**Copper Reactions**

**Description**

This experiment focuses on chemical transformations. It centers on the notion that atoms may be found in elements or compounds, but that chemical processes do not cause those atoms to disappear or change in a fundamental way. In this series of reactions copper metal will be dissolved in nitric acid. Copper (II) hydroxide is subsequently formed by reaction with sodium hydroxide followed by the formation of copper (II) oxide via heating of the solution . Copper (II) oxide is dissolved in acid and finally the copper (II) ions are reduced with magnesium metal to produce copper metal. You will be graded partially on your per cent recovery of elemental copper.

**Background:**

The purpose of this laboratory experiment is to illustrate different types of chemical reactions and show how a quantity of an element can be carried through a series of chemical transformations without significant loss of mass, thereby illustrating the law of conservation of matter, and to provide experience in fundamental laboratory procedures such as transferring a reagent from a reagent bottle, transferring a solution or a solid from one vessel to another, decanting, filtering, washing, and dissolving a precipitate.

A massed quantity of copper will be carried through the following transformations:

Cu → Cu(N03)2 → Cu(OH)2 → CuO → CuSO4 → Cu

In Part A, copper metal is oxidized by nitric acid to produce a blue solution containing cupric nitrate, Cu(N03)2, and a brown poisonous gas of nitrogen dioxide, NO2, as shown in Equation A:

Cu(s) + 4HNO3(aq) → Cu(NO3)2(aq) + 2NO2(g) + 2H2O(1)  *Equation A*

In Part B, the blue copper (II) nitrate solution, Cu(NO3)2, reacts with sodium hydroxide, NaOH, in a double replacement reaction to produce a blue precipitate of copper (II) hydroxide, Cu(OH)2 according to Equation B:

Cu(NO3)2(aq) + 2NaOH(aq) → Cu(OH)2(s) + 2NaNO3(aq) *Equation B*

An acid-base neutralization reaction also occurs in Part B between sodium hydroxide, NaOH, and the excess nitric acid, HNO3, from Part A according to Equation B2:

NaOH(aq) + HNO3(aq) → NaNO3(aq) + H2O(1) *Equation B2*

In Part C, the blue copper (II) hydroxide solid, Cu(OH)2, is decomposed upon heating into the black copper (II) oxide solid, CuO, according to the decomposition reaction in Equation C:

Cu(OH)2(s) → CuO(s) + H20(l) *Equation C*

Part D involves sulfuric acid, H2SO4, dissolving the copper (II) oxide, CuO, to produce a blue cupric sulfate solution, CuSO4, and water as shown in Equation F:

CuO(s) + H2SO4(aq) → CuSO4(aq) + H2O(g) *Equation D*

The final reaction in Part E involves the replacement of a less active metal (copper) by a more active metal (magnesium). The magnesium, Mg, replaces the copper in copper (II) sulfate, CuSO4, forming magnesium sulfate, MgSO4, and solid copper, Cu, according to the single

replacement redox reaction shown in Equation E:

Mg(s) + CuSO4(aq) → MgSO4(aq) + Cu(s)  *Equation E*

The excess magnesium in Part E, over and above that required to replace all of the copper, is dissolved by further addition of sulfuric acid, H2SO4, according to another single replacement redox reaction shown in Equation E2:

Mg(s) + H2SO4(aq) → MgSO4(aq) + H2(g) *Equation E2*

**Safety**

* Nitric acid is severely corrosive, a strong oxidant, and toxic by ingestion and inhalation.
* Sodium hydroxide solution is a corrosive liquid, can cause skin burns, and is very dangerous to eyes.
* Sulfuric acid solution is corrosive to eyes, skin, and other tissue.
* Avoid contact of all acids and bases with eyes and all body tissue.
* Clean up all spills immediately; neutralize any acid spills with a weak base; neutralize any base spills with a weak acid; wipe up with water.
* Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron.
* Do not attempt this experiment without a hood for the nitric acid step.
* Several of the chemicals are toxic.
* Nitric acid stains skin.
* Wear goggles and aprons.
* Wash spilled chemicals immediately with large amounts of water.
* Do not ingest the chemicals.
* Wash hands frequently.
* The gas produced when copper reacts with nitric acid is toxic. Perform this reaction under a hood or with ventilation such that none of the gas (at all) is inhaled.

**Materials-**

* distilled water
* 0.2 g copper
* 5 mL of 6 M HNO3
* 5 mL of 6 M NaOH
* 5 mL of 6 M H2SO4
* magnesium
* pH paper (1-14)
* fume hood
* test tubes with test tube rack
* plastic transfer pipet
* hot plate or other heat source
* glass stirring rod
* (disposal jars, vinegar, NaHCO3,)
* stopper
* 2 250-mL beakers

**A. Dissolving copper:** Cu(s) + 4HNO3(aq) → Cu(NO3)2(aq) + 2NO2(g) + 2H2O(1)  *Equation A*

1. Obtain measure and record approximately 0.20 g of copper and be sure to measure to the nearest hundredth.
2. Place in a test tube or small beaker.
3. **Do not attempt the next step without a good working hood.**
4. Under the fume hood, add 6 M HNO3 **drop wise**. Do not inhale the brown gas produced in this conversion; NO2 is toxic and noxious. If reaction ceases with unreacted copper strands present, continue to add more of 6 M HNO3. Repeat this step until all of the copper has been reacted.
5. Add 5 mL of distilled water.
6. Wash hands.
7. Record your observations.

