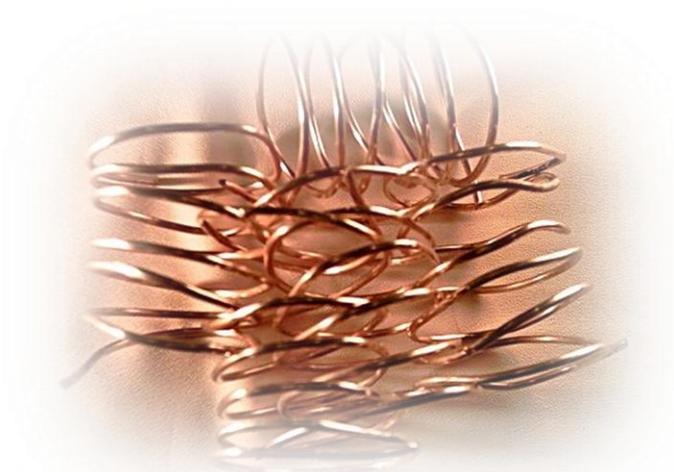




**Green Chemistry Module
Level: High School Regents**

Types of Reactions: The Copper cycle



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Types of Reactions: The Copper Cycle

In this laboratory experiment, students will perform a series of reactions known as the copper cycle. The reaction series includes single replacement, double replacement, synthesis, and decomposition reactions. In each of two cycles, students will complete a series of reactions that results in the final product regenerating the original starting material.

This experiment should take one 80-minute session to complete. Students will complete one of two cycles. As a class, both cycles can be completed in one lab period, and results shared between groups.

Some substances require a bit of time to dissolve. Students should be encouraged to work on the questions and observations while waiting for reactions to complete.

Two versions of the lab are available:

Basic Level Instruction: this would be appropriate for a Regents chemistry class. Each pair of students completes one of the two cycles of reactions and then shares their findings with the rest of the class. The lab is a qualitative rather than a quantitative experience, focusing on reaction types.

Advanced Level Instruction: For an advanced class (AP), the lab can be completed as a quantitative experiment. The advanced version assumes the student starts in cycle A with copper wire, completes both cycles of the reactions, and finishes with the regeneration of elemental copper from copper sulfate. Students will make quantitative measurements of the products, calculate percent yield, and will complete an independent lab write-up.



Types of Reactions: Teacher's Guide

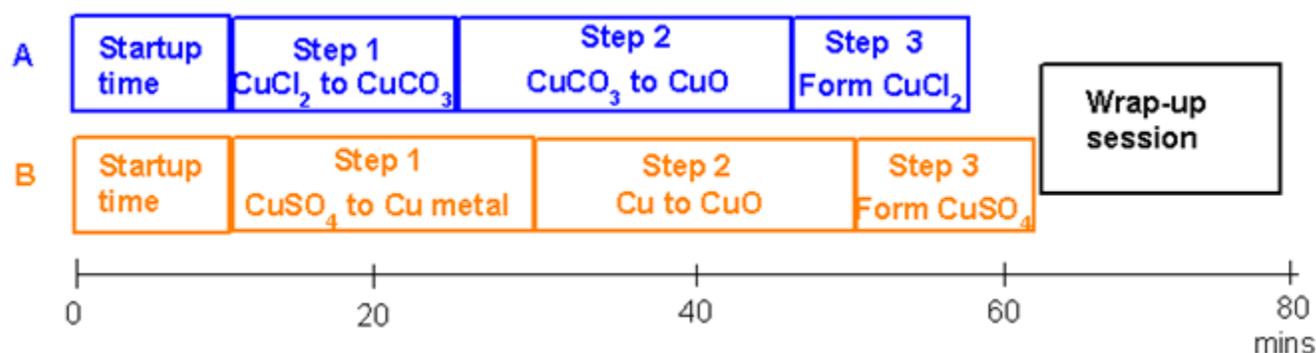
Intended Audience: High School Regents Chemistry Students

This experiment is aimed at students in high school learning about chemical changes and reaction types. The experiment would also be suitable for an introductory college laboratory.

Recommended Student Background: Students should be familiar with single replacement, double replacement, synthesis and decomposition reactions.

Activity Timeline:

It is suggested that some students perform cycle A, while other students perform cycle B. In this way, both cycles can be completed inside an 80 minute time period.



Safety Issues: Wear approved safety goggles and suitable clothing when working with or near all chemicals in this experiment. As they leave the laboratory, students should wash hands well. In the case of skin exposure, students should wash skin continuously for 15 minutes.

Copper (II) chloride and sulfate have a very slight toxicity, and they should be washed off the hands with a large amount of cold water (without soap). Do not touch the filter paper with your hands. Any spills can be cleaned up with water.

Magnesium powder is combustible, and has been known to catch fire in the presence of water or damp materials. Once burning, magnesium fires require special extinguishers to put out the fire. When it reacts with sulfuric acid, flammable hydrogen gas is released.

Sulfuric acid, hydrochloric acid and sodium carbonate solution are corrosive materials that should be handled with care.

Open flames should be kept well away from flammable materials such as organic solvents.

Keys to Success: Students need to be patient, and wait until reactions are complete, otherwise later reactions may not work as desired.

When transferring materials, care should be taken to avoid loss of products, especially when scraping the copper (II) carbonate from the filter paper in cycle B.



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Advanced Preparation:

The teacher should stage necessary equipment in a central location or at lab stations as appropriate. Approximate amounts of the starting material for each cycle should be pre-weighed and provided in a small dish or container. If necessary, prepare fresh solutions to augment the supply of recycled starting materials, depending on volume and purity of available solutions. It may also be necessary to dilute the acids and prepare the sodium acetate solution ahead of time.

