ChemMatters®

Demystifying Everyday Chemistry

Teacher's Guide

December 2020

www.asc.org/chemmatters

ACS Chemistry for Life®

ChemMatters™
Demystifying Everyday Chemistry

Teacher's Guide

The Chemistry of Convenience

December 2020

Table of Contents

Anticipation Guide

Name: _____

Directions: ***Before reading the article*****,** in the first column, write "A" or "D," indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.
As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. PFAS (polyfluoroalkyl) substances are synthetic.
		2. All synthetic chemicals are harmful.
		3. PFAS contain oxygen, nitrogen, carbon, and fluorine atoms.
		4. The covalent bond formed between carbon and fluorine is one of the strongest single bonds in nature.
		5. The covalent bond between carbon and fluorine is longer than other covalent bonds.
		6. PFAS can cause health problems in several different human body systems.
		7. A huge amount of data must be collected in lab experiments to make predictions about how PFAS move in our bodies
		8. Filtering out PFAS molecules from water is fairly easy with common filtration technology.
		9. An ordinary incinerator can destroy PFAS molecules.
		10. A few specific PFAS can no longer be manufactured in the U.S.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Which two elements are present in every polyfluoroalkyl (PFAS) compound?

2. What are some primary uses of PFAS chemicals?

3. Why do PFAS compounds remain for a long time in the environment? What specific types of bonds cause PFAS compounds to be known as “forever chemicals”?

4. PFAS chemicals are considered to be inert and thus do not react with other chemicals in the body. The effects of PFAS chemicals accumulating in the body are not yet fully understood, but what are some potential health risks associated with PFAS chemicals in the body mentioned in the article?

5. What are some ways scientists are having success removing PFAS chemicals from the environment?

6. PFAS durability, inertness, and water/oil repelling properties have made the compounds extremely popular. Examine the structure of $C_7H_{15}COOH$ on page 6 of the article. What characteristics of the structure make $C_7H_{15}COOH$ an excellent choice for outerwear clothing?

7. Examine the electronegativity trends on the periodic table on page 6 of the article. Electronegativity tends to decrease as you move down columns on the table and increases as you move across a row. Explain the trends in electronegativity based on your knowledge of periodic trends and the atom.

8. The table on page 7 of the article indicates the bond energy of various binary chemical bonds. The article explains how an increased electronegativity difference results in an electrostatic attraction and a shorter, stronger covalent bond. Why do you suppose the F-F bond energy is significantly lower than the O-O bond energy even though fluorine is smaller than oxygen and can form a shorter bond? (Note: since these bonds are diatomic, the electronegativity difference in each bond is zero.)

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Regulations have been put into place that have helped limit the accumulation of PFAS in the environment. The best method of preventing PFAS compounds from entering the environment is to avoid, if possible, using materials that contain "forever chemicals." Identify 3 items that you use daily that contain PFAS compounds and attempt to find PFAS free alternatives to these items.

2. Create a public service announcement about the dangers of PFAS compounds accumulating in the environment in hopes convincing individuals to limit their exposure and use of PFAS compounds. You may use a YouTube video, Infographic, TikTok, or Twitter to present your announcement. In the video, inform the public about PFAS compounds and their uses, the dangers of PFAS compounds, and how limit exposure/use of PFAS compounds.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe how the chemistry terms relate to the chemistry of PFAS.

Chemistry Term	Relate to the chemistry of PFAS
Hydrophilic	
Covalent bond	
Electronegativity	
Bond energy	
Inert	
Predictions	
Reverse osmosis	

Summary: Write a one-sentence summary (15 words or less) about the chemistry of PFAS.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **Which two elements are present in every polyfluoroalkyl (PFAS) compound?**
   Carbon (C) and fluorine (F) are present in every PFAS compound.

2. **What are some primary uses of PFAS chemicals?**
   Water resistant/repellent clothes, non-stick cookware, and food wrappers.

3. **Why do PFAS compounds remain for a long time in the environment? What specific types of bonds cause PFAS compounds to be known as "forever chemicals"?**
   The carbon to fluorine bonds are very strong due to the large electronegativity different between carbon and fluorine, which causes a permanent net dipole and strong electrostatic attraction between the two atoms. This strong attraction causes a short, strong bond between the atoms and gives PFAS compounds their durable properties.

4. **PFAS chemicals are considered to be inert and thus do not react with other chemicals in the body. The effects of PFAS chemicals accumulating in the body are not yet fully understood, but what are some potential health risks associated with PFAS chemicals in the body mentioned in the article?**
   Health concerns associated with PFAS chemicals inside the body include pregnancy complications, kidney and testicular cancer, liver damage, and asthma.

