Research Question

What is the impact of time electrolyzed on the mass of copper deposited at the cathode (a silver medium-sized paperclip) in an electrolytic cell?

Introduction

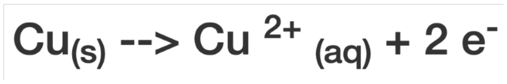
Growing up I was always fascinated by the way in which jewelry, coins, car parts, and medals were plated. I couldn't wrap my head around the concept of coating an object with a specific material to change its color. Since I have a deep interest in the automotive industry and plan on working in the industry once I am older, I want to better understand the reasons for electroplating car parts and the factors that impact electroplating. For that reason, after learning about the electroplating process in Chemistry, I decided to explore topic 9/19 in more depth for my IA. I aim to investigate the impact of time electrolyzed on the mass of copper deposited at the cathode in an electrolytic cell.

Background Knowledge

Electroplating is a chemical process that involves plating a metal onto another metal object using electrolysis. Electrolysis is the process by which a current is used to drive a non-spontaneous series of redox chemical reactions, where ionic substances are decomposed and transferred (The-mad-scientist.net; Raman). Electroplating is often used for aesthetics in order to enhance the appearance of objects (e.g. jewelry, car parts), as well as to increase the electrical conductivity and corrosion resistance of objects, which is very important in the jewelry and automotive industries (Rapid Direct).

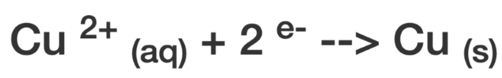
In electroplating, there are two electrodes involved, an anode and a cathode. Oxidation occurs at the anode and reduction occurs at the cathode. The anode is always a metal object that facilitates the electroplating process, as it is used to plate another object (Khan Academy). The cathode is also a metal, however it is the object that is to be electroplated, meaning it receives ions from the anode and is coated in a layer of metal that was deposited from the anode (Owen et al.). The electroplating process begins by submerging the two electrodes into an electrolyte solution that contains metal ions, then an electric current is applied to the solution using a battery or power supply, causing the metal ions from the anode to be reduced onto the surface of the object used as the cathode (Admin). In this investigation, the process of copper electroplating will take place, in order to electroplate a medium sized paperclip, plating it in a coat of copper ions thus altering its color from silver to brown. A copper strip will be used as the anode to provide copper ions for the process and the paperclip will be used as the cathode to receive deposited copper ions in order to be plated.

Figures 1 and 2 display the half-reactions for the copper strip and the paperclip. These reactions are the two parts of a redox reaction which displays how electrons are transferred between Cu and Cu^{2+}.



$$Cu_{(s)} \dashrightarrow Cu^{2+}_{(aq)} + 2\,e^{-}$$

Fig. 1. Half-reaction of The Copper Strip (Anode) (Oxidation) (Thomson's).



$$Cu^{2+}_{(aq)} + 2\,e^{-} \dashrightarrow Cu_{(s)}$$

Fig. 2. Half-reaction of The Paperclip (Cathode) (Reduction) (Thomson's).

Similarly to most chemical processes, there are several factors that have an influence on the electroplating process. In topic 9, the texbook and other sources state that the following factors have a significant effect on the electroplating process: concentration of electrolyte, type of electrolyte, time of electroplating process, type of electrodes, voltage/current applied to the solution, temperature of the solution, and more (Khan Academy). Through this investigation, the effect of time electrolyzed will be explored. As electroplating time increases, the copper strip will start to deposit more ions, erode faster, and lose more mass (Core and Aygar). The main method used to measure the impact of time electrolyzed on the mass of copper deposited at the cathode is by measuring the mass lost at the anode (copper strip), because by the end of the process the anode should lose mass due to its deposition of copper ions, as it facilitates electroplating) (Owen et al.).

Hypothesis

It can be hypothesized that as the time of electroplating a paperclip increases, the mass of the anode, copper strip, will decrease, therefore, the average change in mass of the copper strip will increase. The mass of the copper strip will decrease as the time electrolyzed increases because the copper strip at the anode will have more time to transfer Cu2+ ions to the cathode to electroplate the paperclip, thus, the copper strip will dissolve more, decreasing its mass. To add on, as the electrolyzed time increases, the quantity of charged carriers (copper ions) passing through the electrolytic cell increases, thus, the time electroplated should be directly proportional to the mass deposited by the anode (Core and Aygar).

In order to measure the accuracy of the experimental results of this investigation, Faraday's equation was used to calculate the mass of the oxide layer that would be deposited on the Copper electrode. Faraday's equation provides a set of theoretical values, which can be compared to the experimental results, thus, displaying the level of accuracy in the experimental results obtained and calculated (Owen et al.).