Materials Check List:

Chemicals needed per group to run both cycles (assuming 50% spare capacity)

CYCLE A

15 mL	1.0 M Copper (II) sulfate
0.6 g	Magnesium powder
30 mL	1.0 M Sulfuric acid
15 mL	5% Sodium acetate solution

CYCLE B

15 mL	0.5 M Copper (II) chloride
15 mL	0.5 M Sodium carbonate
15 mL	1.0 M Hydrochloric acid

Equipment needed (per group) to run both cycles

50 mL Erlenmeyer flask	125 mL Erlenmeyer flask (2)
Glass stirring rod	Glass stirring rod
10 mL graduated cylinder	10 mL graduated cylinder
150 mL beaker	Bunsen burner and matches OR hotplate
Crucible and crucible cover	Spatula
Clay triangle	100 mL beaker
Ring stand with iron ring OR tripod	Distilled water for rinsing
Bunsen burner and matches	Gloves
Tongs	Funnel
Spatula	Filter paper
100 mL beaker	Watch glass
Distilled water for rinsing	
pH paper	

Measurements:

Volume measurements can be performed using graduated cylinders.

Masses can be measured in grams using a simple electronic balance; tenths precision (0.1g) is acceptable, though hundredths precision (0.01g) is recommended (necessary for the advanced level).

Recycling and disposal:

A container to store the regenerated copper (II) sulfate and copper (II) chloride solutions is required in order to reuse the material for future labs. Choose a container that is large enough to contain the material and is capable of being closed and properly stored.



Green Chemistry: Making materials sustainably

Chemical manufacturing is as old as civilization and the discoveries of bronze and iron came to define the eras that ensued. In modern times, we take for granted a plentiful supply of metals, plastics, dyestuffs and medicines. We have come to depend on the chemical industry to provide us with all the materials we need for our "materialist" society.

But the supply of these materials is not infinite. As the human population grows, and demands an ever higher standard of living, the consumption of the Earth's materials is in danger of getting out of control. It is therefore essential that chemists become responsible stewards of the raw materials that remain. We need to develop methods for chemical processing that are both chemically and environmentally efficient, and which move us towards a sustainable society. We need new materials that can provide what we need without destroying the Earth.

Green chemistry is designed to help us meet these needs. It aims not just to treat waste, but to avoid producing waste in the first place. Products and processes should be "benign by design," but they must also be practicable.

In this lab manual, we will explore how this can be achieved in practice – how we can use chemistry to help solve our environmental problems. We will never be able to build a sustainable society if we don't understand the basic science of where our materials come from, and how they are produced. The goal of this manual is to provide that science, presented within the context of green chemistry.

The Twelve Principles of Green Chemistry

The basic principles of green chemistry were first laid out by two US chemists, Paul Anastas and John Warner, in their 1998 book, "Green Chemistry: Theory and Practice:"

1. **Prevent waste:** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.
3. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
4. **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
5. **Use catalysts, not stoichiometric reagents:** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.
6. **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
7. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
8. **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.
9. **Increase energy efficiency:** Run chemical reactions at ambient temperature and pressure whenever possible.
10. **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
11. **Analyze in real time to prevent pollution:** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.



12. **Minimize the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

It must be recognized that these represent a target, and we will not be able to satisfy every principle immediately with every process and product. Nevertheless, if we design our chemistry with these principles in mind, we will make great strides towards achieving sustainability.

Why should you teach about types of reactions?

1. Chemical reactions are what make chemistry both distinctive and useful. The four types of reactions in the Regents curriculum provide a simple description applicable to most inorganic chemical changes.
2. The changes seen in this experiment such as solid to/from liquid, color changes and gas evolution are common observations when chemical changes occur. They are also interesting to experience!

Why should you use a cycle experiment?

1. Reuse and recycle are becoming essential ways to manage resources, as we find that our world has limited supplies of most materials. It is critical for the next generation to learn about sustainability in the laboratory, not just in textbooks. In this experiment students experience this very clearly – with the starting color and appearance being regenerated at the end of the experiment. How can we try to teach sustainability, then run an experiment where every product is thrown away as waste?
2. This experiment is designed to minimize both resources and waste. Both of these factors help to keep down the cost of running the chemistry laboratory.

Correlation of the experiment with Green Chemistry

- Green Chemistry Principles:
1. Prevent waste
 4. Use renewable feedstocks

The experiment clearly is designed to prevent waste by reusing the final product as the starting material for a subsequent experimental run. By illustrating the concept of recycling, ending with the original starting material after a series of reactions, the experiment is demonstrating a method of renewing feedstocks. Although the copper-based starting materials are not renewable as a raw material, the concept of renewing feedstocks through recycling is clearly demonstrated.

Curriculum alignment

Alignment to the NYS Regents Chemistry Curriculum:

III.8 Types of chemical reactions include synthesis, decomposition, single replacement, and double replacement. (3.2b)

This experiment correlates directly with the following section of the New York State Core Curriculum:

Standard 4: The Physical Setting.

Key Idea 3: Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.

Performance Indicator 3.2 Use atomic and molecular models to explain common chemical reactions.

Major Understandings 3.2b Types of chemical reactions include synthesis, decomposition, single replacement, and double replacement.



Background and Fundamentals for Basic Level Instruction:

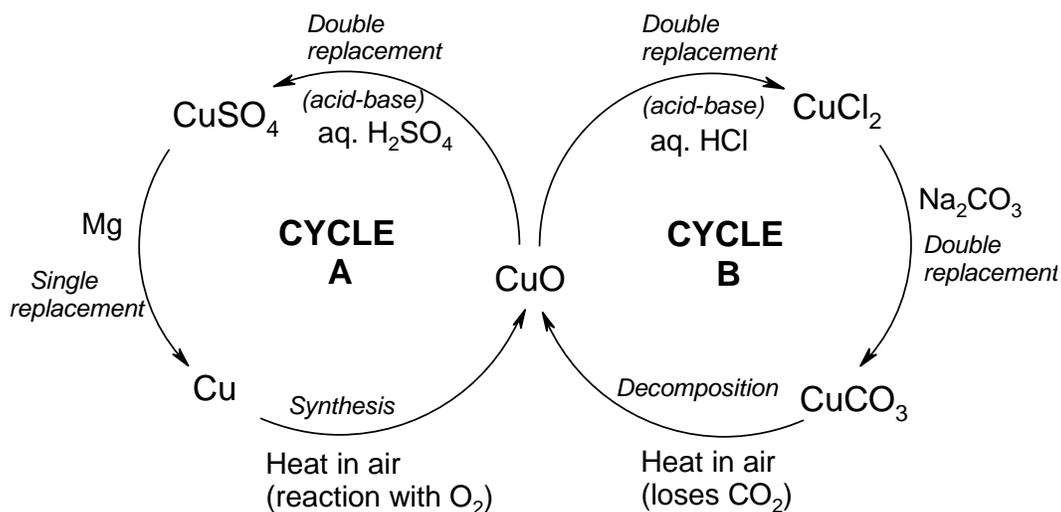
Types of Reactions: The Copper Cycle

Students learn the standard classes of chemical reactions, which in New York are defined as *single replacement*, *double replacement*, *synthesis* and *decomposition*. A wide choice of reactions is available, yet often highly toxic materials have been used (such as lead(II) nitrate) because they provided attractive examples. The complete *set* of reactions illustrated here

- illustrate all reaction types,
- are visually attractive,
- produce no hazardous waste at all, and
- demonstrate the concept of recycling by allowing the product from one reaction to be used as the starting material in the next experiment.

