Chemistry of Copper

Lab 3

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Introduction

- Copper is found in group 11, MW = 63.456
- Shiny (orange/red color), Malleable, Ductile
- Oxidizes in air (turns a green color – patina)
- Oxidation States are Cu(I) = $3d^{10}$, Cu(II) =$3d^{9}$
- Cu(II) compounds are usually blue or green in color

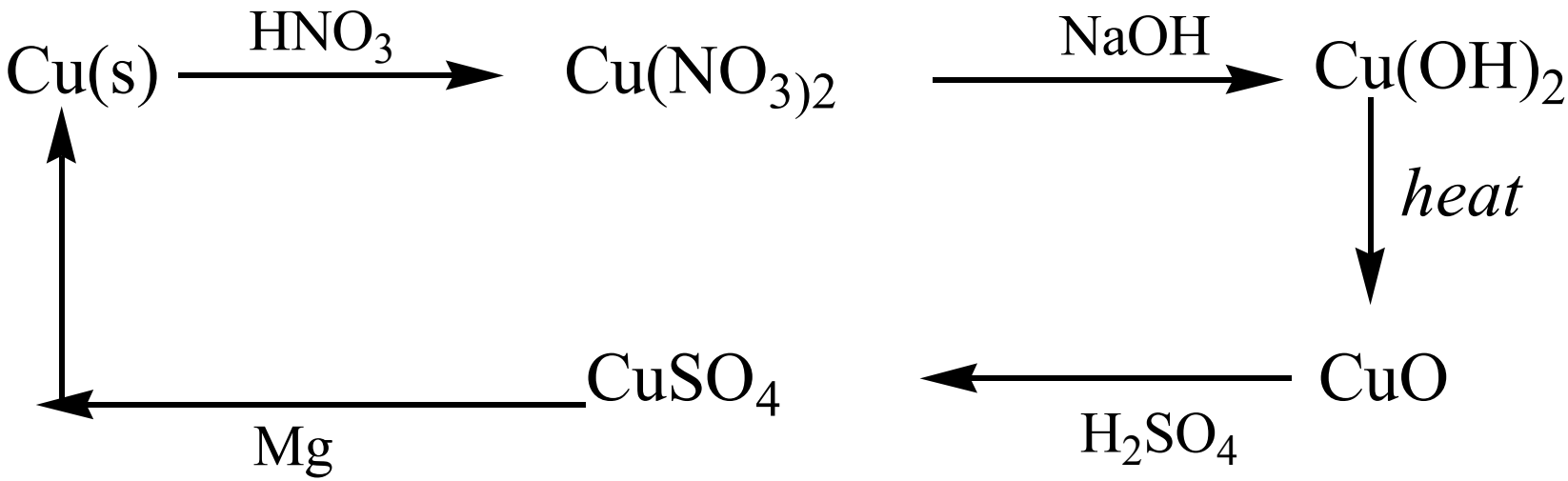
Lab Objectives

- Observation of Copper's Chemical Properties
- Isolation of five copper compounds
- Determination of percent recovery of Cu

- In this experiment you will take a copper sample through a series of five reactions

- The end product will be your original copper sample, making this a cycle of reactions.

- With careful attention to quantitative lab practices, you should be able to recover all the copper you started with.


Cu(s)
HNO3
Cu(NO3)2
NaOH
Cu(OH)2
heat
CuO
H2SO4
CuSO4
Mg

What will you do?

- Perform each reaction and write your observations.
  - Color change, precipitate, gas evolved
- Use equations to interpret observations
- Retain as much copper as possible

Think about your reactions

- What kind of reaction is it?
  - Acid/base, gas evolved, redox, precipitate
- What is your reactant?
- How do you know if the reaction is complete?
- How can you minimize loss of Cu and its compounds?

