

Electroplating

Electrochemistry deals with chemical reactions involving electrical energy. A system where **chemical reactions produce electric current** is called a **voltaic cell**. A battery is an everyday example of a voltaic cell. A system where an **electric current produces chemical reactions** is called an **electrolytic cell**. Electroplating, in which a metal is plated onto another object (e.g., chrome-plated trim or wheels on a car, chrome-plated bathroom fixtures, gold-plated or silver-plated jewelry) is an example of an electrolytic cell. This activity will explore two examples of electroplating. In Part 1, zinc from a galvanized nail (an iron nail which has been coated with zinc by dipping it in molten zinc) will be plated onto a copper penny. In Part 2, copper from a penny will be plated onto a nickel.

SAFETY

- wear eye protection as appropriate
- follow appropriate disposal techniques

Materials

galvanized nail	water
4 copper pennies (as bright and shiny as possible)	3 nickels (as bright and shiny as possible)
0.5M hydrochloric acid (0.5M HCl) -- see Notes & Comments section for instructions for making the solution	
0.1M copper sulfate solution-- see Notes & Comments section for instructions for making the solution	
3 plastic cups	100 mL graduated cylinder or graduated beaker
plastic film can with lid (see Figures 1 & 2 -- not all film cans will work)	
2 1-inch brass fasteners	1.5 volt C battery
2 alligator clip leads	toothbrush
powdered cleanser (e.g., Bon Ami)	small piece of sponge
3 paper clips, #1 size (bare metal, not plastic-covered)	foam double-stick mounting tape, 1/2 in wide
appropriate eye protection	paper towels
newspaper (to protect tables)	utility knife

Part 1: Plating Zinc onto Copper

(Instructions are intended for a three-person lab group.)

1. Use the utility knife to make a small slit in the bottom of the film can, and in the center of the lid. Insert the legs of a brass fastener through each slit, and then bend the legs as shown in Figure 1. Place the battery in the film can, with the negative (flat) end at the bottom, and the positive (knob) end at the top (see Figure 2). Put the lid tightly on the film can.



Figure 1



Figure 2

2. Obtain a cup and fill it half full of water. Use the toothbrush and cleanser to thoroughly clean three pennies (one for each member of the lab group). A convenient way to do this is to lay the pennies on the damp sponge while scrubbing them, and then dip them in the cup of water to rinse. Clean, bright pennies will plate significantly better than dull ones. When clean, rinse the pennies and dry them with a paper towel.

3. Bend a paper clip as shown in Figures 3a,b and c.

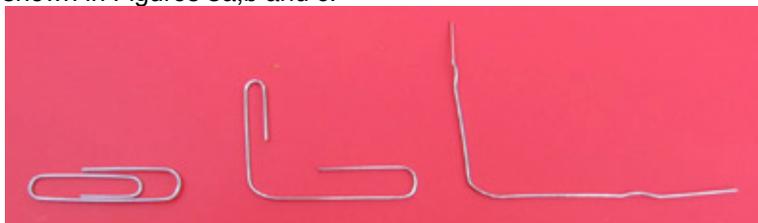


Figure 3a

Figure 3b

Figure 3c

4. Line up the three pennies, and place the long leg of the bent paper clip across them, as shown in Figure 4a. (If you want Lincoln's head plated, put the wire on the opposite side.) Use a 2-inch length of mounting tape to fasten the paper clip to the coins as shown in Figure 4b. Be sure you press the tape tightly against the paper clip and coins, so the paper clip makes good contact with each coin (important for electrical purposes in the plating process), and the coins are securely held together as a "gang" of three coins that can be moved as a single unit.

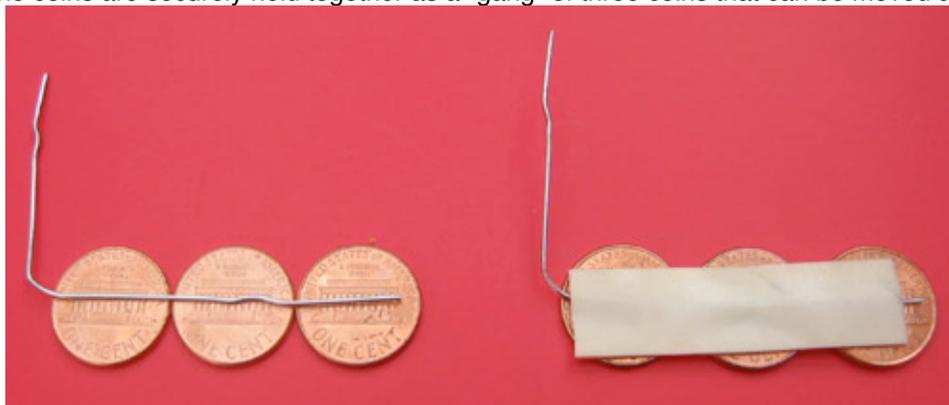


Figure 4a

Figure 4b

5. Use one of the alligator clip leads to connect the **negative** end of the battery to the gang of **pennies**. Use the other lead to connect the **positive** end of the battery to the pointed end of the zinc-coated (galvanized) **nail**. Place the gang of pennies and the nail in the plastic cup, but be sure the pennies and the nail do not touch each other. See Figures 5 and 6. If necessary, use pieces of masking tape near the top of the cup to hold things in place.