Sample Calculations:

Theoretical Value of Average Change in Mass of Copper Strip Using Faraday's Equation for 5 mins (300s):
$Q = (I)(t)$
$Q = (\text{current})(\text{time})$
$Q = (0.88)(300)$
$Q = 264\ C$

m = Mass of oxide layer deposited
Q = Charge passed in coulombs
F = Faraday's Constant (96,485 C mol^{-1})
M = Mr of Copper (63.54 g mol-1) z =
Valence number of electrons (2 e^{-1})

$m = (Q \div F)(M \div z)$
$m = (246 \div 96{,}485)(63.546 \div 2)$
$m = 0.0869\ g$

Time (minutes) **(± 0.012)**	**5**	**10**	**15**	**20**	**25**
Theoretical Average Change in Mass of Copper Strip (g) **(± 0.001)**	0.0869	0.174	0.261	0.348	0.435

Fig. 6. Theoretical Values of Average Change in Mass of Copper Strip (g).

The graph in figure 7, It was graphed using the theoretical values of mean change in mass of a copper strip that were calculated in figure 6. Figure 7 also shows the results and trends that should have been achieved in this experiment.

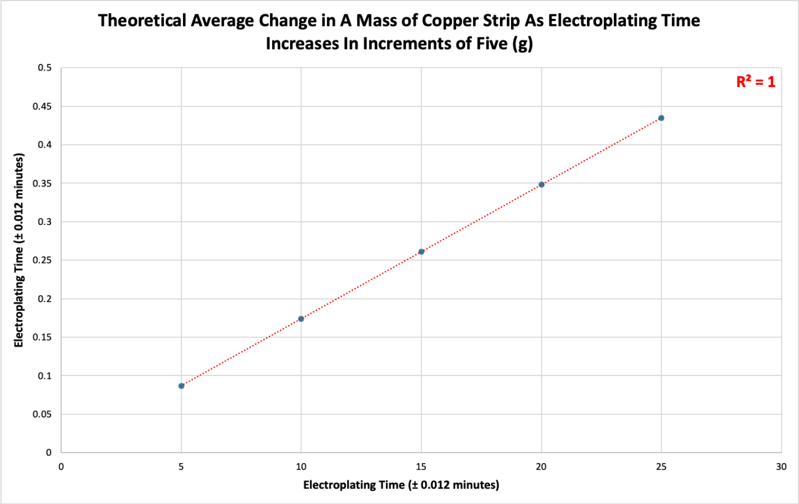


Fig. 7. Means Graph Displaying the Theoretical Average Change in Mass of the Copper Strip (g).

Variables

The independent variable in this investigation is the time intervals; the electroplating process time. For this IA the time intervals will start at 5 minutes and end at 25 minutes (± 0.012 minutes). The dependent variable is the average change in mass of the copper strip, placed at the anode to facilitate electrolysis (± 0.001 g).

Control Variable	How does the variable affect the electroplating process?	How is the variable controlled in this investigation?
Type of metal at anode & Type of electrolyte solution	If the metal at the anode has the same ions as the ions present in the electrolyte solution, it's easier for the electrodes to lose/gain electrons, instead of waiting for the ions in the solution to perform electrolysis.	For this experiment, a copper strip was used as the anode to facilitate the electroplating process and the electrolyte was copper sulfate (CuSO4). This ensures the metal at the anode (copper strip) is depositing its copper ions directly onto the object at the cathode (paperclip), thus, no factor other than time has an effect on the loss of mass at the anode after electroplating (Admin).
Object to be electroplated	Objects have varying surface areas and electroplating strengths, which require a different quantity of copper ion deposition to fully electroplate, thus, the mass lost at the anode could either increase or decrease.	A medium-sized, silver colored paperclip was used as the cathode throughout this experiment, ensuring the electroplating process is as fair as possible and the conditions are the same for all electrolytic cells.

Temperature of electrolyte solution	As the temperature of the electrolyte increases, the kinetic energy of the ions also increases, therefore, more frequent collisions occur between ions. An increase in collisions will lead to a higher deposition of copper ions in the electrolyte.	In this investigation, the temperature of the electrolyte solution was controlled, by conducting all of the trials at room temperature (20°C) (Noble Metal Coating L.L.C).
Current applied to electrolytic cell	A larger current will result in a faster rate of oxidation, causing a higher deposition of copper ions, thus, more mass is lost from the copper strip at the anode (Core and Aygar).	The power of current flowing through the cell was controlled by altering the rectifier (power supply) to supply the desired current. This guarantees that the copper strips are losing similar quantities of mass in electroplating. For all trials of this experiment, the voltage was 15.0 V and the current was 0.88 A.
Concentration of electrolyte solution	A higher concentration of the electrolyte solution will lead to an increase in copper electroplating time. A faster electroplating process leads to an increase in the mass of copper deposited, thus, interfering with the exploration of the effect of time on the mass of the copper strip.	To prevent the copper strip from losing a significantly high quantity of mass in this investigation from a factor other than the electrolyzed time, all of the trials used a copper sulfate concentration of 0.5 M.

