

Identifying Solutions using Copper and Iron

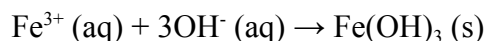
Standard CHEM 3.3 - **Plan and carry out an investigation** to observe the change in properties of substances in a chemical reaction to relate the macroscopically observed properties to the molecular level changes in bonds and the symbolic notation used in chemistry.

Background Information

Every substance has its own unique chemical properties and when these properties change then a new substance has formed and a chemical reaction has taken place. One unique chemical property transition metals have, for example, is their very specific electron configuration. Transition metals have partially filled d-orbitals, and when in their elemental form, they have two valence electrons. However, they are commonly found as ions that have zero valence electrons. This allows them to participate in a unique type of bonding with molecules or ions that have lone pairs (ligands). These ligands can donate both electrons from the lone pair to form a *coordinate covalent bond* with the transition metal ion. The new molecule formed is called a coordination compound, and if it has a charge, it's known as a complex ion.

A complex ion has a metal ion at the center and ligand ions or molecules arranged around the metal, each contributing a lone pair of electrons to a coordinate covalent bond with the metal. For example, CuCl_4^{2-} is a tetrahedral complex ion; copper is at the center and four chloride ions act as ligands. Because the ligand molecules or ions interact with the electrons on the transition metal, coordination compounds and complex ions tend to be brightly colored. Thus, when complex ions are formed you can observe the chemical change because of a change in the solution's color.

You can also see chemical changes due to the formation of precipitates. A precipitate is a solid that forms during a chemical reaction. Precipitates can simply look like the solution is cloudy, or they can be more like a gel, or they can be a powder that sinks to the bottom of the test tube. For example, the formation of $\text{Fe}(\text{OH})_3$, could be represented by the chemical equation:



This precipitate is an orange-red powder that is produced when iron(III) ions form bonds with hydroxide ions.

Transition metals and the ligands that bind to them play a very important role in biology and chemistry. For example, hemoglobin is a protein in your body that transports oxygen. When the oxygen ligand is not bound, the iron complex appears more purple. But when oxygen forms a coordinate covalent bond to the iron, the complex changes color and appears bright red. This chemical reaction is the reason that blood in your veins (where there is little oxygen) appears more purple, while blood in your arteries (where there is a lot of oxygen) appears more red.

Objective

We were working with two transition metal solutions in the lab, Iron (III) Nitrate and Copper (II) Nitrate, but we forgot to label the other four solutions (HCl, NaOH, KSCN, NH₃) when we made them and we don't know which ones are which. Your objective is to identify the four solutions based on their chemical reactions and properties. You will need to design an experiment with a series of steps to follow, any materials necessary, and a description of the tests and observations needed to identify the four unknown solutions. You must also explain how your procedures and observations can be used to identify the solutions using experimental evidence.

Designing an Effective Procedure

Without a concise set of procedures time will be wasted in an experiment. Study the four aqueous solutions, and the transition metals given to you, then create a series of tests to distinguish them. Will a complex ion form before or after a precipitate? The amounts or concentrations might also affect your results; maybe add a little and then a lot, or think about the ratios in the chemical formulas. Keep these ideas in mind when designing your procedure. Use a data table, like the one below, to help you organize your observations and inferences. Focus on making quality observations and being precise (colors, precipitates, amounts).

	Fe ³⁺	Cu ²⁺	Identity
Solution A			
Solution B			
Solution C			
Solution D			

Materials

Required Materials:

Solutions A-D

- 1 M HCl
- 1 M NaOH
- 1 M NH₃
- 1 M KSCN

Known Solutions

- 0.1 M Fe(NO₃)₃
- 0.1 M Cu(NO₃)₂

Available Lab Materials

- Test Tubes
- Pipettes
- Beakers
- Test Tube Rack
- Sharpies
- White tape
- Gloves
- Goggles

Formulas & Colors of Common Complex Ions (solutions)			
CuCl_4^{2-}	FeCl_4^-	FeSCN^{2+}	$\text{Cu}(\text{NH}_3)_4^{2+}$
Light blue	Yellow	Dark Red	Dark Blue

Formulas & Colors of Common Precipitates		
$\text{Cu}(\text{OH})_2$	$\text{Fe}(\text{OH})_3$	$\text{Cu}(\text{SCN})_2$
Gelatinous Blue Solid	Orange Red Precipitate	Black Precipitate

Pre-Lab

1. Describe the types of evidence that will help you identify the four solutions. Use this information to design your procedure.
 - a. What evidence will tell you which solution is KSCN?
 - b. What evidence will tell you which solution is HCl?
 - c. What evidence will tell you which solution is NH₃?
 - d. What evidence will tell you which solution is NaOH?

