P.O. Box 219 • Batavia, IL 60510
(800) 452-1261 • Fax (866) 452-1436
www.flinnsci.com • E-mail: flinn@flinnsci.com

Catalog No. FB1442

Publication No. 10267

Lung Model

Student Laboratory Kit

Introduction

We breathe twenty-four hours a day, every day, without consciously thinking about it. What causes air to rush into our lungs and then rush out again?

Concepts

- Differential air pressure
- Inhalation
- Exhalation

Materials

Balloon, large

Balloon, small

Plastic cup with hole, transparent

Rubber stopper, 1-hole

Scissors

Safety Precaution

Wear protective goggles when working with balloons as they may snap off when stretched. Follow all laboratory safety guidelines.

Procedure

1. Place the small balloon over the large end of the one-hole stopper as shown in Figure 1.
2. Insert the rubber stopper securely into the hole from the inside of the plastic cup.
3. Use sharp scissors to cut the large balloon as shown in Figure 2.
4. Have a lab partner hold the cup containing the small balloon. Stretch the large balloon over the end of the cup. Your final model should look like Figure 1.
5. Carefully move the center of the large balloon up and down. Do not pull or push too hard.
6. Answer the questions on the Lung Model Worksheet.

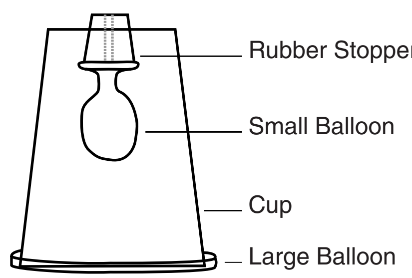


Figure 1. Completed Model

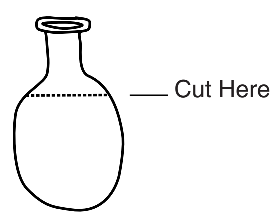


Figure 2. Cutting Large Balloon

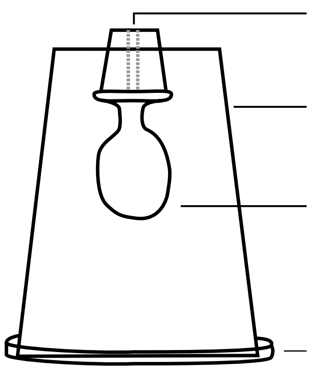
IN10267
122115

Name: ________________________________

Lung Model Worksheet

Circle the correct answers or fill in the blanks.

1. When the large balloon is pulled down, it makes the total volume inside the cup chamber (larger, smaller). When this happens the small balloon (inflates, deflates).
2. When the large balloon is pushed up, it makes the total volume inside the cup chamber (larger, smaller). When this happens the small balloon (inflates, deflates).
3. When the cavity inside the cup chamber gets smaller, the air pressure inside the chamber (increases, decreases). This pressure difference between the inside and outside of the chamber causes air to (move into, move out of) the small balloon.
4. When the cavity inside the cup chamber gets larger, the air pressure inside the chamber (increases, decreases). This pressure difference causes air to (move into, move out of) the small balloon.
5. Fill in the blanks.



Hole in stopper represents ______________________.

Cup represents ________________________________.

Small balloon represents ______________________.

Large balloon represents ______________________.

6. When the diaphragm contracts, the chest cavity gets (larger, smaller), the air pressure inside the lungs (increases, decreases), air (enters, leaves) the lungs and they (inflate, deflate).
7. When the diaphragm relaxes, the chest cavity gets (larger, smaller), the air pressure inside the lungs (increases, decreases), air (enters, leaves) the lungs and they (inflate, deflate).
8. In the model the chest cavity cannot expand. In our body the chest cavity expands and contracts. How is this expansion and contraction coordinated with diaphragm movements?

Teacher's Notes

Lung Model

Materials Included in Kit

Balloons, large, 32
Balloons, small, 32
Plastic cups, transparent, 32
Rubber stoppers, 1-hole, 30
Lung Model Worksheet Master
Cork borer

Additional Materials Needed (for each lab group)

Scissors

Pre-Lab Preparation

Use the cork borer provided in the kit to cut a hole in the center of the bottom of each cup. Place each cup on a piece of wood or cardboard and cut the hole from the inside of the cup. Apply an even, twisting motion to cut a hole through the bottom of the cup. A glove might be worn to protect your hand. *Be careful,* the cork borer is a potentially dangerous cutting device. **Do not** let students cut the holes. *Note:* upon difficulty cutting, gently heat the sharp edge of the cork borer using a bunsen burner or safety lighter.