Types of Reactions

- Combustion
- Synthesis
- Single Displacement
- Double Displacement (Metathesis)
- Decomposition
- Acid – Base

(single, double displacement and acid base, can also be redox or double displacement and acid base)

Combustion

- A combustion reaction is when oxygen combines with another compound to form water and carbon dioxide. These reactions are exothermic, meaning they produce heat.
- An example of this kind of reaction is the burning of methane:

$$\mathbf{CH_4 + O_2 \rightarrow 10\ CO_2 + 2H_2O}$$

Decomposition Reaction

- A more complex substance breaks down into its more simple parts. One reactant yields 2 or more products.
- For example, water can be broken down into hydrogen gas and oxygen gas.

$$H_2O \rightarrow \frac{1}{2} O_2 + H_2$$

- The chemical equation for a decomposition reaction looks like:

$$\text{reactant} \rightarrow \text{product} + \text{product}$$

Synthesis

- A synthesis reaction is when two or more simple compounds combine to form a more complicated one. These reactions come in the general form of:

$$A + B \rightarrow AB$$

- One example of a synthesis reaction is the combination of iron and sulfur to form iron (II) sulfide:

$$8\ Fe + S_8 \rightarrow 8\ FeS$$

Single displacement

- This is when one element trades places with another element in a compound. These reactions come in the general form of:

$$A + BC \rightarrow AC + B$$

- One example of a single displacement reaction is when magnesium replaces hydrogen in water to make magnesium hydroxide and hydrogen gas:

$$Mg\ (s) + 2\ H_2O\ (l) \rightarrow Mg(OH)_2\ (s) + H_2\ (g)$$

Double displacement

- This is when the anions and cations of two different molecules switch places, forming two entirely different compounds. These reactions are in the general form:

$$AB + CD \rightarrow AD + CB$$

- One example of a double displacement reaction is the reaction of lead (II) nitrate with potassium iodide to form lead (II) iodide and potassium nitrate:

$$Pb(NO_3)_2 + 2\ KI \rightarrow PbI_2 + 2\ KNO_3$$

Acid-base

- This is a special kind of double displacement reaction that takes place when an acid and base react with each other. The H^+ ion in the acid reacts with the OH^- ion in the base, causing the formation of water. Generally, the product of this reaction is some ionic salt and water:

  HA + BOH → H_2O + BA

- One example of an acid-base reaction is the reaction of hydrobromic acid (HBr) with sodium hydroxide:

  HBr + NaOH → NaBr + H_2O

What type of reaction is taking place?

Follow this series of questions. When you can answer " yes: " to a question, then stop.

1) Does your reaction have oxygen as one of it's reactants and carbon dioxide and water as products?

   Yes: it's a combustion reaction

2) Does your reaction have two (or more) chemicals combining to form one chemical?

   Yes: it's a synthesis reaction

3) Does your reaction have one large molecule falling apart to make several small ones?

   Yes: it's a decomposition reaction

4) Does your reaction have any molecules that contain only one element?

Yes: it's a single displacement reaction

5) Does your reaction have water as one of the products?

Yes : it's an acid-base reaction

6) If you haven't answered " yes " to any of the questions above, then you've got a double displacement reaction

Equations for lab

1) $4HNO_3\ (aq) + Cu\ (s) + O_2(g) \longrightarrow Cu(NO_3)_2\ (aq) + 2H_2O\ (l) + 2NO_2\ (g)$

single displacement reaction

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

double displacement reaction

- (3) $Cu(OH)_2$ (s) (heat) $\rightarrow$ CuO (s) + H_2O (l)
  Decomposition Reaction

- (4) CuO (s) + H_2SO_4 (aq) $\rightarrow$ $CuSO_4$(aq) + H_2O (l)
  Acid base Reaction

- (5) $CuSO_4$ (aq) + Mg (s) $\rightarrow$ $MgSO_4$ (aq) + Cu (s)
  Single Displacement Reaction

Copper Nitrate

$$8HNO_{3\,(aq)} + 3Cu_{\,(s)} + O_{2\,(g)} \rightarrow 3Cu(NO_3)_{2\,(aq)} + 4H_2O_{\,(l)} + 2NO_{2\,(g)}$$

- Crystalline $Cu(NO_3)_2(H_2O)_{2.5}$ features octahedral Cu centers surrounded by water and the nitrate anions.
- This hydrate decomposes at *ca*. 170 °C into copper(II) oxide, nitrogen dioxide and oxygen:
  - $2Cu(NO_3)_{2(s)} \rightarrow 2CuO_{(s)} + 4NO_{2(g)} + O_{2(g)}$

Precautions

- Conc. HNO_3 is corrosive
- Use a fume-hood – $NO_2(g)$ is generated which is toxic if inhaled
- Observe the color of the gas evolved
- Only had enough nitric acid so as your copper dissolves (more is not better!)