**B. Forming the hydroxide:** Cu(NO3)2(aq) + 2NaOH(aq) → Cu(OH)2(s) + 2NaNO3(aq) *Equation B*

 NaOH(aq) + HNO3(aq) → NaNO3(aq) + H2O(1) *Equation B2*

1. Gather pH paper, pH standards (usually on the container), stirring rod, NaOH, and Cu solution to measure the pH.
2. Use a glass stirring rod to place a drop of the solution from the test tube on a piece of pH test paper. If the color of the paper indicates a pH of less than 7, the solution is acidic. A pH of 7 is neutral and a pH above 7 indicates a basic solution. Find and record the pH of the copper (II) nitrate solution.
3. Place a drop of sodium hydroxide solution on the other end of the pH test paper. Find and record the pH of the NaOH solution.
4. Place the test tube into a beaker with water.
5. Slowly and cautiously add NaOH, and **carefully mix** the solution. Continue adding NaOH until the solution is basic (has a pH greater than 7 on the pH paper).
6. Wash hands.
7. Centrifuge your test tube for 30 seconds to 1 minute. **Be sure to balance the centrifuge!**
8. Wash hands.
9. Record your observations. **This is a stopping point if time is running low.**

**C. Forming the oxide:** Cu(OH)2(s) → CuO(s) + H20(l) *Equation C*

1. Decant the supernatant.
2. Add 10 mL of distilled water.
3. Place the test tube in a hot water bath on a hot plate and heat it, with occasional stirring, until all the solid material is converted to a black-brown substance.
4. Remove the test tube from the heat, label, stopper it loosely, and store it to allow the CuO to settle. Or centrifuge if you have one available and enough time to go on.
5. Wash hands.
6. Record your observations. **This is a stopping point if time is running low.**

**D. Dissolving the oxide:** CuO(s) + H2SO4(aq) → CuSO4(aq) + H2O(g) *Equation D*

1. Decant the supernatant. Be careful not to lose any of the precipitate. A small amount of liquid may be left behind.
2. Place the tube in a water bath. Add 6 mL of 6M H2SO4 to the precipitate in small amounts and stir gently until the oxide dissolves with the formation of a blue copper (II) sulfate solution.
3. Wash hands.
4. Record your observations.

**E. Recovering the copper metal:** Mg(s) + CuSO4(aq) → MgSO4(aq) + Cu(s)  *Equation E*

1. Place the test tube in a cold tap water bath in a 250-mL beaker.
2. Add 5 mL of distilled water.
3. Polish 5 cm of magnesium ribbon.
4. Add 1 cm of magnesium ribbon at a time to precipitate elemental copper.
5. Keep adding magnesium until the solution turns clear. Break up the coating with your stirring rod.
6. Stir occasionally with a glass stirring rod until the blue color disappears.
7. A milky solution indicates the production of magnesium hydroxide. If this occurs, add a few drops of sulfuric acid to react with the magnesium hydroxide.
8. Once the reaction has stopped add enough sulfuric acid to react away all of the magnesium.

Mg(s) + H2SO4(aq) → MgSO4(aq) + H2(g) *Equation E2*

1. Carefully pour the liquid out of the test tube into the disposal jar provided being careful not to lose any of the solid.
2. Measure the mass of your solid.
3. Wash hands.
4. Record your observations.
5. Label the test tube with your name, stopper it, and place it in the storage device (test tube rack) provided by the instructor so that the product may be inspected.

**Questions**

1. Which law does this lab test?
2. How would testing the pH of your copper (II) hydroxide solution affect your results?
3. Why does testing for pH indicate the completion of the precipitation reaction?
4. What gas is evolved upon addition of magnesium?
5. The disappearance of the blue color in the reduction of the copper ion with magnesium metal signals that the reaction is complete. Explain.
6. Fill in the following chart with the appropriate formulas and colors for the compounds used in this experiment:

|  |  |  |
| --- | --- | --- |
| Compound | Formula | Color |
| nitric acid |  |  |
| sodium hydroxide |  |  |
| sulfuric acid |  |  |
| copper(II) oxide |  |  |
| copper(II) sulfate |  |  |
| copper(II) hydroxide |  |  |
| copper(II) nitrate |  |  |
| zinc sulfate |  |  |
| nitrogen dioxide |  |  |

**Curriculum-**

* This experiment focuses on chemical transformations. It centers on the notion that atoms may be found in elements or compounds, but that chemical processes do not cause those atoms to disappear or change in a fundamental way. This experiment, therefore, is usually performed early in an introductory course.
* This experiment takes several days to complete. Usually students can get from copper metal to copper oxide in one 45-minute period. They can dissolve the copper oxide and treat it with zinc during part of a second period. Finally, isolation of the copper metal requires a third period.
* Teachers often use the chemicals without indication of their concentrations. Postponing the notion of concentration may help to focus learners on the key issue of conservation of atoms that is taught early in the course.