Safety Precautions

Be sure precautions are given about working with balloons.

Disposal

Students can take their models home and teach family members about lung functioning or you can reuse all the materials for additional classes.

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
Form and function
Content Standards: Grades 5–8
Content Standard C: Life Science, structure and function in living systems
Content Standard F: Science in Personal and Social Perspectives; personal health
Content Standards: Grades 9–12
Content Standard C: Life Science, matter, energy, and organization in living systems
Content Standard F: Science in Personal and Social Perspectives; personal and community health

Tips

- Enough materials are provided in the kit to make 30 models. Several extra cups and balloons are provided in case of breakage or poor hole cutting. The activity can easily be completed in one class period with discussion.
- You may want to have students assemble their models and then have the class manipulate their models simultaneously. This way you can complete the worksheet as an all-class discussion. Alternatively, all students can work individually.
- If you are unfamiliar with cutting objects with a cork borer, practice on some paper or cardboard prior to cutting the tougher plastic cup.
- Make one of the models prior to the class operation. Practice stretching the large balloon over the bottom of the cup. Students might need assistance at this step. Be sure to cut the balloon just below the neck of the balloon. If the balloon is cut too close to the center, it will rip easily.

- This model, like any model, has its limitations. The real breathing mechanism, as described in the discussion section, points out the multiple contractions involved in breathing. Be sure students realize that, even though this model is fun to operate and does illustrate the general principle of breathing, it doesn't show all of the muscles involved in breathing. Be sure to read the discussion carefully and augment your class discussion as appropriate for your students and your class goals.

Discussion

The human breathing mechanism is, in principle, a simple concept. The nervous/muscular coordination, however, is complex. The basic principle is that muscular contractions alter the size of the internal chest cavity and create an air pressure differential between the inside of the chest cavity and the atmospheric air pressure outside the body. When the atmospheric air pressure outside the body is greater than inside the lungs, air enters the lungs. When the pressure is greater inside the lungs than outside the body, air leaves the lungs.

Two sets of muscles are basically involved in breathing. Intercostal muscles between the ribs and certain thoracic muscles can contract and relax which results in the raising and lowering of the rib cage. The contraction of the rib cage muscles causes the rib cage to be raised and the chest cavity to enlarge. (See Figure 2A — Inspiration.) While this is happening, the diaphragm (a very strong muscle) simultaneously contracts. This contraction lowers the diaphragm making the internal chest cavity even larger. Because of this chest cavity expansion, the air pressure inside the chest cavity is reduced and becomes less than the outside atmospheric pressure — air rushes into the lungs. These muscle contractions are alternately followed by a relaxation of the diaphragm and rib cage muscles which results in a decrease in the chest cavity size and an increase in air pressure inside the lung cavity. This increased pressure results in air being expelled from the lungs. (See Figure 2B — Expiration.)

In summary, changes in the size of the chest cavity affect the air pressure in the lungs. When the chest expands, the pressure within the chest falls. Because of this reduced air pressure, air is forced in from the outside, where it is under greater atmospheric pressure. When the chest cavity is reduced, the internal pressure becomes greater than the atmospheric pressure and air is forced out of the breathing passages. The autonomically controlled, rhythmic increase and decrease in the chest cavity's volume is the mechanical "pump" that drives air into and out of the lungs.