Cycle A begins with a blue solution of copper (II) sulfate being reduced to copper metal. This is roasted in air to give black copper (II) oxide, which can be redissolved to regenerate the starting solution of copper (II) sulfate.

Cycle B starts with a solution of copper (II) chloride, which is used to precipitate basic copper carbonate. This greenish-blue solid decomposes to black copper (II) oxide on heating. The black solid oxide rapidly dissolves in dilute hydrochloric acid to give the original solution in the cycle, copper (II) chloride. Note that both cycles have copper (II) oxide in common.



No hazardous waste is produced in this experiment. There is a small amount of acidic magnesium sulfate produced, but this can be neutralized by sodium acetate to produce a nontoxic waste suitable for washing down the sink. Other than small losses on filter papers, the copper is completely recycled so that the final product solutions are collected and ready (without further prep) to be re-used in a future lab.

Furthermore, this experiment illustrates to students how industry recycles materials such as copper.

Guidance Notes:

For good recycling, it is necessary to make sure that students do not leave large amounts of material behind when performing transfers. This is especially true when transferring solid copper (II) carbonate from the filter paper.



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In Cycle A, the oxidation of copper should be evaluated based on color change to black. It may take as little as 5 minutes or up to 20 minutes, depending on the intensity of the Bunsen Burner used.

In Cycle A, the neutralization step can be eliminated if the school is equipped with a proper aqueous waste stream receptacle.

In Cycle B, step 4, students can use a hot plate rather than an open flame for drying and decomposition of the copper carbonate.

Note that the final products may be impure. Students should look for similarities in color, rather than exact replication of the starting color of the solutions.

Lab Procedure for *Types of Reactions: The Copper Cycle*

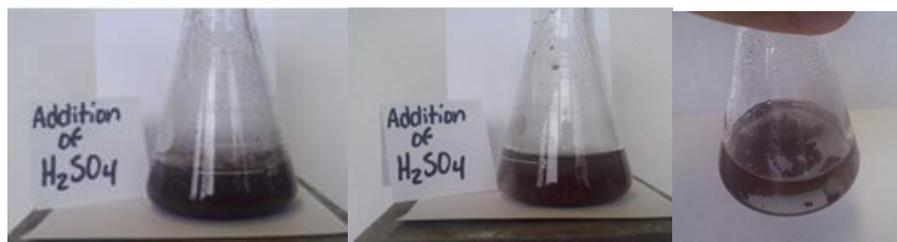
Cycle A



1. Add magnesium powder to copper (II) sulfate solution



2. Slowly add 10 mL 1.0 M sulfuric acid.



3. Decant the aqueous solution into a 150 mL beaker, and then rinse the metal with 2 mL water. Transfer the washed metal to a crucible.



4. Gently dry the metal over a Bunsen burner.



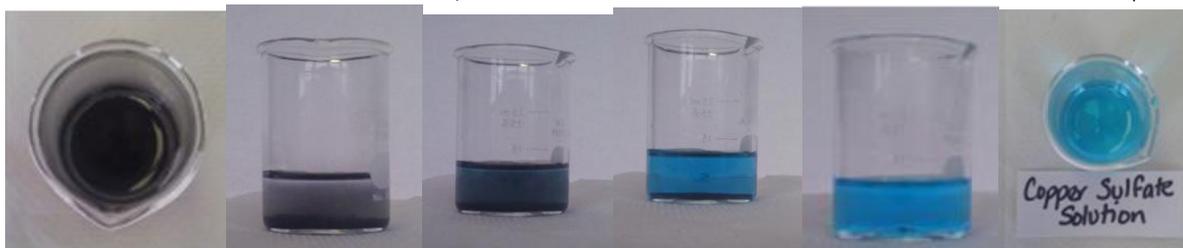
5. Once the sample is dry, heat it *strongly* in the Bunsen burner to "burn" the copper to black copper (II) oxide. This will take anywhere from 5-20 minutes. The step is complete when there is a uniform black color.



6. Meanwhile, neutralize residual acid in the beaker using sodium acetate.

7. Allow the crucible to cool.

8. Transfer the solid to a 100 mL beaker, and then add 10 mL 1.0 M sulfuric acid to remake CuSO_4 .



Cycle B

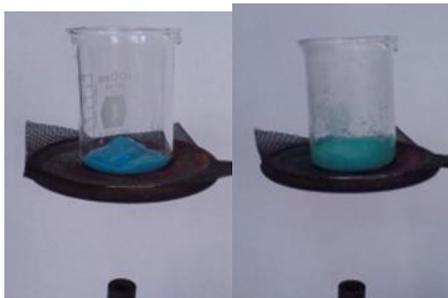


Procedure for cycle B

1. Measure out 10 mL 0.5 M solution of copper (II) chloride dihydrate in water, and add this to a 125 mL Erlenmeyer flask. Then add 10 mL of 0.5 M sodium carbonate solution (with continual swirling). Record observations, and then filter off the precipitate using gravity filtration. The liquid filtrate can be washed away down the drain.



2. Wearing gloves, use a spatula to scrape the solid (basic copper (II) carbonate) off the filter paper into a 100 mL beaker. Be sure to recover all of the blue solid that you can.
3. Heat the wet solid *gently* for five minutes over a Bunsen burner or on a hot plate, in order to drive off water.



