SASTA OLIPHANT

SCIENCE AWARDS

SOUTH AUSTRALIAN SCIENCE TEACHERS ASSOCIATION

Prize Winner

Science Investigation

Year 9 - 10

Ray Mao

Glenunga International High School

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Government of South Australia

Department for Education

SASTA South Australian Science Teachers Association

Title: Investigating the effect of sodium carbonate concentration on the electrochemical restoration efficiency of tarnished sterling silver

Abstract

This investigation examined the effect of sodium carbonate (Na_2CO_3) electrolyte concentration on the electrochemical restoration efficiency of tarnished sterling silver. Tarnished sterling silver rings were restored in sodium carbonate solutions (0.1-0.5 mol/L) in contact with aluminium foil for one minute. Restoration efficiency was quantified using Fiji (ImageJ). Results demonstrated a non-linear increase in restoration efficiency from 6.894% to 77.559%. However, the rate of improvement flattened above 0.3 mol/L. Although the highest restoration efficiency was achieved at 0.5 mol/L, most of the efficiency gain had already been achieved by 0.3 mol/L. Overall, the hypothesis was supported, confirming that sodium carbonate concentration significantly influenced restoration efficiency within the investigated range.

Introduction

Silver reacts with sulfur-containing compounds in the environment to form a black tarnish layer of silver sulfide (Ag_2S). Electrochemical restoration provides a method for removing this tarnish without mechanically removing silver from the surface. In this process, aluminium acts as a sacrificial metal while an electrolyte solution allows ions to move through the system and support the redox reaction.

Sodium carbonate was selected because it provides mobile ions for electrochemical restoration. This investigation examined how sodium carbonate concentration affected the restoration efficiency of tarnished sterling silver.

Research Questions

1. What is the relationship between sodium carbonate concentration and the restoration efficiency of tarnished sterling silver?
2. At what concentration do further increases in sodium carbonate produce only limited improvements in restoration efficiency?
3. How does sodium carbonate concentration influence the electrochemical restoration process?

Hypothesis

If sodium carbonate concentration increases, the restoration efficiency of tarnished sterling silver will increase, because higher ionic concentrations are expected to facilitate the electrochemical restoration process.

Variables

I. Independent variable:

Variable	Description
Sodium carbonate concentration	0.1, 0.2, 0.3, 0.4 and 0.5 mol/L

II. Dependent variable:

Variable	Description
Restoration efficiency (%)	Calculated from changes in Fiji mean gray values before and after restoration

III. Control variable:

Variable	How it was controlled
Silver sample type	All samples were identical 925 sterling silver jump rings (5 mm × 0.8 mm).
Number of silver rings	Four rings were used in each trial.
Tarnishing method	All rings were tarnished in the same sealed container using sulfur released from boiled egg yolks.
Tarnishing duration	All rings were exposed to sulfur for approximately 3.5 hours.
Electrolyte volume	100 mL of sodium carbonate solution was used for each trial.
Aluminium foil size	Aluminium foil pieces of identical dimensions were used in every trial.
Reaction time	All samples were restored for 1 minute.
Water temperature	All restoration trials were conducted using room-temperature water.
Image analysis method	All images were analysed using Fiji with the same grayscale conversion and brightness measurement procedure.
Background during photography	A black notebook background was used for all photographs.
Camera	The same smartphone camera was used throughout the investigation.

Materials

The following materials and equipment were used for the experiment:

1. ## Reagents and Sample

- 925 sterling silver rings (experimental test samples)
- Sodium carbonate (Na_2CO_3)
- Distilled water
- Boiled eggs (sulfur source for inducing silver tarnishing)

2. ## Glassware and Measuring Instrument

- Measuring cylinder
- 250 mL beakers
- 250 mL volumetric flasks
- Spatula
- Pipette
- Stopwatch
- Electronic balance
- Stirring rod
- Filter funnel

3. ## Imaging and Data Analysis Tools

- Digital camera (smartphone)
- Fiji (ImageJ) software (to measure the mean gray value)

4. ## Others

- Aluminium foil
- Black background paper
- Plastic containers
- Tissue paper

Figure 1. Pre-experimental setup for inducing tarnishing on sterling silver samples. Labeled samples are organized by concentration and trial, ready to be exposed to sulfur vapor from hard-boiled eggs.