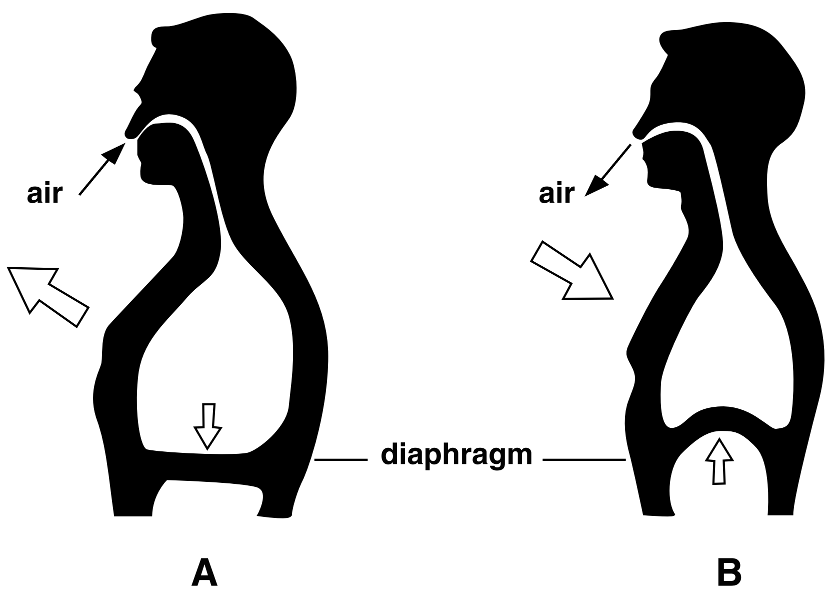


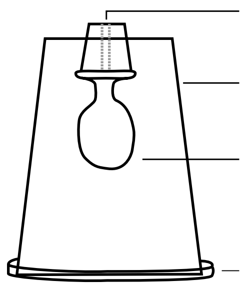
Figure 2 A. Inspiration — diaphragm contracted and chest muscles contracted raising rib cage causing increased volume and decreased air pressure.

Figure 2 B. Expiration — diaphragm relaxed and chest muscles relaxed lowering rib cage and causing decreased volume and increased air pressure.

Answers to Lung Model Worksheet

Circle the correct answers or fill in the blanks. **(Answers in bold.)**

1. When the large balloon is pulled down, it makes the total volume inside the cup chamber (**larger**, smaller). When this happens the small balloon (**inflates**, deflates).
2. When the large balloon is pushed up, it makes the total volume inside the cup chamber (larger, **smaller**). When this happens the small balloon (inflates, **deflates**).
3. When the cavity inside the cup chamber gets smaller, the air pressure inside the chamber (**increases**, decreases). This pressure difference between the inside and outside of the chamber causes air to (move into, **move out of**) the small balloon.
4. When the cavity inside the cup chamber gets larger, the air pressure inside the chamber (increases, **decreases**). This pressure difference causes air to (**move into**, move out of) the small balloon.
5. Fill in the blanks.



Hole in stopper represents **trachea, etc.**.

Cup represents **chest cavity**.

Small balloon represents **lung**.

Large balloon represents **diaphragm**.

6. When the diaphragm contracts, the chest cavity gets (**larger**, smaller), the air pressure inside the lungs (increases, **decreases**), air (**enters**, leaves) the lungs and they (**inflate**, deflate).
7. When the diaphragm relaxes, the chest cavity gets (larger, **smaller**), the air pressure inside the lungs (**increases**, decreases), air (enters, **leaves**) the lungs and they (inflate, **deflate**).
8. In the model the chest cavity cannot expand. In our body the chest cavity expands and contracts. How is this expansion and contraction coordinated with diaphragm movements?

   The chest cavity expands up and outward (muscles contract) when the diaphram contracts.

The *Lung Model—Student Laboratory Kit* is available from Flinn Scientific, Inc.

Catalog No.	Description
FB1442	Lung Model—Student Laboratory Kit
FB1110	Functioning Lung Model

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

The Expanding Marshmallow

Introduction

Help students explore and understand Boyle's Law with this simple demonstration. See how a change in pressure affects the volume of marshmallow. Students will easily remember the relationship between pressure and volume after participating in this activity.

By simply placing a marshmallow inside a syringe and using the plunger to increase and decrease the pressure, your students can watch the marshmallow expand and shrink to get a clear understanding of Boyle's Law.

Concepts

- Pressure
- Boyle's Law
- Volume
- Gas laws

Materials

Syringe, without needle, plastic, 35-mL
Miniature marshmallow, fresh
Felt-tip pen (optional)
Syringe tip cap (optional)

Safety Precautions

This laboratory activity is considered nonhazardous. Follow all normal laboratory procedures.