Sample Calculation:

The sample calculation displayed below shows how the dilution formula was used in order to calculate the concentration of the electrolyte solution used in this electroplating experiment.

Electrolyte Solution Concentration = Dilution Formula

-> $C_1 V_1 = C_2 V_2$

-> $(1\ \text{M})(50\ \text{ml}) = C_2 (100\ \text{ml})$

-> $C_2 = (1\ \text{M})(50\ \text{ml}) \div (100\ \text{ml})$

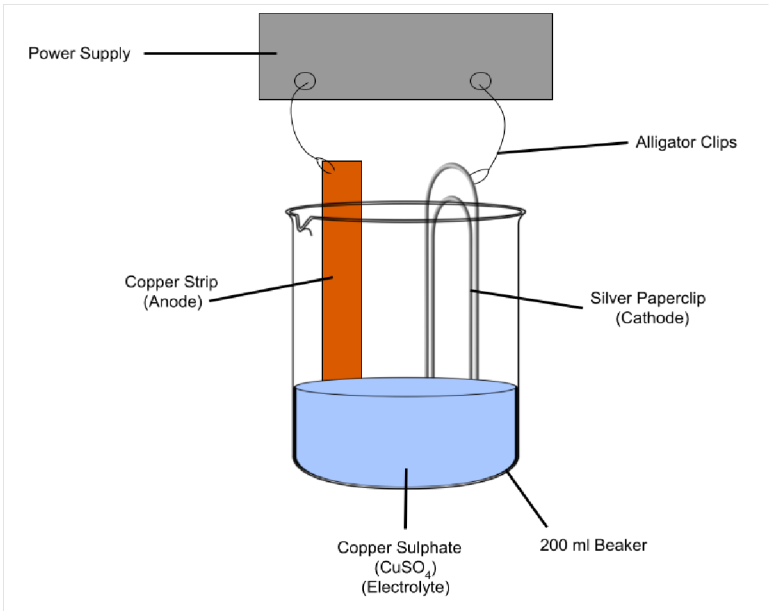
-> $C_2 = 0.5\ \text{M}$

Methodology

The following apparatus and procedures will be used in this copper electroplating experiment in order to obtain the necessary results and carry out the experiment properly. These materials were used for this IA, because they are easily accessible at school and are found in larger quantities, thus, ensuring no shortages or interruptions occur while carrying out the experiment for this IA.

Materials:

- 200 ml beaker (x1) (± 10 ml) (Daley)
- Stopwatch (x1) (± 0.012 minutes)
- Power supply (x1) (± 0.01 V)
- Ammeter (x1)
- Electronic balance (x1) (± 0.001 g)
- Alligator clip wires (x4)
- Copper strip (x1)
- 50 ml of 1 M $CuSO_4$ (± 0.1 M)
- 50 ml of distilled water
- Paperclip (x1)



The images to the right displays the experimental set-up used in this IA. It was drawn using Google Drawings.

Procedure:

1. Prepare 100 ml of the electrolyte solution in a 200 ml beaker by diluting 50 ml of 1 M $CuSO_4$ with 50 ml of distilled water.
2. Mass the copper strip on an electronic balance and record the initial mass in grams.
3. Connect the anode, the copper strip, to the positive side of the power supply using an alligator clip.
4. Connect the cathode, the paperclip, to the negative side of the power supply using an alligator clip.
5. Connect the power supply to a voltmeter to read the voltage of the current using two alligator clips.
6. Connect the alligator clips that are connected to the voltmeter to the anode and cathode.
7. Turn on the power supply to a power of 0.015 V.
8. Connect the cell to an ammeter to ensure that the current applied to the cell is 0.88 Amps.
9. Place both the copper strip (anode) and the paperclip (cathode) into the beaker with the electrolyte.
10. Start the timer for five minutes.
11. Observe the copper electroplating the paperclip.
12. Remove the copper strip and paperclip out of the beaker once the five minutes are over.
13. Dry the copper strip gently using a paper towel.
14. Mass the copper strip on an electronic balance and record the final mass in grams.
15. Repeat steps 1 - 13 to obtain three results (three trials).
16. Repeat steps 1 - 14 for the varying electroplating process times (10, 15, 20, and 25 mins).

After the data collection process, various statistical tests were utilized. The statistical tests incorporated in this investigation are: descriptive statistics, standard deviation, and R^2. These statistical tests were conducted in order to analyze and interpret the relationship present between time electrolyzed and mass lost at the copper strip (anode). The results will specifically show the type, strength, and statistical significance of the correlation between both variables.