5. **What are some ways scientists are having success removing PFAS chemicals from the environment?**
   Water chemists have been able to remove PFAS from water sources through filtration methods such as activated carbon and reverse osmosis.

6. **PFAS durability, inertness, and water/oil repelling properties have made the compounds extremely popular. Examine the structure of $C_7H_{15}COOH$ on page 6 of the article. What characteristics of the structure make $C_7H_{15}COOH$ an excellent choice for outerwear clothing?**
   $C_7H_{15}COOH$ (perfluorooctanoic acid) has a large non-polar or hydrophobic portion of the molecule which will repel water which is a desirable characteristic of outerwear clothing. Polar compounds such as water, like and dissolve in other polar compounds. Non-polar compounds such as oil, like and dissolve in other non-polar compounds.

7. **Examine the electronegativity trends on the periodic table on page 6 of the article. Electronegativity tends to decrease as you move down columns on the table and increases as you move across a row. Explain the trends in electronegativity based on your knowledge of periodic trends and the atom.**
   Electronegativity decreases as you move down a column on the table because additional energy levels are added to the atom. Additional energy levels cause valence electrons to be further from the nucleus and experience more shielding from inner electrons which limits the atoms ability to attract bonding pairs of electrons. Electronegativity increases across a row due to the fact that valence electrons are at the same distance from the nucleus (same energy level), however additional protons are added to the nucleus you move across a row increasing the effective nuclear charge and increasing the atoms ability to attract electrons in a bond.

8. **The table on page 7 of the article indicates the bond energy of various binary chemical bonds. The article explains how an increased electronegativity difference results in an electrostatic attraction and a shorter, stronger covalent bond. Why do you suppose the F-F bond energy is significantly lower than the O-O bond energy even though fluorine is smaller than oxygen and can form a shorter bond? (Note: since these bonds are diatomic, the electronegativity difference in each bond is zero.)**
   The fluorine to fluorine bond is a single bond while the oxygen to oxygen bond is a double bond. Double bonds tend to be shorter in length and have higher bond energy compared to single bonds because an extra shared pair of electrons needs to be separated.

Questions for Further Learning

1. **Regulations have been put into place that have helped limit the accumulation of PFAS in the environment. The best method of preventing PFAS compounds from entering the environment is to avoid, if possible, using materials that contain "forever chemicals." Identify 3 items that you use daily that contain PFAS compounds and attempt to find PFAS free alternatives to these items.**
   Student answers will vary. Example: Using PFAS free take-out containers or Teflon free cookware.

2. **Create a public service announcement about the dangers of PFAS compounds accumulating in the environment in hopes convincing individuals to limit their exposure and use of PFAS compounds. You may use a YouTube video, Infographic, TikTok, or Twitter to present your announcement. In the video, inform the public about PFAS compounds and their uses, the dangers of PFAS compounds, and how limit exposure/use of PFAS compounds.**
   Student answers will vary.

Graphic Organizer Rubric

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

Additional Resources

Labs and demos

Periodic Table Trends: In this lesson, students will investigate trends of the periodic table.
https://teachchemistry.org/classroom-resources/periodic-table-trends

Simulations

Periodic Trends: Ionization Energy, Atomic Radius & Ionic Radius: In this simulation, students can investigate the periodic trends of atomic radius, ionization energy, and ionic radius. By choosing elements from the periodic table, atoms can be selected for a side by side comparison and analysis.
https://teachchemistry.org/classroom-resources/periodic-trends-simulation

Lessons and lesson plans

Making Connections between Electronegativity, Molecular Shape, and Polarity: In this activity, students will find the electronegativity values of a variety of elements, draw the Lewis structures of select molecules that are made with those elements, and identify the molecular shape of each molecule.
https://teachchemistry.org/classroom-resources/making-connections-between-electronegativity-molecular-shape-and-polarity

Bond Polarity Modeling Activity: Students will kinesthetically demonstrate the use of electronegativity in determining covalent bond types.
https://teachchemistry.org/periodical/issues/may-2019/modeling-polarity

AACT Chemical Bonding Unit Plan: The AACT high school classroom resource library has everything you need to put together a unit plan for your classroom: lessons, activities, labs, projects, videos, simulations, and animations. https://teachchemistry.org/classroom-resources/chemical-bonding-unit-plan

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Molecules & bonding
- Molecular structure
- Intermolecular forces
- Electronegativity

Correlations to Next Generation Science Standards

This article relates to the following performance expectations and dimensions of the NGSS:

HS-PS1-3
Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

HS-ETS1-3
Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraint, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- PS1.A: Structure and Properties of Matter
- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Cause and Effect: Mechanism and explanation.
- Structure and Function

Science and Engineering Practices:

- Analyzing and interpreting data
- Constructing explanations and designing solutions

Nature of Science:

- Science addresses questions about the natural and material world.