Procedure

1. If desired, use a felt-tip pen to draw a happy face on the end of a miniature marshmallow.
2. Remove the end cap from the tip of a 35-mL plastic syringe.
3. Remove plunger from the syringe and insert the marshmallow into the syringe.
4. Place plunger back in syringe so the volume reading is approximately at the 15-mL mark.
5. Place a syringe tip cap over the tip of the syringe. Pull the plunger out—decreasing the pressure inside the syringe. The marshmallow should expand—it's volume increases.
6. Now push the syringe in—increasing the pressure inside the syringe. The marshmallow should shrink—its volume decreases.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The marshmallow should be removed from syringe and put into the trash according to Flinn Suggested Disposal Method #26a. Clean work area and wash hands thoroughly with soap and water before leaving the laboratory.

Tip

- A finger may be used to "seal" the syringe instead of a syringe tip cap, if needed.

Discussion

When the syringe plunger is pulled out, the volume of the chamber increases but the amount of gas remains constant because it is in a closed system. The pressure inside the syringe chamber decreases. The lower pressure on the marshmallow causes its volume to increase according to Boyle's Law. The expansion is due to the many trapped air bubbles (like small "internal balloons") within the marshmallow that initially are at atmospheric pressure. As the pressure outside these air bubbles (within the chamber) is reduced, the bubbles will expand to many times the original volume in order to equilibrate the pressure on either side of the bubble wall. Thus as the pressure decreases (P↓), volume increases (V↑) in an inverse relationship according to the following equations.

$$PV = nRT$$ *Equation 1 – Ideal Gas Law*

$$P_1 \times V_1 = P_2 \times V_2$$ *Equation 2 – Boyle's Law*

This increase in volume makes for a memorable visual event and a great stimulus for the discussion of the elements of Boyle's Law. Students can visualize the loss in pressure and easily see the increase in volume.

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 5–8
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter

Materials for *The Expanding Marshmallow* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1732	Syringe, 35 mL
AP1297	Felt-tip Pen, black
AP8958	Syringe tip cap

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

P.O. Box 219 • Batavia, IL 60510
(800) 452-1261 • Fax (866) 452-1436
www.flinnsci.com • E-mail: flinn@flinnsci.com

Catalog No. AP7926
Publication No. 7926

Cartesian Diver Design Challenge Kit

Guided-Inquiry Kit

Introduction

Explore the world of Cartesian divers! Cartesian divers are fun toys that can be used to teach the concepts of density and Boyle's law. After examining the design of a basic Cartesian diver, be prepared to modify the design to perform different challenges! Dive right in to this fun activity!

Concepts

- Density
- Boyle's Law
- Engineering design

Materials

Beaker, 600-mL
Food dye (optional)
Forceps (optional)
Glue gun and sticks
Hex nuts, 10
Magnets, 2
Paper clips, 2
Paper towels
Pipets, disposable plastic, 10
Plastic soda bottle, with cap, 1- or 2-L
Scissors
Water
Weighing dish, 3
Wire, insulated, 12 inches

Safety Precautions

The materials in this activity are considered nonhazardous. Exercise caution when handling the hot glue gun. Wipe up any water spills immediately. Please follow all laboratory safety guidelines.

Procedure

Part A. Making a Cartesian Diver

1. Fill the 600-mL beaker approximately 4/5 full with tap water.
2. Screw the hex nut securely onto the stem. The hex nut will form its own threads as it turns. Cut off the remaining pipet stem (see Figure 1).

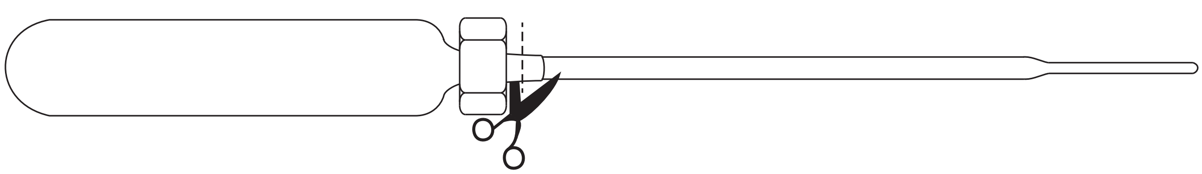


Figure 1. Cutting the Pipet

3. Place the pipet-nut diver assembly into the 600-mL beaker of water and observe that it floats in an upright position with the hex nut acting as ballast.