Methodology

Part A: Preparation of Tarnished Silver Samples (do this at home)

1. Ten groups of sterling silver rings (four rings per group) were cleaned and labelled as 0.1MT1-0.5MT2.
2. Three boiled egg yolks were crushed into small pieces.
3. The crushed egg yolks and all sterling silver rings were placed in a sealed plastic container. Dry paper tissue was used to separate the egg yolks from the rings while allowing sulfur-containing gases to reach the silver surface.
4. The container was sealed and left undisturbed for approximately 3.5 hours to allow sulfur-containing gases released from the egg yolks to tarnish the silver rings.
5. After approximately 3.5 hours, the tarnished silver rings were removed from the container.
6. The tarnished silver rings were photographed in their labelled groups before restoration. Image brightness was analysed using Fiji by measuring the Mean Gray Value of each ring.

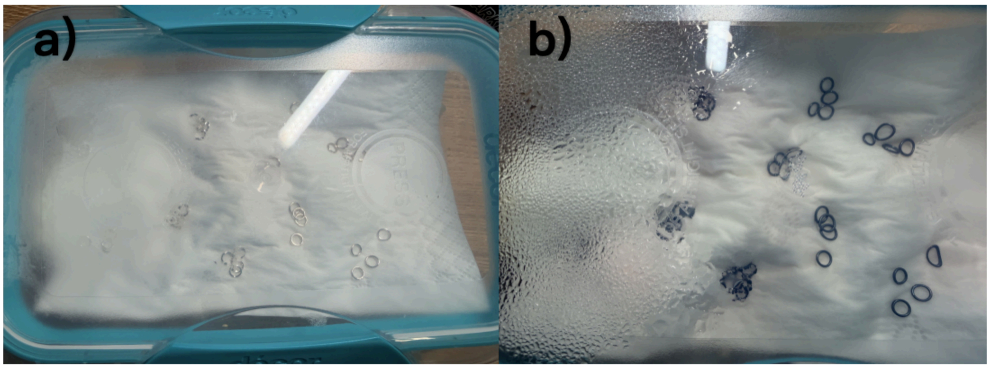

Figure 2. Sulfur tarnishing process of sterling silver samples. a)The sterling silver samples at the initial stage. b)The sterling silver after exposure to sulfur vapor shows obvious surface darkening due to the formation of silver sulfide. Water droplets of reaction by-product can be observed, which verifies the reaction $4Ag + 2H_2S + O_2 \rightarrow 2Ag_2S + 2H_2O$

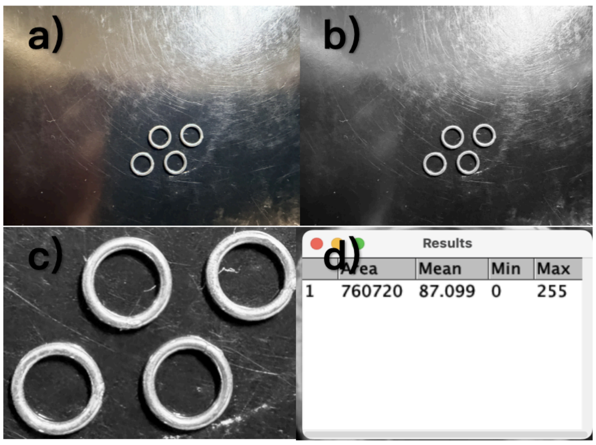

Figure 3. Fiji (ImageJ) brightness analysis of tarnished sterling silver jump rings from the 0.1 mol dm−3 Trial 1 sample group.a) Original image of the tarnished silver samples.b) 8-bit grayscale image used for brightness analysis.c) Enlarged image of the tarnished silver rings.d) Fiji measurement results showing the Mean Gray Value of the selected region.

Part B: Preparation of Electrolyte Restoration

1. The required mass of sodium carbonate for each concentration (0.1, 0.2, 0.3, 0.4 and 0.5 mol/L) was calculated.
2. The calculated mass of sodium carbonate was weighed using an electronic balance and transferred into a volumetric flask.
3. Distilled water was added until the sodium carbonate had completely dissolved before the solution was diluted to the calibration mark.
4. Each volumetric flask was inverted several times before use.

Part C: Electrochemical Restoration

1. Each sodium carbonate solution was transferred from the volumetric flask into a labelled beaker. Each beaker contained 100 mL of sodium carbonate solution.
2. One group of tarnished silver rings was immersed in each beaker together with aluminium foil, ensuring direct contact between the silver rings and aluminium foil.
3. The restoration reaction was allowed to proceed for one minute at room temperature.
4. Following restoration, the contents of each beaker were carefully emptied, and the silver rings were rinsed with distilled water and gently dried with paper towels.
5. The restoration procedure was repeated independently to obtain two trials for each sodium carbonate concentration.

