The Chemistry of Copper Electrolysis

Hands-On Activity Objectives

- Apply basic chemistry principles to understand the process of electrolysis
- Understand how electrolysis is used in the processing of copper ores

Time Required

Thirty minutes to set up and up to 60 minutes to run the electrolysis.

Hands-On Activity Overview

This experiment demonstrates the process of **electrolysis**, which is used in the commercial purification of ores such as **copper** sulfide ore. Electrolysis uses an electrical current to move **ions** in an **electrolyte** solution between two **electrodes**. In copper electrolysis, when a current is applied, positively-charged copper ions (called **cations**) leave the **anode** (positive electrode) and move toward the **cathode** (negative electrode).

In this experiment (Figure 1), a U.S. penny acts as the copper source/anode and a U.S. dime serves as the cathode (a dime, versus another penny, makes the movement of copper more obvious). A dilute **aqueous** solution of copper sulfate and sulfuric acid is used as the electrolyte. An electric current is provided by a 9 volt (V) battery.

When electric current is supplied to the anode (penny) via the positive terminal of the battery, copper atoms are **oxidized** to form cations with a positive charge (Cu^{2+}). The cations are set free in the electrolyte solution and are attracted to the cathode (dime), which is connected to the negative terminal of the battery. Additionally, the copper sulfate electrolyte solution contains copper in the form of positively-charged cations, which are also attracted to the negative electrode (the cathode, a dime).

Positive Anode (penny): $Cu_{(solid)} \rightarrow Cu^{2+}_{(aqueous)} + 2\ e^-$

Negative Cathode (dime): $Cu^{2+}_{(aqueous)} + 2\ e^- \rightarrow Cu_{(solid)}$

This results in the net loss of copper from the anode (penny) and the gain of a copper coating on the cathode (dime).

MATERIALS


Figure 1: Materials needed for copper electrolysis lab.

- Copper sulfate electrolyte solution (200 g $CuSO_4 \cdot 5H_2O$ + 25.0 mL concentrated H_2SO_4 solution in enough distilled or deionized water to make 1.0 L of solution)
- Coin cleaning solution (1 tsp table salt dissolved in ¼ cup vinegar)
- Pre-1982 penny (contains 95% copper, versus only 2.5% copper post-1982)
- Dime (any year)
- 9V battery (use a new 9V battery for each experiment)
- 18-gauge copper wire
- Four alligator clips (2 each of red and black)
- Wire stripper and needle-nosed pliers
- Two 250-mL beakers
- Cardboard circle (approx. 15 cm diameter)
- Precision scale (optional)

SAFETY PRECAUTIONS

Gloves and goggles should be worn throughout this experiment. Sulfuric acid can cause burns so please handle with care. Although the power source is relatively weak, the electrodes and connecting wires should not be handled when the cell is operating. The 9V battery can become quite hot during use; use caution when handling it.

PROTOCOL

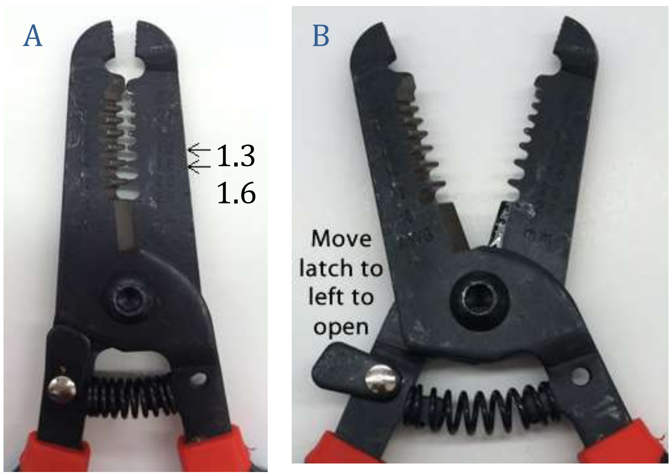
1. Clean the penny with salt/vinegar mixture; rinse with water and dry (dime does not need to be cleaned).
2. Prepare the wire assembly:
   a. Cut a 33 cm length of 18-gauge copper wire (Figure 2).