Use of Copper Nitrate

- Copper nitrate can be used to generate nitric acid by heating it until decomposition and passing the fumes directly into water. This method is similar to the last step in the Ostwald process. The equations are as follows:
  - $2Cu(NO_3)_2 \rightarrow 2CuO + 4NO_2\,(g) + O_2\,(g)$
  - $NO_2 + H_2O \rightarrow 2\,HNO_3 + NO\,(g)$
- Copper nitrate soaked splints of wood burn with an emerald green flame. Addition of Magnesium nitrate gives a lime green color.

Copper Nitrate to Copper Hydroxide

$$Cu(NO_3)_{2\,(aq)} + 2NaOH_{\,(aq)} \rightarrow Cu(OH)_{2\,(s)} + 2NaNO_{3\,(aq)}$$

The driving force of the reaction is the formation of a precipitate.

Sodium Hydroxide is a strong base – use with caution.

- The precipitate is separated through using a centrifuge.

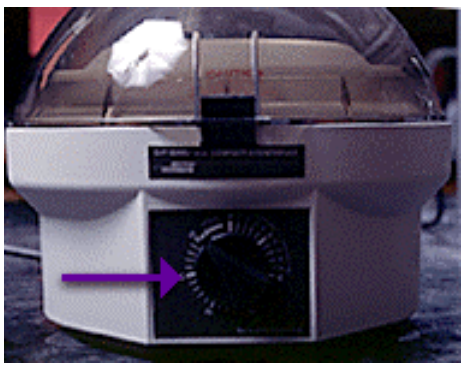
- Ensure complete precipitation has occurred by adding a few extra drops of NaOH after using the centrifuge.

- The liquid above the precipitate is called the supernatant

Lab Techniques

- Using a centrifuge

- A centrifuge separates a heterogeneous mixture of solid and liquid by spinning it. After a successful centrifugation, the solid precipitate settles to the bottom of the test tube and the solution, called the supernatant (centrifugate), is clear.

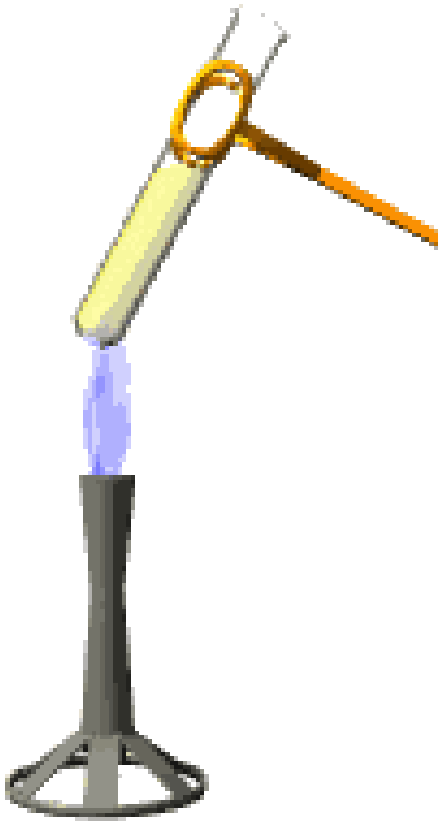


Place test tube in centrifuge holder.

Balance with another test tube filled to the same level in the opposite holder.

Close cover and turn on. Centrifugation takes a minute or more. Note that you must turn off the centrifuge with the switch and wait for it to stop spinning, to effectively separate the precipitate and solution.

Copper Hydroxide to Copper Oxide



$$Cu(OH)_{2\,(s)}\ (heat\ ) \rightarrow CuO_{\ (s)} + H_2O_{\ (l)}$$

- Never heat a closed container, and be sure that open test tubes point away from you and others while being heated. Always heat the test tube at an angle from the flame.