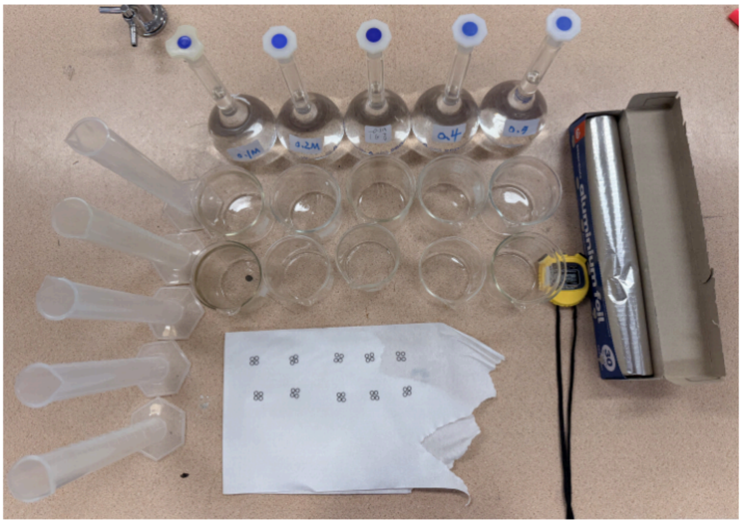

Figure 4. Experimental setup for the silver tarnish removal study, showing the prepared sodium carbonate solutions, beakers, aluminium foil, and pre-tarnished sterling silver samples prior to cleaning.

Part D: Image Analysis

1. All restored silver rings were photographed in their original labelled groups using the same smartphone camera under identical lighting, distance and black background conditions.
2. The images were analysed using Fiji (ImageJ).
3. Each image was converted to 8-bit grayscale before the Mean Gray Value of every silver ring was measured using the same selection procedure for all samples.
4. Restoration efficiency was then calculated and compared across the five sodium carbonate concentrations.

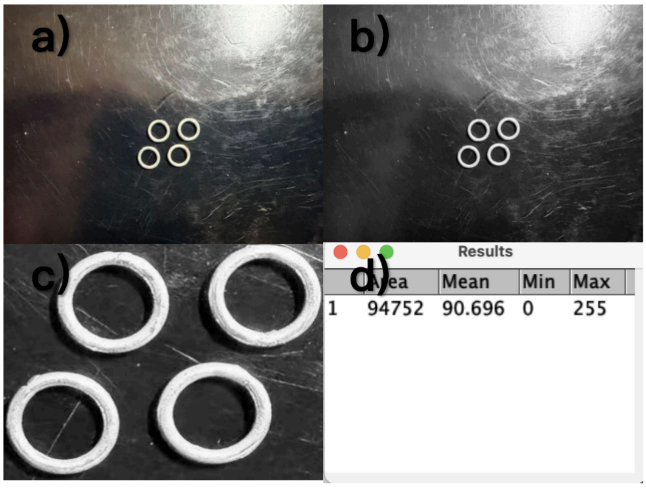

Figure 5. Fiji (ImageJ) brightness analysis of restored sterling silver jump rings from the 0.1 M Trial 1 sample group.a) Original image of the restored silver samples.b) 8–bit grayscale image used for brightness analysis.c) Enlarged image of the tarnished silver rings.d) Fiji measurement results showing the Mean Gray Value of the selected region.

Results

Data processing

Restoration efficiency was defined as the percentage increase in Mean Gray Value after electrochemical treatment relative to the tarnished condition. Higher efficiency values indicated greater restoration of the silver surface following electrochemical treatment.

$$Efficiency\ (\%) = \frac{Gray_{after} - Gray_{before}}{Gray_{before}} \times 100\%$$

where:

- Gray(after) = Mean Gray Value after restoration
- Gray(before) = Mean Gray Value before restoration

Restoration efficiency was calculated for each trial using the equation above. The mean restoration efficiency for each sodium carbonate concentration was then determined from two independent trials.

Example Calculation (0.1 mol/L, Trial 1)

$$Efficiency = \frac{90.696-87.099}{87.099} \times 100\% = 4.13\%$$

Table 1. Mean Gray Values of Tarnished Sterling Silver Samples			
Concentration (mol/L)	**Trial 1**	**Trial 2**	**Mean Gray Value**
0.1	87.099	85.156	86.1275
0.2	89.191	88.021	88.606
0.3	86.25	89.046	87.648
0.4	91.758	85.236	88.497
0.5	92.484	83.258	87.871