Safety & Environmental Concerns

Safety is extremely crucial for this experiment to ensure no person, tree, or animal is harmed. The copper sulfate used in the electrolyte solution can cause mild irritation if it comes in contact with eyes and skin. To protect your eyes and skin, wear safety goggles, don't rub your eyes, and wear a lab coat and latex gloves. If your skin or eyes come into contact with the copper strip or copper sulfate, then wash your skin or flush your eyes with water for 5 to 10 minutes (Lenntech). Also, do not drink the copper sulfate, because it is mildly hazardous and will lead to poisoning and damage to vital organs. In addition, copper sulfate is toxic to the environment, so at the end of the experiment pour the solution into a disposable bottle, seal the bottle, and throw it away in the trash can. Another way to dispose of the copper sulfate solution is by further diluting the solution in water and then pouring the solution down the drain in small quantities over a long period of time, such as 30 minutes, ensuring the copper sulfate isn't highly concentrated, thus, reducing the hazards (Lenntech). There are no ethical concerns related to this copper electroplating experiment.

Experimental Results

The data tables shown below figures 3 and 4, show the data collected for each trial of the experiment. All of the data points in figure 3 are rounded to two significant figures, while the data points in figure 4 are rounded to three significant figures. This specific number of significant figures was used in this investigation, in order to ensure the data points are as precise and accurate as possible.

Sample Calculations:

The formulas displayed in the sample calculations below were used in order to calculate the numbers in the data tables in figures 3 and 4.

Change in Mass of Copper Strip (Trial 5 @ 25 min) = Initial mass of copper strip - Final mass of Copper strip
= 13.791 - 13.780
= 0.011 g

Average Change in Mass of Copper Strip for 5 mins = Total change in mass ÷ Total number of trials
= (0.002+0.002+0.000+0.001+0.000) ÷ 5
= 0.001 g

Data Table Displaying the Change in Mass the Copper Strip for Trials 1, 2,3, 4, and 5

	Time (minutes) **(± 0.012)**	**5**	**10**	**15**	**20**	**25**
Trial 1	**Change in Mass of Copper Strip (g)** **(± 0.001)**	0.0020	0.0030	0.0050	0.0080	0.012
Trial 2	**Change in Mass of Copper Strip (g)** **(± 0.001)**	0.0020	0.0040	0.0070	0.010	0.013
Trial 3	**Change in Mass of Copper Strip (g)** **(± 0.001)**	0.0000	0.0020	0.0050	0.0090	0.011

Trial 4	**Change in Mass of Copper Strip (g)** **(± 0.001)**	0.0010	0.0030	0.0060	0.010	0.014
Trial 5	**Change in Mass of Copper Strip (g)** **(± 0.001)**	0.0000	0.0010	0.0040	0.0080	0.011

Fig. 3. Data Table Displaying the Change in Mass the Copper Strip for Trials 1, 2,3, 4, and 5.

Data Table Displaying the Average Change in Mass of the Copper Strip for Each Time Increment

Time (minutes) **(± 0.012)**	**5**	**10**	**15**	**20**	**25**
Average Change in Mass of Copper Strip (g)	0.00100	0.00260	0.00540	0.00900	0.0122

Fig. 4. Average Change in Mass of Copper Strip (g).

Qualitative Observations

The first observation made was a decrease in the size of the electrode as the copper strip eroded. Also, throughout the electroplating process the color of the electrolyte solution remained the same, a royal blue color. In addition, the color of the copper strip faded as the electrolyzed time increased; the color slightly changed from a dark orange brownish color to a lighter orange color. Furthermore, it was observed that as the electrolyzed time increased, the color change of the paperclip became more obvious, the color of the paperclip became a stronger shade of orange/red, and the color of the paperclip resembled the color of the copper strip more (dark orange brownish color); the paperclips rapidly electroplated.

Uncertainty Calculations

Uncertainty in chemistry is the inability to accurately predict the outcome of a chemical reaction or the properties of a molecule. It is often caused by incomplete knowledge about the system being studied or by the complexity of the system itself (Chem Libre; The York School; Owen et al.).

Sample Calculations:

Probable Range of Uncertainty in the Mean @5 minutes = (Max Value - Min Value) ÷ Total Number of Values
= (0.002 - 0.000) ÷ 5
= ± 0.0004 g

% Uncertainty in the Mean @5 minutes = (Uncertainty of mean change in mass ÷ Mean change in mass) x 100
= (0.0004 ÷ 0.001) x 100
= ± 40%

The table in figure 5, shows the percentage uncertainty in each average change in mass of the copper strip for all five time increments (5, 10, 15, 20, 25) in each trial conducted.

Time (minutes) (± 0.012)	**5**	**10**	**15**	**20**	**25**
Probable Range of Uncertainty (g)	± 0.0004	± 0.0006	± 0.0006	± 0.0004	± 0.0006
Percent Uncertainty (%)	± 40.00	± 23.08	± 11.11	± 4.44	± 3.28

Fig. 5. Percentage Uncertainty Average Change in Mass of Copper Strip for all Five Trials.

