Chemical Reactions of Copper and Percent Yield

EXPERIMENT

6

OBJECTIVE

To gain some familiarity with basic laboratory procedures, some chemistry of a typical transition element, and the concept of percent yield.

APPARATUS AND CHEMICALS

0.5-g piece of no. 16 or no. 18 copper wire	evaporating dish
250-mL beakers (2)	weighing paper
conc. HNO_3	6.0 *M* H_2SO_4
graduated cylinder	granular zinc
3.0 *M* NaOH	methanol
carborundum boiling chips	acetone
stirring rod	towel
iron ring and ring stand	balance
wire gauze	aluminum foil cut in 1-in. squares
Bunsen burner	conc. HCl

DISCUSSION

Most chemical syntheses involve separation and purification of the desired product from unwanted side products. Some methods of separation, such as filtration, sedimentation, decantation, extraction, and sublimation, were described in Experiment 3. This experiment is designed as a quantitative evaluation of your individual laboratory skills in carrying out some of these operations. At the same time you will become more acquainted with two fundamental types of chemical reactions like those described in Experiment 4—redox reactions and metathesis reactions. By means of these reactions, you will carry out several chemical transformations involving copper, and you will finally recover the copper sample with maximum efficiency. The chemical reactions involved are the following:

$$Cu(s) + 4HNO_3(aq) \longrightarrow Cu(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(l)$$ Redox [1]

$$Cu(NO_3)_2(aq) + 2NaOH(aq) \longrightarrow Cu(OH)_2(s) + 2NaNO_3(aq)$$ Metathesis [2]

$$Cu(OH)_2(s) \xrightarrow{\Delta} CuO(s) + H_2O(g)$$ Dehydration [3]

$$CuO(s) + H_2SO_4(aq) \longrightarrow CuSO_4(aq) + H_2O(l)$$ Metathesis [4]

$$CuSO_4(aq) + Zn(s) \longrightarrow ZnSO_4(aq) + Cu(s)$$ Redox [5]

Each of these reactions proceeds to completion. Metathesis reactions proceed to completion whenever one of the components is removed from the solution, such as in the formation of a gas or an insoluble precipitate.

This is the case for reactions [1], [2], and [3], where in reactions [1] and [3] a gas and in reaction [2] an insoluble precipitate are formed. Reaction [5] proceeds to completion because zinc has a lower ionization energy or oxidation potential than copper. More discussion of this type of reaction can be found in Experiment 15.

The object in this experiment is to recover all of the copper you begin with in analytically pure form. This is the test of your laboratory skills.

The percent yield of the copper can be expressed as the ratio of the recovered weight to initial weight, multipled by 100:

$$\% \text{ yield} = \frac{\text{recovered wt of Cu}}{\text{initial wt of Cu}} \times 100$$

PROCEDURE

Weigh approximately 0.500 g of no. 16 or no. 18 copper wire (1) to the nearest 0.0001 g and place it in a 250-mL beaker. IN THE HOOD add 4–5 mL of concentrated HNO_3 to the beaker. After the reaction is complete, add 100 mL distilled H_2O. Describe the reaction (6) as to color change, evolution of a gas, and change in temperature (exothermic or endothermic) on the report sheet.

Add 30 mL of 3.0 *M* NaOH to the solution in your beaker and describe the reaction (7). Add two or three boiling chips and carefully heat the solution—while stirring with a stirring rod—just to the boiling point. Describe the reaction on your report sheet (8).

Allow the black CuO to settle; then decant the supernatant liquid. Add about 200 mL of very hot distilled water, stir, and then allow the CuO to settle. Decant once more. What are you removing by the washing and decantation (9)?

Add 15 mL of 6.0 *M* H_2SO_4. What copper compound is present in the beaker now (10)?

Your instructor will tell you whether you should use zinc or aluminum for the reduction of Cu(II) in the following step.

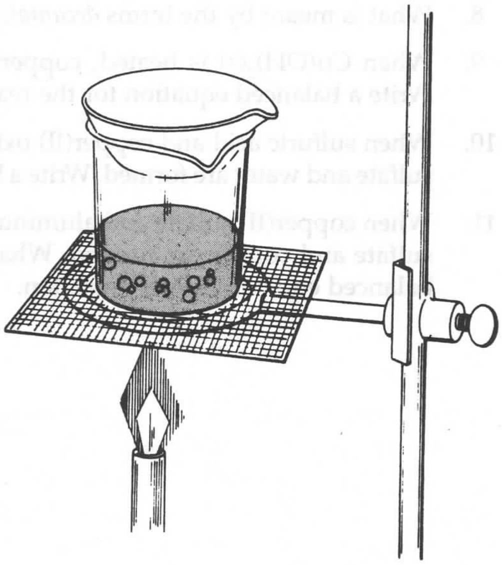
A. Reduction with Zinc

In the hood, add 2.0 g of 30-mesh zinc metal all at once and stir until the supernatant liquid is colorless. Describe the reaction on your report sheet (11). What is present in solution (12)? When gas evolution has become *very* slow, heat the solution gently (but do not boil) and allow it to cool. What gas is formed in this reaction (13)? How do you know (14)?

