

## Electroplating Lab

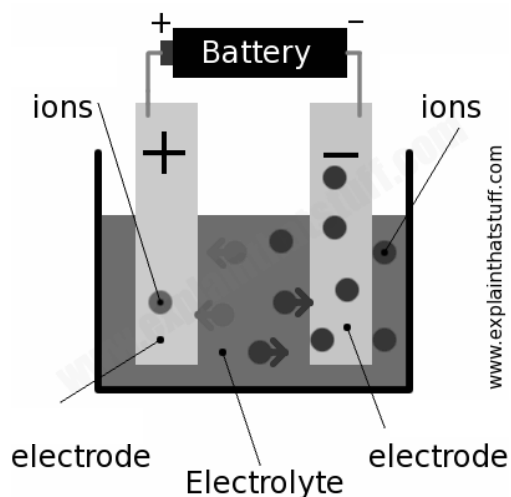
### Objective

In this lab you will be electroplating zinc onto a penny, copper onto a nickel, and calculating the number of moles of each metal deposited onto the coins.

### Background

#### *Electroplating*

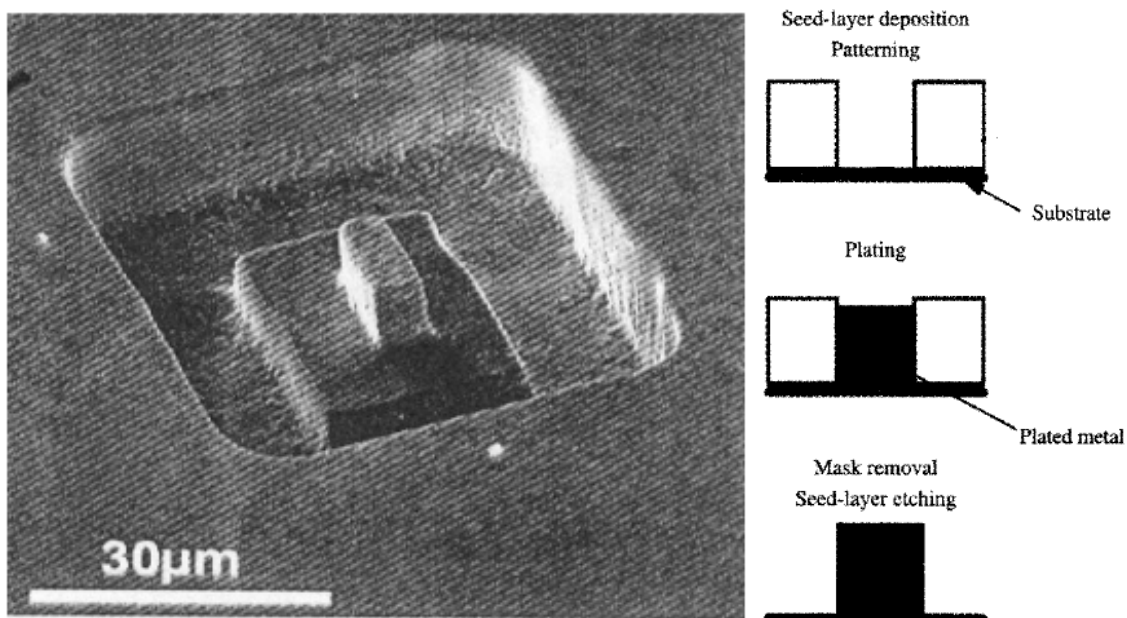
Electroplating involves the deposition of a metal onto an object composed of a different metal. An electric current reduces the cations in solution to form a thin layer on a conductive material. This current is run from the anode to the cathode. Both nodes are completely immersed in a salt solution, which allows for the flow of electricity through the circuit. The direct current applied at the anode allows for the metal ions to be oxidized, which in turn allows them to dissolve into the solution. These dissolved ions are then reduced at the cathode, which is what plates the metal ions onto the conductive material. This is shown in the figure below.



Electroplating is a very useful technique because it allows for careful control of the surface composition. The deposited layer thickness can be tuned by controlling the operating conditions, such as electric current and rate of mixing (of ions in solution).

A common technique used in the manufacturing of microelectronics involves applying a patterned 'mask' on an object to selectively block the deposition of metal so that deposition only occurs on the area left exposed. The figure below shows the deposition process: first the mask is applied to the sample; then the metal is deposited selectively in the exposed area; and finally the mask is removed using a solvent. The reverse of this process can be done by etching the metal from a precisely controlled area called electrochemical micromachining.

Also pictured is a SEM (scanning electron microscope) micrograph of an electrochemically machined component of an electronic circuit board. This manufacturing technique allows for control of the surface structure and composition on the micro/nanometer scale.



Left: An electrochemically etched piece or a circuit board Right: The process of depositing metal on a surface.

**Redox Reactions**

Redox reactions, or oxidation-reduction reactions, describe the transfer of electrons between two chemical species. These reactions are made up of two half-reactions which always occur simultaneously. The **reduction half reaction** represents the **gain** of electrons to the **oxidizing agent**. The **oxidation half reaction** represents the **loss** of electrons to the **reducing agent**. A simple way to remember the difference between oxidation and reduction is to use the mnemonic 'OIL RIG,' which stands for 'oxidation is loss; reduction is gain,' and represents the movement of the electrons. When put together, these two  $\frac{1}{2}$  reactions will simplify to the overall balanced net ionic equation.

**Faraday's Law**

Using Faraday's Law, the amount of anode material deposited on the cathode can be calculated:

$$\text{Mass deposited} = \frac{I \cdot t \cdot \mathcal{M}}{F \cdot n}$$

$I$  represents the amount of current (in Amperes),  $t$  is the deposition time (in seconds),  $\mathcal{M}$  is the molar mass of the anode material,  $F$  is Faraday's constant ( $96,500 \frac{A \cdot s}{mol}$ ), and  $n$  is the number of moles of electrons per mole of anode material (i.e. the oxidation number).

