The Copper Cycle

Exploring reactions and their products

The results of this lab will be presented as a PowerPoint presentation not as a Lab Report.

- You will form a team of four students (two pairs) to perform this experiment. Your team will be asked to create a PowerPoint and to present it
  - ⇒ Some lab instructors may allow a poster presentation instead
- The score for this lab is based on three components:
  - ⇒ (1) Pre-lab assignment: 20 pts; (2) PowerPoint presentation: 10 pts; (3) PowerPoint content (data, reasoning, and claims) 70 pts
- **Extra Credit**: up to 10 pts to be earned for answering 3 post lab questions. To be eligible, you must upload your answers within 48 hrs. of the end of your lab.

Introduction:

With 118 chemical elements currently known, it is astounding to think of how many different kinds of molecules exist and how many types of reactions are possible. In this lab, you will explore a little slice of the diversity of copper compounds and the types of reactions they undergo.

Copper compounds have distinct physical and chemical properties allowing them to participate in a multitude of chemical processes. Many copper compounds play important roles in industrial and agricultural practices (and even pyrotechnics!). For example, copper (II) sulfate is used as an agricultural fungicide and prevents the growth of algae in water reservoirs. Copper (II) chloride is used in part of the process of refining petroleum. Copper (II) nitrate is used to color fireworks and ceramics. Below are some illustrations of some of these different compounds. Note the differences in color and solubility behavior:

Some common copper compounds:

Copper (I) oxide
Formula: Cu_2O
Description: Red solid, insoluble in water

Copper (II) oxide
Formula: CuO
Description: Black solid, insoluble in water

Copper (II) sulfate
Formula: $CuSO_4$
Description: Light blue solid, soluble in water: aqueous light blue solution

Copper (II) hydroxide
Formula: $Cu(OH)_2$
Description: Light blue solid, not soluble in water

Copper (II) chloride
Formula: $CuCl_2$
Description: blue-green solid, soluble in water: green to blue aqueous solution

Copper (II) nitrate
Formula: $Cu(NO_3)_2$
Description: Light blue solid, soluble in water: aqueous dark blue solution

The reactions you will investigate today start with copper metal and end in its re-formation, thus comprising a cycle. Along the way, you will synthesize four different copper compounds. The synthesis of each intermediate compound is vital to the next step in the reaction cycle. Your job will be to explain the underlying chemistry of how the cycle is possible by characterizing each reaction:

Scientific Question: How does the series of reactions you performed result in the re-formation of copper metal?

To answer this question, you will need to carefully observe each reaction in the cycle and use these observations as evidence to deduce which copper compound formed in each step. By identifying each product, you should be able to determine what type of reaction occurred and its balanced chemical equation. This will allow you to explain how the cycle is possible. Below is a list of reactions that metals and metal compounds commonly undergo to guide you:

Some common reactions of metals and metal compounds:

Metal oxides can act as bases and neutralize acids:

$$FeO(s) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2O(l)$$

When an ionic compound (a salt) and water are formed in the reaction between an acid and a base, a **neutralization reaction** has occurred.

Metal hydroxides form metal oxides and water when heated:

$$Ca(OH)_2(s) + heat \rightarrow CaO(s) + H_2O(l)$$

Reactions that produce water molecules are called **dehydration reactions.**

Metals can be oxidized by strong acids:

$$Zn(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + H_2(g)$$

Reactions that involve the transfer of electrons from one chemical species to another are called **oxidation-reduction reactions**. The species that loses electrons is "oxidized" and the species that gains electrons is "reduced."

Ionic metal compounds can exchange anions:

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

A reaction that results in the exchange of anions is a **double displacement reaction.** Double displacement reactions can result in the formation of a precipitate if one of the products is insoluble.

Throughout this experiment, you are encouraged to consult with other groups and discuss your determinations of the types of reactions and compounds formed. Your laboratory instructor is familiar with the types of reactions and products of the copper cycle and may also be used as a resource if you get stuck.