Copper Oxide

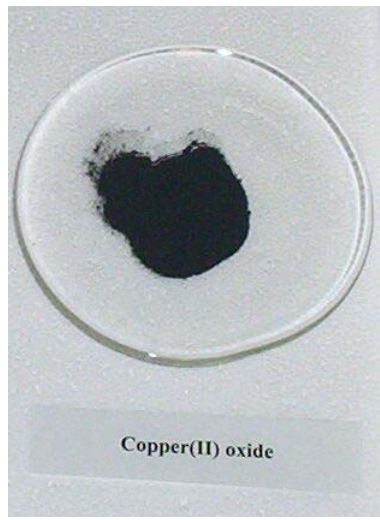
- Copper(II) oxide is a basic oxide, so it dissolves in mineral acids such as hydrochloric acid, Sulfuric acid or nitric acid to give the corresponding copper(II) salts:

$$CuO + 2\ HNO_3 \rightarrow Cu(NO_3)_2 + H_2O$$

- It can also be reduced to copper metal using hydrogen or carbon monoxide:

$$H_2 + CuO \rightarrow Cu + H_2O$$

- Copper (II) oxide has uses as semiconductor



Copper Oxide to Copper Sulfate

$$CuO_{(s)} + H_2SO_{4\,(aq)} \rightarrow CuSO_{4\,(aq)} + H_2O_{(l)}$$

- Add approx 1ml of H_2SO_4 to the copper oxide
- The solution should change color.
- Record your observations.
- Add enough acid until all your oxide is dissolved.
- Slight heating may be required

Copper Sulfate

- This has the formula **$CuSO_4$**, and is a common salt of copper.
- Copper sulfate exists as a series of compounds that differ in their degree of hydration.
- The anhydrous form is a pale green or gray-white powder, while the hydrated form is bright blue. The archaic name for copper(II) sulfate is **blue vitriol**

Synthesis

- It is made by the action of sulfuric acid on a variety of copper(II) compounds, such copper(II) oxide and copper carbonate.
- Such reactions are considered acid-base reactions.
- Copper sulfate most occurs in nature as the pentahydrate ($CuSO_4 \cdot 5H_2O$).
- This mineral is called chalcanthite.

Uses

- Copper sulfate is also used to test blood for anemia. A drop of the patient's blood is dropped into a container of copper sulfate, if it sinks within a certain time, then the patient has sufficient hemoglobin levels and is not anemic. If the blood floats or sinks too slowly, then the patient is iron-deficient and may be anemic.
- In a flame test, copper ions emit a deep blue-green light, much more blue than the flame test for barium.

More Uses

- Copper(II) sulfate is a desiccant.
- Copper sulfate is a commonly included chemical in children's chemistry sets and is often used in high school crystal growing and copper plating experiments.
- A very dilute solution of Copper sulfate is used to treat aquarium fish of various parasitic infections. However, as the copper ions are also highly toxic to the fish, care must be taken with the dosage.

Copper Sulfate to Copper

- $CuSO_{4\,(aq)} + Mg_{\,(s)} \rightarrow MgSO_{4\,(aq)} + Cu_{\,(s)}$

- Why Magnesium metal?
- (Note the manual says zinc, we will use magnesium instead).

- Magnesium is a more reactive metal than copper
- It is an alkali earth metal that is found in group 2
- It is a reducing agent and is therefore oxidized itself
- $Mg(s) \rightarrow Mg^{2+} + 2e'$

- Whenever something is oxidized, something else in the reaction needs to be reduced.

- The Cu^{2+} (as $CuSO_4$) picks up the 2 electrons forming Cu(s) and $MgSO_4$

- This is a single displacement reaction

$$A + BC \rightarrow AC + B$$

- Cu reacts readily with oxidizing agents.
- Oxidizing agents are reduced themselves

OILRIG

Oxidation Is Loss Reduction Is Gain

In chemical reactions, whenever an oxidation occurs a reduction is also present (and vice versa).

% of Copper Recovered

- The amount of Cu that you start with is recorded = Mi = Initial Mass
- The amount recovered is recorded, Mf = Final Mass
- % Recovered = Mf / Mi x 100