Table 2. Mean Gray Values of Restored Sterling Silver Samples			
Concentration (mol/L)	**Trial 1**	**Trial 2**	**Mean Gray Value**
0.1	90.696	93.381	92.0385
0.2	120.213	129.649	124.931
0.3	142.345	152.692	147.5185
0.4	150.418	148.234	149.326
0.5	153.436	157.534	155.485

Table 3. Calculated restoration efficiency (%) for each trial and mean values at varying sodium carbonate concentrations								
Concentration (mol/L)	**Before T1**	**After T1**	**Efficiency T1 (%)**	**Before T2**	**After T2**	**Efficiency T2 (%)**	**Mean Efficiency (%)**	**Standard Deviation**
0.1	87.099	90.696	4.130	85.156	93.381	9.659	6.894	3.910
0.2	89.191	120.213	34.782	88.021	129.649	47.293	41.037	8.847
0.3	86.250	142.345	65.038	89.046	152.692	71.475	68.257	4.552
0.4	91.758	150.418	63.929	85.236	148.234	73.910	68.920	7.058
0.5	92.484	153.436	65.905	83.258	157.534	89.212	77.559	16.480

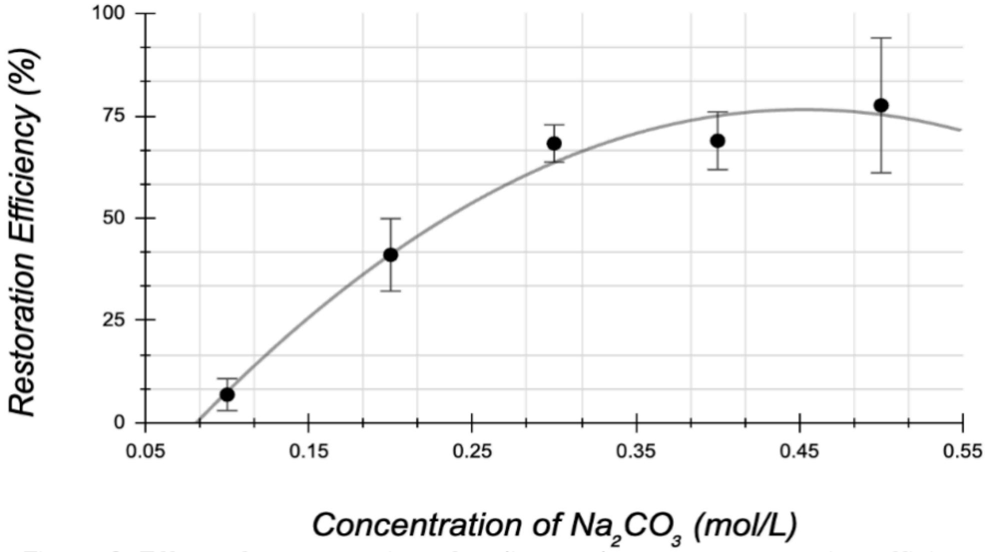

Figure 6. Effect of concentration of sodium carbonate on restoration efficiency. The data points show the mean efficiency of two replicate trials, with error bars representing the standard deviation. A non-linear trend line illustrated the positive correlation between concentration and restoration performance.