4. Squeeze out some of the air from the bulb and draw some water up into the pipet. Now check the buoyancy. If you draw up too much water, the diver will sink. If this happens, simply lift it out of the water, squeeze out a few drops of water and let air back in to replace the water.
5. Using this technique, adjust the amount of water in the diver so that it just barely floats in the beaker.
6. Place the diver assembly in a plastic 1- or 2-L bottle completely filled with water and screw on the cap securely (Figure 2). Observe how the diver assembly dives to the bottom as you squeeze the bottle and how it rises to the surface as you release the squeeze.
7. Answer the questions below and then go on to Part B.

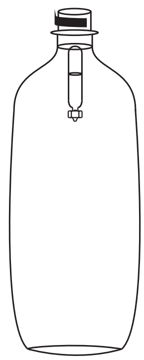


Figure 2.

Questions

Form a working group with other students. Observe the Cartesian diver made in Part A and discuss the following questions.

1. Explain what is happening when the diver rises and falls.
2. Using forceps, remove the diver. Let out five drops of water and retest the diver.
3. Continue to adjust the amount of water in the diver, in five-drop increments. Record observations and test the diver again. continue testing until the diver will no longer dive.
4. Consider the pressure applied to the bottle. How did the amount of pressure required to sink the diver change as the amount of water in the diver decreased? Explain.
5. How did the beginning density of the diver change when the above adjustments were made?
   a. What variables were changed?
   b. What variables were held constant?

Part B. Making a Closed-System Diver

1. Follow steps 1–5 of Part A.
2. Remove the diver from the beaker and squeeze out one or two drops of water. Using a paper towel, pat dry the inside rim of the open stem.
3. Holding the bulb with the stem end upward, squeeze the bulb very slightly to expel a very small amount of air. Hold the squeeze while carefully placing a drop of hot, melted glue in the stem opening of the diver and then relax the squeeze. The drop of hot glue will be pulled into the stem (see Figure 3).

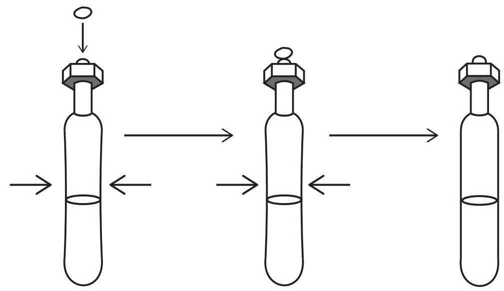


Figure 3.

4. Wait 1–2 minutes for the drop of glue to harden and seal the mouth of the diver.
5. Place the diver assembly in the plastic 1- or 2-L bottle completely filled with water and screw on the cap securely (Figure 2). Observe how the diver assembly dives to the bottom as you squeeze the bottle and how it rises to the surface as you release the squeeze.
6. Compare and contrast the open and closed divers.
7. What are the advantages and disadvantages to each?

Part C. Design Challenge

Your instructor will assign a Design Challenge to your group.

Design Challenge I. Create a diver that retrieves a sunken diver from the bottom of the bottle.

Before creating the divers, brainstorm with your group.

1. How is the diver going to retrieve the sunken diver at the bottom?
2. What requirements are necessary for the sunken diver? Why?
3. What requirements are necessary for the retriever diver? Why?
4. Will the divers be open or closed for your design? Explain your reasoning.
5. What materials are needed?
6. What safety precautions should be taken?
7. How will the diver be tested once it is finished? What data will be recorded?
8. What criteria make for a successful design?
9. What are the strengths and limitations of this design?

Design Challenge II. Design a set of 3 divers that descend in a specific order.

Before creating the divers, brainstorm with your group.

1. Will the divers be open or closed for your design? Explain your reasoning.
2. What materials will be needed?
3. What safety precautions should be taken?
4. How will the final design be tested? What data will be recorded?
5. What variables are going to change with each diver? Why?
6. What variables will be held constant? Why?
7. What criteria make for a successful design?
8. What are the strengths and limitations of this design?

Design Challenge III. Create a diver that spins the most on one dive.

Before creating the diver, brainstorm with your group.

