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Recycling Copper

A Four-Reaction Copper Cycle

Introduction

How old is the copper penny in your pocket? It may be older than you think! Not only is copper one of the most widely used metals, second only to iron in annual consumption, it is also the most widely reused metal. Almost as much copper is recovered every year from recycled copper scrap as is produced from newly mined copper ore. What reactions can be used to recycle or recover copper metal?

Concepts

- Oxidation–reduction
- Double replacement
- Single replacement
- Percent yield

Background

Copper is a reddish-brown metal with excellent electrical and thermal conductivity. Traditional applications of copper include its use in electrical wiring and plumbing. The modern electronics industry also uses copper to make computers run faster and last longer. Copper is the best choice for these applications because it does not oxidize in air or corrode as fast as most other metals.

Oxidation of copper requires concentrated nitric acid, a strong acid that is also a good oxidizing agent. Copper reacts with nitric acid to form copper(II) nitrate, a blue-green ionic compound that is soluble in water (Equation 1). Copper(II) nitrate, in turn, can be converted into other copper compounds via double replacement reactions with a precipitating agent, such as sodium hydroxide (Equation 2). Copper metal can be regenerated or recovered from copper(II) compounds by single replacement reactions with a more reactive metal, such as zinc (Equation 3).

Oxidation of copper

$$Cu(s) + 4HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(l) \qquad \textit{Equation 1}$$

Double replacement reaction

$$Cu(NO_3)_2(aq) + 2NaOH(aq) \rightarrow Cu(OH)_2(s) + 2NaNO_3(aq) \qquad \textit{Equation 2}$$

Single replacement reaction

$$Cu(NO_3)_2(aq) + Zn(s) \rightarrow Cu(s) + Zn(NO_3)_2(aq) \qquad \textit{Equation 3}$$

Experiment Overview

The purpose of this experiment is to carry out a sequence of chemical reactions illustrating the properties of copper and its compounds. The "copper cycle"—which starts with copper and ends with copper—demonstrates how copper might be recycled or recovered from copper scrap. The percent recovery of copper will be determined and the efficiency of the four-reaction copper cycle will be analyzed.

Pre-Lab Questions

Read the entire *Procedure* and the recommended *Safety Precautions* before answering the following questions.

1. Concentrated strong acids, such as hydrochloric and sulfuric acid, are severely corrosive to skin and eyes. What additional hazard arises in this experiment when working with nitric acid? What safety precaution will protect you against this hazard?

2. The four-reaction copper cycle featured in this experiment is summarized below. Fill in the blanks to show the reagents that will be used in each step.

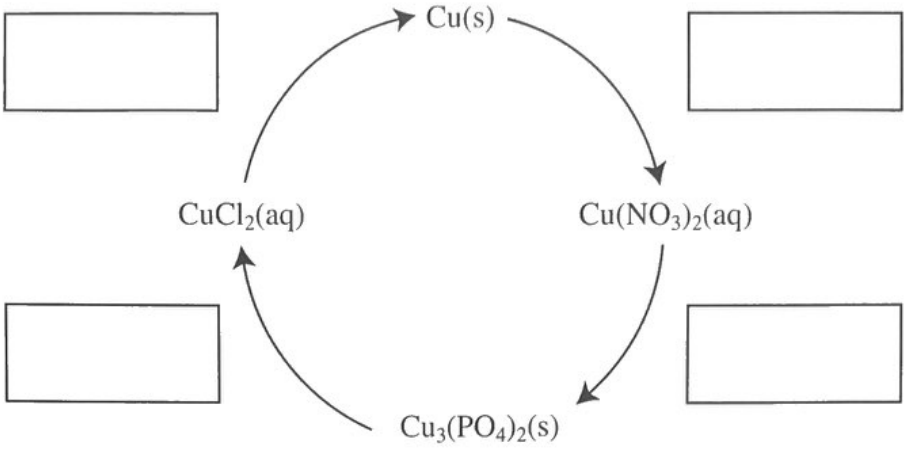

Figure 1.

3. The amount of copper obtained at the end of the experiment provides a good test of laboratory technique—each operation must be carried out without losing any copper. In Part B, aqueous copper(II) nitrate will be converted to solid copper(II) phosphate, and the resulting mixture will be filtered. How will you be able to tell that no copper is being "lost" during this step?

Materials

Acetone, 10 mL
Copper powder, Cu, 0.25–0.30 g
Hydrochloric acid, HCl, 3 M, 25 mL
Magnesium turnings, Mg, 0.6 g
Nitric acid, HNO_3, 6 M, 6 mL
Sodium hydroxide solution, NaOH, 6 M, 8 mL
Sodium phosphate solution, Na_3PO_4, 0.3 M, 10 mL
Water, distilled, and wash bottle
Balance, 0.01-g precision
Weighing paper
Tongs
Beakers, 50- and 250-mL
Boiling stones
Evaporating dish
Erlenmeyer flasks, 125-mL, 2
Funnel and filter paper
Graduated cylinders, 10- and 25-mL
Hot plate
Paper towels
pH paper
Pipets, Beral-type, 4
Spatula
Stirring rod

Safety Precautions

Nitric acid is severely corrosive, a strong oxidizing agent, and toxic by ingestion and inhalation. Reactions of nitric acid with metals generate nitrogen dioxide, a toxic, reddish-brown gas. Work with nitric acid in a fume hood or in a well-ventilated lab only. Hydrochloric acid is corrosive to skin and eyes and toxic by ingestion and inhalation. Sodium hydroxide solution is a corrosive liquid and can cause skin burns. It is especially dangerous to the eyes. Notify the teacher and clean up all acid and base spills immediately. Copper powder and magnesium metal are flammable solids; copper powder is a health hazard if inhaled as a dust or fume. Acetone is a flammable solvent. Do not use any flames in this experiment. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the lab.