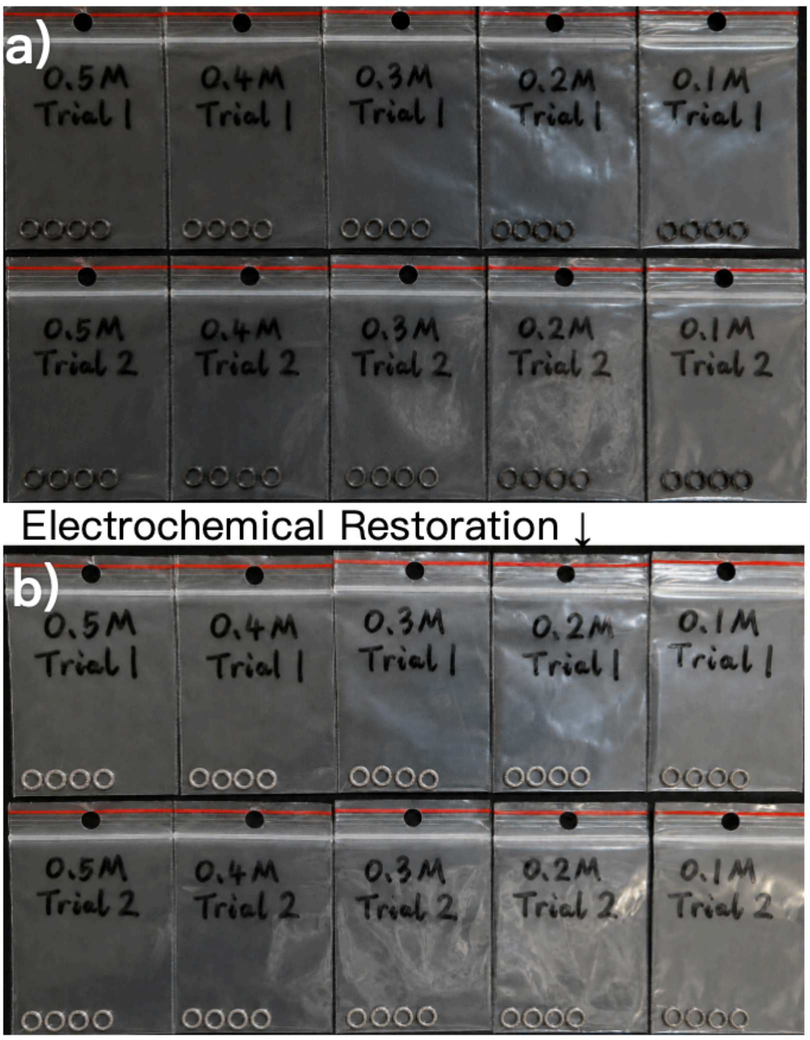

Figure 7. Comparison of tarnished and restored sterling silver samples. (a) Samples after sulfur tarnishing.(b) Samples after electrochemical restoration.

Note. Restored silver rings were photographed outside the resealable bags to minimise glare and improve visibility.

Analysis

Table 3 and Figure 6 illustrate that restoration efficiency increased as sodium carbonate concentration increased from 0.1 to 0.5 mol/L. However, the increase was not proportional across the concentration range. Mean restoration efficiency rose sharply from 6.894% at 0.1 mol/L to 68.257% at 0.3 mol/L. In contrast, increasing the concentration further to 0.5 mol/L produced only an additional 9.302 percentage point increase. This indicates that increasing sodium carbonate concentration produced progressively smaller improvements in restoration efficiency.

One plausible explanation for the rapid increase in restoration efficiency between 0.1 and 0.3 mol/L is improved ionic conductivity of the electrolyte. At low concentrations, fewer ions were available to carry charge through the solution, limiting the electrochemical restoration process. As sodium carbonate concentration increased, ionic conductivity would be expected to improve, allowing the restoration to proceed more efficiently. Although ionic conductivity was not directly measured, this interpretation is consistent with the trend observed in Table 3 and Figure 6. Aluminium acted as the sacrificial anode, supplying electrons that reduced silver sulfide (Ag_2S) back to metallic silver according to the overall reaction below.

$$3Ag_2S\ (s)\ +\ 2Al\ (s)\ \rightarrow\ 6Ag\ (s)\ +\ Al_2S_3\ (s)$$

Although restoration efficiency continued to increase above 0.3 mol/L, the improvement was much smaller than at lower concentrations. Between 0.3 and 0.4 mol/L, restoration efficiency increased by less than 1%, despite a 33% increase in electrolyte concentration. This suggests that increasing sodium carbonate concentration beyond 0.3 mol/L provided little additional improvement under the conditions of this investigation. Although the increase between 0.3 and 0.4 mol/L was very small, both independent trials showed the same pattern, suggesting that the limited improvement was unlikely to have resulted solely from random variation. At 0.5 mol/L, restoration efficiency increased again to 77.559%. However, this concentration also produced the largest standard deviation (16.480), indicating that the exact magnitude of the improvement should be interpreted with greater caution. Nevertheless, both trials at 0.5 mol/L still produced higher restoration efficiencies than all lower concentrations, supporting the overall trend observed throughout the investigation. Because concentrations above 0.5 mol/L were not investigated, it remains unclear whether restoration efficiency would eventually reach a maximum value or continue to increase beyond the tested range.

Evaluation

Random Errors

The principal source of random error arose during image acquisition. The "before" and "after" photographs were taken manually under ambient fluorescent lighting, so slight differences in camera angle, distance and hand position could have altered image brightness. Although a black notebook was used as a consistent background, the small size of the silver rings made identical positioning difficult. Because Fiji calculates Mean Gray Values directly from image pixels, even small variations in image brightness could influence the calculated restoration efficiencies. Random variation was also introduced during manual immersion and removal of the silver rings. Although the intended restoration time was one minute, small differences of a few seconds between samples were unavoidable. These timing differences may have contributed to the greater variability observed, particularly at higher sodium carbonate concentrations where restoration occurred more rapidly. Despite these sources of random error, the overall trend is unlikely to have resulted solely from experimental variation. All samples were photographed and analyzed using the same imaging and image analysis procedures. Both trials showed the same overall trend.