7. Measure 100 mL of 0.5M HCl into a graduated cylinder or graduated beaker. Carefully pour the HCl into the plastic cup until the pennies are completely covered, but **DO NOT ALLOW THE ACID TO TOUCH ANY PART OF THE ALLIGATOR CLIP**. Normally you should be able to add the entire 100 mL, but use less if necessary to avoid immersing the alligator clip. Figure 5 shows the complete setup, and Figure 6 shows a close-up of the pennies and nail in the cup with the HCl.

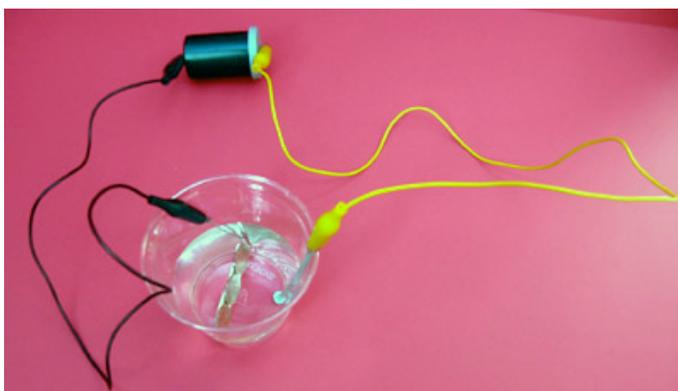


Figure 5

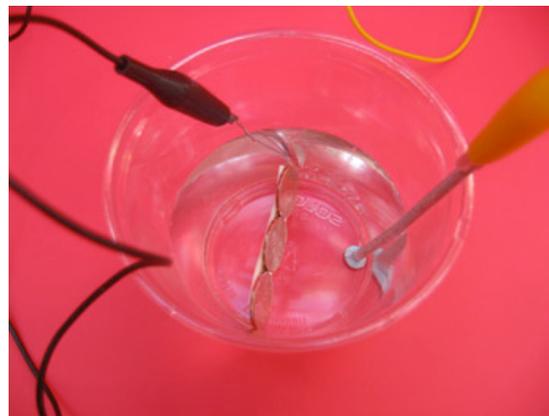


Figure 6

8. If the process is proceeding, you should see bubbles at each of the electrodes, and the penny should become coated with a silvery (or sometimes dull or dark gray) coating. Allow the process to proceed until the penny seems thoroughly coated -- this should take place within 5 minutes.

9. Remove the gang of pennies from the acid solution, disconnect them from the alligator clip, and dip them in the cup of water to rinse. If they are dull or black, use the toothbrush and cleanser to polish them. If all has gone well, each person in the lab group should end up with a reasonably shiny zinc-plated penny (on one side!).

10. Don't discard the HCl solution from Part 1 yet, in case you want to use it again if time permits.

Part 2: Plating Copper onto Nickel

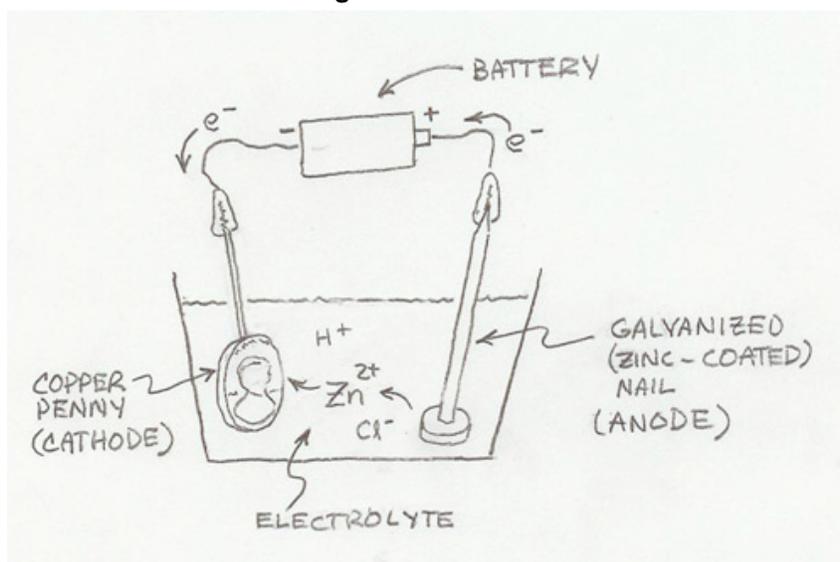
Materials and procedure are essentially identical to Part 1, with the following exceptions and notes:

