

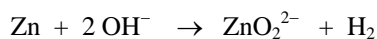
# AN EXPERIMENT IN ALCHEMY: COPPER TO SILVER TO GOLD

© 2005, 2000, 1996, 1979 by David A. Katz. All rights reserved

## INTRODUCTION

One of the goals of the ancient alchemists was to convert base metals into gold. Although this goal was never attained by chemical methods, the alchemists were able to perform many color changes to make metals resemble gold. In this experiment you will produce some color changes to a copper token and demonstrate diffusion in the solid state.

In this reaction, zinc dissolves in the hot concentrated sodium hydroxide solution to form sodium zincate, commonly written as  $\text{Na}_2\text{ZnO}_2$  or, as obtained in solid form from concentrated solutions,  $\text{NaZn(OH)}_3$ . As an ionic equation this can be written:



When the copper token is added to the solution, an electrochemical couple formed by the copper-zinc contact causes the zincate ion to migrate to the copper surface where it is decomposed and reduced to metallic zinc by hydrogen which forms a coating on the token. The resulting token will be silver in color due to a coating of zinc on its surface. When the token is heated, the zinc diffuses into the copper to form a layer of the alloy brass, which results in the gold color.

It should be noted that the reduction of the zincate ion to zinc will only take place if the copper metal is in direct contact with zinc metal. Also, no copper dissolves in the solution during the reaction.

## SAFETY PRECAUTIONS

Goggles or safety glasses must be worn at all times in the laboratory.

Acetic acid fumes may be irritating. Work in a well ventilated area or in the hood.

Do not allow the sodium hydroxide solution in this experiment to actively boil. Sodium hydroxide is caustic and may splatter causing severe damage to the skin or eyes. In case of contact, wash it off immediately with cold water until the skin no longer feels soapy. In the event that sodium hydroxide gets into your eye, wash the eye well with water for at least 10 minutes and get medical help immediately.

## DISPOSAL

Disposal should be in accordance with local regulations.

The 5% acetic acid solution can be safely disposed of by diluting with water and pouring it down the drain.

The sodium hydroxide solution should be placed in the appropriate waste container.

The zinc metal can be reused. The zinc should be rinsed with water and placed in the appropriate container supplied in the laboratory. Do not pour any zinc metal down the drain.

## EXPERIMENTAL PROCEDURE

### Apparatus required

100-mL or 150-mL beaker  
2 beakers: 250-mL or 400-mL  
evaporating dish

Hot plate or Bunsen burner  
ring stand with ring support or tripod (used with Bunsen Burner)  
striker or matches  
Graduated cylinder, 25-mL or 50-mL  
Crucible tongs  
towels (paper or cloth)

### Reagents needed

copper tokens - (Note: U.S. copper pennies dated 1982 or earlier work best in this experiment, but any "copper" penny can be used.)  
5% acetic acid solution (by volume) or vinegar  
sodium chloride  
3 M sodium hydroxide solution  
distilled water  
zinc - granulated (20 or 30 mesh)

### Procedure

Obtain three copper tokens.

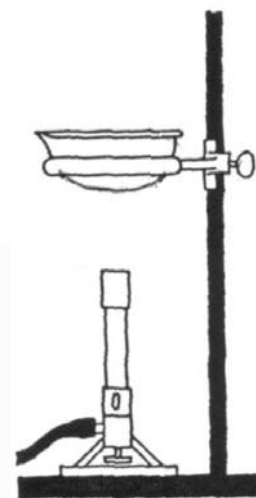
Weigh out 3.0 grams of sodium chloride and place it in a clean 100-mL or 150-mL beaker. Add 15 mL of 5% acetic acid solution (or vinegar) and stir. Clean the copper tokens by placing them in the sodium chloride/acetic acid mixture and stir until they are shiny. Remove the tokens immediately after they are clean to prevent etching of the surface by extended contact with the acetic acid-sodium chloride solution. Wash the tokens well with water and dry them with a towel. Do not handle the tokens with your hands as oils from your skin will interfere with the reaction.