Figure 2. 33 cm length of 18-gauge copper wire.

b. Peel apart to separate red- and black-coated wires (Figure 3).

Figure 3. A) Peeling apart red and black coated wires; B) separated red and black wires.

c. Use 1.6 mm gauge setting on wire stripper to remove ~1.5 cm length of rubber coating from both ends of each wire to expose the copper filaments, being careful not to sever copper filaments (Figure 4).



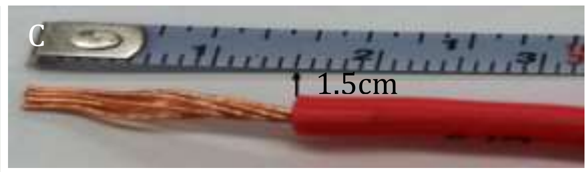


Figure 4. A) Closed wire stripper; B) open wire stripper; and C) 1.5 cm length of rubber coating removed from copper wires to expose copper filaments.

d. Twist filaments together tightly and fold in half (Figure 5).

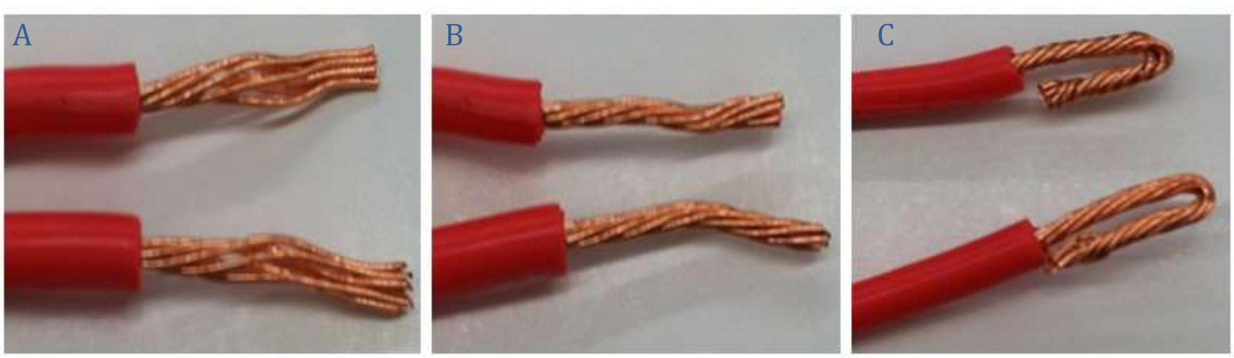


Figure 5. A) Exposed copper filaments; B) twisted copper filaments; and C) final product of twisted and folded copper filaments.

e. Make two holes in the cardboard an inch apart from each other.
f. Push the red wire through one hole and the black wire through the other.
g. Insert each folded end of the wires into the handle of a matching alligator clip so that the wire touches the metal inside the clip handle (red wire should have a red alligator clip at each end; black wire should have a black alligator clip at each end; Figure 6).

h. Clip the penny into the red electrode and clip the dime into the black electrode (Figure 7).

→ OPTIONAL step to be completed before inserting wires into cardboard: Weigh each coin/copper wire assembly (penny/red wire/red clip; dime/black wire/black clip) separately and record the mass.

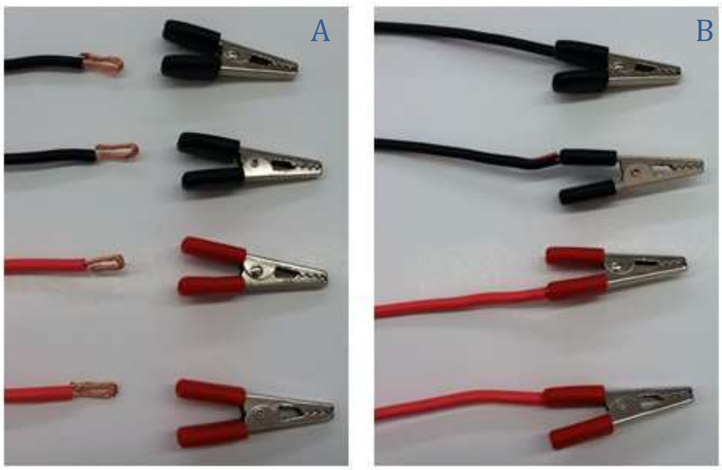


Figure 6. A) Unattached copper wires; B) copper wires attached to alligator clips.

