

# Exploring Faraday's Law of Electrolysis

Electroplating is an important branch of electrochemistry with many applications in modern technology. For example, the automobile industry relies upon nickel and chromium electroplating to protect steel from corrosion. Noble metal electroplating of the coinage metals is used for decorative purposes such as fabricating jewelry. Electroplating is also an essential tool for manufacturing state-of-the-art electronic devices. Electrodeposited copper metal interconnects within integrated circuits to play an important role in the devices used to build the information superhighway.

In this lab experiment, you will explore basic principles of electroplating by plating thin films of copper onto screen-printed carbon electrodes. You will use inexpensive screen-printed electrodes (SPE) as a convenient (and disposable) alternative to larger-sized bulk metal electrodes. Each SPE consists of a carbon working electrode, a carbon counter electrode, and a silver/silver chloride reference electrode (see Figure 1).

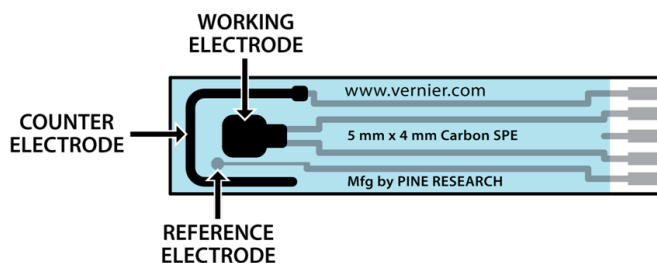


Figure 1 Screen-printed electrode (SPE)

To accurately control the electrode potential used for electroplating, you will insert the SPE into a Go Direct Cyclic Voltammetry System (CVS), a modern three-electrode potentiostat. The CVS can apply and maintain a constant potential between the working and reference electrodes while simultaneously accurately measuring the flow of charge (current) through the working electrode.

As the potential of the working electrode moves toward more negative values, electrons at the working electrode surface become more readily available to reduce ions in the solution. Copper(II) cations in solution are reduced to copper metal.

Faraday's law of electrolysis states that the extent of chemical reaction (i.e., mass of electroplating metal,  $m$ ) caused by the flow of current is proportional to the amount of electric charge ( $Q$ , in C/s) passed through the electrochemical cell:

$$m_{\text{theoretical}} = \frac{M}{nF} Q$$

where  $M$  is the molar mass of the deposited metal,  $n$  is the number of electrons transferred in the reaction (oxidation state of the metal ion), and  $F$  is Faraday's constant (96,485 C/mol).

During this experiment, you will use the CVS to apply a constant potential to a SPE; current will be measured as a function of time. The data generated is called a chronoamperogram. From Faraday's law, you know that the total amount of charge passed during electrolysis is proportional

## Experiment 3

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to the mass of metal reduced to the working electrode surface. During analysis, you will determine the charge passed during the total electrolysis.

### OBJECTIVES

- Use an electrochemical technique called bulk electrolysis (BE) to confirm Faraday's law of electrolysis.
- Observe electroplating on screen-printed electrodes by copper.

### MATERIALS

One of the following

- Chromebook, computer, or mobile device with Vernier Instrumental Analysis app<sup>1</sup>
- LabQuest 2 (software is pre-installed; v2.9.0 or newer required)<sup>2</sup>
- LabQuest 3 (software is pre-installed; v3.0.7 or newer required)<sup>2</sup>

Go Direct Cyclic Voltammetry System and stand

screen-printed electrode (SPE)

scintillation vial(s)

goggles

1.0 M copper sulfate in 1.0 M sulfuric acid

balance with 0.001 g resolution

### PRE-LAB ACTIVITY

Write the redox half reaction for copper plating.