4. Heat the dried blue solid strongly with the Bunsen burner or hot plate for 10 minutes, to decompose the basic copper carbonate (releasing CO_2) to copper (II) oxide.



- After heating, the solid should have turned to black CuO. Allow this to cool to near room temperature.
- Once the beaker has cooled, add 10 mL 1.0 M hydrochloric acid. Use the liquid to wash the walls of the beaker. Stir the mixture in the beaker periodically with a glass rod to dissolve the CuO (regenerating aqueous CuCl₂). This should take around 15 minutes.



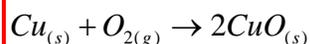
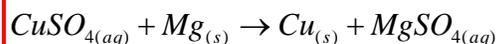
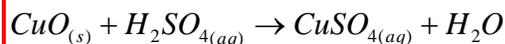
- Return the copper (II) chloride solution to your teacher for recycling.

Answers

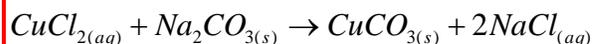
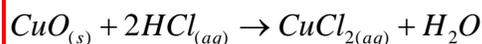
Pre-lab Questions

- Write the balanced equations for all six reactions performed in cycle A and cycle B. Indicate the waste products from the reactions (i.e., the products which are not used in the following step).

Cycle A :



Cycle B :



Questions

- In this lab, you observed that metals being heated in air will produce oxides. Predict what would happen if you heated a metal in an atmosphere of argon.

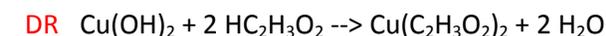
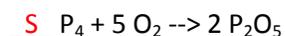
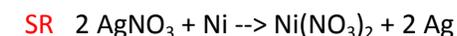
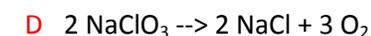
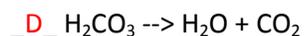
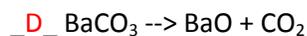
Nothing except heating, and that's the best part! Argon is a noble gas and is therefore nearly un-reactive due to its full valence electron shell. For this reason argon is often used as an environment for reactions and



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storage of air sensitive materials and compounds. Under argon the materials are unchanged by reactions with oxygen, nitrogen, and water which are present in the air.

2. Classify each of the following reactions as Synthesis (S), Decomposition (D), Single Replacement (SR) or Double Replacement (DR).



Extension Activities

1. In Cycle A, a single replacement reaction with magnesium reduced the copper in the copper sulfate solution to elemental copper. Using your Chemistry Reference Tables, identify two other metals that could be used to perform this reduction.

Students should use Table J to identify any two metals listed above copper on the table.

2. For each of these metals, write a balanced chemical equation for the resulting single replacement reaction. Answers will vary depending on the metals chosen from Table J. Check to be certain chemical formulas are properly written and the equations properly balanced. All equations should be single replacement reactions showing copper sulfate and the metal as reactants, and copper metal and a metal sulfate of the other metal involved.
3. Using any available resources, compare the health effects and costs of the two metals identified above to the originally used magnesium. In your opinion and based on your research, which of these metals would be the “greenest” metal to use in this step of the reaction cycle? Support your answer with evidence from your research.

Students should compare the toxicity of the chosen metals to magnesium and choose whichever has the lower toxicity. Some may also consider relative cost of the metals in their evaluations, though stoichiometric ratios may play into these calculations. The students should show logical thinking related to toxicity of raw materials and byproducts in their evaluation.



Background and Fundamentals for Advanced Level Instruction:

The background and fundamentals of the lab are the same as in the basic level: the lab illustrates several different types of chemical reactions, all utilizing one common element (copper). The lab models an important industrial process of recycling where, after a series of reactions, the original substance is regenerated.

In this advanced version of the lab, quantitative measurements are used to calculate percent yield after completing the reaction series. Students will complete the reactions of both cycles in the process utilizing the common CuO product as the “crossover” point. The first step of the process will be repeated at the end in order to generate the solid copper product which can then be massed in order to calculate percent yield. The recovered copper can then be processed through the cycle to regenerate one of the starting solutions for a future class.

Guidance Notes:

For the advanced class, it is recommended to begin with freshly prepared 1.0M CuSO₄ solution. Since students will be doing a % yield calculation based on the theoretical amount of copper in the initial solution, it is important for this solution to be carefully prepared.

Depending on the class schedule, it may be necessary to split the lab over more than one class period. Carefully evaluate the amount of time each step will take, and if necessary, cover and store the products at the end of a given step with students' initials marking their material in order to resume the cycle during the following class period.

For good recycling and for maximum yields of the final product, it is necessary to make sure that students do not leave large amounts of material behind when performing transfers. This is especially true when transferring solid copper (II) carbonate from the filter paper.

In Cycle A, the oxidation of copper should be evaluated based on color change to black. It may take as little as 5 minutes or up to 20 minutes, depending on the intensity Bunsen Burner used.

In Cycle A, the neutralization step can be eliminated if the school is equipped with a proper aqueous waste stream receptacle.

In Cycle B, step 4, students can use a hot plate rather than an open flame for drying and decomposition of the copper carbonate.

Note that the final products may be impure. Students should look for similarities in color, rather than exact replication of the starting color of the solutions.

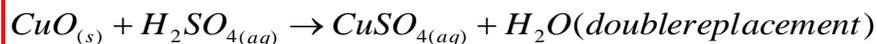


Answers:

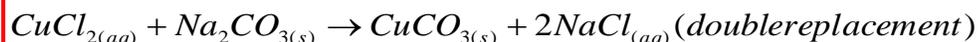
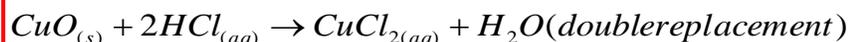
Pre-Lab:

1.