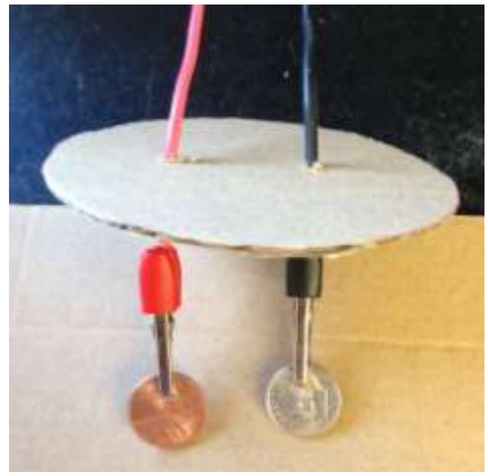


Figure 7. Complete wire assembly: red and black wires pushed through cardboard with alligator clips attached and coins inserted.

3. Pour 150 mL of the copper sulfate electrolyte solution into the beaker.
4. Place the wire assembly over the beaker so that the coin "electrodes" are immersed in the electrolyte solution as illustrated in Figure 8.

→ *Note:* the two electrode assemblies must not touch one another.

5. Clip each connecting wire to the terminals of the 9V battery: Clip the red to the positive terminal, and black to the negative terminal (Figure 9).

Figure 8. Electrodes immersed in the electrolyte solution.

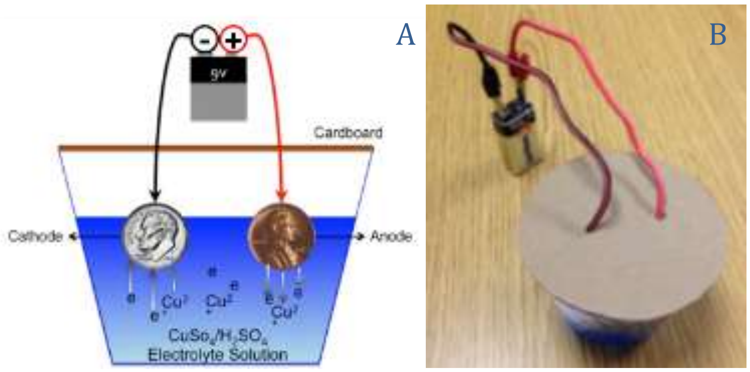


Figure 9. A) Cross-section illustration of final complete copper electrolysis lab set-up. ; B) Actual photograph of complete copper electrolysis lab set-up.

6. Allow the **electrolytic cell** to operate for 30-60 minutes.

→ OPTIONAL: Record the length of time the cell was operating.

7. Remove the cardboard with the coin/copper wire assemblies and hang to dry in an empty cup or beaker until it is dry (approximately 5-10 min), being careful not to touch the coins, so as not to lose any of the copper plating.
8. Examine the coins for changes.

→ OPTIONAL: Weigh each coin/copper wire assembly and record the mass. Calculate the difference in starting and ending mass.

Disposal

Coins used in this experiment should not be reused as currency. Coin/copper wire assemblies may be discarded in the trash or recycled. Electrolyte solution can be reused; to dispose of the solution, it should be flushed down the drain with plenty of water. 9V batteries can be disposed of in the trash.

Relevance

For purifying copper commercially, large slabs of impure copper (called blister copper) are used as anodes and placed in large vat containing an electrolyte solution of copper sulfate and sulfuric acid. Thin “starter sheets” of highly pure copper foil are used as the cathodes, which are placed in between the anodes. When current is applied (over 200 amperes), copper (as well as other metals) leaves the anode and moves through the solution toward the cathode. The other metals (sometimes valuable, but considered to be impurities in copper processing) either remain in solution or fall to the bottom of the tank, where they can be later captured for use as a by-product. Over the course of 1-2 weeks, the copper ions plate onto the cathode, resulting in a 300-pound sheet of 99.9% pure copper.