The percent uncertainty values displayed in figure 5, were used to analyze the range of possible values that could be true for the average change in mass of the copper strip. For this investigation, as the time of the electroplating process increased, the percentage uncertainty of average change in mass of copper decreased. Overall, there is a significantly high degree of uncertainty associated with the measurement of average change in mass of copper, for the electroplating times of 5 and 10 minutes. A percent uncertainty of ± 40.00% for the 5 minutes electroplating time, suggests that the measured value could be off by as much as 40 percent in either direction. While a percentage uncertainty of ± 3.28% for the 25 minutes electroplating time, indicates that the measured value has a very low degree of uncertainty associated with the value for average change in mass.

Final Error Calculations

Percentage error was calculated as shown below in the sample calculation, in order to compare the experiment values obtained in this investigation and the theoretical values which were calculated using Faraday's equation. The values in the table below highlight that there is around 98% error for all the electroplating process times, suggesting that the data collected is highly unreliable. However, given that the graph in figure 11 displays the same strong and positive correlation between both variables that is shown in figure 7, which is the theoretical values (the values that should have been obtained), then the overall conclusions drawn in this investigation are still accurate and valuable (The York School).

Sample Calculations:

% Error of Mean Change in Mass for 5 Minutes = ((Theoretical - Experimental) ÷ Theoretical) x 100

= ((0.0869 - 0.001) ÷ 0.0869) x 100

= 98.85%

Time (minutes) (± 0.012)	**5**	**10**	**15**	**20**	**25**
Percentage Error (%)	98.85	98.51	97.93	97.41	97.20

Fig. 8. Unit & Percentage Error Values for Mean Change in Mass of Copper Strip.

Statistical Analysis

In this investigation, multiple descriptive statistics tests were conducted in order to accurately investigate the presence of a correlation between the electroplating process time and the mass of the copper strip used to facilitate electroplating. Despite standard deviation not being a statistical test, it was also calculated and analyzed. Figure 9 displays the formula used by excel was the sample standard deviation formula (STDEV.S). It can be concluded from figure 10 that the standard deviation values for all five time increments of the indented variable are extremely low. A standard deviation value range between 0.00100 and 0.00130, indicates that most of the data points are clustered around the mean, thus, suggesting that the data points collected for the mean change in mass of the copper strip is very reliable (Bargen).

$$s = \sqrt{\frac{\sum(X - \bar{x})^2}{n - 1}}$$

Fig. 9. Sample Standard Deviation Formula (STDEV.S) (Cue Math).

Time (minutes) **(± 0.012)**	**5**	**10**	**15**	**20**	**25**
Standard Deviation of Average Change in Mass of Copper Strip (g)	0.00100	0.00114	0.00114	0.00100	0.00130

Fig. 10. Sample Standard Deviation Values for The Average Change in Mass of Copper Strip (g).

The graph displayed in figure 11, shows the type of relationship that is existent between the electroplating process time and the mass of the copper strip used to facilitate electroplating. It is inferable from the linear trendline on the means graph in figure 11 that there is a positive correlation between the electroplating process time and the average mass loss of the copper strip at the anode, which facilitates electroplating. In addition, using Excel a coefficient of determination was calculated, in order to draw conclusions about the strength of the positive correlation that exists between both variables. An R^2 value of 0.983 indicates that the positive correlation between both variables is extremely strong, meaning as the electroplating process time increases, the copper strip (anode) will lose more mass, therefore the average change in mass of the copper strip will also increase. Furthermore, the error bars in figure 11 were constructed in Excel using the percentage uncertainty values calculated in figure 5. In the graph, the error bars do not overlap, indicating that the data is statistically significant, meaning the relationship between both variables is real and not due to chance (Bargen).

