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#14 Experimenting with Copper(II) Solutions

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INTRODUCTION

Description



This experiment helps students determine that the relative concentration of copper ions in water can be determined by a color comparison. Students make a copper(II) sulfate solution of a given concentration. Students dilute their initial solutions until their solutions are colorless. Students work in groups of 3–4, comparing solutions to discover any relationship between color and concentration.

A portion of each solution will be mixed with concentrated ammonia solution, forming a dark blue copper-ammonia complex. Students decide if the complex can be used to find the useful concentration of copper ions in a swimming pool water sample.

Student Audience

This experiment is suitable for high school and college general chemistry students.

Goals

Skills that will be developed or practiced:

- use of pipette,
- calculating concentrations,
- making dilutions, and
- compiling data from peers.

Knowledge introduced or reinforced:

- Copper(II) solutions are blue.
- Copper-ammonia complex solutions are a deeper and more intensely colored blue.
- The color of a specific solution is directly proportional to its concentration.
- A colored substance can be so diluted that its color is not detectable.

Recommended Placement in the Curriculum

The experiment can be done any time after students have calculated molar concentrations and dilutions. It will be useful to encourage thinking on the atomic level.

Student Handout

Experimenting with Copper(II) Solutions

Purpose

In this experiment you will investigate the color of various solutions. The color relationship to concentration and to chemical substance needs to be determined. To do this you will make a solution of a certain concentration and then dilute this solution using a pipette.

Scenario

You are a pool owner, and you know that copper(II) salts, usually CuSO_4 , can be used to retard or prevent algae growth in swimming pools. Algae actually require Cu^{2+} to sustain their life processes, but too high a concentration is toxic. A concentration of one part per million or 4.0×10^{-6} M is needed for Cu^{2+} to act as an algacide. Copper(II) in water is blue.

Your task is to devise a method to determine the concentration of Cu^{2+} in a solution. Using this method, what is the lowest concentration that can be determined?

Materials

$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$
100-mL volumetric flasks
1-mL pipettes, pipette bulbs
8–10 clean, small test tubes
15 M $\text{NH}_3(\text{aq})$

Safety and Disposal

Do not use your mouth to pipette. Review the MSDS for any chemical used in the experiment for information regarding safety and handling. Use the fume hood when dispensing the NH_3 in Part C of the procedure.

Dispose of all solutions in the waste container provided by your instructor. Copper sulfate solutions may be able to be washed down the drain with water. Solutions containing ammonia will be collected and neutralized with acid before being disposed of in the same way as other copper solutions.

Procedure

A. Pipetting

Practice using the pipette with water until you can accurately take up and transfer exactly 1 mL. Your instructor may check your skill sometime during the lab.

B. Copper(II) Sulfate Solutions

Weigh out a specified amount of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$. (Your instructor will specify the amount.) Record the exact weight. Transfer the $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ to a 100-mL volumetric flask. Fill the flask half full with distilled water, swirling to dissolve the solid. Add more distilled water to bring the volume of solution up to the mark on the neck of the flask. Stopper the flask and invert it several times to mix the contents well. Record the molarity of this solution in moles per liter.

Label a small test tube, fill it close to the top with your solution, and place it in a test tube rack. (It might be helpful to put a white paper background under the test tube rack for better viewing.) When the others in your group have their test tubes ready, try to line them up in order by color.

Observe the colors by looking down through the liquid from the top of each tube. Compare the order with the amounts of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ used. Describe any relationship.

If there are not enough 100-mL volumetric flasks, pour your solution into another clean, dry container. Rinse the volumetric flask well so that it can be used to make a diluted solution. (The volumetric flask does not need to be dried.) Using a pipette, transfer 1.00 mL of your first solution into a 100-mL volumetric flask. Add water up to the mark on the flask and mix well.

Make four dilutions by pipetting 50, 25, 10, and 1 mL. Be sure to label each solution. Fill a small, labeled test tube with each of your dilute solutions. Note the relationship of color and concentration. Observe the whole set of solutions from your group of students.

Find out if it is possible to tell the difference between any two solutions picked from the whole set. How different must the concentrations be in order to see a color difference? Do all individuals in your group agree? Is it easier to tell the difference between two dilute or two more concentrated solutions?

C. Copper/Ammonia Complex Ions

Copper(II) ions form an intense blue complex with ammonia, $[\text{Cu}(\text{NH}_3)_4]^{2+}$. Perhaps this would be a more sensitive test for the presence of copper(II) ions.