2. Write a detailed experimental procedure. This should include enough information that a high school student could read it and carry out the experiment correctly. For example, be sure to include what lab equipment and amounts of chemicals you will be using. You will only have 2 mL each of the iron(III) nitrate and copper(II) nitrate solutions.

Report

- Write the chemical reactions for the formation of:
 - $\text{Cu}(\text{OH})_2(\text{s})$

 - $\text{Fe}(\text{SCN})^{2+}(\text{aq})$

- When you added ammonia to the copper and iron solutions, you might have seen something unexpected--the formation of blue $\text{Cu}(\text{OH})_2(\text{s})$ and red $\text{Fe}(\text{OH})_3(\text{s})$. How is it possible that these substances formed when you added NH_3 ?

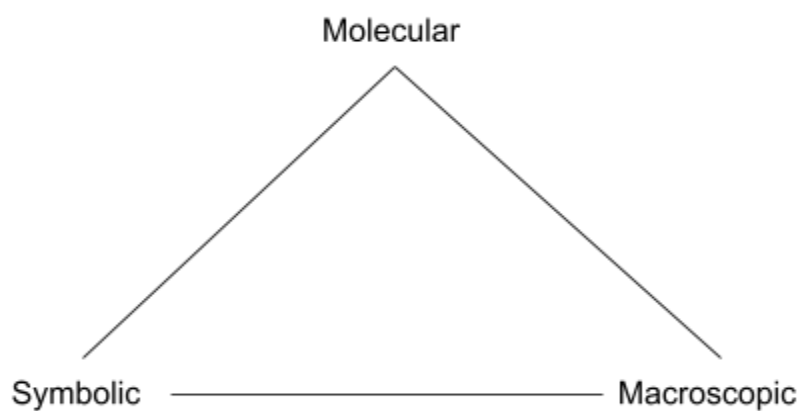
- You have 1 M Cu^{2+} and 1 M NH_3 (hint: look at the chemical formulas given)
 - If you start with the solid, $\text{Cu}(\text{OH})_2$ how much NH_3 would you need to add to dissolve the solid and change the copper to a complex ion? Explain why you chose that ratio.

 - If you had 1 M Ni^{2+} instead of Cu^{2+} , and you were trying to change it to the complex ion $\text{Ni}(\text{NH}_3)_6^{2+}$, what ratio of nickel to ammonia would you need to use? Explain why you chose that ratio.

- Draw the molecular structures for:
 - $\text{Cu}(\text{OH})_2$ (an ionic compound)

 - CuCl_4^{2-}

5. Chemists use different types of representations to describe chemicals and chemical reactions. These include molecular diagrams like ball and stick models, symbolic notation like chemical formulas, and macroscopic information like observations from experiments. Using the triangle below, write or draw the symbolic, molecular, and macroscopic representations for the tetrachloroiron(III) ion.



Teacher Notes/Information

Standard CHEM.3.3 **Plan and carry out an investigation** to observe the change in properties of substances in a chemical reaction to relate the macroscopically observed properties to the molecular level changes in bonds and the symbolic notation used in chemistry. *Emphasize that the visible macroscopic changes in chemical reactions are a result of changes on the molecular level. Examples of observable properties could include changes in color or the production of a solid or gaseous product.*

This lab's disciplinary core ideas are symbolic, molecular, and macroscopic levels of chemistry. The SEP is **plan and carry out an investigation**, and the CCC is change and stability. Make or buy all of the solutions beforehand; these are all very common solutions so you can purchase them easily. Have 1 mL pipettes, test tubes, and test tube racks available for all students. If supplies or solutions are limited you can give students more specific procedures or limit them to 1 mL of Cu and 1 mL of Fe to divide between all of their trials. Limiting the amount of Cu and Fe they can use will cause them to look more carefully at the ratios they are adding which will help them in the report

Lab Safety:

- Make sure students are wearing gloves, goggles, lab aprons, closed toed shoes, long pants. You can find other safety information (SDS sheets) for all the chemicals on Flinn Scientific.