1. What design is your group going to use and why? Remember you are creating a diver to spin the most in one dive.
2. Will the diver be open or closed for your design? Explain your reasoning.
3. What materials will be needed?
4. What variables might affect the number of turns the diver makes?
5. What safety precautions should be taken?
6. How will the diver be tested once it is finished? What data will be recorded?
7. What variables will be held constant? Why?
8. What criteria make for a successful design?
9. What are the strengths and limitations of this design?

Teacher's Notes
Cartesian Diver Design Challenge Kit

Materials Included in Kit (for 30 students working in pairs)

Hex nuts, 200

Magnets, 35

Paper clips, 1 box

Pipets, disposable plastic, 200

Plastic soda bottle, with cap, 1-L, 3*

Weighing dishes, 50

Wire, 1 spool

*Three bottles are included for teacher examples.

Additional Materials Needed (for each lab group)

Beaker, 600-mL

Food dye (optional)

Forceps, 10″

Glue gun and sticks

Hole punch

Paper towels

Scissors

Water

Pre-Lab Preparation

1. Cut the wire into 12-inch pieces. Each group will get one piece.
2. Optional: Prepare an example of the Design Challenges.
3. Design Challenge I (optional): Magnets can be used to retrieve the sunken diver. Another option is to use a hook and loop.
4. Design Challenge II (optional):
   a. Create three divers using Part A of the instructions.
   b. Test and adjust each diver in the 600-mL beaker of water until you have three different densities.
   c. Make sure there is a minimal amount of air in each diver or it will be very difficult to make the divers descend.
   d. Place all three in a plastic soda bottle full of water, screw on the cap, and apply pressure slowly.
   e. If they do not descend separately, try again with gentle pressure at first.
   f. If gentle pressure does not work, take the divers out and adjust the densities again.
   g. (Optional) Letters or phrases can be attached to the divers to spell a word or tell a joke.
   h. (Optional) The divers can be made closed divers. Closed divers can also be dyed different colors. To make a colored diver, add a drop or two of food coloring to a small beaker of water. Then, fill the diver with the colored water, check its density, and then seal with the hot glue (see Part B for how to create the closed-system diver design).

5. Design Challenge III (optional):
   a. Multiple versions of a spinning diver can be made. Students can make propellers, pinwheels, and other attachments to create a spinning diver.
   b. One example is the propeller. To prepare a spinning diver, cut a small circle out of the plastic weighing dish. Use a hole punch to punch a hole in the center.
   c. Make 4–8 incisions around the circle (represented on Figure 4, with the dotted lines). Then bend the petals with one corner up and one corner down, like a propeller (fold lines are represented with the gray lines on Figure 4).
   d. Fit the propeller onto the stem of the pipet, just above the hex nut.
   e. Finish making the diver according to Part A, steps 2–6 (see Figure 5).
   f. Mark one of the blades to help with counting rotations.
   g. Another version of the spinning diver can be done with the design in Figures 6 and 7.

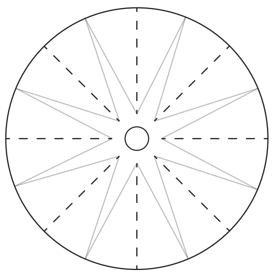


Figure 4.

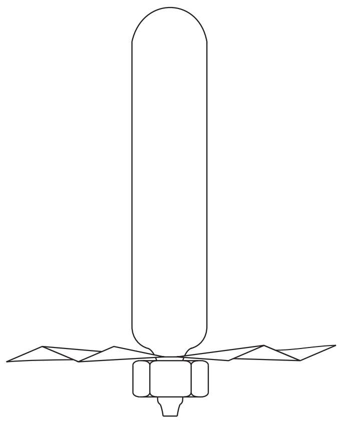


Figure 5.

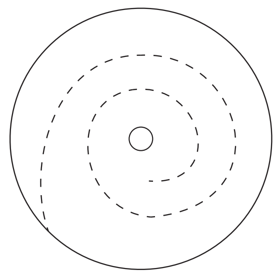


Figure 6.

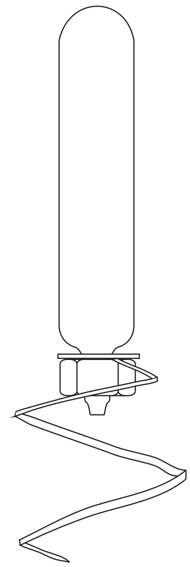


Figure 7.

