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Catalog No. AP6363
Publication No. 6363

Mole Ratios

Copper and Silver Nitrate

Introduction

The reaction of copper wire with silver nitrate in aqueous solution shows chemistry in action—delicate silver crystals grow on the wire surface and the color of copper(II) ions gradually appears in solution. What relationships govern the relative quantities of reactants and products in this chemical reaction?

Concepts

- Mole ratio
- Stoichiometry
- Balanced chemical equation
- Single replacement reaction

Background

Stoichiometry is the branch of chemistry that deals with the numerical relationships and mathematical proportions of reactants and products in a chemical reaction. One of the most important lessons of stoichiometry is that the amounts of the reactants and products in a chemical reaction are related to one another on a mole basis. Chemical reactions are normally represented by balanced chemical equations. The coefficients in a balanced chemical equation summarize the relative number of moles of each reactant and product involved in the reaction. The ratios of these coefficients represent the mole ratios that govern the disappearance of reactants and appearance of products. Knowing the *mole ratios* in a balanced chemical equation is essential to solving stoichiometry problems.

The reaction of copper metal with silver nitrate solution is a single replacement reaction, represented by the following unbalanced chemical equation.

$$\boldsymbol{a}\,\mathrm{Cu(s)} + \boldsymbol{b}\,\mathrm{AgNO_3(aq)} \rightarrow \boldsymbol{c}\,\mathrm{Cu(NO_3)_2(aq)} + \boldsymbol{d}\,\mathrm{Ag(s)}$$

The values of the coefficients *a, b, c,* and *d* can be determined experimentally by measuring the mass of copper wire that reacts and the mass of metallic silver that is produced in the above reaction.

Experiment Overview

The purpose of this experiment is to determine the number of moles of reactants and products in the reaction of copper and silver nitrate and calculate their mole ratio. The mole ratio relating the disappearance of copper and the formation of silver metal will be used to write the balanced chemical equation for the reaction.

Pre-Lab Questions

Copper(II) chloride ($CuCl_2$; 0.98 g) was dissolved in water and a piece of aluminum wire (Al; 0.56 g) was placed in the solution. The blue color due to copper(II) chloride soon faded and a red precipitate of solid copper was observed. After the blue color had disappeared completely, the leftover aluminum wire was removed from the solution and weighed. The mass of the leftover aluminum wire was 0.43 g.

1. Calculate the number of moles of copper(II) chloride and of aluminum that reacted.
2. What is the mole ratio of copper(II) chloride to aluminum metal? Express this to the nearest whole number ratio.
3. What happened to the aluminum metal that was consumed in this reaction? Write the formula of the most probable aluminum-containing product.
4. Write a balanced chemical equation for the single replacement reaction of copper(II) chloride with aluminum.

Materials

Acetone, CH_3COCH_3, 125-mL, in a 250-mL beaker*

Copper wire, Cu, 25 cm

Nitric acid, HNO_3, 3 M, 3 drops

Silver nitrate, $AgNO_3$, 1.5 g

Balance, centigram (0.01-g precision)

Labeling or marking pen

Beakers, 50- and 100-mL

Erlenmeyer flask, 125-mL

Spatula

Stirring rod

Wash bottle and distilled or deionized water

Wooden splint

*This is an acetone rinse beaker and it should be shared with other groups of students. Your instructor will determine safe locations for these beakers.

Safety Precautions

Nitric acid is a corrosive liquid and a strong oxidizer. Silver nitrate is a corrosive solid and is toxic by ingestion; it will stain skin and clothes. Acetone is a flammable liquid; avoid contact with flames and other sources of ignition. Avoid contact of all chemicals with eyes, skin, and clothing. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Obtain a clean and dry 50-mL beaker. Zero (tare) the balance with the beaker on the balance pan and then carefully add 1.4–1.6 g of silver nitrate to the beaker. *Caution:* Use a spatula to transfer the solid—do not touch the silver nitrate. Carefully clean up any silver nitrate spills in the balance area or on the bench top.
2. Measure and record the exact mass of silver nitrate in the data table.
3. Fill the beaker to the 30-mL mark with distilled water and stir the solution with a stirring rod until all of the solid has dissolved. Rinse the stirring rod with distilled water.
4. Cut a 25-cm piece of copper wire and loosely coil it into the shape shown in Figure 1.
5. Find the initial mass of the copper wire to the nearest 0.01 g and record it in the data table.

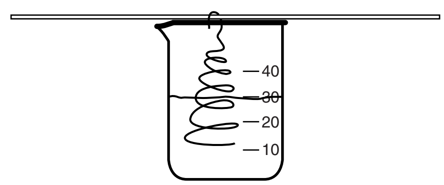

Figure 1.

6. Use a wooden splint to suspend the copper wire in the silver nitrate solution, as shown in Figure 1. The copper wire should not be touching the bottom or sides of the beaker.
7. Carefully add 3 drops of 3 M nitric acid to the beaker. Do NOT stir the solution.
8. Allow the beaker to sit undisturbed on the lab bench for 15 minutes. Try not to jostle or shake the suspended copper wire during this time.
9. Observe any signs of a chemical reaction occurring in the beaker and record all observations in the data table.
10. While the reaction is taking place, label a 100-mL beaker with your name and class/period number. Measure and record the mass of this beaker in the data table.
11. After 15 minutes, gently lift the wooden splint to remove the copper wire from the solution.
12. Holding the wire with the wooden splint, place the copper wire above the clean, 100-mL beaker. Rinse the wire with a steady stream of distilled water from the wash bottle. The silver crystals should easily fall off the wire into the beaker. Gently shake the wire and rinse with water until no more silver adheres to the wire. *Note:* Use a total of about 40 mL of distilled water.
13. When all of the silver has been removed, lift the copper wire out of the beaker and place it in the acetone rinse beaker. The acetone will clean the wire surface and allow it to dry more quickly.
14. Remove the copper wire from the acetone rinse beaker and allow it to air dry for 2–3 minutes.

15. Measure and record the final mass of the copper wire. Note the appearance of the leftover wire and record your observations in the data table.
16. Examine the beaker containing the silver product. Most of the silver should settle into a dense mass at the bottom of the beaker. Carefully decant the liquid into a waste flask (125-mL Erlenmeyer) to remove most of the water. *Note:* Try not to lose any of the solid in the process.
17. Rinse the solid with 5–10 mL of distilled water from a wash bottle. Decant the rinse water into the waste flask as well.
18. Repeat the rinsing/decanting cycle with a second portion of distilled water.
19. Dispose of the waste solution as directed by your instructor.
20. When all of the liquid has been decanted, place the labeled beaker containing the silver product in a secure location, as directed by your instructor.
21. Allow the solid to dry overnight.
22. When the solid is dry, measure and record the final mass of the beaker plus silver solid.

Name: ______________________________

Mole Ratios

Data Table

Mass of silver nitrate	
Mass of copper wire (initial)	
Observations—Reaction of copper and silver nitrate	
Mass of empty 100-mL beaker (step 10)	
Mass of leftover copper wire	
Appearance of leftover copper wire	
Mass of beaker plus silver product (step 22)	

Post-Lab Calculations and Analysis *(Show all work on a separate sheet of paper.)*

1. Calculate the mass and moles of copper wire that reacted in this experiment.
2. Calculate the mass and moles of silver metal produced in the reaction.
3. Determine the mole ratio—the ratio of the number of moles of silver to the number of moles of copper. *Note:* Round the result to the nearest whole number.
4. Use the silver/copper mole ratio to write the balanced chemical equation for the reaction of copper and silver nitrate.
5. Did all of the silver nitrate react in this experiment? Show all calculations and explain your reasoning.
6. What factors might account for the answer to Question #5?
7. Silver is a precious metal. The price of silver fluctuates daily as it is traded on the open market. Look up the current market value of silver in the financial section of the daily newspaper or on the Internet and record the price. *Note:* The price of metals is usually quoted per Troy ounce, where 1 Troy ounce = 31.0 grams.
8. Calculate the current market value of the silver produced in this experiment.

Teacher's Notes
Mole Ratios

Materials Included in Kit

Acetone, 250 mL*

Copper wire, Cu, 18-gauge, 15 ft (457 cm)

Nitric acid, HNO_3, 3 M, 10 mL†

Silver nitrate, $AgNO_3$, 25 g

Wooden splints, 15

*Several student groups should share acetone rinse beakers. Place two rinse beakers containing about 125 mL of acetone in the hood or in a central location for ease of use.

†The nitric acid is in a dropper bottle for safety and ease of use.

Additional Materials Needed (per lab group)

Balance, centigram (0.01-g precision), 3

Beaker, 50-mL, 15

Beaker, 100-mL, 15

Beaker, 250-mL, 2

Erlenmeyer flask, 125-mL, 15

Labeling or marking pen, 3

Spatula, 15

Stirring rod, 15

Wash bottle, 15

Water, distilled or deionized

Wire cutters

Safety Precautions

Nitric acid is a corrosive liquid and a strong oxidizer. Silver nitrate is a corrosive solid and is toxic by ingestion; it will stain skin and clothes. Acetone is a flammable liquid; avoid contact with flames and other sources of ignition. Avoid contact of all chemicals with eyes, skin, and clothing. Wear chemical splash goggles and chemical-resistant gloves and apron. Remind students to wash hands thoroughly with soap and water before leaving the laboratory. Please consult current Material Safety Data Sheets for additional safety, handling, and disposal information.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The solution remaining after the silver-clad copper wire has been removed contains excess silver nitrate and should be disposed of by precipitating silver chloride, according to Flinn Suggested Disposal Method #11. The aqueous rinse solution may be flushed down the drain with excess water according to Flinn Suggested Disposal Method #26b. Acetone may be allowed to evaporate in the hood according to Flinn Suggested Disposal Method #18a. Leftover silver metal and copper wire may be disposed of in the solid waste according to Flinn Suggested Disposal Method #26a. Many teachers allow their students to keep their silver in a small vial as a souvenir. It is also possible to recycle the silver: collect the silver, place it in a hollow formed in a block of charcoal, and fuse it into a little silver nugget using a mini torch.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement

Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions

Lab Hints

- The experiment as written can easily be completed within one 50-minute lab period. A few minutes of time will be needed on the following class day to measure the mass of silver metal produced in the reaction.
- The procedure for this experiment has been written to make the most efficient use of lab time. Under the reaction conditions described in the procedure, the mole ratio of copper and silver can be determined and is in good agreement with theory. The mole ratio for copper and silver nitrate cannot be determined, however, because the reaction does not proceed to completion. In order to achieve complete conversion of silver nitrate to silver metal, the reaction mixture should be allowed to sit overnight. An alternative procedure describing this modification, which allows students to calculate both the copper/silver and the copper/silver nitrate mole ratios, is presented in the *Supplementary Information* section (pages 8 and 9). Representative sample data are also provided.
- To save time, cut the wire in 25-cm lengths before class.
- Almost any single replacement reaction can be adapted for use in a similar experiment. Excellent results are obtained for the reaction of iron with copper(II) sulfate, as well as for the reaction of aluminum with copper(II) chloride. Call, write, or e-mail Flinn Scientific to obtain a complimentary copy of our ChemFax demonstration, Publication No. 416.00, for the reaction of iron with copper(II) sulfate. The reaction of aluminum wire with copper(II) chloride has been adapted into a student laboratory kit, "Leftover Aluminum Wire," which is also available from Flinn Scientific (Catalog No. AP4678).
- Silver nitrate solutions are notorious for leaving black stains on hands and arms. These stains are not removable except through normal skin regeneration. Wear gloves whenever handling silver nitrate.
- If the copper wire is touching the bottom or sides of the beaker, the silver crystals may adhere to the beaker instead of the copper wire. Nitric acid is added as a promoter in this reaction to initiate reaction at the metal surface. The waste solution contains excess silver nitrate—see the Disposal section for disposal recommendations.
- Any gauge copper wire will work for this lab. The sample data shown on page 7 was obtained using 18 gauge wire.

Tips

- Transform chemistry into art by viewing the progress of this reaction under a microscope. Cut a small sliver of copper foil or copper wire and place it on a microscope slide. Add a few drops of 0.1 M silver nitrate, and watch as delicate crystals of silver grow in tree-like fashion on the piece of copper. Beautiful needles and branches will continue to grow before your eyes for 10–15 minutes.
- This experiment can also be extended to discuss other concepts in stoichiometry, such as the idea of limiting reactants and percent yield. Is it possible for all of the copper wire to react in the experiment as written? Which reagent is the limiting reactant? Calculate the theoretical yield and percent yield of silver metal produced in the reaction.
- Stoichiometry—what a strange word! The word is derived from the Greek words stoicheion, meaning element, and metrike, meaning measure. The term was first introduced in 1792 by J. B. Richter, a German scientist, to describe the relative amounts of acids and bases that neutralize each other.

Answers to Pre-Lab Questions *(Student answers will vary.)*

Copper(II) chloride ($CuCl_2$; 0.98 g) was dissolved in water and a piece of aluminum wire (Al; 0.56 g) was placed in the solution. The blue color due to copper(II) chloride soon faded and a red precipitate of solid copper was observed. After the blue color had disappeared completely, the leftover aluminum wire was removed from the solution and weighed. The mass of the leftover aluminum wire was 0.43 g.

1. Calculate the number of moles of copper(II) chloride and of aluminum that reacted.

$$\textit{Moles of } CuCl_2 = \frac{0.98\ g}{134.45\ g/mole} = 0.0073\ moles$$

$$\textit{Moles of Al} = \frac{0.56\ g - 0.43\ g}{26.98\ g/mole} = 0.0048\ moles$$

2. What is the mole ratio of copper(II) chloride to aluminum metal? Express this to the nearest whole number ratio.

   $$\text{Mole ratio } (CuCl_2{:}Al) = \frac{0.0073 \text{ mole } CuCl_2}{0.0048 \text{ moles } Al} = 1.5{:}1$$

   The nearest whole number ratio of $CuCl_2$ to Al is 3:2.

3. What happened to the aluminum metal that was consumed in this reaction? Write the formula of the most probable aluminum-containing product.

   The aluminum metal dissolved and was converted to aluminum (Al^{3+}) ions upon reaction with Cu^{2+} ions. The most probable aluminum-containing product is $AlCl_3$.

4. Write a balanced chemical equation for the single replacement reaction of copper(II) chloride with aluminum.

   $3CuCl_2(aq) + 2Al(s) \rightarrow 3Cu(s) + 2AlCl_3(aq)$

Sample Data Table (*Student data will vary.*)

Mass of silver nitrate	*1.50 g*
Mass of copper wire (initial)	*1.84 g*
Observations—Reaction of copper and silver nitrate	*Within 1 min, a silvery gray coating appeared on the wire. After 5 min, the wire was covered with a thick layer of silver crystals. The crystals adhered to the wire and did not fall off. The solution turned light blue within 5–10 minutes. The final solution was clear and light blue.*
Mass of empty 100-mL beaker (step 10)	*41.80 g*
Mass of leftover copper wire	*1.63 g*
Appearance of leftover copper wire	*The leftover copper wire appears dull, slightly pitted and has a rough surface.*
Mass of beaker plus silver product (step 22)	*42.48 g*

Answers to Post-Lab Calculations and Analysis (*Student answers will vary.*)

1. Calculate the mass and moles of copper wire that reacted in this experiment.

   Mass (Cu) = 1.84 g – 1.63 g = 0.21 g
   Moles (Cu) = 0.21 g × (1 mole/63.55 g) = 0.0033 moles

2. Calculate the mass and moles of silver metal produced in the reaction.

   Mass (Ag) = 42.48 g – 41.80 g = 0.68 g
   Moles (Ag) = 0.68 g × (1 mole/107.87 g) = 0.0063 moles

3. Determine the mole ratio—the ratio of the number of moles of silver to the number of moles of copper. *Note:* Round the result to the nearest whole number.

   Mole ratio (Ag:Cu) = 1.9:1
   The ratio may be rounded to give a whole-number mole ratio of 2:1 for the amount of silver produced per mole of copper consumed. This represents a 5% error.

4. Use the silver/copper mole ratio to write the balanced chemical equation for the reaction of copper and silver nitrate.

   $Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$

5. Did all of the silver nitrate react in this experiment? Show all calculations and explain your reasoning.

   The original number of moles of $AgNO_3$ in the aqueous solution was
   1.50 g/(169.87 g/mole) = 0.0088 moles.
   The number of moles of silver produced was only 0.0063 moles (see Question #2).
   It appears that only about 72% of the silver nitrate reacted.

6. What factors might account for the answer to Question #5?

   The reaction did not proceed to completion. Several factors may be responsible for the reduced yield of silver.
   - *The reaction time was too short.*
   - *There was a loss of silver product during the transferring step.*
   - *The copper wire became coated with a thick layer of silver, which prevented contact between the copper wire and the silver nitrate solution.*

7. Silver is a precious metal. The price of silver fluctuates daily as it is traded on the open market. Look up the current market value of silver in the financial section of the daily newspaper or on the Internet and record the price. *Note:* The price of metals is usually quoted per Troy ounce, where 1 Troy ounce = 31.0 grams.

   The current market price of silver in 2003 was about $4.90 per Troy ounce.

8. Calculate the current market value of the silver produced in this experiment.

   The amount of silver produced in this experiment was 0.59 g.

   $$\textit{The market value of this silver} = \frac{\$4.90}{\text{Troy oz.}} \times \frac{1 \text{ Troy oz.}}{31.0 \text{ g}} \times 0.59 \text{ g} = \$0.09$$

   Nine cents!