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<sup>1</sup> Instrumental Analysis v1.3 or newer required; download the most recent version for free at [www.vernier.com/ia](http://www.vernier.com/ia)

<sup>2</sup> Download the most recent version of LabQuest software for free at [www.vernier.com/downloads](http://www.vernier.com/downloads)

## PROCEDURE

1. Put on safety goggles.
2. Set up the Cyclic Voltammetry System by following the directions for your equipment:

### Instrumental Analysis

- a. Launch Instrumental Analysis.
- b. Connect the Go Direct Cyclic Voltammetry System (CVS) to your device via USB or Bluetooth wireless technology. If using Bluetooth, click or tap Connect an Instrument, connect to your CVS, and click or tap Done.
- c. Click or tap Voltammetry.
- d. Set the Voltammetry Mode to Bulk Electrolysis.
- e. Set the BE Profile settings to the values in Table 1.

### LabQuest

- a. Connect the Go Direct Cyclic Voltammetry System (CVS) to your device via USB or Bluetooth wireless technology. If using Bluetooth, tap the Sensors menu and choose Wireless Device Setup ► Go Direct. Select your instrument and tap OK.
- b. Choose Data Collection from the Sensors menu.
- c. Set the Voltammetry mode to Bulk Electrolysis.
- d. Set the BE Profile settings to the values in Table 1.

Table 1	
Sample rate (mV/s)	10
Duration (s)	2400
Electrolysis potential (mV)	-600
Current range	High

3. Weigh the screen-printed electrode (SPE) to at least the nearest 0.001 g. Record this value in Table 2.
4. Insert a SPE into the SPE connector on the Cyclic Voltammetry System (see Figure 2).

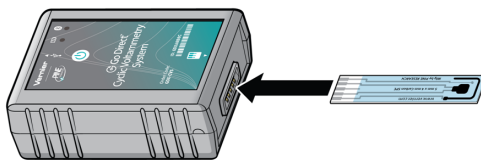


Figure 2

### Experiment 3

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5. Fill the scintillation vial about halfway full (~10 mL) with your solution. Insert the scintillation vial into the clip on the stand. Carefully guide the Cyclic Voltammetry System with SPE attached downward into the vial and snap the instrument into place, as shown in Figure 3.

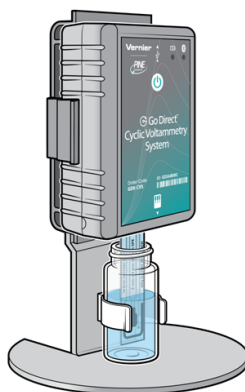



Figure 3

6. Start data collection. Observe the working electrode surface at several intervals during the electrolysis. Record observations in your notebook and include the electrolysis duration time that has elapsed when making these observations. Data collection will stop automatically.
7. Analyze the chronoamperogram.
  - Instrumental Analysis: Click or tap Graph Options, , and select View Integral. Using the integral information, record the charge (C) in Table 2.
  - LabQuest: From the Analyze menu, choose Integral. Using the integral information, record the charge (C) in Table 2.
8. Carefully remove the Cyclic Voltammetry System from the stand by pulling back on the top tab. Remove the SPE from the Cyclic Voltammetry System. Rinse the SPE with distilled water, and dry it by gently blotting the electrode surface with a piece of paper towel.  
**Important:** Do not invert the Cyclic Voltammetry System with a damp SPE attached. You want to avoid getting liquid inside the SPE connector.
9. When the SPE is completely dry, weigh it and record its mass in Table 2.
10. Dispose of your samples as instructed.

**DATA TABLE**

Table 2	
Starting mass of SPE (g)	
Final mass of SPE (g)	
Plating charge (C)	
Molecular weight of copper (g/mol)	
Charge of copper ions (from $\text{CuSO}_4$ )	
Actual mass gain (g)	
Theoretical mass gain (g)	
Electrodeposition efficiency (%)	

**DATA ANALYSIS**

1. Complete Table 2 and calculate the electrodeposition efficiency using Faraday's law. Pay close attention to units.
2. What is the color of the copper metal? When two electrons are removed from copper, what color will result? Do your results align with theory?
3. Did you observe anything on the surface of the electrode as the potential was applied and the deposition occurred? What did you see and what do you think it could be? (Hint: A molecule of water is composed of two atoms of hydrogen and one atom of oxygen.)
4. Was your average plating efficiency less than or greater than one hundred percent? Why do you think this was the case?
5. Take a picture of your electrode and include it with your lab report.