Safety Precautions

The materials in this activity are considered nonhazardous. Exercise caution when handling the hot glue gun. Wipe up any water spills immediately. Please follow all laboratory safety guidelines.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
- MS-PS2 Motion and Stability: Forces and Interactions
  - PS2.A: Forces and Motion
- MS-ETS1 Engineering Design
  - ETS1.A: Defining and Delimiting Engineering Problems
  - ETS1.B: Developing Possible Solutions
  - ETS1.C: Optimizing the Design Solution

Science and Engineering Practices
- Asking questions and defining problems
- Developing and using models
- Constructing explanations and designing solutions

Crosscutting Concepts
- Patterns
- Cause and effect
- Structure and function

Lab Hints

- Enough materials are provided in this kit for 30 students working in pairs, or for 15 groups of students. All parts of the laboratory activity can reasonably be completed in two 50-minute class periods.
- The plastic from the weighing dishes makes great spinning divers.
- Enough pipets are given so each lab group can have 12 pipets to work with during the lab and Design Challenges.
- Depending on how in-depth the testing is and if all the Design Challenges are performed, this activity could be expanded to take longer than the two 50-minute class periods.
- It is much easier to adjust the density of the diver and to test for flotation using a 600-mL beaker or a cup of water, rather than testing in the bottle itself.
- Placing a mark on the spinning diver helps when counting rotations.
- Forceps can be used to remove the diver when it is inside the plastic bottle (Flinn Catalog No. AB1093).
- When filling the plastic bottle, fill it completely with water. If there is too much air in the bottle, the pressure could compress the air in the bottle instead of the smaller air pocket in the diver.
- One advantage of the closed diver is that a drop or two of food coloring may be added before sealing the pipet stem with a drop from the glue gun. The main disadvantage is the bulb must be reopened if any adjustments need to be made to the density. One method is to heat a stiff wire in a flame and use the hot end to melt a hole in the plug of glue.
- The manufacturers of plastic pipets change their designs and specifications occasionally. Therefore, the ¼-inch hexnut may not exactly fit the pipet. In this case, wrap the stem of the pipet near the bulb with clear tape to increase its diameter.
- Have plenty of paper or cloth towels handy to wipe up spills. Setting the 1-L plastic bottle in a large disposable weighing dish (Flinn Catalog No. AP1279) or other plastic dish will help catch spills.
- When finished with the Cartesian divers, remove the divers from the bottle with forceps. If the divers are left in the water for long periods of time, the hex nuts will rust.

Teaching Tips

- This is a great hands-on activity for incorporating STEM, engineering design, and scientific inquiry. This activity also helps to emphasize Boyle's law and density.
- Each challenge can be assigned to different groups. Alternatively, the entire class may attempt one challenge and see which group can create the best product.
- It is important to allow students time to brainstorm ideas and consider the pros and cons of each proposed design. If time allows, students may present their designs to the class.
- For Design Challenge I, hints can be given to use magnets or hooks to retrieve objects.
- For all the Design Challenges, students can add creativity by decorating their divers. Pipe cleaners, food dye, permanent markers, and glitter are just some of the things that can be used to enhance the diver.
- For Design Challenge II, additional conditions may be added to students' designs. The divers could spell a word or tell a joke as the divers descend. Up to ten divers in a 2-L bottle is possible, but squeezing the bottle enough to get all the divers to descend may be difficult.
- This assembly is formally known as a Cartesian diver after Rene Descartes, a 17th century French mathematician.
- Additional divers can be shown to students. Two manufactured divers are Squidy and Hook Cartesian Divers. These are available from Flinn Scientific (Catalog Nos. AP8721 and AP4548, respectively).
- Two videos of this lab activity are available for viewing as part of the Flinn Scientific "Best Practices for Teaching Chemistry" video series. Cartesian Divers, presented by Jesse Bernstein, and Cartesian Diver-sions, presented by Bob Becker are located in Flinn's Teacher Resource Videos. Please visit the Flinn Website at http://flinnsci.com for viewing information.

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

Part A. Making a Cartesian Diver

1. Explain what is happening when the diver rises and falls.

   When external pressure is applied, additional water is pushed into the opening of the diver, increasing the mass. Since the volume of the diver stays the same, the density then increases (density = mass/volume) and the diver sinks when the density is greater than water.