Weigh the tokens and record the mass of each token. You may use the date on the token to identify it. (If you have more than one token with the same date, you will have to determine a method to identify them.)

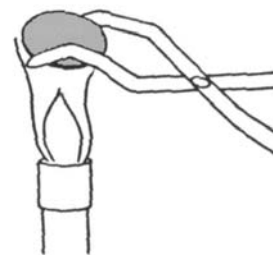
Weigh out 1.0 gram of zinc and place it in a clean evaporating dish. Add 25 mL of 3 M sodium hydroxide solution. Set the evaporating dish and its contents on a hot plate (preferred) or on a ring support on a ring stand and heat gently until the solution is hot and starts to bubble. **CAUTION: DO NOT ALLOW THE SOLUTION TO ACTIVELY BOIL, HOT SODIUM HYDROXIDE IS VERY CAUSTIC AND IT MAY SPATTER.** Using the tongs, place two copper tokens into the hot solution and continue to heat gently. Almost immediately, the copper tokens should begin to turn silvery white and small bubbles of gas will fizz from the solution. Occasionally, using the tongs, rub the tokens into the zinc and turn the tokens over. When the tokens have become completely silver, remove them from the solution and immerse them in a beaker of distilled water. Wash the tokens well to remove any sodium hydroxide and dry them.

Weigh the silver tokens and record the mass of each token.

Using the tongs, hold one of the silver tokens by the edges and heat it in the outer cone of the Bunsen burner flame. Within a few seconds, the token will change color. Heat it for three more seconds and then immediately quench it in a beaker of distilled water. (Note: Heating a post-1983 token in the burner flame for too long may result in



**Figure 1.** Heating an evaporating dish on a hot plate (left) and on a ring support (right).



**Figure 2.** Heating a copper token

melting of the token.) The resulting gold token can be dried and polished with a towel.

Repeat this procedure with a second silver token.

Weigh the gold tokens and record the mass of each token.

If you wish to convert more copper tokens in the zinc/sodium hydroxide coloring bath, it may be necessary to add distilled water to the solution to replenish any liquid that has evaporated. It is **not** necessary to add any additional sodium hydroxide. The bath will be sufficient to color several additional tokens.

### **Extension (Optional)**

Repeat this experiment using 1.0 g of granular tin in place of zinc in the evaporating dish.

How do the final tokens compare to the gold tokens prepared earlier? How do they compare with shiny, unreacted tokens?

### **Clean up**

Clean up all apparatus with soapy water and appropriate brushes. Rinse well before placing apparatus in your laboratory drawer or locker.

## Explanation

A study was done by this author on this reaction in 1979.

In the first part of this study, the reaction was run as described in this experiment except that 6 M sodium hydroxide, NaOH, was used. After the reaction, the solution containing sodium zincate, was carefully decanted into a clean evaporating dish. A clean copper token (a U.S. penny) was added to the solution. There was no reaction observed, even with heating. A piece of mossy zinc was then added to the evaporating dish, but was not in contact with the copper token. Again, there was no reaction, even with heating. Finally, the mossy zinc was placed in direct contact with the copper token, at which point, the copper surface became coated with gas bubbles and the formation of the zinc coating on the copper began.

Ten copper tokens were reacted in the solution to obtain zinc coatings. The solution was decanted and then checked, qualitatively, for the presence of copper and zinc by Dr. Peter Keliher (now deceased) on a Varian Techtron atomic absorption spectrophotometer at Villanova University. It was found that zinc was present in the solution, but there was essentially no copper present. This was suspected since the solution was colorless and did not exhibit the characteristic blue color of copper ions.