Materials:

Chemicals:	**Equipment & Supplies:**
Distilled water	Litmus paper
Copper wire turnings Cu	Büchner Funnel
8M Nitric Acid (HNO_3)	Filter paper
6M Sodium Hydroxide (NaOH)	Bunsen burner
3M Sulfuric Acid (H_2SO_4)	
Zinc metal granules Zn	

Special safety note for this lab: Please perform this lab under the hood.

Pre-Lab Assignment (20 pts):

1. Please write a short summary of the experiment you will perform today.

2. Please prepare a safety table that lists the chemicals, their hazards, and the precautions you will take when handling them.

3. Please write down one question you have about the material you read and be prepared to share it with the class.

Laboratory Guide:

Reaction 1. Copper reacts with nitric acid to form the first copper compound

$$Cu(s) + 4HNO_3(aq) \longrightarrow \textbf{?} + 2NO_2(g) + 2H_2O(l)$$

1. Weigh out approximately 1 g of copper wire or turnings, and record the mass to the nearest 0.001 g. Place the copper wire in a 125 mL Erlenmeyer flask. **In the bench hood**, carefully and slowly add a two-fold excess of nitric acid (8 M HNO_3). Place the flask in the hood, and allow the copper to react.

The brown NO_2 gas generated during this step is very toxic. **Keep the flask with evolving NO_2 gas under the hood at all times.**

2. Allow the solution to cool to room temperature.

3. While you wait, record your observations of what happened during this reaction and use them to justify your answers to the following questions:

Q: What kind of reaction is this?
Q: What copper compound was formed?
Q: Determine the balanced chemical equation for this reaction.

Reaction 2. Addition of sodium hydroxide (NaOH) to the new solution creates the second copper compound

1. Transfer the new solution to a 250 mL beaker. To do this, carefully pour as much of the solution as possible into the beaker, and then rinse the flask with about 25 mL of distilled water. Add this rinse to the solution. This ensures that all the solution has been transferred from the flask to the beaker.

2. Very carefully, add 30.0 mL 6 M sodium hydroxide (NaOH), and stir the resulting mixture. Test the acidity of the solution with litmus paper by placing a drop of the mixture on a piece of neutral litmus paper (use your stirring rod; do not place the strip directly in the solution). If the strip remains pink, add more NaOH (approximately 10 mL) and test again with litmus paper. Continue to add the base (NaOH) until the litmus paper turns blue. This indicates that you now have a basic solution.

3. Record your observations of what happened during this reaction and use these observations to justify your answers to the following questions:

Q: What kind of reaction do you think this is?
Q: What new copper compound has formed?
Q: Determine the balanced chemical equation for this reaction

Reaction 3. Addition of heat to the blue precipitate results in the formation of the third copper compound

1. Carefully heat the blue precipitate with a Bunsen burner, stirring constantly with a stir rod. Be sure to use a wire gauze on the ring stand to prevent the beaker from breaking and keep the stir rod in the beaker. Watch the mixture very carefully, as splattering may occur if the mixture is heated too vigorously, or is not stirred.

2. Continue to heat until the blue solid is completely converted to a black solid. If this has not happened after 10 minutes of heating, add approximately 20 mL additional sodium hydroxide solution and continue to heat. After no more blue solid can be observed, heat for an additional 2-3 minutes to aid in coagulating the new precipitate.

3. Record your observations of what happened during this reaction and use these observations to justify your answers to the following questions:

> **Q:** What kind of reaction do you think this is?
> **Q:** What new copper compound has formed?
> **Q:** Determine the balanced chemical equation for this reaction

Reaction 4. Sulfuric acid reacts with the black precipitate to create the fourth copper compound

1. To isolate the black precipitate you created, vacuum filter the mixture using a Büchner funnel. Wash the product with two portions of approximately 25 mL of distilled water.

2. When most of the liquid has been removed from the black precipitate, turn off the vacuum, and discard the filtrate (the solution in the flask) if clear. If there is a significant amount of small black particles in the filtrate, re-filter onto the same piece of filter paper until the solution is clear.