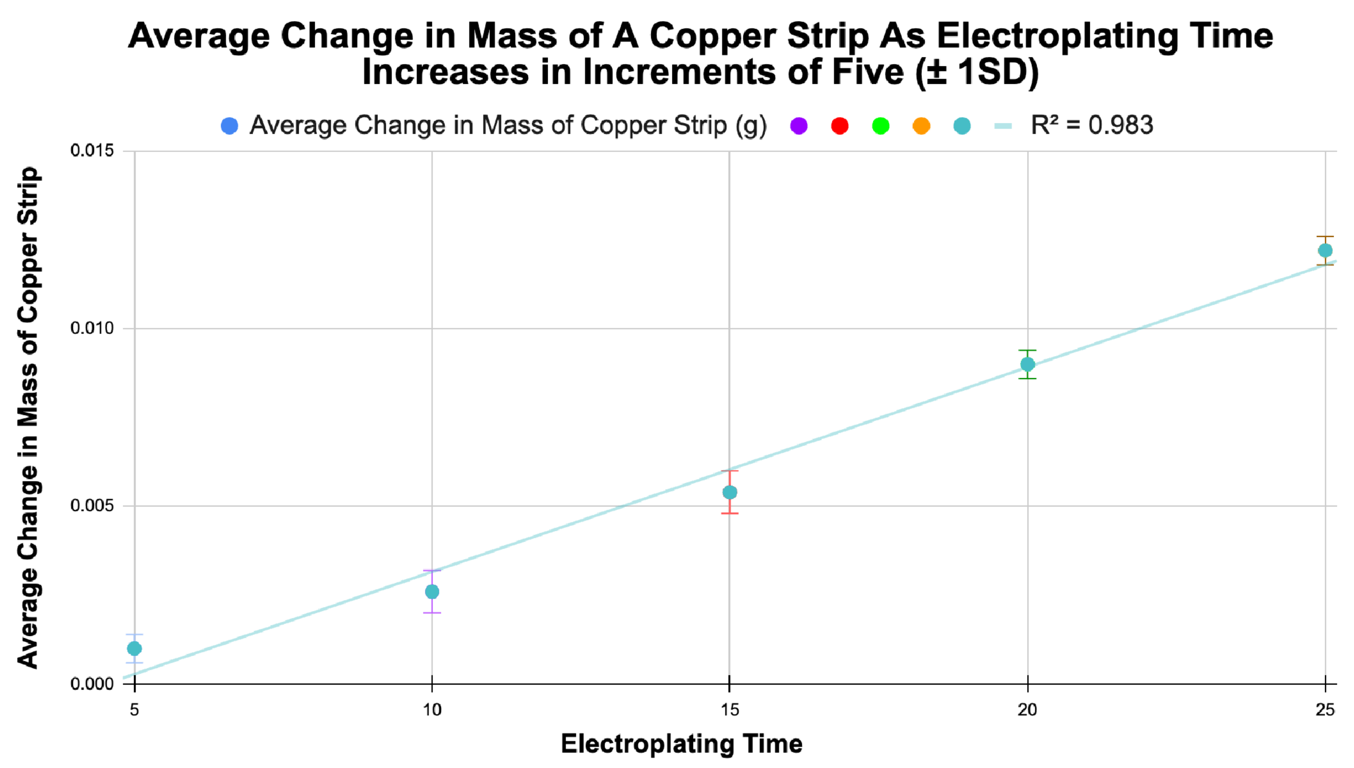
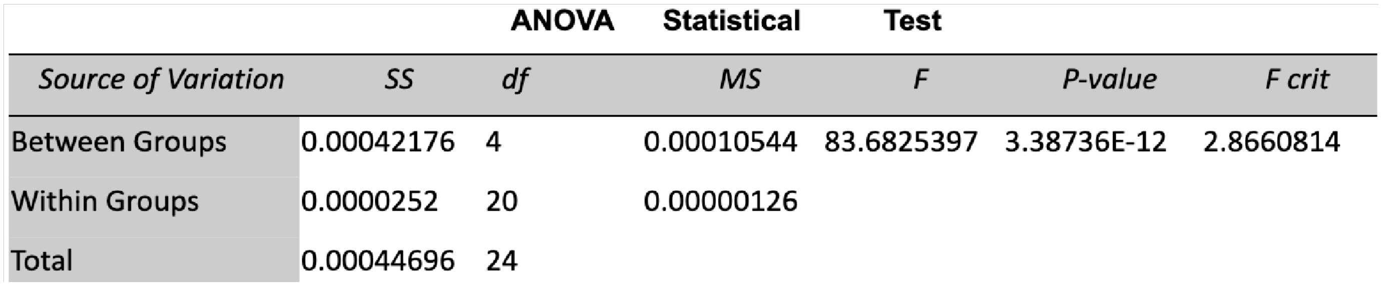


Fig. 11. Mean Graph Displaying the Link Between Average Change in Mass of A Copper Strip (g) & the Electroplating Process Time (min).

For further investigation of the positive correlation between the electroplating process time and the average mass loss of the copper strip at the anode, an ANOVA test was conducted using Excel. In figure 12, the P-value is approximately 3.39×10^{-12}, F-calculated value is 83.68, and the F-critical value is 2.87. The P-value is less than 0.05, and the F critical value is very close to 3.9, reinforcing the idea that the results are statistically significantly different (Bargen, Von). In addition, the F-calculated value of 83.68 proposes that the data is of high variation, thus, the results are statistically significantly different (Feldman). Overall, the P, F-calculated, and F-critical values obtained in this ANOVA test, further indicate that there is a positive correlation between both variables, as well as that the data is statistically significant, meaning the positive correlation is a real relationship and not due to chance (Bargen, "ANOVA").



ANOVA Statistical Test

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00042176	4	0.00010544	83.6825397	3.38736E-12	2.8660814
Within Groups	0.0000252	20	0.00000126			
Total	0.00044696	24				

Fig. 12. ANOVA Statistical Test Results.