Systematic Errors

One important limitation of the experimental design was the use of a single restoration time for all sodium carbonate concentrations. Preliminary observations showed that the reaction proceeded much faster than expected, requiring the planned treatment time to be shortened from five minutes to one minute. However, a fixed one-minute treatment may not have been equally appropriate for every concentration. At higher concentrations, some silver rings may have reached near-complete restoration before the end of the treatment period, whereas low-concentration samples may not yet have reached complete restoration. Consequently, restoration efficiencies at higher concentrations may have underestimated the true effect of sodium carbonate concentration, contributing to the apparent plateau observed above 0.3 mol/L. Another systematic limitation was that restoration efficiency was estimated from image brightness rather than directly measuring the amount of silver sulfide removed. Although Mean Gray Value provided a consistent quantitative basis for comparison, image brightness may also have been influenced by surface reflection and ring orientation. Consequently restoration efficiency should be interpreted as a relative indicator of surface recovery rather than an absolute measure of silver sulfide removal.

Suggested Improvements

Future investigations should determine the optimum restoration time for each concentration before quantitative testing. The accuracy of restoration measurements could also be improved by using controlled lighting and a fixed camera setup. If available, instrumental techniques such as reflectance spectrometry would provide a more direct and objective assessment of surface changes than image brightness alone. Finally, increasing the number of replicate trials would reduce the influence of random variation and improve confidence in the calculated mean restoration efficiencies. Extending the investigation beyond 0.5 mol/L and investigating shorter restoration times at higher concentrations would help determine whether restoration efficiency eventually reaches a maximum value or continues to increase at higher sodium carbonate concentrations.

Conclusion

The results of this investigation supported the hypothesis that increasing sodium carbonate concentration improves the electrochemical restoration efficiency of tarnished sterling silver. Mean restoration efficiency increased from 6.894% (0.1 mol/L) up to 77.559% (0.5 mol/L).

The greatest increase in restoration efficiency occurred between 0.1 and 0.3 mol/L, whereas further increases in sodium carbonate concentration produced only modest improvement. Although the highest restoration efficiency was obtained at 0.5 mol/L, most of the improvement had already occurred by 0.3 mol/L. This suggests that improvements became limited above approximately 0.3 mol/L.

The observed trend suggests that increasing sodium carbonate concentration promoted a more effective electrochemical restoration process. A higher concentration likely provided more mobile ions within the electrolyte, facilitating charge transport and increasing restoration efficiency. However, because ionic conductivity was not measured directly, this explanation should be regarded as a scientifically supported interpretation rather than a direct experimental finding.

Overall, sodium carbonate concentration was identified as an important factor influencing the electrochemical restoration of tarnished sterling silver within the investigated concentration range.

References

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Declaration of AI-Assisted Writing

AI Tool Used: Google Gemini (Large Language Model)
Nature of Assistance: Linguistic refinement and academic prose polishing
Statement of Use:
As an international student whose first language is not English, I used Google Gemini to improve the grammar, vocabulary and clarity of my scientific writing. All experimental design, laboratory work, data collection, image analysis, calculations, data interpretation and conclusions were completed independently by me. AI was used only for language refinement and did not generate the scientific ideas, experimental results or conclusions presented in this report.

Project Title:

Investigating the Effect of Electrolyte Concentration on the Electrochemical Restoration Efficiency of Tarnished Sterling Silver

Research Logbook

16 May 2026 – Sample Preparation and Tarnishing

Objective:
To prepare tarnished sterling silver samples for electrochemical restoration testing.

Procedure:

1. Forty sterling silver jump rings were organized into ten sample groups.
2. Three boiled egg yolks were crushed and placed in a sealed plastic container.
3. A layer of tissue paper was placed between the crushed eggs and silver samples.
4. The silver rings were exposed to sulfur-containing gases released from the egg yolks.

Observation:

1. The silver rings turned dark.
2. Water droplets formed on the container wall.
3. The tissue between the eggs and silver became wet.

Outcome:
Successfully prepared tarnished silver samples for later electrochemical restoration experiments.

Photo 1. Tarnished sterling silver rings after approximately 3.5 hours of exposure to sulfur-containing gases released from boiled egg yolks

Reflection:
The tarnishing process occurred much faster than expected. This confirmed that boiled egg yolks could provide sufficient sulfur-containing gases to produce visible silver tarnish within a relatively short time. The tarnished samples were suitable for the restoration experiment.