3. Remove the Büchner funnel containing the black precipitate from the vacuum flask and place it in a beaker. Use a ring stand or clamp to hold the funnel so that the tip of the funnel does not touch the bottom of the beaker. Pour 25.0 mL dilute (3 M) sulfuric acid (H_2SO_4) onto the black precipitate and paper, then allow the solution to slowly run through the funnel. Do not use any vacuum. The black precipitate should slowly disappear. To aid in dissolving the solid, you may gently swirl the mixture in the funnel. (Do not use your stirring rod to stir the solution!) If solid remains after all the sulfuric acid has filtered through, transfer the filtrate into a beaker, and pour the filtrate onto the solid again. Repeat this procedure until all of the solid has reacted. Wash the filter paper twice with 15 mL distilled water.

4. The filter paper in the funnel may now be discarded in the appropriate waste container.

5. Record your observations of what happened during this reaction and use these observations to justify your answers to the following questions:

> **Q:** What kind of reaction do you think this is?
> **Q:** What copper compound has formed?
> **Q:** Determine the balanced chemical equation for this reaction

Reaction 5. Adding zinc metal to the fourth copper compound results in the re-formation of copper metal

$$Zn(s) + \textbf{?}\,(aq) \longrightarrow ZnSO_4(aq) + Cu(s)$$

1. Add a two-fold excess of zinc granules to your new solution. (Hint: Use the initial number of moles of copper you started with to calculate the mass of zinc to add.)

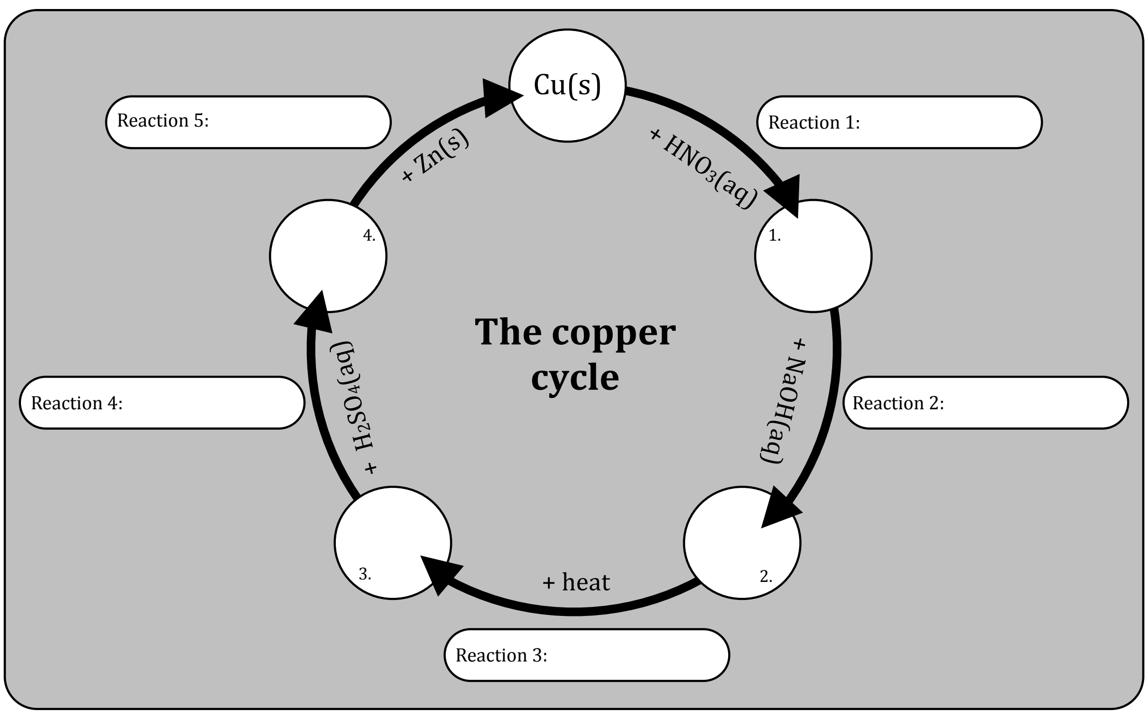
2. Stir occasionally until the solution becomes colorless (about 15-20 minutes). The zinc is oxidized from Zn to Zn^{2+}as it reduces the copper from Cu^{2+} to Cu. The big chunks you are seeing are copper metal! The cycle is complete.