Conclusion

Coming back to the research question: What effect does the electroplating process time have on the mass of the copper strip used to facilitate electroplating? It is evident from the experiment carried out that the results collected support the hypothesis, which states that as the time of electroplating a paperclip increases, the mass of the anode, copper strip, will decrease, therefore, the average change in mass of the copper strip will increase. In addition, the error bars on the graph in figure 11, R^2 value of 0.983, the P-value of 3.39×10^{-12}, the F-critical value of 2.87, and the F-value of 83.68, indicate that the relationship between the electroplating process time and the mass of the copper strip used to facilitate electroplating, is statistically significant, thus, is not due to chance, rather there is an actual relationship present. To add on, the values are indicative of a positive correlation between both variables, thus, supporting the hypothesis. Furthermore, as seen in the graph in figure 11, the linear trendline and the values for mean change in mass of the copper strip further supports the hypothesis of this investigation, because as the electroplating process time increases, the mean change in mass of the copper strip also increases. Lastly, when the graphs in figure 7 and 11 are compared - theoretical against experimental values - it can be concluded that both graphs clearly show a strong and positive correlation is present between both variables.

When comparing the results of this investigation with published scientific reports, the results are fairly similar, which further supports the hypothesis that there is a positive correlation between the electroplating process time and the mass of the copper strip used to facilitate electroplating. An exploration similar to the study experimented in this IA, is a research report published in AIP Conference Proceedings, where researchers investigated the factors that influence the electro-deposition of Cu^{2+}, similar to the measurement of mass lost from the copper anode during electroplating. In this research paper, the researchers conducted a "regressive orthogonal experiment" in order to conclude that "Cu^{2+} concentration, current density and electro-deposition time have linear positive correlation" (Sui et al.).

Evaluation

The main strength of this investigation is that multiple statistical tests were consulted and descriptive statistical values were calculated, thus, an in-depth statistical analysis was conducted and continuously re-assured the results about the strong, statistically significant, and positive correlation present between the electroplating process time and average change in mass of the copper anode. Another strength of this IA is that the experimental results obtained displayed the same trends regarding the relationship between both variables as the theoretical values calculated, indicating that the experiment was a success and the hypothesis stated prior to the experiment was strongly supported by the data.

Weakness/Limitation/Error	**Impact on Data Collected**	**Improving the Investigation**
Current applied to the cell	The current applied to the electrolytic cell to provide a power supply for electrolysis to occur could have been a bit low. The current applied to an electrolytic cell affects the charge that passes through the cell per unit time, which plays a role in the quantity of copper ions that are oxidized at the anode. Using a low power supply is one of the reasons behind the extremely low values obtained for average change in mass of the copper strip at the anode, facilitating copper electroplating.	Therefore, to eliminate this systematic error, a higher current could be applied to the cell while undergoing copper electroplating, as it will increase the number of copper ions being oxidized, thus, more mass is lost from the copper strip at the anode (West 167-172).

Distance between electrodes (the distance between the anode and cathode wasn't controlled)	To add on, the distance between both electrodes - the copper strip and the paperclip - was not controlled effectively using two clamps, therefore, the distance between both electrodes varied in each trial. Increasing the distance between both electrodes would increase the distance traveled by the copper ions in the electrolyte solution, however, the mass of copper deposited onto the paperclip at the cathode would decrease. In addition, a larger distance between electrodes increases the resistance inside the electrolytic cell, therefore, the mass lost from the anode decreases as less ion deposition occurs.	This random error can be solved by improving the experiment through the use of two stands and clamps. The electrodes would be held by the clamps, which are always measured to be 5 cm apart from each other, therefore, controlling the distance between both electrodes and minimizing the number of random errors that may occur during the copper electroplating process (Jyoti Biswal et al.).
Percentage error values	The data collected in this investigation is highly unreliable and subject to a high degree of uncertainty, given that it has a range of percentage errors between 97% and 98% for all five electroplating time processes.	The significantly high percent error values indicate that the experiment conducted involves several systematic and random errors, which must be addressed to obtain valuable results.
Experimental set-up (connecting the cell to the power supply and ammeter)	The ammeter and power supply were poorly connected to the anode and cathode; the set-up could be improved. Having a minor set-up issue, specifically with the power supply and ammeter is not acceptable, because it creates more potential for errors to occur, such as a varying amount of current to be applied to the cell. This suggests that the data collected is unreliable, because the power supply was not controlled successfully and consistently.	For future investigations, preliminary trials can be conducted in order to ensure the electrolytic cell has the best and most effective set-up for the electroplating process, thus producing more accurate and reliable results.