Put about 1 mL of each of your solutions in a labeled, small test tube and add about 1 mL of 15 M $\text{NH}_3(\text{aq})$. USE THE FUME HOOD.

Compare all of the ammonia complexes made by your group of students. Comment on any relationship between concentration and color. Which solution, copper(II) sulfate or copper-ammonia complex, is easier to use to distinguish between concentrations?

Use the pipette to transfer 1 mL of your most dilute copper-ammonia complex solution to a 100-mL volumetric flask and dilute to 100 mL with water. Use continued dilution, as before, to find a solution that has no detectable color. What concentration is this solution?

Points to Ponder

Include answers to these questions on your report sheet.

1. Suggestion is a powerful thing. It might be that you see the color of Cu^{2+} ions because you think it should be there. How would you prevent this? Decide on a procedure as a small group and test your procedure with another group in the class.
2. What was the minimum concentration of Cu^{2+} in moles per liter and ppm that could be detected by its blue color? What was the minimum concentration of the copper complex that could be detected? As a pool owner, would color be a useful test for you?
3. Sketch, using some type of symbols, a portion of a 5 M aqueous solution of CuSO_4 . Draw enough to show the ratio of all ions and molecules present. Which of the CuSO_4 solutions that you made could reasonably be sketched in this way?

Think about things that could be used as models for the particles of your solutions, M & M's, for example. Make a model of one of your solutions by next week and be prepared to explain it to the class.

Would your model system work for any of the CuSO_4 solutions? If not, why not?

Suggested Reading

Read about copper(II) sulfate in a chemical dictionary or encyclopedia.

Possible resources are:

The Merck Index; Merck & Co, Inc.: Rahway, NJ, any edition.

Kirk-Othmer Encyclopedia of Chemical Technology; Wiley: New York, Vol 7, 3rd Ed., 1979.

Instructor Notes

Experimenting with Copper(II) Solutions

Time Required

A verbal introduction to the experiment takes 15 minutes. Students with no experience in pipetting need to practice first with water. The laboratory work requires 90 minutes to 2 hours when students work in groups of three or four. It may require more time if students need to first practice with a pipette.

Group Size

The size of the class is limited only by the amount of volumetric glassware available. Students should work in groups of 3 or 4.

Materials Needed

- $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (anhydrous CuSO_4 could also be used)
- 15 M $\text{NH}_3(\text{aq})$
- water, deionized
- acid (for neutralization)
- balances
- 100-mL volumetric flasks or 100-mL graduated cylinders
- 1-mL pipettes, pipette bulbs (preferably TD pipette, not graduated, and pipette bulbs)
- 8–10 clean, small test tubes
- test tube racks
- labels or wax pencils
- (optional) white paper to put under the test tube rack

Safety, Handling, and Disposal

CuSO_4 solution in high concentrations is toxic to humans and other animals.

Concentrated ammonia should be dispensed from a hood; it is most conveniently done from a dropper bottle. Copper-ammonia complex solutions can be observed on the bench top, but should be covered when not being observed. Dispose of used reagents according to local ordinances. Copper sulfate solutions may be able to be washed down the drain with water. Solutions containing ammonia should be collected and neutralized with acid before being disposed of in the same way as other copper solutions.

CuSO_4 may also be recycled. CuSO_4 is easily recrystallized if the solutions are collected and the solution is evaporated and recrystallized.

Pre-Lab Discussion

- Give instruction in pipetting and explain how to use volumetric flasks if students have not had previous experience.
- You may want to discuss why solutions of substances such as CuSO_4 are colored.
- Arrange students in groups of three or four. Assign an initial mass to each student.
- Emphasize that the concentrated ammonia solution needs to be kept in a hood. The copper-ammonia complex solutions can be observed on the bench tops, and should be covered when not in use.

Procedural Tips and Suggestions

Assign a variety of masses within each small group for students to weigh out and from which to calculate their concentrations. The more concentrated the solution, the more dilutions will be needed. Less concentrated solutions require small amounts of solute, and if students are not careful, errors will result in making up the initial solution. Between 3.0×10^{-2} M (requires 0.749 g of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ for 100 mL) and 6.0×10^{-3} M (0.150 g) are practical concentrations for starting solutions.

Check students' calculations before they make up their first solutions.