Buying the solutions:

- Available through Flinn Scientific you can purchase the following solutions for this lab (item #)
- 1 M HCl, 1L (H0057)
- 1 M NaOH, 500 mL (S0148)
- 1 M NH₄OH, 1L (A0097)
- 1 M KSCN, 500 mL (P0226)
- 0.2 M Fe(NO₃)₃, 500 mL (F0046)
- 1 M Nitric Acid Solution, 500 mL (N0050)
- (Prepare the 0.1 M Fe(NO₃)₃ by combining the 0.2 M Fe(NO₃)₃ with the 1 M nitric acid in a 1:1 ratio. This will also turn the solution colorless.)
- 0.1 M Cu(NO₃)₂ (C0245), this will work in place of 0.25 M

Or to prepare the solutions yourself:

- M = mol/V
1. 1 M HCl
 - a. Find the concentration of the HCl, and then calculate the mass of HCl solution needed. Dilute it to 1M by adding the appropriate mass of HCl to a volumetric flask with about 600 mL of distilled water (always add acid to water), then add more water until the final volume is 1L. (if you have 36% HCl use 86 mls/L)

2. 1 M NaOH
 - a. Measure out 58.44 g of NaOH pellets in a flask and then cap it. Then measure out 900mL of distilled water in a large beaker and add a large stir bar to it. NaOH is very reactive in water so place the beaker of water in an ice bath and on top of a stir plate. Turn on the stir plate and slowly add a few of the NaOH pellets to the water, once they are dissolved you can add more. Keep adding pellets until they are dissolved then fill the rest of the beaker with distilled water until the final volume is 1L. (this process might take 30 minutes)
3. 1 M NH₃
 - a. Find the concentration of the NH₃ or NH₄OH, and then calculate the mass of solution needed. Dilute it to 1M by adding the appropriate mass of solution to a volumetric flask with about 600 mL of distilled water, then add more water until the final volume is 1L. (if you have 28% concentrated NH₃ you will use 69 mls/L)
4. 1 M KSCN
 - a. Measure out 97.18 g of KSCN, place it in a large beaker or volumetric flask and add distilled water until the final volume is 1L. Place a large stir bar in the beaker and place on a stir plate, stir the mixture until dissolved.
5. 0.1 M Fe(NO₃)₃
 - a. Measure out 40.4 g of Fe(NO₃)₃•9H₂O. Add this to a volumetric flask or large beaker and dissolve in about 30 mL of distilled water. Then add concentrated nitric acid to the flask until the solution turns clear. Add more distilled water to the beaker until the final volume is 1L.
6. 0.1 M Cu(NO₃)₂
 - a. Measure out 23.26 g of Cu(NO₃)₂ and place in a large beaker or volumetric flask. Add distilled water to the beaker until the final volume is 1L. Place a large stir bar in the beaker and place on a stir plate, stir the mixture until dissolved.

Answer Key:

Solution A: 1 M HCl

Solution B: 1 M NH₃

Solution C: 1 M KSCN

Solution D: 1 M NaOH

	Fe ³⁺	Cu ²⁺	Identity
Solution A	Bright yellow complex ion	No change Light blue color	HCl
Solution B	Orange/brown precipitate	Add less = cloudy blue precipitate Add more = Deep blue/purple	NH ₃

		complex ion	
Solution C	Blood red complex ion	Green solution with a black precipitate (If you don't use the molarity in the directions, this complex ion will still form but the precipitate won't)	KSCN
Solution D	Orange/brown precipitate	Add less = light blue gelatinous solid (always forms) Add more = light blue complex ion (blue solid should dissolve eventually, might need to swish solution around. Sometimes this complex ion is tricky and doesn't form, or it takes a few hours for it to dissolve into a light blue complex ion)	NaOH

In the image below copper test tubes are on the left and iron test tubes are on the right.. The solutions from front to back were: NH_3 , HCl , KSCN , and NaOH .



Pre-Lab

1. Describe the types of evidence that will help you identify the four solutions. Use this information to design your procedure.

- a. What evidence will tell you which solution is KSCN?

We will see a blood red complex ion form when KSCN is added to Fe. We will see a black precipitate form when KSCN is added to Cu.

- b. What evidence will tell you which solution is HCl?

We will see a yellow complex ion when HCl is added to Fe, and no change will happen when it is added to Cu. The Cu will remain a pale blue color

- c. What evidence will tell you which solution is NH₃?

We will see a dark blue complex ion when a lot of NH₃ is added to Cu. When a small amount of NH₃ is added to Cu we will see a pale, cloudy blue gelatinous solid formed. When NH₃ is added to Fe an orange/brown precipitate will form.

- d. What evidence will tell you which solution is NaOH?

We will see a bright blue gelatinous solid formed when NaOH is added to Cu, if you add more NaOH this gelatinous solid will dissolve. We will see an orange/brown precipitate formed when NaOH is added to Fe.