Correlations to Common Core State Standards

See how *ChemMatters* correlates to the **Common Core State Standards** at www.acs.org/chemmatters.

Teaching Strategies

Consider the following tips and strategies for incorporating this article into your classroom:

- **Alternative to Anticipation Guide:** Before reading, ask students how innovative products may harm people and the environment. Also, ask them how strong they think the bonds between atoms might be in products that remain in the environment for a long time. As they read, students can find information to confirm or refute their original ideas.
- After they read, ask students what they learned about PFAS and how they will use their new understanding.
- "Open for Discussion: A Balancing Act" in this month's issue (page 4) has important information about how the benefits and potential risks of products are analyzed.

- In the *The Chemistry of Convenience* article (bottom of page 6), there is a question posed to students relating to electronegativity and bonding: *Which molecule would you expect to have a stronger carbon-halogen bond, methyl chloride (CH_3Cl) or methyl iodide (CH_3I)?*
  Answer: Methyl chloride (CH_3Cl) will have a stronger carbon-halogen bond because chlorine (Cl) is more electronegative than iodide (I). When chlorine is bonded to carbon, chlorine will pull more on the electrons and create a slight negative charge. Similarly, when iodine is bonded to carbon, iodine will pull more on the electrons and create a slight negative charge. However, since chlorine is more electronegative than iodide, chlorine will pull more on the electrons compared to iodide, creating a bigger difference between charges. This larger difference in charges between carbon and chlorine (which creates a dipole) makes the bond stronger compared to the carbon iodine bond.

ChemMatters™
Demystifying Everyday Chemistry

Teacher's Guide

How to Raise a Jellyfish

December 2020

Table of Contents

Anticipation Guide

Name: _____

Directions: ***Before reading the article*****,** in the first column, write "A" or "D," indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.
As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Many jellyfish are predators.
		2. Jellyfish live in every ocean on Earth.
		3. Less than 90% of the dissolved ions in seawater come from NaCl.
		4. The pH of the ocean is slightly acidic.
		5. Sodium bicarbonate ($NaHCO_3$) can help maintain the pH of a solution by reacting with added acids or bases.
		6. The CO_2 in the air does not enter Earth's oceans.
		7. Over the past 200 years, the pH of the world's oceans has decreased slightly.
		8. Planting seagrasses along coastlines could lower the ocean's pH.
		9. In the polyp stage of its life, a jellyfish is attached to an underwater surface.
		10. Keeping saltwater organisms alive in an aquarium requires constant adjustment of chemicals.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. According to the article, how long have jellyfish been present on Earth?

2. While overfishing and climate change negatively impact some species of sea life, what is happening to the population of jellyfish?

3. What pH range of water is necessary to support jellyfish?

4. List three water quality factors that are important to jellyfish survival in an aquarium.

5. As sea animals release waste into the water, what happens to the pH level of the water?

6. How many ephyra can a polyp shed?

7. Explain what the pH scale measures.

8. If the pH of aquarium water is 4, what substance can be added to increase the pH?

9. If the pH of aquarium water is 10, what substance can be added to lower the pH?

10. Complete the chart below by drawing or describing what a jellyfish looks like in each of the stages of its life cycle.

Larva	Polyp	Strobila	Ephyra	Medusa

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Describe the laboratory technique that can be used to monitor calcium ion levels in an aquarium.

2. Explain why the seemingly small decrease of pH by 0.1 pH units is really a large change.

3. Explain two ways that the ocean's CO_2 levels might be reduced and the potential drawbacks of those methods.

4. Use LeChatelier's principle to explain how CO_2 in the air impacts the level of CO_2 in the ocean.

5. Perform additional research about potential methods for reducing CO_2 in the ocean. Create an infographic explaining the method and why it would be successful.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe how to maintain the pH of a saltwater aquarium.

Desired pH		
Effect of adding limewater	Effect on pH:	
Effect of adding vinegar	Effect on pH:	
Effect of adding sodium bicarbonate	Effect on pH:	**Equation:**
Effect of adding CO_2	Effect on pH:	**Equation:**
Effect of Ca^{2+}	Effect on pH:	**Explanation:**
Adding iron	Effect on pH:	**Explanation:**
Planting seagrasses	Effect on pH:	**Explanation:**

Summary: Write a short description of the chemistry of seawater.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **According to the article, how long have jellyfish been present on Earth?**
   Jellyfish have been in the ocean for at least 500 million years.

