

Exploring Faraday's Law of Electrolysis

This experimental procedure is designed to illustrate the electroplating process for the general chemistry laboratory student. Students plate a thin film of copper onto a screen-printed carbon electrode. The plating process is accurately controlled using a traditional three-electrode electrochemical cell arrangement. Each screen-printed electrode pattern includes all three required electrodes (working, reference, and counter). Copper is plated onto the working electrode from a conventional copper electrolysis plating solution. The electrode is weighed before and after deposition of the metal. By weighing the patterned electrode before and after deposition, the student obtains the mass of copper actually deposited onto the working electrode. This mass result used with Faraday's law allows the student to compute the efficiency of the electrode position process.

ESTIMATED TIME

We estimate that this experiment can be completed in one, 3-hour class period.

TIPS

1. In the Electronic Resources you will find PDF and word-processing files of the student experiment. You can print the PDF, distribute it to students electronically, or post the file to a password-protected class web page or learning management system. Edit the word-processing file if you would like to tailor the experiment to suit your equipment and students. Sign in to your account at www.vernier.com/account to access the Electronic Resources.
2. It is prudent to try this experiment with the solutions you have prepared prior to giving the solution to your students to ensure proper concentrations and experimental parameter setting.
3. This experiment can be done with various metal solutions to plate the SPE. We have also tested nickel and tin plating with these solutions:

Nickel Plating

- a. To prepare 1 L of standard Watts plating solution, add 290 g nickel sulfate hexahydrate ($\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$), 30.0 g of boric acid (H_3BO_3), and 8 g of sodium chloride (NaCl) to a 1 L volumetric flask and dilute to the mark with distilled water. This nickel plating solution is rather stable.
- b. In Instrumental Analysis and LabQuest, adjust the bulk electrolysis parameters to -1200 mV for 40 minutes at 10 mV/s with the Current Range set to High.

Tin (II) Plating

- a. The solution was prepared with 0.1 M tin (II) chloride in 0.1 M KCl with enough 6 M HCl to remove the tin oxide formed upon mixing. The resulting solution will be around pH ~ 2 .
- b. In Instrumental Analysis and LabQuest, adjust the bulk electrolysis parameters to -600 mV for 40 minutes at 10 mV/s with the Current Range set to High.

4. Instrumental Analysis and LabQuest are used to monitor the current at the working electrode throughout the plating process. The current is a measure of how fast the electrons flow from the working electrode and reduce chemical species in the solution, including but not limited to, the copper cations.
5. Initially, students will observe a larger current that fairly rapidly decays (exponentially). As more copper ions are reduced to the electrode surface, the solution around the working electrode becomes depleted of additional copper. Therefore, the current, a measure of electron transfer at the working electrode (reduction of copper ion to copper metal), will decay slowly over time. Left long enough, no additional copper would plate onto the electrode unless the solution was stirred.
6. For electroplating operations that last for one hour or more, add pure ethanol (to a final 10% concentration) to the plating solution. The ethanol is an easy target for oxidation at the counter electrode and helps prevent the counter electrode from being oxidized.
7. After the experiment is complete, a visibly thick layer of copper should have formed on the working electrode surface.

HAZARD ALERTS

The chemical safety signal words used in this experiment (**DANGER** and **WARNING**) are part of the Globally Harmonized System of Classification and labeling of Chemicals (GHS). Refer to the Safety Data Sheet (SDS) that came with the chemical for proper handling, storage, and disposal information. SDS can also be found online from the manufacturer.

Boric acid, solid, H_3BO_3 : **DANGER**: May be harmful if swallowed. May damage fertility or the unborn child. Do not handle until all safety precautions have been understood. Use personal protective equipment as required.

Copper sulfate electrolyte solution, containing sulfuric acid: **DANGER**: Do not eat or drink when using this product—toxic if swallowed. Causes skin and serious eye irritation.