Cycle A:



Cycle B:



2. sulfuric acid (H_2SO_4) and hydrochloric acid (HCl)

3. $(35.55\text{g} - 31.47\text{g}) / (125.16\text{g} - 120.84\text{g}) \times 100 = 94.44\%$

Report:

- Calculate the amount of copper in the original solution, assuming that the solution concentration is 1.0M.
 $10\text{ ml} \times 1.0\text{M CuSO}_4 = 0.01\text{ moles of CuSO}_4 = 0.01\text{ moles of Cu} = 0.01 \times 63.546 = 0.635\text{g}$
- Calculate the percent yield of the copper based on the theoretical mass in the original sample and the final mass of the recovered copper.
 $(\text{recovered mass}) / 0.635\text{g} \times 100\%$
- List two sources of error that could have resulted in higher than expected yields of copper.
Answers will vary but may include overheating of the copper recovered in the last step to CuO; failure to completely dry the copper in the last step; if all of the magnesium did not react in the final step, there could be some excess Mg mixed in with the copper.
- List two sources of error that could result in lower than expected yields of copper.
Answers will vary but may include copper may have been lost during the decanting process; the original solution may not have been exactly 1.0M CuSO_4 so the starting amount may have been less than theoretical;
- What observations did you make that indicated a chemical reaction was taking place?
Color changes, precipitates, evolution of gases
- In Cycle A, a single replacement reaction with magnesium reduced the copper in the copper sulfate solution to elemental copper. Identify two other metals that could be used to perform this reduction. For each of these metals, write a balanced chemical equation for the resulting single replacement reaction.



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Students may list almost any metal except those less reactive than copper (gold, silver). Balanced equations will vary depending on the metal chosen but should be single replacement reactions with copper sulfate and the metal as reactants, and solid copper and a soluble metal sulfate as products.

7. Using any available resources, compare the health effects and costs of the two metals identified above to the originally used magnesium. In your opinion and based on your research, which of these metals would be the “greenest” metal to use in this step of the reaction cycle? Support your answer with evidence from your research.

Answers will vary but should show evidence of analytical thinking and considerations of the toxicity of the metal being used compared to magnesium.



Types of Reactions: The Copper Cycle

Laboratory Experiment # _____

Name _____

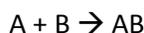
Date _____

Partner _____

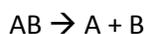
Introduction

There are two main types of process that we ordinarily see in nature: physical changes and chemical changes. Chemical changes involve one or more *chemical reactions*, and with simple inorganic compounds these may be classified into four types:

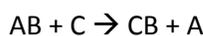
Synthesis



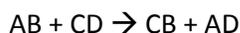
Decomposition



Single replacement



Double replacement



In this experiment, you will study some reactions of copper and its compounds, and will see all four types of reactions.

In a world with dwindling natural resources, it is important to recover and recycle valuable metals such as copper. These experiments are designed to work in a cycle, so that the end product is approximately the same as the starting material – either 1.0 M copper (II) sulfate solution (cycle A) or 0.5 M copper (II) chloride (cycle B). In this way no copper waste is generated in the experiment, and your final product can be recycled for use with the next class.

NOTE: In practice, the copper (II) carbonate is in combination with some copper (II) hydroxide, so we will refer to this as "basic copper (II) carbonate." When heated, copper (II) hydroxide also decomposes to copper (II) oxide and so this does not cause any problems with our cycle.

What is Green Chemistry?

The goal of green chemistry is to design chemicals and processes that reduce or eliminate negative environmental impacts. This includes products and processes that use or generate less hazardous substances, reduced waste products, less or non-toxic components, and using substances more efficiently. Green chemistry is a highly effective approach to pollution prevention because it applies innovative scientific solutions to real-world environmental situations.

Green chemistry provides a number of benefits, including:

- reduced waste, eliminating costly end-of-the-pipe treatments
- safer products
- reduced use of energy and resources
- improved competitiveness of chemical manufacturers and their customers.

There are twelve principles that green chemistry relies on that were first laid out by two US chemists, Paul Anastas and John Warner, in their 1998 book, "Green Chemistry: Theory and Practice":



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1. **Prevent waste:** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.
3. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
4. **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
5. **Use catalysts, not stoichiometric reagents:** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.
6. **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
7. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
8. **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.
9. **Increase energy efficiency:** Run chemical reactions at ambient temperature and pressure whenever possible.
10. **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
11. **Analyze in real time to prevent pollution:** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.
12. **Minimize the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

Why is this experiment green?

This experiment clearly is designed to prevent waste by reusing the final product as the starting material for a subsequent experimental run. By illustrating the concept of recycling, ending with the original starting material after a series of reactions, the experiment is demonstrating a method of renewing feedstocks. Although the copper-based starting materials are not renewable as a raw material, the concept of renewing feedstocks through recycling is clearly demonstrated.

Safety

- Wear approved safety goggles and suitable clothing when working with or near all chemicals.
- Copper (II) chloride and sulfate have a very slight toxicity, and they should be washed off the hands with a large amount of cold water (without soap).
- Do not touch the filter paper with your hands. Use gloves.
- Any spills can be cleaned up with water.
- Long hair must be tied back when using open flame.
- Keep all combustible materials off lab benches when using open flames.



Materials and Equipment

CYCLE A

15 mL 1.0 M Copper (II) sulfate
0.6 g Magnesium powder
30 mL 1.0 M Sulfuric acid
15 mL 5% Sodium acetate solution

CYCLE B

15 mL 0.5 M Copper (II) chloride
15 mL 0.5 M Sodium carbonate
15 mL 1.0 M Hydrochloric acid