   The sinking diver can also be explained using Boyle's Law. The external pressure on the bottle compresses the air pocket in the diver making the volume of the gas smaller, changing the density of the diver, and causing it to sink (Boyle's law states pressure and volume have an inverse relationship. Therefore, an increase in pressure causes a decrease in volume of the gas).

2. Using forceps, remove the diver. Let out five drops of water, and retest the diver.
3. Continue to adjust the amount of water in the diver, in five-drop increments. Record observations and test the diver again. Continue testing until the diver will no longer dive.

   The diver gradually becomes more difficult to sink. More pressure was needed to sink the diver as less water was placed in the initial diver, increasing the buoyancy of the diver.

4. Consider the pressure applied to the bottle. How did the amount of pressure required to sink the diver change as the amount of water in the diver decreased? Explain.

   As the water inside the diver decreased, more pressure was needed to sink the diver. Since the gas inside the diver was increasing, more pressure was needed to decrease the volume of the gas to the volume necessary for the diver to sink.

5. How did the beginning density of the diver change when the adjustments were made above?

   The diver becomes less dense as more water was removed from the diver.

   a. What variables were changed?

   b. What variables were held constant?

   Multiple variables can be examined and discussed. Some variables students may explore are

   - *Volume of water in the diver*
   - *Volume of air in the diver*
   - *Mass of the diver*
   - *Pressure applied*
   - *Pipet bulb assembly*
   - *Plastic bottle used*
   - *Temperature of the water*
   - *Temperature of the room*

Part B. Making a Closed-System Diver

6. Compare and contrast the open and closed divers.

   The open and closed diver, have the same setup, except the closed diver cannot take in more water due to the glue plug. The closed system diver does not take in extra water when the bottle is squeezed. Instead, the sides of the closed diver curve inward, decreasing the volume. Since the volume is decreased and the mass stays the same, the density increases and the diver descends.

7. What are the advantages and disadvantages to each?

   Adjustments are difficult to make with the closed diver. In order to adjust the diver, the plug must be reopened with a hot wire and then resealed again. An advantage to the closed diver is that it can be filled with colored water, making it easier to see in the bottle. An open diver is easier to adjust since it is not sealed.

The *Cartesian Diver Design Challenge Guided-Inquiry Kit* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP7921	Cartesian Diver Design Challenge Kit
AP9011	Glue Gun
AP9012	Glue Sticks, 24/pkg
AB1093	Forceps, 10″

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

P.O. Box 219 • Batavia, IL 60510
(800) 452-1261 • Fax (866) 452-1436
www.flinnsci.com • E-mail: flinn@flinnsci.com

FLINN SCIENTIFIC
"Your Safer Source for Science Supplies"

Catalog No. AP7189
Publication No. 7189

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
- Reducing sugars
- Tollens' test
- 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.

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

Structure of dextrose:

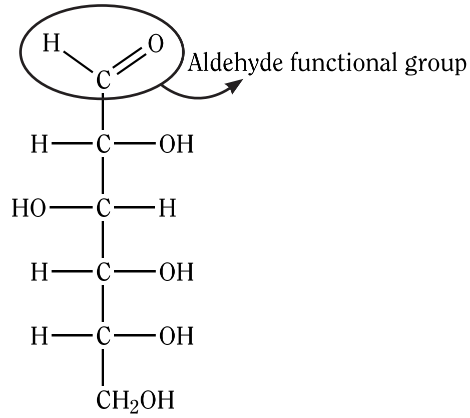


Figure 1. Structure of Dextrose.

IN7189
052311

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.

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

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 $= \dfrac{139 - 126}{139} \times 100 = 9\%$

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.

Teacher's Notes *continued*

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 µm $= 1 \times 10^{-6}$ 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 µm × 1000 nm/µm = 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: $AgNO_3(aq) + 2NH_4NO_3(aq) + 3NaOH(aq) \rightarrow \underbrace{Ag(NH_3)_2OH(aq)}_{\text{Tollens' reagent}} + 3NaNO_3(aq) + 2H_2O(l)$

Acknowledgements

We are grateful to Edmund Escudero, Summitt Country Day School, Cincinnati, OH, for providing Flinn Scientific with the idea and instructions for this activity.

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.