**Penny Composition**

The United States penny is composed of copper plated zinc. Before 1982, the penny was made up of 95% copper and 5% zinc. Since 1983, the penny has been made up of 97.5% zinc and 2.5% copper.

**Nickel Composition:**

The United States nickel is composed of copper-nickel alloy. Since 1938, the nickel has been made up of 25% nickel and 75% copper.

## Materials

- 0.1M Copper Sulfate Solution
- 0.5M HCl
- Power source
- Alligator clips
- Paper clips (3/group)
- Electrical Tape
- Beakers (3/group)
- Galvanized Zinc Nails (1/group)
- Coin Penny (Pre-1982) (1/person)
- Coin Nickel (1/person)

## Procedure

*Safety:* Goggles.

### ***Part 1 - Electroplate copper penny with zinc***

1. Clean your copper penny and galvanized nail (surface covered with zinc) with steel wool.
2. Weigh coin and nail, record masses.
3. Straighten out paper clip and tape a penny to one end.
4. Connect the galvanized nail to the positive electrode with alligator clip.
5. Connect the remaining end of the paper clip to the negative electrode.
6. Obtain 100 mL stock solution of 0.5 M hydrochloric acid.
7. Place both penny and nail into a 100mL beaker with ~50mL of HCl. Make sure the alligator clips stay out of the solution. (Don't let the coin and nail touch each other.)
8. Turn on power source, set voltage to achieve a current of 0.6 amps.
9. Remove coin and nail after 5 minutes, rinse with DI bottle, rinse with acetone, and carefully pat dry with paper towel.
10. Record mass of cathode and anode.
11. Obtain a new penny and repeat part 1 two more times with power source set to achieve currents of 0.2 amps and 0.4 amps. (Use the same solution)
12. Dispose of waste in the proper container.

### ***Part 2 - Electroplate nickel coin with copper***

1. Obtain 50 mL of 0.1M copper sulfate solution, add ~ 7 mL of 0.5M HCl to solution.
2. Repeat part 1 with this new solution using a nickel coin as the cathode, a penny as the anode.
3. Set voltage to achieve a current of ~0.4 amps.



**Post Lab Questions**

1. What is the mass of the Zn deposited onto the copper coins for each current (0.2, 0.4, 0.6). Compare to your calculations in the pre-lab. Calculate the percent error.
2. Why are the measured masses different from the calculated mass deposited? Include sources of error in the measurement.
3. For Part 2, based on the number of moles of anode material lost, how many moles should have been electroplated onto the cathode? Does this match what you observed? If it doesn't match, explain why.
4. What affects deposition rate?
5. Explain any unexpected observations in part II.

**Extra Credit: Investigation into Current Density**

The current density of an electrolyte solution is similar to the flow of electrons through a wire and is defined as the flow of charge per area ( $A/m^2$ ). However, unlike in a wire the charges that are moving are positively and negatively charged ions instead of electrons. The flow of ions can be induced by applying a voltage across an electrolyte solution. As the voltage across the solution is increased the current density also increase.

In a wire, where electrons carry the electric charge, the current will continuously increase as the voltage is increased. In an electrolyte there is a limiting current, which happens when further increasing the voltage does not affect the current density. This happens because there reaches a point when the flow of ions is limited by the diffusion (movement of ions from high concentration to low concentration), and this movement is independent of the applied voltage.

The limiting current density can be calculated using the following equation, where  $F$  is Faraday's constant,  $D$  is the diffusion coefficient of the ion,  $z$  is the charge of the ion,  $C_0$  is the concentration of the ions being deposited in solution, and  $L$  is the distance between electrodes.

$$i_L = \frac{4FDzC_0}{L}$$

4. Sketch the current as a function of voltage, keeping in mind how the redox potential and limiting current will affect the graph. Label this sketch as 1.
5. Assuming sketch 1 is for Ag ions, sketch the current as a function of voltage for Cu ions used as the electrolyte, label as 2. This does not need to be quantitative, just show the qualitative trends based on the properties of each metal.





**Pre-lab Questions**

1. Write balanced redox reactions for electroplating:
  - a.  $\text{Zn}^{2+}$  onto  $\text{Cu}^0$
  
  
  - b.  $\text{Cu}^{2+}$  onto  $\text{Ni}^0$
  
2.
  - a. What is the difference between spontaneous redox and nonspontaneous redox?
  
  
  
  
  
  
  
  
  
  
  - b. Are the redox reactions in question 1 spontaneous? Explain.
  
  
  
  
  
  
  
  
  
  
3. Determine the anode and cathode when plating:
  - a. a copper penny with zinc in Part 1
  
  
  
  
  
  
  
  
  
  
  - b. a nickel with copper in Part 2
  
  
  
  
  
  
  
  
  
  
4. Which direction are the electrons flowing when electroplating:
  - a.  $\text{Zn}^{2+}$  onto  $\text{Cu}^0$
  
  
  
  
  
  
  
  
  
  
  - b.  $\text{Cu}^{2+}$  onto  $\text{Ni}^0$

- Calculate the mass of Zn deposited on your penny after 5 minutes for the following applied current:
  - 0.2 amps
  
  
  
  
  
  
  
  
  
  - 0.4 amps
  
  
  
  
  
  
  
  
  
  - 0.6 amps
  
- Prepare data tables for parts 1 and 2 in your lab notebook to record: cathode, anode, initial masses of cathode and anode, applied current, deposition time, final masses of cathode and anode, change in mass of cathode and anode, and key observations.
  
- Bring in a post-1938 nickel and a pre-1982 penny.**