Worksheet

1. Write your hypothesis about what will happen in this experiment:
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____
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2. Start Time:___________________________
3. End Time: ___________________________

Optional

Table 1. Determining the mass of copper plating.

Initial mass of dime [g]		Initial mass of penny [g]	
Final mass of dime [g]		Final mass of penny [g]	
Difference in mass [g]		Difference in mass [g]	

Questions

1. Was your hypothesis correct? If not, why do you think it was not?

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2. At the end of the experiment, the dime should be coated with copper. What are the possible sources of this coating? How could you determine which sources contributed to the coating, and how much?

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3. Calculate the final concentration of $CuSO_4$ in the copper sulfate electrolyte solution.

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4. Why do you think copper wire is used for the wire assemblies?

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5. What differences would you expect if the electrolytic experiment were allowed to run for a short time versus a long time?

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6. What would you expect to see if you made the dime the anode and the penny the cathode, and/or used different coins in the experiment? Would you need to change anything else?

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7. To reach commercial scale, how do you think you would need to change the materials from this small experiment to make a 300-pound copper cathode?

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8. Fill in the diagram below of commercial-scale electrolytic refining by labeling the anodes and cathodes, and by drawing in the movement of copper ions (Figure 10).

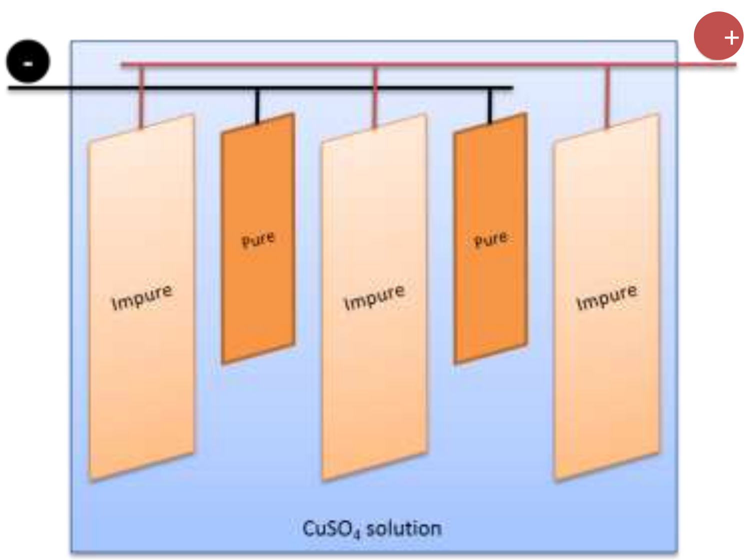

Figure 10. Diagram of commercial-scale electrolytic refinement.

Answers

1. Possible sources include the penny, the solution, the copper wires – by weighing before and after, students should be able to determine where the mass came from (i.e., if the loss of weight from the penny does not account for the whole gain on the dime, it must have gotten copper from the solution. Although the copper wires may also act as a source, they are not weighed separately, so this determination cannot be made empirically.)

2. 200 g $CuSO_4$ / 1 L solution = **20% $CuSO_4$**

   Or, molecular weight of $CuSO_4$ = 159.607 g/mol

   [(Cu=63.546) + (S=32.065) + (O_4=15.999 x 4) = 159.607]

   and 200 g $CuSO_4$ / 159.607 g/mol = **1.25M $CuSO_4$**

3. Copper wire is used because copper is known for its properties as an excellent electrical conductor (it likely does not contribute significantly to the plating of copper on the dime).

4. The longer the experiment is run, the more copper plating will appear on the dime.

5. One would have to know what the content of each coin is – modern dimes actually contain copper, so you might still see it transferring to the penny. In order to make different metals move from different coins, one would need to optimize the electrolyte solution for that metal. This is why other metals are not plated in the commercial copper process – because of their different solubilities/chemistries, they either remain in solution or precipitate out.