B. Reduction with Aluminum

In the hood, add several 1-in. squares of aluminum foil and a few drops of concentrated HCl. Continue to add pieces of aluminum until the supernatant liquid is colorless. Describe the reaction on your report sheet (11). What is present in solution (12)? What gas is formed in this reaction (13)? How do you know (14)?

For Either Reduction Method When gas evolution has ceased, decant the solution and transfer the precipitate to a preweighed porcelain evaporating dish (3). Wash the precipitated copper with about 5 mL of distilled water, allow it to settle, decant the solution, and repeat the process. What are you removing by washing (15)? Wash the precipitate with about 5 mL of methanol (KEEP THE METHANOL AWAY FROM FLAMES—IT IS



▲ **FIGURE 6.1** Steam bath.

FLAMMABLE!!) Allow the precipitate to settle, and decant the methanol. (METHANOL IS ALSO EXTREMELY TOXIC: AVOID BREATHING THE VAPORS AS MUCH AS POSSIBLE.) Finally, wash the precipitate with about 5 mL of acetone (KEEP THE ACETONE AWAY FROM FLAMES—IT IS EXTREMELY FLAMMABLE!!), allow the precipitate to settle, and decant the acetone from the precipitate. Prepare a steam bath as illustrated in Figure 6.1 and dry the product on your steam bath for at least 5 min. Wipe the bottom of the evaporating dish with a towel, remove the boiling chips and weigh the evaporating dish plus copper (2). Calculate the final weight of copper (4). Compare the weight with your initial weight and calculate the percent yield (5). What color is your copper sample (16)? Is it uniform in appearance (17)? Suggest possible sources of error in this experiment (18).

REVIEW QUESTIONS

Before beginning this experiment in the laboratory, you should be able to answer the following questions:

1. Give an example, other than the ones listed in this experiment, of redox and methathesis reactions.
2. When will reactions proceed to completion?
3. Define percent yield in general terms.
4. Name six methods of separating materials.
5. Give criteria in terms of temperature changes for exothermic and endothermic reactions.
6. If 1.70 g of $Cu(NO_3)_2$ are obtained from allowing 1.04 g of Cu to react with excess HNO_3, what is the percent yield of the reaction?
7. What is the maximum percent yield in any reaction?

8. What is meant by the terms *decantation* and *filtration*?
9. When $Cu(OH)_2(s)$ is heated, copper(II) oxide and water are formed. Write a balanced equation for the reaction.
10. When sulfuric acid and copper(II) oxide are allowed to react, copper(II) sulfate and water are formed. Write a balanced equation for this reaction.
11. When copper(II) sulfate and aluminum are allowed to react, aluminum sulfate and copper are formed. What kind of reaction is this? Write a balanced equation for this reaction.

Name ____________________ Desk ____________

Date ____________ Laboratory Instructor ____________

REPORT SHEET | EXPERIMENT

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1. Weight copper initial ________
2. Weight of copper and evaporating dish ________
3. Weight of evaporating dish ________
4. Weight copper final ________

5. % yield (show calculations) ________

6. Describe the reaction $Cu(s) + HNO_3(aq) \longrightarrow$

7. Describe the reaction $Cu(NO_3)_2(aq) + NaOH(aq) \longrightarrow$

8. Describe the reaction $Cu(OH)_2(s) \xrightarrow{\Delta}$

9. What are you removing by this washing? ____________
10. What copper compound is present in the beaker? ________
11. Describe the reaction $CuSO_4(aq) + Zn(s)$, or $CuSO_4(aq) + Al(s)$
12. What is present in solution? ____________
13. What is the gas? ____________
14. How do you know? ____________
15. What are you removing by washing? ____________
16. What color is your copper sample? ____________

17. Is it uniform in appearance? ______________________________

18. Suggest possible sources of error in this experiment.

QUESTIONS

1. If your percent yield of copper was greater than 100%, what are two plausible errors you may have made?

2. Consider the combustion of methane, CH_4:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

Suppose 2.5 mol of methane is allowed to react with 3 mol of oxygen.
(a) What is the limiting reagent?

(b) How many moles of CO_2 can be made from this mixture? How many grams of CO_2?

3. Suppose 8.00 g of CH_4 is allowed to burn in the presence of 6.00 g of oxygen. How much (in grams) CH_4, O_2, CO_2, and H_2O remain after the reaction is complete?

4. How many milliliters of 3.0 *M* H_2SO_4 are required to react with 0.80 g of CuO according to Equation [4]?

5. If 3.00 g of Zn is allowed to react with 1.75 g of $CuSO_4$ according to Equation [5], how many grams of Zn will remain after the reaction is complete?

6. What is meant by the term limiting reagent?

NOTES AND CALCULATIONS