17 May 2026 – Fiji Image Analysis (1)

Objective:
To quantitatively analyse the brightness of silver samples before restoration.

Procedure:

1. Images were imported into Fiji (ImageJ).
2. Photographs were converted to 8-bit grayscale.
3. Mean Gray Value measurements were obtained for each sample group.

Observations:

1. Numerical brightness values were obtained for all trials.
2. Fiji analysis allowed quantitative comparison between concentration groups.

Outcome:
Data were collected for statistical analysis and calculation of restoration efficiency

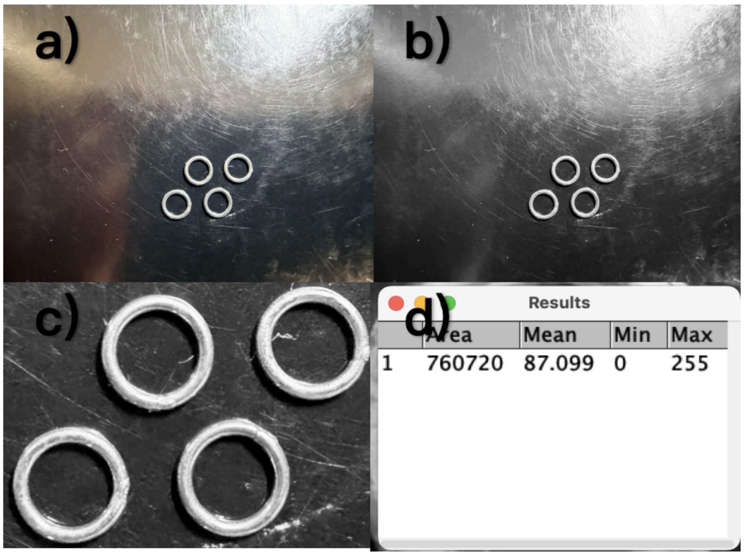

Photo 2. Fiji (ImageJ) analysis of tarnished silver rings before electrochemical restoration

Reflection:
Using Fiji allowed the colour change of the silver rings to be quantified more objectively rather than relying on visual observation alone. This provided a more objective method for comparing restoration efficiency.

28 May 2026 – Preparation of Sodium Carbonate Solutions

Objective:
To prepare electrolyte solutions of different concentrations.

Procedure:

1. Sodium carbonate solutions were prepared using distilled water.
2. Following discussion with the supervising teacher, the original concentration (0.3M–1.1M was revised to 0.1M–0.5M to reduce chemical usage while maintaining a suitable concentration range.
3. Five concentrations were prepared: 0.1 M, 0.2 M, 0.3M, 0.4M, 0.5M

Observation:

1. Sodium carbonate dissolves readily in room-temperature water.
2. The solution appeared clear and colourless.

Outcome:
Electrolyte solutions were successfully prepared for the restoration experiment.

Reflection:
Preparing the electrolyte solutions carefully was important to ensure that sodium carbonate concentration remained the only independent variable throughout the investigation.

1 June 2026 – Electrochemical Restoration Experiment

Objective:
To investigate the effect of electrolyte concentration on the restoration efficiency of tarnished sterling silver.

Procedure:

1. Aluminium foil was placed in contact with tarnished silver samples.
2. 100ml sodium carbonate solution was measured with measuring cylinders.
3. Each sample group was immersed in its assigned sodium carbonate solution.
4. Initially, the planned reaction time was set to 5 minutes. However, the silver brightened much faster than expected, so the observation time was adjusted to 1 minute.
5. Two trials were completed for each concentration.

Observations:

1. Restoration occurred rapidly after immersion.
2. Visible brightening of silver rings occurred within approximately 1 minute.
3. Differences between concentrations were difficult to distinguish visually.

Outcome:
All tarnished samples were successfully restored and photographed for image analysis.

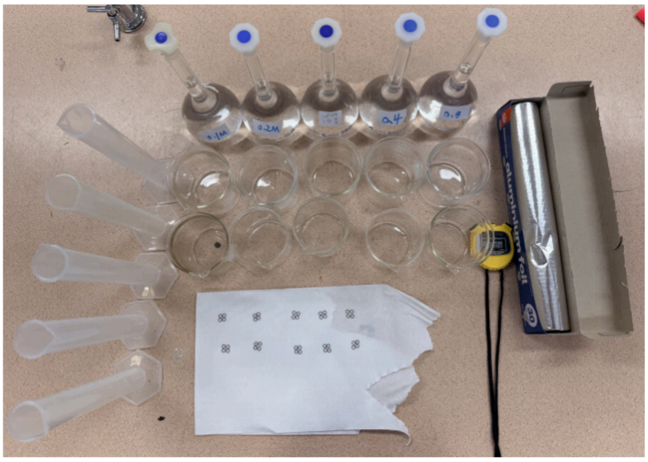

Photo 3. Experimental setup for electrochemical restoration using sodium carbonate soution and aluminium foil.