Procedure

Part A. Copper and Nitric Acid

1. In a 50-mL beaker, weigh out 0.25–0.30 g of copper powder. Record the mass of copper to the nearest 0.01 g in the data table. *Place the beaker containing the copper in a fume hood.*
2. Using a Beral-type pipet, transfer 6 mL of 6 M nitric acid into a graduated cylinder. Add the acid slowly and carefully to the copper powder in the beaker.
3. Observe the evidence for the chemical reaction and record all observations in the data table.
4. Gently swirl the beaker to make sure all of the copper reacts. When the copper metal has dissolved, add 5 mL of distilled water to dilute the solution.
5. Take the beaker to the lab bench for Part B. *Caution:* Do not remove the beaker from the hood until all reddish-brown fumes have completely disappeared.

Part B. Copper(II) Nitrate and Sodium Phosphate

6. Neutralize the acidic copper(II) nitrate solution: Slowly add ~~6~~ 4 mL of 6 M sodium hydroxide with constant stirring until the mixture is *slightly* cloudy. *Note:* A pale blue solid may precipitate out initially when the base is added. The precipitate should redissolve with stirring.
7. Test the solution with pH paper—the solution should be neutral or slightly acidic (pH 6–7). Tweak, if not.
8. Measure 10 mL of 0.3 M sodium phosphate into a clean, graduated cylinder and add the solution to the aqueous copper(II) nitrate in the beaker. Stir to mix thoroughly.
9. Observe the evidence for the chemical reaction and record all observations in the data table.
10. Fold a piece of filter paper into a funnel and filter the reaction mixture into a clean Erlenmeyer flask.
11. Wash any traces of solid from the beaker into the funnel using a gentle stream of distilled water from a wash bottle.
12. Rinse the solid with about 5 mL of distilled water and discard the filtrate (liquid). Save the solid in the funnel for Part C.

Part C. Copper(II) Phosphate and Hydrochloric Acid

13. Place a clean 125-mL Erlenmeyer flask beneath the filter funnel.
14. Slowly and carefully pour 20 mL of 3 M HCl directly into the funnel and collect the filtrate in the Erlenmeyer flask.
15. Observe the evidence for the chemical reaction and record all observations in the data table.
16. When all of the solid has dissolved, rinse the filter paper with about 5 mL of distilled water. Collect the rinse water in the same flask as the filtrate and save the filtrate for Part D.

Part D. Copper(II) Chloride and Magnesium

17. Prepare a boiling water bath for use in step 26: Half-fill a 250-mL beaker with tap water, add a boiling stone, and heat the water to a gentle boil on a hot plate.
18. Obtain about 0.5 g of magnesium turnings on weighing paper and add the magnesium to the filtrate from Part C.
19. Observe the evidence for the chemical reaction and record all observations in the data table.
20. Swirl or stir the flask for 5–10 minutes until the liquid is colorless. If necessary, add another piece of magnesium to the flask to make sure the reaction is complete.
21. When the copper(II) chloride color has faded to colorless, add an extra 3 mL of 3 M hydrochloric acid to the flask. The acid will react with any leftover magnesium (but not with the copper).
22. When the gas bubbling subsides, decant (pour off) most of the liquid into a waste beaker. Use care to avoid losing any copper during this process.
23. Wash the copper with about 10 mL of distilled water and discard the wash water in the waste beaker.

24. Weigh a clean and dry evaporating dish and record the mass in the data table.
25. Use a gentle stream of water from a wash bottle to flush the copper from the Erlenmeyer flask into the evaporating dish.
26. Allow the copper to settle, then use a pipet to remove as much of the water as possible from the evaporating dish.
27. Rinse the copper metal with two 5-mL portions of acetone. Remove the acetone rinses using a pipet.
28. Place the evaporating dish over the boiling water bath and heat the copper to dryness.
29. Use tongs to remove the evaporating dish from the boiling water bath and place the dish on paper towels. Allow the dish to cool to room temperature and then thoroughly dry the dish using a paper towel.
30. Weigh the dry evaporating dish with the recovered copper and record the combined mass in the data table.
31. Dispose of the reaction product and any waste solutions as directed by the instructor.

Name: _____

Recycling Copper

Data Table

Part	Evidence of Chemical Reaction and Properties of Product(s)
A	
B	
C	
D	

Mass of Copper Metal (initial)	
Mass of Evaporating Dish	
Mass of Evaporating Dish + Copper	

Post-Lab Questions *(Use a separate sheet of paper to answer the following questions.)*

1. Write a balanced chemical equation for each reaction in Parts A–D. Classify each reaction as a single replacement, double replacement, and/or oxidation–reduction reaction.
2. Determine the mass of copper recovered at the end of the "four-reaction copper cycle" and calculate the percent recovery.

$$\text{Percent recovery} = \frac{\text{Mass of copper (final)}}{\text{Mass of copper (initial)}} \times 100\%$$

3. List at least three sources of experimental error that might lead to a mass of recovered copper less than that originally used. Be specific!
4. List at least three sources of experimental error that might lead to a mass of recovered copper greater than that originally used. Be specific.