Copper strip drying method before weighing (after electroplating)	After each trial the copper strip that was used to facilitate the electroplating process, was dried gently using a paper towel before measuring the mass. While drying the copper strip, some of the copper could have been removed by the paper towel, thus, reducing the mass of the copper strip and affecting the reliability of the data regarding the final masses and average change in mass of the copper strip.	This systematic error can be improved by using acetone to dry the copper electrode. Acetone is a liquid product often used as a nail polish remover and for drying electrodes once electroplating is complete. The electrodes should be rinsed with distilled water to remove any electrolyte solution and then placed in a beaker of acetone. The acetone will quickly evaporate, leaving the electrodes clean and dry, providing more accurate and reliable data about the mass of the copper strip after electroplating (Flinn Scientific).
Electroplating method used (electrolyte solution wasn't stirred)	A systematic error that occurred is that the electrolyte solution was not stirred during the electrolysis. Stirring the electrolyte during electroplating is generally favored, because stirring makes it easier for the metal ions to move from the anode to the cathode. Since the copper sulfate electrolyte was not stirred in this investigation, the copper ions had no support in diffusing to the cathode, thus, the electroplating process was slowed down, decreasing the values of change in mass.	In order to improve this investigation, the electrolyte solution will be stirred every 30 seconds for each trial of the experiment, which will increase the rate of diffusion of the copper ions as they are transferred to the paperclip (Ra and Naghib).

Extension

When further investigating the impacts of various factors (e.g. electroplating time) on the mass of the copper strip used to facilitate electroplating, there are several factors that could be implemented in the research to obtain results of higher importance to researchers, companies, and factories. An interesting factor that can be investigated is current applied to the electrolytic cell. For instance, the independent variable could be five different increments of current applied to the cell and the dependent variable could be the average mass lost from the copper strip (anode). This would be investigating the correlation between an increasing power supply on the electroplating process. Another interesting aspect to investigate is the effect of increasing the concentration of the electrolyte solution on the mass of the copper strip used to facilitate electroplating. Similarly to this investigation, every variable would remain the same however the independent variable would consist of five different increments of copper sulfate concentrations. This would explore the relationship between the concentration of electrolyte solutions and the average mass lost at the anode during the electroplating process. Furthermore, an investigation of the effect of the temperature of the electrolyte solution on the mass of the copper strip used to facilitate electroplating, would be a fascinating topic. Lastly, instead of measuring the mass lost at the anode, these listed variables could measure the effectiveness of the copper electroplating process by measuring the mass gained at the cathode. A higher average mass gain suggests the variable being changed (IV) has a stronger effect during the electroplating process (Core and Aygar; Owen et al.).

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Appendix

The data tables below represent the raw data collected during the conduction of the electroplating experiment. These were the data points used to calculate the values found in figure 3.

Time (minutes) (± 0.012)	**5**	**10**	**15**	**20**	**25**
Initial Mass of Copper Strip (g) (± 0.001)	13.824	13.823	13.826	13.832	18.834
Final Mass of Copper Strip (g) (± 0.001)	13.822	13.820	13.821	13.824	18.822
Change in Mass of Copper Strip (g) (± 0.001)	0.0020	0.0030	0.0050	0.0080	0.012

Data Collected for The 1st Trial.

Time (minutes) (± 0.012)	**5**	**10**	**15**	**20**	**25**
Initial Mass of Copper Strip (g) (± 0.001)	13.785	13.782	13.787	13.784	13.781
Final Mass of Copper Strip (g) (± 0.001)	13.783	13.778	13.780	13.774	13.768
Change in Mass of Copper Strip (g) (± 0.001)	0.0020	0.0040	0.0070	0.010	0.013

Data Collected for The 2nd Trial.

Time (minutes) (± 0.012)	**5**	**10**	**15**	**20**	**25**

Initial Mass of Copper Strip (g) (± 0.001)	13.794	13.797	13.799	13.795	13.792
Final Mass of Copper Strip (g) (± 0.001)	13.794	13.795	13.794	13.784	13.781
Change in Mass of Copper Strip (g) (± 0.001)	0.0000	0.0020	0.0050	0.0090	0.011

Data Collected for The 3rd Trial.

Time (minutes) (± 0.012)	**5**	**10**	**15**	**20**	**25**
Initial Mass of Copper Strip (g) (± 0.001)	13.810	13.815	13.813	13.812	13.819
Final Mass of Copper Strip (g) (± 0.001)	13.809	13.812	13.807	13.802	13.805
Change in Mass of Copper Strip (g) (± 0.001)	0.0010	0.0030	0.0060	0.010	0.014

Data Collected for The 4th Trial.

Time (minutes) (± 0.012)	**5**	**10**	**15**	**20**	**25**
Initial Mass of Copper Strip (g) (± 0.001)	13.797	13.794	13.795	13.792	13.791
Final Mass of Copper Strip (g) (± 0.001)	13.797	13.793	13.791	13.784	13.780

Change in Mass of Copper Strip (g) (± 0.001)	0.0000	0.0010	0.0040	0.0080	0.011

Data Collected for The 5th Trial.