If large numbers of volumetric flasks are not available, students can reuse one flask. They can pour their solution into a clean beaker, clean the flask, and use it for the dilution. The experiment could also be done without precision volumetric glassware, measuring with graduated cylinders and transferring to an Erlenmeyer flask. Concentrations would be known to fewer significant figures, but the color/concentration relationship will still be observable.

A different dilution can be done. Using more than one milliliter will mean more dilutions will be needed to get to colorless solutions.

If students need guidance in preparing a report, an example report form (See Appendix) gives a format without disclosing expected results.

Sample Results

Students can make a number of errors in preparing their first solution. They may make errors in calculating amount of solute to use or may not transfer the solid completely. They may make errors in diluting, especially in using a pipette. Therefore, a range of values will be reported for the colorless solutions. Colorless copper solutions will probably be about 10^{-3} M. Colorless copper-ammonia complex solutions will probably be about 10^{-5} M.

Answers to Student Questions

Most students thought concentration differences were easier to see with the copper-ammonia complex.

A good procedure for insuring that a solution is really colored is to have a test tube of water (a control) and to make observations without knowing which test tube contains water and which contains the solution. This requires at least two people, an observer and someone to arrange the tubes for observation. Using a white background under the test tube rack may also help when making these observations.

A concentration of 4×10^{-6} M is not detectable even with the copper-ammonia complex. So the swimming pool owner will have to find another way to check the copper ion concentration in his pool.

A sketch of 5 M copper sulfate will have about 11 water molecules for each copper and sulfate ion. A 5×10^{-3} M solution would require 1,000 times as many water molecules, not a practical sketch to make.

Extensions and Variations

The analysis could be done using a spectrophotometer to determine the amount of color present. Students could be asked if human observation or the instrument is more sensitive. (An example procedure for doing this extension is provided at the end of this lab.)

A copper solution of unknown concentration could be introduced. Students would be asked to find its concentration by comparison with their solutions.

Students could be asked to find the limit of color detection. Once a solution is judged to be colorless, the previous colored solution would be used. Different amounts of dilution would be done to find at what concentration the color is not detectable.

References

Irgolic, Kurt; Peck, Larry; O'Connor, Rod, *Fundamentals of Chemistry in the Laboratory*; Harper & Row: New York, 1997, Investigation 12.

Kirk-Othmer Encyclopedia of Chemical Technology; Wiley: New York, Vol 7, 3rd Ed., 1979.

The Merck Index; Merck & Co, Inc.: Rahway, NJ, any edition.

Appendix

Model Report Form

Name _____

Report on Experimenting with Copper(II) Solutions

A. Pipetting

Technique observed by instructor:

B. Copper(II) Sulfate Solutions

Initial CuSO_4 concentration to make:

Calculations:

Mass of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ actually used:

Actual concentration of CuSO_4 solution:

Color observation:

Dilutions
Concentrations

Color observations

Group Analysis

Solutions ranked in color order

Solution concentrations

C. Copper/Ammonia Complex Ions

Concentrations

Color observations

Dilutions
Concentrations

Color observations

Group Analysis

How different must concentrations of two solutions be to see a color difference?

Is it easier to tell the difference between two dilute or two concentrated solutions?

Is it easier to tell the difference in concentrations between copper(II) sulfate solutions or between copper-ammonia complex solution?

Points to Ponder

Include answers to the questions here.

Extension Activity

Determination of the Absorption Spectrum of Cu^{2+} : An Introduction to the Spectrophotometer

Scenario

This scenario is based on a true story. A Japanese company which manufactures parts for automobiles built a very modern, attractive manufacturing plant which included large reflecting pools which the workers and visitors could observe from meeting rooms, break rooms, etc. The problem that developed was the growth of algae in the pools. The management learned that copper (II) sulfate could be added to the water to kill the algae and they also learned how much to add per gallon. Because the pools were irregular in shape, they could not determine the volume of the pools easily. Your challenge: If they added 25 pounds of copper (II) sulfate pentahydrate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, to one of the pools, devise a procedure for determining the volume of the pool by using a sample of water from the treated pool.

Procedure

Prepare 100 mL each of 0.10, 0.05, and 0.025 M solutions of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$.