6. One would need to start with a big anode (ie, not a penny!), adjust the electrolyte solution (more concentrated in both CuSO4 and acid than this experiment), and apply more power (this simple one-hour experiment can exhaust a 9V battery that delivers approximately 5.4 watts an hour).

7. Diagram of commercial-scale electrolytic refinement.

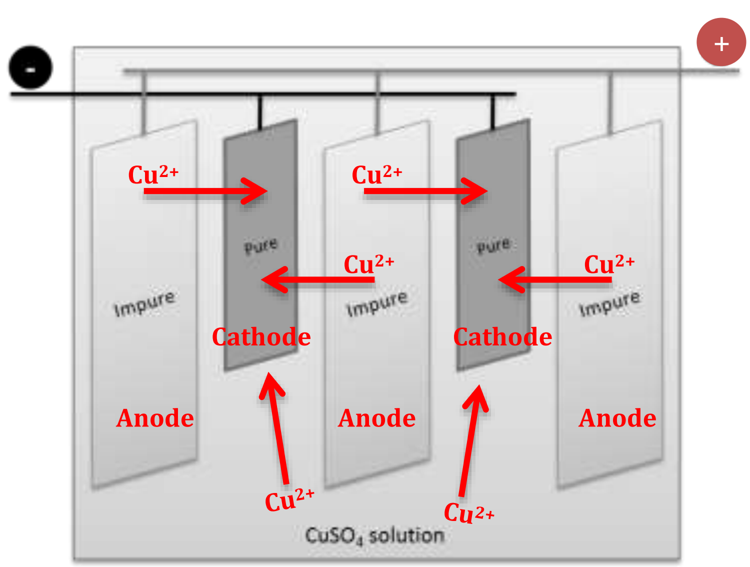

Figure 10. Diagram of commercial-scale electrolytic refinement.

Glossary

anode

1. An **electrode** through which conventional current flows into a polarized electrical device; in **electrolysis**, it is the positive terminal.
2. In copper processing, a copper anode is an intermediate product from the smelting furnaces which is used as a copper source from which to make copper **cathodes** during **electrolysis**.

aqueous

Of or containing water, typically as a solvent or medium; i.e., an aqueous solution.

cation

A positively-charged ion that is attracted to the cathode (negative terminal) in electrolysis.

cathode

1. An **electrode** from which conventional current leaves a polarized electrical device; in **electrolysis**, it is the negative terminal.
2. In copper processing, a copper cathode is the final, 99.99% pure product of the **electrolysis** process, and is itself the primary raw material input for the production of finished copper products, such as rode, tubes, and wires.

copper

A reddish-brown, ductile, malleable metallic element that is an excellent conductor of heat and electricity and is widely used for electrical wiring.

electrode

An electrical conductor, though which a current enters or leaves an **electrolytic cell** or other medium.

electrolysis

Generally, a technique that uses an electric current to drive an otherwise non-spontaneous chemical reaction. Typically, an electrical potential is applied across a pair of **electrodes** (**anode** and **cathode**) immersed in an **electrolyte** solution, resulting in the movement of positively charged ions (cations) moving toward cathode and negatively charged ions (anions) toward the anode. For copper sulfide ore, electrolysis is the final stage in the process of pyrometallurgy, in which **anode** copper slabs are hung in a large tank full of a copper-based **electrolyte** solution and an electric current is applied, resulting in the plating of copper onto 99.9% pure copper **cathodes**.

electrolyte

A chemical compound that conducts electricity by changing into ions when melted or dissolved into a solution.

electrolytic cell

A device that contains two **electrodes** in contact with an **electrolyte** and that brings about a non-spontaneous chemical reaction when connected to an outside source of electricity.

electron

A subatomic particle that carries a negative charge.

ion

An electrically charged atom or molecule which can be formed by the gain or loss of an **electron**(s); whether the electrons are gained or lost is indicated by a minus or plus sign, respectively, and a number indicating how many. For example, Cu^{2+} has lost 2 electrons and carries a positive charge.

oxidize

To cause an atom or group of atoms to lose **electrons** during a chemical reaction.