- you won't need to assemble the battery holder, since it's already done
- obtain a new plastic cup for Part 2
- connect a copper penny to the positive end of the battery, in place of the galvanized nail used in Part 1 (tape the penny to a paper clip -- **don't immerse the alligator clip!**)
- connect a gang of three nickels to the negative end of the battery, in place of the gang of copper pennies used in Part 1 -- again, **don't immerse the alligator clip!**
- use 100mL of 0.1M copper sulfate solution + 15mL of 0.5M hydrochloric acid rather than the 100mL of 0.5M hydrochloric acid used in Part 1

What's Going On

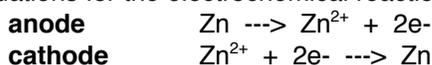
Figure 7 is a diagram of the process you have used to plate zinc onto copper. The battery takes electrons from the zinc coating of the galvanized nail, and moves them to the copper penny. As the zinc atoms lose electrons, they become positively charged zinc ions, and move into the solution. Meanwhile, at the copper penny, the extra electrons combine with the zinc ions in solution, forming zinc metal atoms which plate out on the penny. Every time a metal ion plates out at the cathode, another metal ion goes into solution at the anode.

Figure 7



Now for some electrochemical vocabulary! The entire plating system is called an **electrolytic cell**, in which **electric current** from a **power source** (e.g., the battery) **causes chemical reactions**. The electrode where **electrons are lost** (e.g., the nail, where the zinc atoms lose electrons and become positive zinc ions) is called the **anode**. The electrode where **electrons are gained** (e.g., the copper penny, where positive zinc ions gain two electrons to become zinc atoms plating on the copper), is called the **cathode**. The liquid conducting solution, where charged ions can move, is called the **electrolyte**.

The equations for the electrochemical reactions at the anode and cathode are as follows:



The explanation for Part 2 is essentially the same, except that in Figure 7, the anode is a copper penny, the cathode is a nickel, Zn^{2+} ions are now Cu^{2+} ions, and there are SO_4^{2-} ions present in addition to the Cl^- ions. In the equations for anode and cathode, Zn and Zn^{2+} become Cu and Cu^{2+} .

Special Note for Part 1

In the usual plating process, ions of the metal to be plated are already in the electrolyte, as was the case in Part 2, where the electrolyte contained Cu^{2+} ions and SO_4^{2-} ions. The more conventional approach to the plating of zinc on copper would be to use an electrolyte consisting of a zinc salt, such as zinc sulfate, dissolved in water, with a touch of sulfuric acid to improve the conductivity. But zinc sulfate is not commonly found in drug stores, hardware stores, garden stores, etc., and sulfuric acid is perhaps even more wicked than hydrochloric acid to work with, and is also harder to obtain, since hydrochloric acid, under the common name of muriatic acid, is commonly used in swimming pools and for cleaning bricks and cement, and is readily available in pool supply stores and hardware stores. The vigorous bubbling at the nail is due to the chemical reaction taking place between the zinc and the HCl, in which hydrogen gas is liberated, and zinc and chloride ions go into solution.



It should be noted that this is not an electrochemical reaction. It is essentially a preliminary step to put zinc ions in the electrolyte.

Notes and Comments

- to make 1 liter of 0.5M HCl solution, mix 50 mL of 31% muriatic acid (from a hardware store) with 950 mL water -- the 31% muriatic acid is **approximately** 10M, so the solution you are making is **approximately** 0.5M -- amounts can be scaled up or down, depending on how much solution is needed, as long as the 20-1 dilution factor is maintained -- be sure to wear eye protection, and add acid to water, **NOT** water to acid
- to make the 0.1M copper sulfate solution, mix 25 grams of copper sulfate pentahydrate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, in enough water to make 1 liter of solution -- the copper sulfate will likely be in the form of crystals -- you can speed up the dissolving process by using warm water and/or grinding the crystals in a mortar and pestle before dissolving -- be sure this is a mortar and pestle used only for chemicals -- do NOT use one that will be used for food! -- amounts can be scaled up or down, depending on how much solution is needed, as long as the proportions are maintained, e.g., 5 grams of copper sulfate in enough water to make 200 mL of solution, etc.
- The field of electroplating seems to have a certain element of art or magic, with empirical and proprietary processes developed over long periods of time, but sometimes still not well-understood -- they just work!

Going Further

The following variables provide straightforward avenues for further experimenting:

- concentration of the solution
- electric current
- plating time
- distance between electrodes

References

Bassam Shakashiri, **Chemical Demonstrations: A Handbook for Teachers of Chemistry**, Volume 4, University of Wisconsin Press, 1992. See Chapter 11, Electrochemistry, pp. 90-268. Shakashiri is a classic reference, but the chemicals involved are often sophisticated, and definitely not readily available at the drug store or grocery store.

Don Rathjen and Paul Doherty, **Square Wheels and Other Easy-to-Build, Hands-On Science Activities**, Exploratorium, 2002. See Saltwater Pentacell, pp. 85-88. This is an easily constructed battery, made from copper wire, aluminum foil, and saltwater. It is an example of a voltaic cell, the other side of electrochemistry, where reactions produce electricity (as opposed to the electrolytic cell you have dealt with in this handout, where electricity produces chemical reactions).