**Safety-**

* Do not attempt this experiment without a hood for the nitric acid step.
* Nitric acid, sodium hydroxide, and sulfuric acid are corrosive. Several of the chemicals are toxic. Nitric acid stains skin. Wear goggles and apron. Wash spilled chemicals immediately wit large amounts of water. Do not ingest the chemicals. Wash hands frequently. The gas produced when copper reacts with nitric acid is toxic. Perform this reaction under a hood or with ventilation such that none of the gas (at all) is inhaled.
* The copper dissolving reaction is accomplished faster with concentrated nitric acid, but 6 M HNO3 is safer and gets the job done. Skin is immediately transformed to a tough yellow mixture of compounds with any splash of concentrated HNO3. Use care when preparing solutions.

**Time-**

Teacher Preparation: 15 minutes

Class Time: 80 minutes Store CuO between periods to settle out. Zn reaction takes a while in second class period. Students may leave Zn in tubes between periods if the class period is long enough and centrifuges are available.

**Disposal-**

Disposal jar 1 contains base and disposal jar 2 contains acid. Dilute each jar with an equal volume of water. Wear goggles and apron. Slowly and carefully while stirring add the contents of the jar with the smaller total volume to the other jar. Test the resulting solution with pH paper. Neutralize the solution, as appropriate, with vinegar or sodium bicarbonate, and discard the resulting solution at the sink.

**Lab Hints-**

* This reaction is often done at the beginning of the term before students have any background with the concept of concentration. For this reason, the solutions are often provided to students without an indication of their concentration.
* Be certain to review safety precautions with students. These reagents are dangerous and must be handled properly.

**Background-**

* The chemical reaction for dissolving copper is:

3 Cu + 8 HNO3 --> 3 Cu(NO3)2 + 2 NO + 4 H2O (conc)

or Cu + 4 HNO3 --> Cu(NO3)2 + 2 NO2 + 2 H2O (dilute)

NO is colorless. It goes on to react in air with oxygen to form brown NO2;

2 NO + O2 --> 2 NO2.

* The copper metal dissolves forming a greenish solution and giving off a gas which, in air, is brown. Heat is evolved. When water is added, the reaction mixture turns blue.
* The blue color of the solution is characteristic of the Cu(II) ion in a water solution.
* The sodium hydroxide, a base, neutralizes the unreacted nitric acid and destroys its acidic properties. Neutralization reactions produce a large amount of heat.

HNO3 + NaOH --> NaNO3 + H2O

H+ + OH- --> H2O

* More NaOH leads to a reaction. The pale blue, gelatinous precipitate is copper(II) hydroxide.

Cu(NO3)2 + 2 NaOH --> Cu(OH)2 + 2 NaNO3

* Heating copper(II) hydroxide cause water to be lost.

Cu(OH)2 --> CuO + H2O

* CuO is black. Copper(II) oxide dissolves in acid to form an aqueous copper(II) solution:

CuO + H2SO4 --> CuSO4 + H2O

* Magnesium reacts with the copper(II) sulfate to produce copper metal. Looking quite a bit worse for the wear, the original copper atoms are returned to the elemental metallic state.

CuSO4 + Mg --> Cu + MgSO4

* Excess magnesium reacts with sulfuric acid in the solution producing bubbles of hydrogen gas.

H2SO4 + Mg --> MgSO4 + H2

* The overall result is the reddish solid copper metal beneath a clear, colorless aqueous solution.

**Answers-**

Q1. Suppose the initial weight of the copper sample were 0.54 grams, and the recovered weight of copper were 0.50 grams. Find the yield of copper in this series of reactions.

A1. Yield = ( wt. recovered/ wt. reacted ) x 100% =

= (0.50/ 0.54) x 100

= 93%

Q2. The disappearance of the blue color in the reduction of the copper ion with zinc metal signals that the reaction is complete. Explain.

A2. Copper(II) ion is blue. The disappearance of the blue color indicates that all of the copper(II) has been reacted.

Q3. Fill in the following chart with the appropriate formulas and colors for the compounds used in this experiment:

A3.

|  |  |  |
| --- | --- | --- |
| Compound | Formula | Color |
| nitric acid | HNO3 | colorless |
| sodium hydroxide | NaOH | colorless |
| sulfuric acid | H2SO4 | colorless |
| copper(II) oxide | CuO | black |
| copper(II) sulfate | CuSO4 | blue |
| copper(II) hydroxide | Cu(OH)2 | pale blue |
| copper(II) nitrate | Cu(NO3)2 | blue |
| magnesium sulfate | MgSO4 | colorless |
| nitrogen dioxide | NO2 | brown gas |