Nickel sulfate, solid, $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$: **DANGER**: Do not eat or drink when using this product—toxic if swallowed and harmful if inhaled. Avoid breathing dust or fumes. Causes skin irritation. Nickel compounds are known human carcinogens by inhalation of dust. Suspected of causing genetic defects. Do not handle until all safety precautions have been understood. Use personal protective equipment as required.

Sodium chloride, solid, NaCl : **WARNING**: May be harmful if swallowed. Treat as a non-food-grade chemical. Prudent laboratory practices should be observed.

ANSWER TO PRE-LAB ACTIVITY

The standard half-cell reaction for this process can be described as



Under acidic plating conditions, the reduction of hydronium (H^{+}) to form hydrogen gas is the main side reaction that consumes additional electrical charge. The reduction potential of this reaction is arbitrarily set to 0:



DATA TABLE

Starting mass of SPE (g)	0.5272
Final mass of SPE (g)	0.5290
Plating charge (C)	6.709
Molecular weight of copper (g/mol)	63.55
Charge of copper ions (from CuSO_4)	2
Actual mass gain (g)	0.0018
Theoretical mass gain (g)	0.0022
Electrodeposition efficiency (%)	81.47%

SAMPLE CHRONOAMPEROGRAM

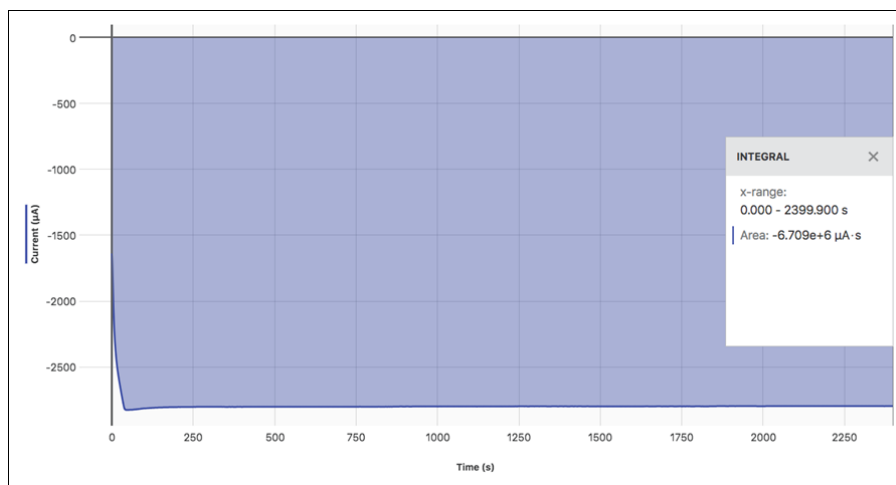


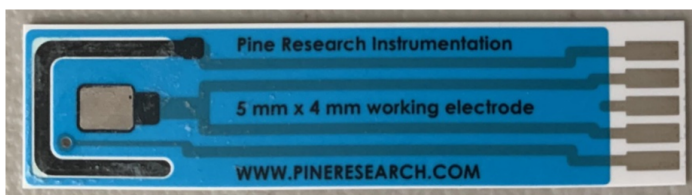
Figure 1 Copper electroplating on a screen-printed electrode

ANSWERS TO ANALYSIS QUESTIONS

1. See Data Table.
2. Copper metal is bronze. When two electrons are removed from copper, the resulting color is bronze, so the results are consistent.
3. Yes, you can see bubbles forming on the surface throughout the electrodeposition. With plenty of water molecules available for electrolysis, while copper is being reduced to the electrode surface, water is also being oxidized according to
$$2\text{H}_2\text{O} \rightleftharpoons 4\text{H}^+ + 4\text{e}^- + \text{O}_2 (\text{g})$$
4. It was less than 100% due to various reasons. The imperfect surface of the SPE is a major contributing factor. In addition, the water oxidation discussed in question 3 would reduce the charge measured. If students report more than 100% efficiency, it is typically due to errors in recording mass and drying the SPE.
5. Students will insert a photo of the SPE they used in the experiment. This is the SPE used in the sample data for copper:



This is an example of plating with nickel:



This is an example of plating with tin:

