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Silver Ornaments

Holiday Laboratory Kit

Introduction

Create a beautiful silver ornament to demonstrate a practical application of an oxidation–reduction chemical reaction. Simply combine four solutions in a glass ornament ball, swirl, and voilá—a thin, lustrous silver coating plates out on the inside of the ornament. The process "reflects" the way silver mirrors are actually produced!

Concepts

- Oxidation–reduction
- Tollens' test
- Reducing sugars
- Metric measurements

Background

Mirrors, also called "looking glasses," have been known since ancient times. The earliest mirror artifacts, dating back more than three thousand years, have been found in China and the Middle East. These mirrors were made by hammering and polishing thin sheets of metal such as bronze, copper or tin until the metal surface was smooth and flat. Glassmaking was developed in ancient Rome, and glass mirrors first appeared in about the 1st century A.D. In the 1600s, craftsmen in Italy perfected a method of lining glass with a thin sheet of reflecting metal. The mirrors made this way were beautiful, but also very expensive—the pinnacle of this art of mirror-making is represented by the "Hall of Mirrors" at the Palace of Versailles (France). In 1835, the German chemist Justus von Liebig invented a silvering process to plate a sheet of glass with a thin layer of silver metal by reducing silver ions with dextrose. This cheaper chemical method of lining glass with a "silver mirror" ushered in the modern era of producing mirrors for common household uses.

The silver mirror reaction invented by Liebig will be used in this lab to make a silver holiday ornament. The overall reaction is a classic *oxidation–reduction reaction* between silver complex ions and dextrose in ammonia solution. Dextrose or glucose ("blood sugar") is a simple carbohydrate. It is an example of a *reducing sugar,* so-named because it is capable of reacting with and reducing mild oxidizing agents such as Ag^+ or Cu^{2+} ions. In this experiment, dextrose molecules reduce $Ag(NH_3)_2^+$ complex ions to form silver metal, which plates out as a thin coating on the inside of the glass ornament (Equation 1). The aldehyde [R–C(H)=O] functional group in dextrose (see Figure 1) is oxidized to a carboxylate functional group ($R–CO_2^-$) in the process.

$$\underset{\text{Aldehyde}}{R–CHO(aq)} + 2Ag(NH_3)_2^+(aq) + 2OH^-(aq) \rightarrow R–COO^-(aq) + 2Ag(s) + NH_4^+(aq) + 3NH_3(aq) + H_2O(l) \qquad \textit{Equation 1}$$

Structure of dextrose:

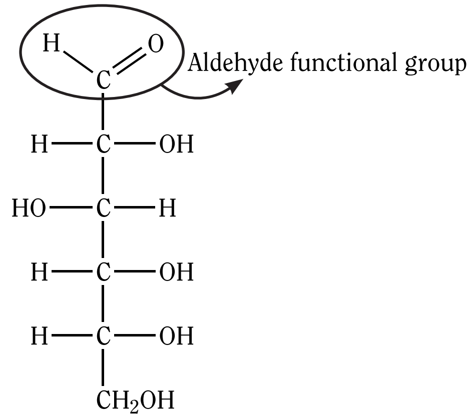

Figure 1. Structure of Dextrose.

The reduction of silver–ammonia complex ions is a general reaction that is characteristic of organic compounds containing the aldehyde functional group. *Tollens' test,* which is based on this reaction, is a simple qualitative test used in organic chemistry to detect aldehydes. A "positive test result" is easy to identify—a silver mirror forms on the inside of a test tube or flask if an aldehyde is present.

Experiment Overview

The purpose of this experiment is to prepare a "silver mirror" holiday ornament by mixing silver–ammonia complex ions with dextrose inside a glass ornament ball. The silver complex ions needed for the reaction will be generated by mixing dilute silver nitrate, ammonium nitrate, and sodium hydroxide solutions. By measuring the mass of silver in the ornament, you can calculate the thickness of the silver mirror and also estimate the number of atoms in the silver layer.

Pre-Lab Questions

1. The diameter of the glass ornament balls used in this experiment is 2-5/8 inches. Convert the diameter of the ball to centimeters and calculate the radius of the glass ball.
2. Use the following equation to calculate the approximate surface area (SA) of the ornament ball, $SA = 4\pi r^2$.
3. Assuming that the glass thickness of the ornament is 1.6 mm, estimate the percent difference in the surface area calculation for the inside versus the outside of the ornament sphere.
4. Oxidation–reduction reactions involve the loss and gain of electrons, respectively. Based on the mole ratios in Equation 1 for the reduction of Ag^+ cations to Ag metal, how many electrons are gained by the aldehyde when it is oxidized to the carboxylate function group? *Hint:* Electrons must be balanced and "cancel out" in an oxidation–reduction reaction.

Materials

Acetone, 5 mL

Ammonium nitrate solution, NH_4NO_3, 1.5 M, 2.5 mL

Dextrose solution, $C_6H_{12}O_6$, 5% solution, 5 mL

Silver nitrate solution, $AgNO_3$, 0.5 M, 2.5 mL

Sodium hydroxide solution, NaOH, 10%, 5 mL

Balance, centigram (0.01-g precision)

Beaker, 50-mL

Glass ornament, 2⅝″

Graduated cylinder, 10-mL

Marking pen

Metric ruler

Parafilm®, 2 cm square

Pipet, Beral-type

Stirring rod

String

Wash bottle and distilled water

Waste beaker

Safety Precautions

Sodium hydroxide solution is a corrosive liquid and is especially dangerous to the eyes. Ammonium nitrate solution is toxic by ingestion. Silver nitrate solution will stain skin and clothing. The mixed solution in the flask may form a potentially explosive material if left standing and allowed to dry. Do NOT mix the solutions beforehand—add them together in the glass ornament ball and follow the instructor's directions for disposing of the leftover solution immediately after use. Rinse with copious amounts of water. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the lab.

Procedure

1. Obtain a plain glass ornament. Wrap a piece of string around the circumference (widest part) of the ornament and mark the length of string.
2. Using a metric ruler, measure the marked off length of string to the nearest 0.1 cm and record the length in the data table.

3. Gently grasp the "ornament holder" and carefully remove it from the top of the ornament ball. Set the ornament holder aside. *Caution:* The glass ornament is fragile—do not exert pressure.
4. Measure and record the mass of the glass ornament ball.
5. Using a Beral-type pipet, add about 2 mL of acetone to the ornament ball and swirl the liquid inside the ornament.
6. Pour the acetone into a waste beaker and allow the ornament ball to dry completely in air.
7. Measure 2.5 mL of silver nitrate solution using a graduated cylinder and pour the solution into a clean, dry 50-mL beaker.
8. Rinse the graduated cylinder with distilled water and pour out all of the rinse water.
9. Measure 2.5 mL of ammonium nitrate solution using the graduated cylinder and pour the solution into the beaker containing silver nitrate. Mix the combined solution using a stirring rod.
10. Rinse the graduated cylinder with distilled water and pour out all of the rinse water. Measure 5 mL of dextrose solution using the graduated cylinder and pour the dextrose into the completely air-dried ornament ball.
11. Rinse the graduated cylinder with distilled water and pour out all of the rinse water. Measure 5 mL of sodium hydroxide solution into the graduated cylinder.
12. Add the combined silver nitrate/ammonium nitrate solution from the beaker to the ornament ball, followed *immediately* by the sodium hydroxide solution.
13. Gently cover the opening of the ornament with a piece of Parafilm and swirl the solution. Keep rotating the ornament to be sure the solution covers the entire inside surface of the ball. An evenly distributed, shiny silver coating will appear throughout the ornament.
14. Carefully remove the Parafilm and pour the remaining solution into a labeled waste container. *Rinse the ornament thoroughly with distilled water.*
15. Using a Beral-type pipet, add about 2 mL of acetone to the inside of the ornament and swirl gently to cover the interior surface. Pour the acetone into a waste beaker and allow the ornament ball to dry completely in air.
16. Measure the mass of the air-dried silver ornament.
17. Carefully replace the ornament holder back on top of the silver holiday ornament.

Name: ________________________________

Silver Ornament Holiday Lab

Data Table

Circumference of glass ornament (cm)	
Mass of ornament ball	
Mass of silver ornament	

Post-Lab Questions

1. Using the measured circumference of the glass ornament, calculate the radius (in cm) and the surface area (cm^2) of the ornament. (The formula for the circumference of a sphere is $2\pi r$.)

2. Calculate (a) the mass and (b) the number of moles of silver lining the inside of the glass ornament.

3. The density of silver is 10.5 g/cm^3. What is the volume of silver metal lining the inside of the glass ornament?

4. Assume that the volume of silver in the ornament can be approximated by the following equation: Volume = Surface area × thickness. Calculate the approximate thickness of the silver lining in centimeters.

5. Convert the thickness of the silver layer to micrometers ($1\ \mu m = 1 \times 10^{-6}$ m) and nanometers ($1\ nm = 1 \times 10^{-9}$ m).

6. The radius (r) of a silver atom is 160 picometers ($1\ pm = 1 \times 10^{-12}$ m). Estimate the thickness of the silver lining in terms of the number (N_{Ag}) of silver atoms. Assume that the thickness is equal to $N_{Ag} \times 2r$. *Hint:* Convert the radius of a silver atom from picometers to centimeters first!

7. Balance the following chemical equation for the formation of Tollens' reagent in this experiment.

$$AgNO_3 + NH_4NO_3 + NaOH \rightarrow \underset{\text{Tollens' Reagent}}{Ag(NH_3)_2OH} + NaNO_3 + H_2O$$

Teacher's Notes

Silver Ornaments

Materials Included in Kit *(for a class of 24 students)*

Acetone, 150 mL

Ammonium nitrate solution, NH_4NO_3, 1.5 M, 75 mL

Dextrose solution, $C_6H_{12}O_6$, 5% solution, 150 mL

Silver nitrate solution, $AgNO_3$, 0.5 M, 75 mL

Sodium hydroxide solution, NaOH, 10%, 150 mL

Glass ornaments, 2⅝″, 24

Parafilm, 4″ × 12″ piece

Pipets, Beral-type, 24

Additional Materials Needed (per lab group)

Balance, centigram (0.01-g precision)*

Beaker, 50-mL

Graduated cylinders, 10-mL, 3

Marking pen

Metric ruler

Stirring rod

String

Wash bottle and distilled water

Waste beaker*†

*May be shared by all groups.

†See the *Disposal* section.

Safety Precautions

Sodium hydroxide solution is a corrosive liquid and is especially dangerous to the eyes. Ammonium nitrate solution is toxic by ingestion. Silver nitrate solution will stain skin and clothing. The mixed solution in the flask may form a potentially explosive material if left standing and allowed to dry. Always mix the solutions fresh and dispose of them immediately after use with large amounts of water. Instruct students to rinse any remaining liquid from the flask into a waste disposal beaker and to rinse the ornaments well with water. Wear chemical splash goggles and chemical-resistant gloves and apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information. Remind students to wash their hands thoroughly with soap and water before leaving the lab.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The mixture remaining in the flask after the silver mirror reaction is complete should be rinsed with excess water into a waste disposal beaker or flask set up in a central location. Test the combined waste solution for the presence of leftover silver ions by adding 1 M hydrochloric acid. If a cloudy, white precipitate of silver chloride is observed, continue adding hydrochloric acid in small amounts until no further precipitation is evident. Filter the mixture—the silver chloride may be packaged for landfill disposal according to Flinn Suggested Disposal Method #26a. The filtrate may be disposed of down the drain with plenty of excess water according to Flinn Suggested Disposal Method #26b.

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
- Content Standard F: Science in Personal and Social Perspectives
- Content Standard G: History and Nature of Science; science as a human endeavor

Lab Hints

- For best results, schedule at least two 50-minute lab periods for this experiment. That will allow enough time for the rinsed ornament to dry completely in air both before and after it has been "silvered."
- Any glassware that will be silvered must be scrupulously clean for the silver mirror to adhere to the glass surface. Check the ornaments for dust or debris and rinse as needed.
- Other types of glassware that are commonly used in silver mirror labs of this type include small test tubes or culture tubes, Florence flasks, etc. If the desired glassware is not clean or new, rinse the glassware first with distilled water, followed by 6 M nitric acid. Pour out the nitric acid cleaning solution, rinse well with distilled water, and then rinse a final time with acetone. Allow to air dry thoroughly before adding the reagents for the Tollens' test reaction.
- The silver mirror holiday ornaments may be protected from oxidation or mechanical stress by coating the inside of the ornament with clear nail polish or shellac.
- The "silver mirror reaction" may be downsized to the microscale level by mixing drops of reagents in the relative amounts and order indicated in the *Procedure* section. See the "Heigh-Ho Silver" student activity kit available from Flinn Scientific (Catalog No. AP8981).

Teaching Tips

- All monosaccharides (glucose, fructose, etc.) and most disaccharides (e.g., maltose and lactose) are reducing sugars. The most well-known exception to this general rule is sucrose ("table sugar"). Sucrose is a nonreducing disaccharide that is composed of one glucose unit joined to one fructose unit via the loss of water. Because the monosaccharides are joined at their carbonyl carbon atoms, sucrose does not have an aldehyde functional group that can be oxidized. All polysaccharides (starch, cellulose, etc.) are nonreducing sugars.
- Special mirrors that require perfectly reflective surfaces with few imperfections are made by coating glass with the metal from the vapor phase. The vapor is obtained by vaporizing silver electrically under high vacuum conditions.

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

1. The diameter of the glass ornament balls used in this experiment is 2⅝ inches. Convert the diameter of the ball to centimeters and calculate the radius of the glass ball.

   2⅝″ = 2.625 in × 2.54 cm/in = 6.67 cm

   Radius = 3.33 cm (rounded to 3 significant figures)

2. Use the following equation to calculate the approximate surface area (SA) of the ornament ball, $SA = 4\pi r^2$.

   $SA = 4(3.14)(3.33\ cm)^2 = 139\ cm^2$

3. Assuming that the glass thickness of the ornament is 1.6 mm, estimate the percent difference in the surface area calculation for the inside versus the outside of the ornament sphere.

   Surface area for inside of sphere $= 4(3.14)(3.33 - 0.16)^2 = 126\ cm^2$

   Percent difference in SA calculation $= \frac{139 - 126}{139} \times 100 = 9\%$

4. Oxidation–reduction reactions involve the loss and gain of electrons, respectively. Based on the mole ratios in Equation 1 for the reduction of Ag^+ cations to Ag metal, how many electrons are gained by the aldehyde when it is oxidized to the carboxylate function group? *Hint:* Electrons must be balanced and "cancel out" in an oxidation–reduction reaction.

   Reduction of Ag^+ to Ag metal involves the gain of one electron. The mole ratio for the reaction, however, requires two moles of Ag^+ ions per mole of aldehyde. The principle of electron balance, therefore, implies that oxidation of an aldehyde to a carboxylate ion involves the loss of two electrons.

Sample Data *(Student data will vary.)*

Circumference of glass ornament (cm)	*20.8 cm*
Mass of ornament ball	*12.35 g*
Mass of silver ornament	*12.57 g*

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

1. Using the measured circumference of the glass ornament, calculate the radius (in cm) and the surface area (cm^2) of the ornament. (The formula for the circumference of a sphere is $2\pi r$.)

   Circumference = 20.8 cm. Radius = 3.3 cm.

   Surface area $= 4\pi r^2 = 138\ cm^2$.

2. Calculate the mass and the number of moles of silver lining the inside of the glass ornament.

   Mass of silver = 0.22 g. Number of moles = 0.22 g/107.9 g/mole = 0.0020 moles

3. The density of silver is 10.5 g/cm^3. What is the volume of silver metal lining the inside of the glass ornament?

   Volume of silver $= 0.22\ g/10.5\ g/cm^3 = 0.021\ cm^3$

4. Assume that the volume of silver in the ornament can be approximated by the following equation: Volume = Surface area × thickness. Calculate the approximate thickness of the silver lining in centimeters.

   Thickness of the silver lining $= V/SA = 0.021\ cm^3/138\ cm^2 = 1.5 \times 10^{-4}\ cm$.

5. Convert the thickness of the silver layer to micrometers ($1\ \mu m = 1 \times 10^{-6}$ m) and nanometers ($1\ nm = 1 \times 10^{-9}$ m).

   1.5×10^{-4} *cm is equal to* 1.5×10^{-6} *m or 1.5 µm*

   $1.5\ \mu m \times 1000\ nm/\mu m = 1500\ nm$

6. The radius (*r*) of a silver atom is 160 picometers ($1\ pm = 1 \times 10^{-12}$ m). Estimate the thickness of the silver lining in terms of the number (N_{Ag}) of silver atoms. Assume that the thickness is equal to $N_{Ag} \times 2r$. *Hint:* Convert the radius of a silver atom from picometers to centimeters first!

   Radius of silver atom $= 160\ pm \times 10^{-12}\ m/pm \times 100\ cm/m = 1.6 \times 10^{-8}\ cm$

   Number of silver atoms $(N_{Ag}) = thickness/2r = 1.5 \times 10^{-4}\ cm/3.2 \times 10^{-8}\ cm = 4700$ *atoms*

7. Balance the following chemical equation for the formation of Tollens' reagent in this experiment.

   Answer: $AgNO_3(aq) + 2NH_4NO_3(aq) + 3NaOH(aq) \rightarrow Ag(NH_3)_2OH(aq) + 3NaNO_3(aq) + 2H_2O(l)$

   Tollens' reagent

Acknowledgements

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Silver Ornaments is available as a Student Laboratory Kit from Flinn Scientific, Inc.

Catalog No.	Description
AP7189	Silver Ornaments—Holiday Laboratory Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.