Part I

1. If the instrument is not on, turn it on and allow it to warm up for a half hour.
2. Using the wavelength control knob, set the instrument to the desired wavelength. For this experiment, start with a wavelength of 375 nm.
3. With nothing in the sample compartment, set the %T reading to zero using the zero control knob. (Some instruments will do this automatically and will not have a zero control knob.)
4. Fill a clean cuvette or cell half full with distilled water and wipe the outside clean with a Kimwipe. Make sure there are no air bubbles inside. This is called the blank.
5. Insert the cuvette with the water into the sample cell, making sure it goes all the way to the bottom and that the alignment mark on the cuvette is in line with the one on the sample compartment. Close the sample compartment lid.
6. Adjust the readout to 100%T with the 100%T knob.
7. Remove the cuvette containing the blank and insert another cuvette containing a 0.10 M copper sulfate solution. Read and record the percent T.
8. Continue this procedure, steps 3–7, increasing the wavelength at intervals of 25 nm until 700 nm is reached.

9. Calculate the absorbance for each measurement using the formula:

$$A = -\log(\%T / 100)$$

10. Make a graph of absorbance on the y-axis and wavelength on the x-axis.

Part II

Prepare a calibration curve by reading percent transmittance on the 0.025, 0.05, and 0.10 M solutions of copper (II) sulfate using a water blank. After calculation the absorbance for each solution:

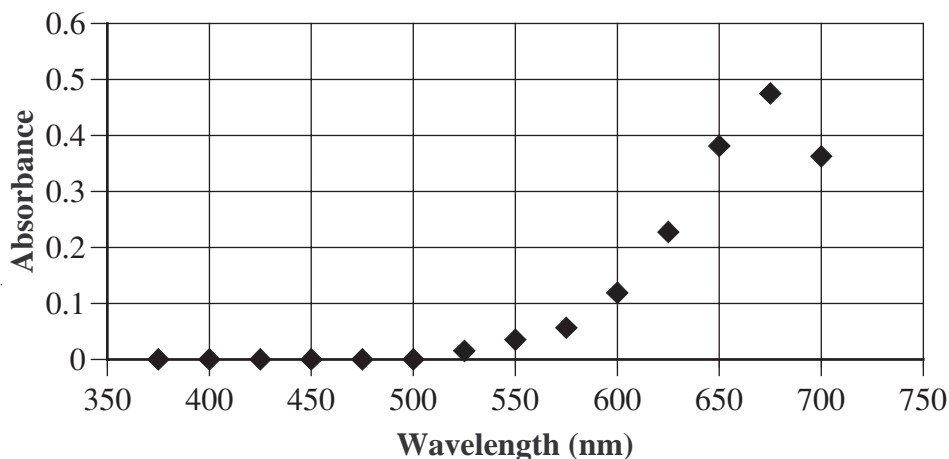
$$A = -\log(\%T / 100)$$

a calibration curve is plotted of concentration on the x-axis and absorbance on the y-axis.

Instructor Notes

The volume of the pool can be calculated by determining the concentration of the copper sulfate solution spectrophotometrically and the information given in the scenario. The students are told to prepare 0.10, 0.05, and 0.025 M solutions $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and using the 0.10 M solution, prepare an absorption spectrum for the blue copper sulfate solution. After plotting the resulting absorption curve, a wavelength is chosen for analysis. A wavelength of 675 nm works well. The students then prepare a calibration curve by reading percent transmittance on the 0.025, 0.05, and 0.10 M solutions of copper (II) sulfate using a water blank. After calculating the absorbance for each solution [using $A = -\log(\%T/100)$], a calibration curve is plotted of concentration on the x-axis and absorbance on the y-axis.

Absorbance as a Function of Wavelength



The students are then given a 0.075 M solution of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and told that the solution was taken from the pool to which 25 pounds of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ were added. By measuring the absorbance of the pool water sample, its concentration in moles per liter can be determined from the calibration curve. An example calculation follows:

From the calibration curve: $\text{Abs.} = 5.11 \times -0.03$

The unknown gave a %T of 41.0% which gives $A = 0.387$. Substituting this value for Abs. in the above equation gives a value of X of 0.082 M for the unknown solution.

25 lb. of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ would be 11.33 kg.

$11,330 \text{ g} \times 1 \text{ mole}/249.68 \text{ g} = 45.38 \text{ moles of } \text{CuSO}_4 \cdot 5\text{H}_2\text{O}$

Since molarity = moles/L, then $0.082 = 45.38 \text{ moles}/X \text{ liters}$.

$X = 553 \text{ liters}$