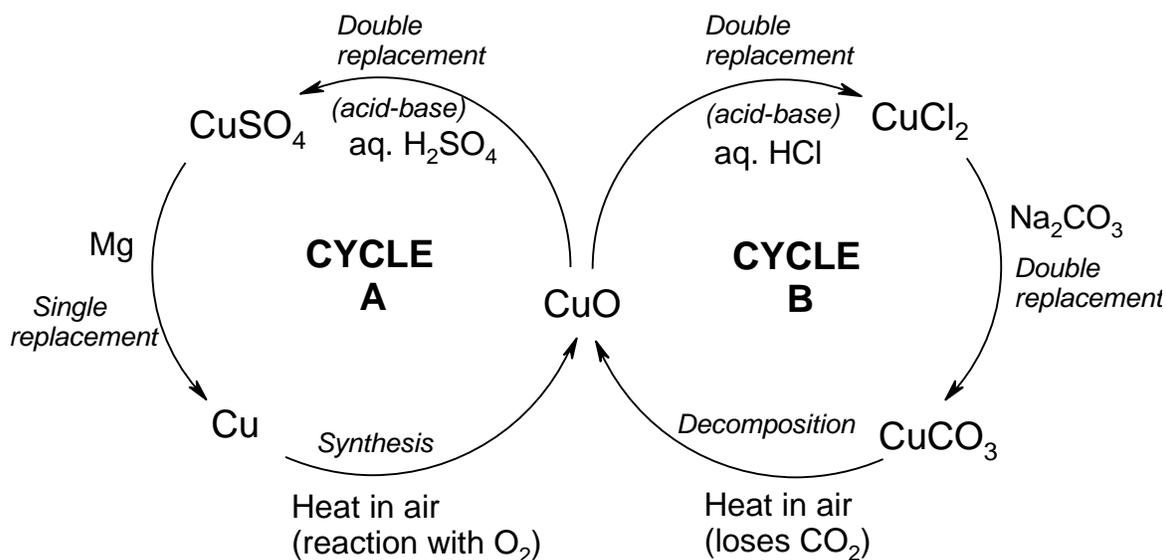
Cycle A	Cycle B
50 mL Erlenmeyer flask Glass stirring rod 10 mL graduated cylinder 150 mL beaker Crucible and crucible cover Clay triangle Ring stand with iron ring OR tripod Bunsen burner and matches Tongs Spatula 100 mL beaker Distilled water for rinsing pH paper	125 mL Erlenmeyer flask (2) Glass stirring rod 10 mL graduated cylinder Bunsen burner and matches OR hotplate Spatula 100 mL beaker Distilled water for rinsing Gloves Funnel Filter paper Watch glass



Experiment

Pre-lab:

1. Write the balanced equations for all six reactions performed in cycle A and cycle B. Indicate the waste products from the reactions (i.e., the products which are not used in the following step).



Cycle A:

- 1.
- 2.
- 3.

Cycle B:

- 1.
- 2.
- 3.

Procedure for Cycle A:

1. Add 10 mL of 1.0 M copper (II) sulfate solution (If the recycled solution is used, this will typically be slightly below 1.0 M, and it will contain some H₂SO₄) into a 50 mL Erlenmeyer flask, and add 0.4 g magnesium powder. There may be some fizzing as the magnesium reacts with any small amounts of aqueous sulfuric acid. Swirl or stir for ten minutes continuously.
2. Slowly add 10 mL 1.0 M sulfuric acid. This will cause additional fizzing, and it is necessary in order to react with any excess magnesium.
3. Decant (pour off) the aqueous solution into a 150 mL beaker. The metal that is left in the flask should be mainly copper metal. Add 2 mL water to the metal then decant this into the same beaker. Transfer the washed metal to a crucible.



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4. Set up the crucible about 6 cm above a Bunsen burner. Carefully dry the sample (over about 3 minutes) by warming with intermittent use of the Bunsen burner.
5. Once the sample is dry, heat it *strongly* in the Bunsen burner to "burn" the copper to black copper (II) oxide. In the early part of this process you may also observe some red-brown copper (I) oxide, which is the result of incomplete oxidation. You will need to continually mix the powder with a spatula to expose the surface of the unreacted metal, and to fully oxidize the copper (I) oxide. This step is complete when the sample is a uniform black color throughout (5-20 minutes, depending on the intensity of the Bunsen burner).
6. While this is heating, neutralize the decanted aqueous solution in the 150 mL beaker by adding 10 mL of 5% sodium acetate solution. Check (using pH paper) that it is between pH 4 and pH10, then wash this solution down the drain. This mixture contains a harmless combination of magnesium and sodium sulfate/acetate, and a little acetic acid (vinegar).
7. Allow the sample from Step 5 to cool for five minutes.
8. Transfer the solid using a spatula to a 100 mL beaker. Add 10 mL 1.0 M sulfuric acid. Use the liquid to wash the contents of the crucible into the beaker. Stir the mixture in the beaker periodically with a glass rod to dissolve the CuO (regenerating aqueous CuSO₄). This should take around 15 minutes.
9. Return the copper (II) sulfate solution to your teacher for recycling.

Procedure for cycle B

1. Measure out 10 mL 0.5 M solution of copper (II) chloride dihydrate in water, and add this to a 125 mL Erlenmeyer flask. Then add 10 mL of 0.5 M sodium carbonate solution (with continual swirling). Record observations, and then filter off the precipitate using gravity filtration. The liquid filtrate can be washed away down the drain.
2. Wearing gloves, use a spatula scrape the solid (basic copper (II) carbonate) off the filter paper into a 100 mL beaker. Take care to recover all of the blue solid that you can.
3. Heat the wet solid gently for five minutes over a Bunsen burner (or hot plate), in order to drive off water. Cover the beaker with a watch glass to prevent splattering.
4. Heat the dried blue solid strongly with the Bunsen burner (or hot plate) for 10 minutes, to decompose the basic copper carbonate (releasing CO₂) to copper (II) oxide. Cover the beaker with a watch glass to prevent splattering.
5. After heating, the solid should have turned to black CuO. Allow this to cool to near room temperature.
6. Once the beaker has cooled, add 10 mL 1.0 M hydrochloric acid. Use the liquid to wash the walls of the beaker. Stir the mixture in the beaker periodically with a glass rod to dissolve the CuO (regenerating aqueous CuCl₂). This should take around 15 minutes.
7. Return your copper (II) chloride solution to your teacher for recycling.

Recycling and disposal: The ending solutions are to be returned to your instructor for recycling in the next lab period.



Observations

Cycle A

Appearance during reaction of CuSO_4 with magnesium

Appearance after addition of 1.0 M sulfuric acid

Appearance of washed copper metal

Observations during heating/mixing

Observations during reaction of copper (II) oxide with 1.0 M sulfuric acid

Cycle B

Appearance after addition of sodium carbonate solution

Observations during filtration

Appearance during the heating steps

Observations after addition of 1.0 M hydrochloric acid

Conclusions:

Cycle A

Summarize the reactions in your own words.