The second part of the study attempted to determine the quantity of zinc which would form on the copper during the reaction. Ten cleaned squares of copper, 2.0 cm x 2.0 cm x 0.013 cm, were plated as described in the procedure, previously. Every 10 minutes, the copper squares were removed from the solution, washed, dried using an acetone wash, and weighed on an analytical balance. The squares were placed back into the solution and the process was continued until a constant mass was obtained for each square. (Note: A constant mass means that the reaction stopped as a result of the zinc coating insulating the copper from further reaction.) The average mass of the zinc coating was found to be  $3.4 \times 10^{-5} \text{ g/cm}^2$ . This was calculated to be a thickness of  $4.7 \times 10^{-6} \text{ cm}$ , or, by using the standard unit cell dimensions for zinc, 192 zinc atoms.

The study suggested that the reaction of coating the copper with another metal could be accomplished if it has similar properties as zinc, namely a soluble hydroxide complex and a negative standard reduction potential. Although several common metals were tested, the only positive results were obtained using tin. In this case, the coating of tin reacts with the copper, on heating, to form bronze. The bronze coating was deeper in color than the brass coating obtained with zinc tending to be closer to the original copper color.

The standard reduction potentials for the three metals are:

|        |   |               |
|--------|---|---------------|
| Copper | $\text{Cu}^{2+} + 2 \text{e}^- \rightarrow \text{Cu}$ | 0.158 volts   |
| Tin    | $\text{Sn}^{2+} + 2 \text{e}^- \rightarrow \text{Sn}$ | -0.1364 volts |
| Zinc   | $\text{Zn}^{2+} + 2 \text{e}^- \rightarrow \text{Zn}$ | -0.7628 volts |

Reference: Weast, Robert C., Editor, *CRCHandbook of Chemistry and Physics*, 60<sup>th</sup> Ed., CRC Press, Inc., Boca Raton, FL, 1979, D-155-157.

# AN EXPERIMENT IN ALCHEMY: COPPER TO SILVER TO GOLD

## DATA AND RESULTS

Name \_\_\_\_\_ Course/Section \_\_\_\_\_

Partner's Name (if applicable) \_\_\_\_\_ Date \_\_\_\_\_

1. Describe the initial appearance of the copper tokens before placing them in the sodium chloride/acetic acid mixture.
  
  
  
  
  
  
  
  
  
  
2. What happens to the copper tokens when they are placed in the sodium chloride/acetic acid mixture?
  
  
  
  
  
  
  
  
  
  
3. Describe the changes that occur while heating the copper tokens in the sodium hydroxide-zinc mixture.

### Copper token data

|  | Token 1 | Token 2 | Token 3 |
|--|---------|---------|---------|
| Date of the token  | _____   | _____   | _____   |
| Mass of clean, dry token   | _____ g | _____ g | _____ g |
| Mass of clean, dry, silver token   | _____ g | _____ g | _____ g |
| Mass of clean, dry, gold token<br>(Note: only two tokens need to<br>be weighed.) | _____ g | _____ g | _____ g |

## Questions

1. Is the silver colored coating on the copper token permanent? Does it rub off easily?
2. Is the gold colored coating on the copper token permanent? Does it rub off?
3. Why is it necessary to quench the copper token in water after heating it to produce the color change? (Note: You may want to try heating a token and allowing it to cool in the air.)
4. Compare the masses you measured, before and after the color change, for each of the tokens. How do the masses compare?
5. The density of copper, zinc, silver, and gold are given in the table below. Based on this information, did you really change the copper token into gold? Explain.

| <b>Metal</b> | <b>Density in<br/>g/mL</b> |
|--------------|----------------------------|
| Copper       | 8.92                       |
| Zinc         | 7.14                       |
| Silver       | 10.5                       |
| Gold         | 19.3                       |

6. One of the goals of the ancient alchemists was to turn metals into gold. How do you think they might have reacted to this experiment? (Note: The ancient alchemists did not use balances to weigh things.)

### **Extension Activities (Optional)**

Record the results of repeating this experiment using 1.0 g of granular tin in place of zinc in the evaporating dish.

How do the final tokens compare to the gold tokens prepared earlier? How do they compare with shiny, unreacted tokens?