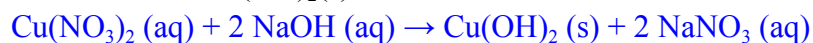
2. Write a detailed experimental procedure. This should include enough information that a high school student could read it and carry out the experiment correctly. For example, be sure to include what lab equipment and amounts of chemicals you will be using. You will only have 2 mL each of the iron(III) nitrate and copper(II) nitrate solutions.

Procedures will vary but should include: adding specific amounts of Fe and Cu to test tubes and then pipetting specific amounts of the solutions into them. Observations, amounts of solutions, and the speed at which the solutions were added should be recorded in the data table. Students can use the data table provided on the lab or can create their own

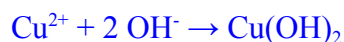
Report

1. Write the chemical reactions for the formation of:

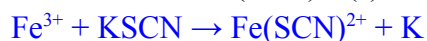
- a. Cu(OH)₂(s)



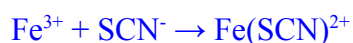
or



- b. Fe(SCN)²⁺ (s)



Or



2. When you added ammonia to the copper and iron solutions, you might have seen something unexpected--the formation of blue $\text{Cu}(\text{OH})_2$ (s) and red $\text{Fe}(\text{OH})_3$ (s). How is it possible that these substances formed when you added NH_3 ?

Ammonia is a base so when added to these solutions it makes hydroxide, therefore we are able to create $\text{Cu}(\text{OH})_2$ and $\text{Fe}(\text{OH})_3$ even though we used NH_3 and not OH .

3. You have 1 M Cu^{2+} and 1 M NH_3 (hint: look at the chemical formulas given)

- a. If you start with the solid, $\text{Cu}(\text{OH})_2$ how much NH_3 would you need to add to dissolve the solid and change the copper to a complex ion? Explain why you chose that ratio.

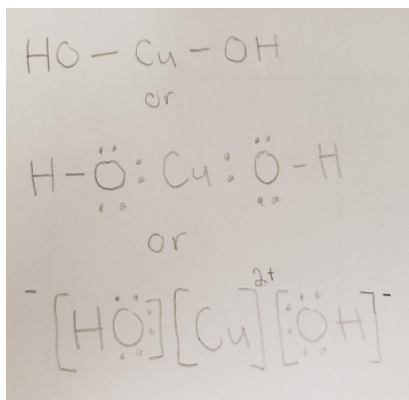
4 NH_3 :1 Cu, because you are trying to make $\text{Cu}(\text{NH}_3)_4^{2+}$ so you need 4 parts of NH_3 to create the complex ion

- c. If you had 1 M Ni^{2+} instead of Cu^{2+} , and you were trying to change it to the complex ion $\text{Ni}(\text{NH}_3)_6^{2+}$, what ratio of nickel to ammonia would you need to use? Explain why you chose that ratio.

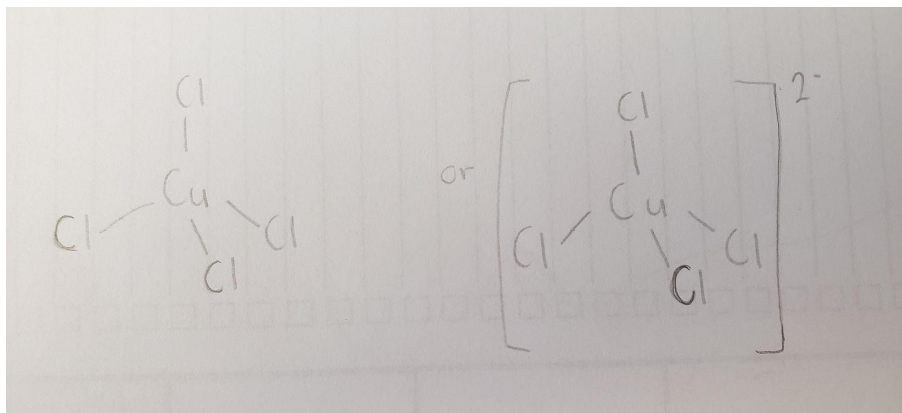
6 NH_3 :1 Ni, based on the chemical formula you need 6 parts NH_3 to one part Ni to create this molecule

4. Draw the molecular structures for:

- a. $\text{Cu}(\text{OH})_2$ (an ionic compound)



- b. CuCl_4^{2-}



5. Chemists use different types of representation to describe chemicals. These include molecular diagrams like ball and stick models, symbolic notation like chemical formulas, and macroscopic information like observations from experiments. Using the triangle below, write the symbolic and draw the molecular and macroscopic representations for the tetrachloroiron (III) ion.