Cycle B

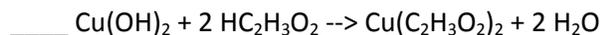
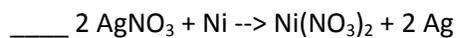
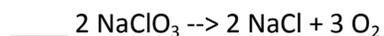
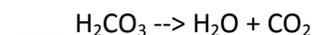
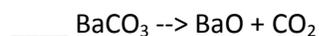
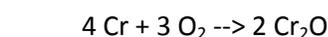
Summarize the reactions in your own words.



Questions:

1. In this lab, you observed that metals being heated in air will produce oxides. Predict what would happen if you heated a metal in an atmosphere of argon.

2. Classify each of the following reactions as Synthesis (S), Decomposition (D), Single Replacement (SR) or Double Replacement (DR).





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Complete the tables below for the Cycle you performed. Cooperate with a lab group who performed the opposite cycle to obtain the information for the other cycle. Be certain to carefully explain to the other lab group the information about your cycle.

Cycle A			
Step	Observations	Reaction Equation	Type of Reaction*
Add magnesium to copper (II) sulfate			
Heat copper metal strongly with Bunsen burner			
Add sulfuric acid			

Cycle B			
Step	Observations	Reaction Equation	Type of Reaction*
Add sodium carbonate to copper (II) chloride			
Strongly heat the solid with a Bunsen burner or hot plate			
Add hydrochloric acid			

* Use S for Synthesis, D for Decomposition, SR for Single Replacement and DR for Double Replacement.



Extension Activities

In Cycle A, a single replacement reaction with magnesium reduced the copper in the copper sulfate solution to elemental copper. Using your Chemistry Reference Tables, identify two other metals that could be used to perform this reduction.

- 1.
- 2.

For each of these metals, write a balanced chemical equation for the resulting single replacement reaction.

- 1.
- 2.

Using any available resources, compare the health effects and costs of the two metals identified above to the originally used magnesium. In your opinion and based on your research, which of these metals would be the “greenest” metal to use in this step of the reaction cycle? Support your answer with evidence from your research.



Types of Reactions: The Copper Cycle

Laboratory Experiment # _____

Name _____

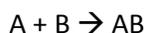
Date _____

Partner _____

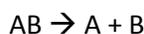
Introduction

There are two main types of process that we ordinarily see in nature: physical changes and chemical changes. Chemical changes involve one or more *chemical reactions*, and with simple inorganic compounds these may be classified into four types:

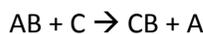
Synthesis



Decomposition



Single replacement



Double replacement



In this experiment, you will study some reactions of copper and its compounds, and will see all four types of reactions.

In a world with dwindling natural resources, it is important to recover and recycle valuable metals such as copper. These experiments are designed to work in a cycle, so that the end product is approximately the same as the starting material – either 1.0 M copper (II) sulfate solution (cycle A) or 0.5 M copper (II) chloride (cycle B). In this way no copper waste is generated in the experiment, and your final product can be recycled for use with the next class.

NOTE: In practice, the copper (II) carbonate is in combination with some copper (II) hydroxide, so we will refer to this as "basic copper (II) carbonate." When heated, copper (II) hydroxide also decomposes to copper (II) oxide and so this does not cause any problems with our cycle.

What is Green Chemistry?

The goal of green chemistry is to design chemicals and processes that reduce or eliminate negative environmental impacts. This includes products and processes that use or generate less hazardous substances, reduced waste products, less or non-toxic components, and using substances more efficiently. Green chemistry is a highly effective approach to pollution prevention because it applies innovative scientific solutions to real-world environmental situations.

Green chemistry provides a number of benefits, including:

- reduced waste, eliminating costly end-of-the-pipe treatments
- safer products
- reduced use of energy and resources
- improved competitiveness of chemical manufacturers and their customers.

There are twelve principles that green chemistry relies on that were first laid out by two US chemists, Paul Anastas and John Warner, in their 1998 book, "Green Chemistry: Theory and Practice":



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1. **Prevent waste:** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.
3. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
4. **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
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Safety

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- Copper (II) chloride and sulfate have a very slight toxicity, and they should be washed off the hands with a large amount of cold water (without soap).
- Do not touch the filter paper with your hands. Use gloves.
- Any spills can be cleaned up with water.
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- Keep all combustible materials off lab benches when using open flames.



Materials and Equipment

CYCLE A

15 mL	1.0 M Copper (II) sulfate
0.6 g	Magnesium powder
30 mL	1.0 M Sulfuric acid
15 mL	5% Sodium acetate solution

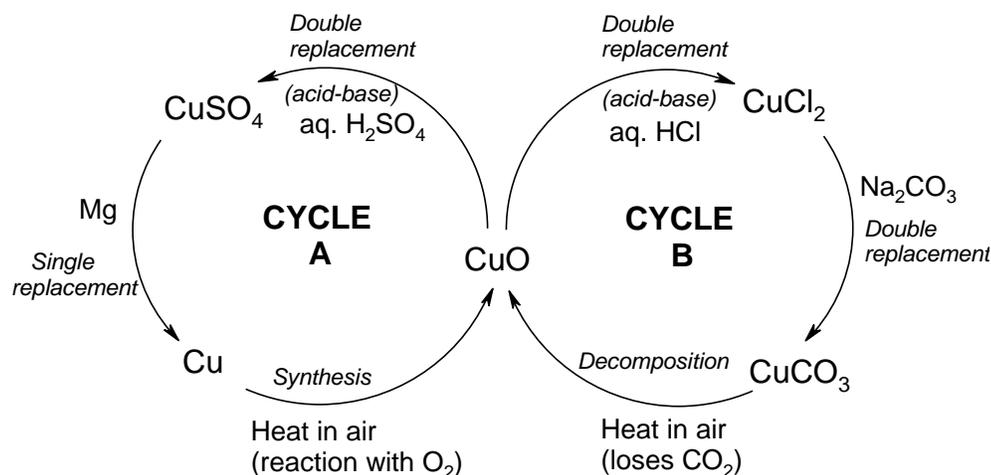
CYCLE B

15 mL	0.5 M Copper (II) chloride
15 mL	0.5 M Sodium carbonate
15 mL	1.0 M Hydrochloric acid

Cycle A	Cycle B
50 mL Erlenmeyer flask Glass stirring rod 10 mL graduated cylinder 150 mL beaker Crucible and crucible cover Clay triangle Ring stand with iron ring OR tripod Bunsen burner and matches Tongs Spatula 100 mL beaker Distilled water for rinsing pH paper	125 mL Erlenmeyer flask (2) Glass stirring rod 10 mL graduated cylinder Bunsen burner and matches OR hotplate Spatula 100 mL beaker Distilled water for rinsing Gloves Funnel Filter paper Watch glass

Pre-Lab:

- Write the balanced equations for all six reactions performed in cycle A and cycle B, and classify each reaction as synthesis, decomposition, single replacement or double replacement. Indicate the waste products from the reactions (i.e., the products which are not used in the following step).





