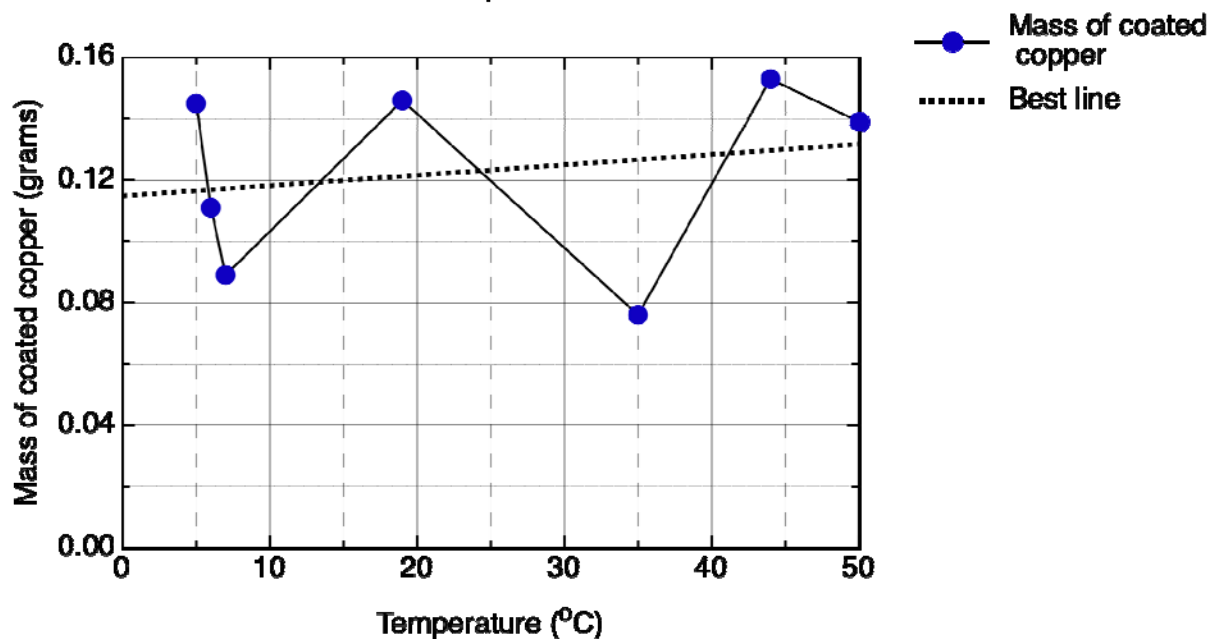
Procedure:

1. Mass the copper mesh.
2. Fill the beaker with $Cu(NO_3)_2$ solution then place the copper mesh into the beaker.
3. Set the apparatus shown in Figure 1. Be sure that the strip and the mesh do not touch each other.
4. Put some water into the big container and heat it with aquarium heater. Put the beaker and the thermometer into the container.
5. Connect the mesh to the negative end of the power supply and the strip to the positive end of the supply.
6. When the temperature is 50^oC turn on the power supply and start the stopwatch spontaneously. Run the experiment for 5 minutes with a current of 1.40 Amp.
7. Disconnect the wires and take the mesh out of the solution.
8. Rinse the mesh with acetone and air dry it for a few minutes.
9. Remass the mesh.
10. As the water's temperature is decreasing repeat the experiment for different temperature values: 35 and 44^oC. For cooler temperature values fill the container with ice and run the experiment for temperatures: 5, 6 and 7^oC. Also run the experiment at room temperature, 20^oC. Be sure that the height of the copper strip is the same for every trial.

Results:

Temperature (^oC) $\pm$ 0.5	The potential difference (V) $\pm$ 0.1	The initial mass of the mesh (g) $\pm$ 0.001	The final mass of the mesh (g) $\pm$ 0.001
5.0	1.5	100.195	100.340
6.0	1.4	105.263	105.374
7.0	1.4	100.418	100.507
19.0	1.1	102.533	102.679
35.0	0.8	105.433	105.509
44.0	0.7	102.563	102.716
50.0	0.6	102.679	102.818

Table 6: Measured values of potential difference, initial and final masses of the mesh for every temperature.

Graph 4

EXPERIMENT F

Materials: 3 500ml beakers, a copper mesh, a silver mesh, an aluminum mesh, 3 leads, 200ml 1M $Cu(NO_3)_2$, $AgNO_3$ and $Al(NO_3)_3$ solutions, power supply, stopwatch, wires, electronic balance, acetone.

Precautions: All the meshes should be waited in the HCl solution for 1 minute, and then wiped.

Procedure:
1. Mass the copper mesh.
2. Fill the beaker with 1M $Cu(NO_3)_2$ solution then place the copper mesh into the beaker.
3. Set the apparatus shown in Figure 1. Use a lead instead of a copper mesh. Be sure that the lead and the mesh do not touch each other.
4. Connect the mesh to the negative end of the power supply and the strip to the positive end of the supply.
5. Turn on the power supply and start the stopwatch spontaneously. Run the experiment for 5 minutes with a current of 1.10Amp.
6. Disconnect the wires and take the mesh out of the solution.
7. Rinse the mesh with acetone and air dry it for a few minutes.
8. Remass the mesh.
9. Repeat the experiment for aluminum and silver, using their electrolytes. Be sure that the height of the lead is the same for every experiment.

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Kind of electrolyte	The magnitude of current (Amp) ± 0.01	The potential difference (V) ± 0.1	Initial mass of the mesh (g) ± 0.001	Final mass of the mesh (g) ± 0.001
1M AgNO₃	2.10	6.3 – 6.0	101.993	116.754
1M Cu(NO₃)₂	2.10	8.4 – 8.0	106.524	106.600
1M Al(NO₃)₃	2.10	10.4 – 10.0	70.416	70.436

Table 7: Shows the measured values of the magnitude of current the potential difference and the final mass of the mesh.

Calculations:

Mass of copper plated: 106.600 – 106.524 = 0.076
Mass of aluminum plated: 70.436 – 70.416 = 0.020

Molar mass of Cu: 63.546
Molar mass of Al: 26.9815

Number of moles of Cu plated: 1.19×10^{-3}
Number of moles of Al plated: 0.742×10^{-3}

According to Faraday's second law of electrolysis:

$$n = \frac{I.t}{F.z}$$

where n is the number of moles of metal produced
I is the magnitude of current
t is the time
F is Faraday's constant
z is the oxidation state of metal.

The time and current applied is the same for these trials. Therefore this relation can be written:

$$n_1.z_1 = n_2.z_2$$

$1.19 \times 10^{-3} \times 2 = 0.742 \times 10^{-3} \times 3$
$2.38 \times 10^{-3} \approx 2.23 \times 10^{-3}$

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