Reflection:
Preliminary observations showed that the restoration reaction occurred much faster than expected. Therefore, the planned treatment time was reduced from five minutes to one minute to allow clearer comparison between concentrations.

2 June 2026 – Fiji Image Analysis (2)

Objective:
To quantitatively analyse the brightness of silver samples after restoration.

Procedure:

1. Images were imported into Fiji (ImageJ)
2. Photographs were converted to 8-bit grayscale.
3. Mean Gray Value measurements were obtained for each sample group

Observations:

1. Numerical brightness values were obtained for all trials.
2. Fiji analysis allowed quantitative comparison between concentration groups

Outcome:
Data were collected for statistical analysis and calculation of restoration efficiency

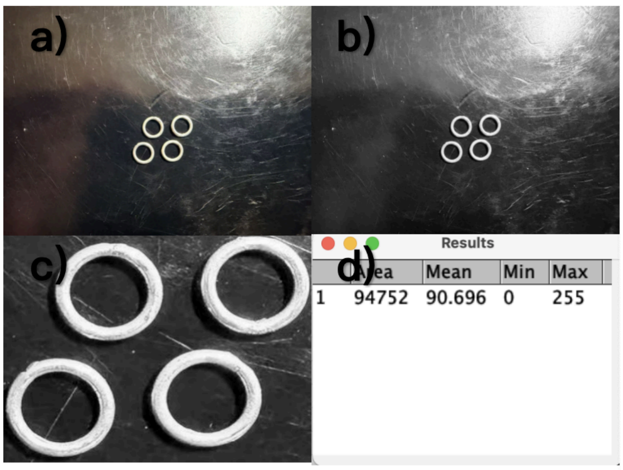

Photo 4. Fiji (ImageJ) analysis of tarnished silver rings before electrochemical restoration

Reflection:
The processed data showed that restoration efficiency increased with sodium carbonate concentration, although the rate of improvement became much smaller above 0.3 mol/L. This observation formed the basis of the data analysis and conclusion presented in the final report.

OSA RISK ASSESSMENT FORM

for all entries in (✓) ☐ Models & Inventions and ☑ Scientific Inquiry

This must be included with your report, logbook or entry. One form per entry.

STUDENT(S) NAME: Ray MAO ID: 260639

SCHOOL: Glenunga International High School

Activity: Give a brief outline of what you are planning to do.

This experiment investigate the effect of sodium carbonate concentration on the electrochemical restoration efficiency of tarnished sterling silver rings. Tarnish the rings with sulfur compound released from eggs. The tarnished rings will put in sodium carbonate solution and aluminium foil for same time, and Fiji(ImageJ) to analyse the brightness.

Are there possible risks? Consider the following:

- Chemical risks: Are you using chemicals? If so, check with your teacher that any chemicals to be used are on the approved list for schools. Check the safety requirements for their use, such as eye protection and eyewash facilities, availability of running water, use of gloves, a well-ventilated area or fume cupboard.
- Thermal risks: Are you heating things? Could you be burnt?
- Biological risks: Are you working with micro-organisms such as mould and bacteria?
- Sharps risks: Are you cutting things, and is there a risk of injury from sharp objects?
- Electrical risks: Are you using mains (240 volt) electricity? How will you make sure that this is safe? Could you use a battery instead? **Only batteries can be used for Models & Inventions entries*
- Radiation risks: Does your entry use potentially harmful radiation such as UV or lasers?
- Other hazards.

Also, if you are using other people as subjects in an investigation you must get them to sign a note consenting to be part of your experiment.

Risks	How I will control / manage the risk
Sodium carbonate solution may irritate skin or eyes	Wear safety glasses, wash hand after handling chemicals.
Spillage of liquids may create slipping hazards	Spills will be cleaned immediately
Sharp edges of aluminium foil may cause minor cuts.	Handled carefully the materials during the experiment.

(Attach another sheet if needed.)

Risk Assessment indicates that this activity can be safely carried out

RISK ASSESSMENT COMPLETED BY (student name(s)): Ray MAO.

SIGNATURE(S): 瑞辽

☑ By ticking this box, I/we state that my/our project adheres to the listed criteria for this Category.

TEACHER'S NAME: K. TOLIOS

SIGNATURE: [signature]

DATE: 12/06