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- Identify the acids used in the experiment. Include both names and formulas.
- Using the data shown below, calculate the percent yield of copper to 4 significant figures.

Mass of beaker and copper wire	125.16 g
Mass of beaker	120.84 g
Mass of dish and final product	35.55 g
Mass of dish	31.87 g

Procedure for Cycle A:

- Add 10 mL of 1.0 M copper (II) sulfate solution (if the recycled solution is used, this will typically be slightly below 1.0 M, and it will contain some H_2SO_4) into a 50 mL Erlenmeyer flask, and accurately determine the starting mass of the solution. Add 0.4 g magnesium powder. There may be some fizzing as the magnesium reacts with any small amounts of aqueous sulfuric acid. Swirl or stir for ten minutes continuously.
- Slowly add 10 mL 1.0 M sulfuric acid. This will cause additional fizzing, and it is necessary in order to react with any excess magnesium.
- Decant (pour off) the aqueous solution into a 150 mL beaker. The metal that is left in the flask should be mainly copper metal. Add 2 mL water to the metal then decant this into the same beaker. Transfer the washed metal to a crucible.
- Set up the crucible about 6 cm above a Bunsen burner. Carefully dry the sample (for about 3 minutes) by warming with intermittent use of the Bunsen burner.
- Once the sample is dry, heat it *strongly* in the Bunsen burner to "burn" the copper to black copper (II) oxide. In the early part of this process you may also observe some red-brown copper (I) oxide, which is the result of incomplete oxidation. You will need to continually mix the powder with a spatula to expose the surface of the unreacted metal, and to fully oxidize the copper (I) oxide. This step is complete when the sample is a uniform black color throughout (5-20 minutes, depending on the intensity of the Bunsen burner).
- While this is heating, neutralize the decanted aqueous solution in the 150 mL beaker by adding 10 mL of 5% sodium acetate solution. Check (using pH paper) that it is between pH 4 and pH10, then wash this solution down the drain. This mixture contains a harmless combination of magnesium and sodium sulfate/acetate, and a little acetic acid (vinegar).
- Allow the sample from Step 5 to cool for five minutes.

Cross over into Cycle B

- Once the crucible has cooled, add 10 mL 1.0 M hydrochloric acid. Use the liquid to wash the walls of the beaker. Stir the mixture in the beaker periodically with a glass rod to dissolve the CuO . This should take about 15 minutes.
- Transfer the contents to a 125 mL Erlenmeyer flask. Then add 10 mL of 0.5 M sodium carbonate solution (with continual swirling). Allow 8-10 minutes with occasional swirling for the reaction to complete, Record observations, and then filter off the precipitate using gravity filtration. The liquid filtrate can be washed away down the drain.
- Wearing gloves, use a spatula scrape the solid (basic copper (II) carbonate) off the filter paper into a 100 mL beaker. Be sure to recover as much of the blue solid that you can.
- Heat the wet solid gently for five minutes over a Bunsen burner (or hot plate), in order to drive off water. Cover the beaker with a watch glass to prevent splattering.



12. Heat the dried blue solid strongly with the Bunsen burner (or hot plate) for 10 minutes, to decompose the basic copper carbonate (releasing CO_2) to copper (II) oxide. Cover the beaker with a watch glass to prevent splattering. After heating, the solid should have turned to black CuO . Allow this to cool to near room temperature.

Cross back over to Cycle A

13. Transfer the solid using a spatula to a 100 mL beaker. Add 10 mL 1.0 M sulfuric acid. Use the liquid to wash the contents of the crucible into the beaker. Stir the mixture in the beaker periodically with a glass rod to dissolve the CuO (regenerating aqueous CuSO_4). This should take around 15 minutes.
14. Add 0.4 g magnesium powder. There may be some fizzing as the magnesium reacts with any small amounts of aqueous sulfuric acid. Swirl or stir for ten minutes continuously.
15. Slowly add 10 mL 1.0 M sulfuric acid. This will cause additional fizzing, and it is necessary in order to react with any excess magnesium.
16. Decant (pour off) the aqueous solution into a 150 mL beaker. The metal that is left in the flask should be mainly copper metal. Add 2 mL water to the metal then decant this into the same beaker. Transfer the washed metal to a crucible.
17. Set up the crucible about 6 cm above a Bunsen burner. Carefully dry the sample (for about 3 minutes) by warming with intermittent use of the Bunsen burner. Be careful not to heat too strongly. Accurately determine the mass of the copper metal.

Recycling and disposal: The copper recovered should be returned to the instructor at the end of the lab.

Report:

The lab report should consist of an introduction, answers to pre-lab questions, brief description of procedures, data table including all relevant data, calculations, and a conclusion. Include answers to the following questions:

1. Calculate the amount of copper in the original solution, assuming that the solution concentration is 1.0M.
2. Calculate the percent yield of the copper based on the theoretical mass in the original sample and the final mass of the recovered copper.
3. List two sources of error that could have resulted in higher than expected yields of copper.
4. List two sources of error that could result in lower than expected yields of copper.
5. What observations did you make that indicated a chemical reaction was taking place?
6. In Cycle A, a single replacement reaction with magnesium reduced the copper in the copper sulfate solution to elemental copper. Identify two other metals that could be used to perform this reduction. For each of these metals, write a balanced chemical equation for the resulting single replacement reaction.
7. Using any available resources, compare the health effects and costs of the two metals identified above to the originally used magnesium. In your opinion and based on your research, which of these metals would be the “greenest” metal to use in this step of the reaction cycle? Support your answer with evidence from your research.