Team Analysis and PowerPoint Presentation Instructions:

Team Analysis

You may return to the breakout room for this portion of the activity

1. Team up with another group and exchange your determination of the products, balanced chemical equation, and the type of each reaction in the cycle.



2. The chemical transformations in the copper cycle starts and ends with the metal copper. The law of conversation of mass indicates that atoms cannot be created or destroyed. If you started with 1.0g of Cu, and **<u>the yield of each step in the copper</u>**

cycle was exactly 90%, how much copper metal would you expect to recover at the end of doing one cycle? Where did the other copper metal end up?

3. Does the oxidation state of copper change during the copper cycle? Please explain.

4. Catalysts are used to speed up reactions and direct chemical reactions towards certain products. There are many copper catalysts that are used in chemical transformations, resulting in reactions that occur under milder conditions with excellent yields for when chemical reactions are slow and require high temperatures. Discuss the copper cycle in terms of developing a useful catalytic transformation.

PowerPoint Presentation instructions.
This week, rather than writing a lab report, you are to construct a PowerPoint presentation in class. The Team Analysis questions are provided to help in the analysis of your presentation.

The score for this lab is based on three components:

(1) Pre-lab assignment: 20 pts;
(2) PowerPoint presentation: 80 pts

Extra Credit: up to 10 pts to be earned for answering the 2 post lab questions. To be eligible, you must upload answers on ICN within 48 hrs. of your lab.

Post lab questions:

1. The first step of the copper cycle involves a change in the oxidation state of copper. While copper metal is insoluble in water, the product of the first step in the copper cycle is soluble. Can you suggest an explanation or suggest a property that changes to help explain this observation?

2. If you wanted to be able to recover 90% of the copper back after one cycle, what would the average yield for the five steps in the copper cycle need to be? Provide an explanation to support your answer.

Rubric for the PowerPoint Presentation

Title and Team Member Names (10 pts)	Your PowerPoint should contain: • Contains title • Authors (Team member names) • Date of experiment/presentation • Overview: brief statement/introduction about the presentation
Data, Results, Evidence: Scientific data that supports the claim. **(25 pts total)**	Your PowerPoint presentation should include a section that organizes data, results, and evidence. The goal of the section is to describe what your team did and what data was collected. Observations are important data to present. • Procedure: reference the lab procedure and any changes to the procedure. • Observations of what happened during each reaction and the products of each reaction. • Provide the balanced chemical equation for each reaction. • Using your initial mass of copper and based on the assumption that each step of the cycle has a 90% yield (see page 7, question 2), determine your theoretical final yield of copper

Analysis of Evidence (Reasoning):
 	
(30 pts total)
	Your PowerPoint presentation should address/analyze the copper cycle looking at the following factors:
	• Present the copper cycle in terms of why the series of reactions result in the re-formation of copper metal, include the following:
	  ○ observations, data, and knowledge of chemical reactions and how they can be used to determine the identity of the resulting copper compounds,
	  ○ Provide a balanced chemical equation for each step,
	  ○ Classify each reaction (What type is it? e.g., neutralization).
	  ○ Identify the oxidation states (e.g. copper) at each step. Provide reasoning to support each reaction type.
	• Discuss how beginning and ending with the same chemical can be part of the design of a useful catalytic transformation.

Claim(s): Statement(s), derived from evidence, using scientific reasoning. **(15 pts total)**	Your PowerPoint slides should present: • Conclusions or claims that you have drawn from the experiment to answer the question: How does the series of reactions you performed result in the re-formation of copper metal?

At least one team member should upload the PowerPoint presentation after presenting it.