   Note to teachers: *Precious metal prices may be found at the following Website, www.kitco.com.*

Supplementary Information

The following alternative procedure allows for complete conversion of silver nitrate to silver metal and thus makes it possible to calculate both silver/copper as well as silver nitrate/copper mole ratios. This procedure requires about 1 hour of actual lab time, divided over three days. Representative sample data and results are provided.

Sample Data

Mass of silver nitrate	1.52 g
Mass of copper wire (initial)	3.77 g
Observations—Reaction of copper and silver nitrate	Within 1 minute, a silvery gray coating appeared on the wire. After 5 min, the wire was covered with a thick layer of silver crystals. The crystals adhered to the wire and did not fall off. The solution turned light blue within 5–10 minutes. The final solution was clear and blue.
Mass of filter paper	1.31 g
Mass of leftover copper wire	3.47 g
Appearance of leftover copper wire	The leftover copper wire appears dull and slightly pitted and has a rough surface.
Mass of filter paper plus silver product	2.31 g

Sample Results

The results of all calculations have been rounded to the appropriate number of significant figures.

Mass and moles of Cu reacted	Mass (Cu) = 0.30 g Moles (Cu) = 0.0047 moles
Moles of $AgNO_3$ reacted (assuming 100% conversion)	Moles ($AgNO_3$) = 0.00895 moles
Mass and moles of Ag produced	Mass (Ag) = 1.00 g Moles (Ag) = 0.00927 moles
$AgNO_3$/Cu Mole ratio	0.00895 moles/0.0047 moles = 1.9:1
Ag/$AgNO_3$ Mole ratio	0.00927 moles/0.00895 moles = 1.04:1
Ag/Cu Mole ratio	0.00927 moles/0.0047 moles = 2.0:1

Procedure

1. Label a clean and dry 100-mL beaker with your name and class/period number.
2. Zero (tare) the balance with the beaker and carefully add about 1.5 g of silver nitrate crystals to the beaker. C*aution:* Use a spatula to transfer the solid. Do not touch the silver nitrate and carefully clean up any silver nitrate spills. Measure and record the exact mass of silver nitrate in the data table.
3. Fill the beaker to the 80-mL mark with distilled water and stir the solution with a stirring rod until all of the solid has dissolved. Rinse the stirring rod with distilled water.
4. Cut a 50-cm piece of copper wire and coil the wire into the shape shown in Figure 1.
5. Find the initial mass of the copper wire to the nearest 0.01 g and record it in the data table.
6. Use a wooden splint to suspend the copper wire in the silver nitrate solution, as shown in Figure 1. The copper wire should not be touching the bottom or sides of the beaker.
7. Carefully add 3 drops of 6 M nitric acid to the beaker. Do NOT stir the solution.
8. Observe the reaction mixture for the next five minutes and record all observations in the data table.
9. Store the beaker overnight in a safe and secure location, as directed by your instructor.
10. The following day, lift the wire out of solution using the wooden splint. Gently shake the wire to allow the crystals to fall back into the reaction mixture. Use a stream of distilled water from a wash bottle to remove any crystals that stick to the wire.
11. When all of the silver has been removed, lift the copper wire out of the beaker and dip it in the acetone rinse beaker to clean the wire surface and allow it to dry.
12. Measure and record the final mass of the leftover copper wire when it is dry. Note the appearance of the leftover wire and record your observations in the data table.
13. Measure and record the mass of a sheet of filter paper. Place the filter paper in a funnel set up over an Erlenmeyer flask.
14. Wet the filter paper with distilled water from a wash bottle, then pour the contents of the original reaction beaker through the filter paper to collect the solid.
15. Rinse the beaker with several portions of distilled water to make sure that all of the solid has been transferred to the funnel.
16. Label a large watch glass with your name and class/period number.
17. When the filtration is complete, remove the filter paper from the funnel, open it up, and place it on the labeled watch glass in a secure location, as directed by your instructor.
18. Allow the solid to dry for 24–48 hours, as needed. When the solid is dry, measure and record the final mass of filter paper plus and solid.

Reference

This activity is from *Flinn ChemTopic™ Labs,* Volume 7, *Molar Relationships and Stoichiometry;* Cesa, I., Ed., Flinn Scientific: Batavia, IL, 2002.

Mole Rations—Copper and Silver Nitrate is available from Flinn Scientific, Inc.

Catalog No.	Description
AP6363	Mole Ratios—Copper and Silver Nitrate

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