2. **While overfishing and climate change negatively impact some species of sea life, what is happening to the population of jellyfish?**
   The jellyfish population are flourishing while other sea life is being threatened.

3. **What pH range of water is necessary to support jellyfish?**
   The optimum pH of water is between 7.8 and 8.6.

4. **List three water quality factors that are important to jellyfish survival in an aquarium.**
   Three water quality factors that are important to jellyfish survival are pH, salinity, calcium levels.

5. **As sea animals release waste into the water, what happens to the pH level of the water?**
   The pH of the water becomes more acidic.

6. **How many ephyra can a polyp shed?**
   Polyps can shed between 10 and 15 ephyra.

7. **Explain what the pH scale measures.**
   pH is the measure of how acidic or basic an aqueous solution is and is a measure of the relative amount of free hydrogen and hydroxide ions in the solution.

8. **If the pH of aquarium water is 4, what substance can be added to increase the pH?**
   Limewater can be added to increase the pH of water.

9. **If the pH of aquarium water is 10, what substance can be added to lower the pH?**
   Hydrochloric acid or vinegar can be added to lower the pH of water.

10. **Complete the chart below by drawing or describing what a jellyfish looks like in each of the stages of its life cycle.**

Larva	Polyp	Strobila	Ephyra	Medusa
Responses should look like the drawings from the Life Cycle of the Moon Jelly inset.				

Questions for Further Learning

1. **Describe the laboratory technique that can be used to monitor calcium ion levels in an aquarium.**
   Calcium ion levels can be monitored by using a titration. Titration is a common lab method that involves the slow addition of a solution with a known concentration and volume to an unknown solution until there is a color change.

2. **Explain why the seemingly small decrease of pH by 0.1 pH units is really a large change.**
   The pH scale is logarithmic, so a drop of 0.1 represents a change in hydrogen ion concentration from 6 x 10^{-9} M to 8 x 10^{-9} M.

3. **Explain two ways that the ocean's CO_2 levels might be reduced and the potential drawbacks of those methods.**
   Adding limestone to the ocean could cause it to dissolve and consume CO_2. Iron fertilization is another method that could reduce CO_2 levels because it would cause phytoplankton to grow more rapidly. The phytoplankton would then consume CO_2 as it goes through photosynthesis. The downsides of these methods are that they would require too much energy and could have unwanted side effects.

4. **Use LeChatelier's principle to explain how CO_2 in the air impacts the level of CO_2 in the ocean.**
   LeChatelier's principle is that when a system at equilibrium is disturbed, the system shifts to counteract the disruption. Before the Industrial Revolution CO_2 moved between the oceans and the atmosphere until equilibrium was achieved. Over time more CO_2 has been introduced into the atmosphere which has increased the partial pressure of CO_2. This change in partial pressure shifts the equilibrium so more CO_2 is entering the oceans than the air.

5. **Perform additional research about potential methods for reducing CO_2 in the ocean. Create an infographic explaining the method and why it would be successful.**
   Student responses will vary.

Graphic Organizer Rubric

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

Additional Resources

Labs and demos

The Egg-straordinary Issue: In this lab students will determine the percent composition of calcium carbonate contained in an eggshell by using a back titration in order to address a farmer's concerns about his hen's fragile eggs. https://teachchemistry.org/classroom-resources/the-egg-straordinary-issue

Simulations

Salts and Solubility: Students can utilize this PhET simulation to learn about and experiment with the solubility of different types of salts. https://phet.colorado.edu/en/simulation/legacy/soluble-salts

pH Scale: Students can utilize this PhET simulation to learn about the pH of various substances on both a macro and micro level. https://phet.colorado.edu/en/simulation/ph-scale

CO_2, Shell Building and Ocean Acidification: This simulation uses chemical reactions to show where organisms must use energy to expel hydrogen ions (H^+) from bicarbonate ions (HCO_3^{2-}) to release carbonate ions (CO_3^{-2}) needed for shell building. http://www.whoi.edu/ocean-acidification/

Lessons and lesson plans

Iron Fertilization: In this lesson plan students learn about the Ocean Iron Fertilization Hypothesis and review data from the Monterey Bay Aquarium Research Institute to track the chemical changes that occur during an upwelling event. http://masweb.vims.edu/bridge/datatip.cfm?Bridge_Location=archive0504.html

Projects and Extension Activities

Research project on "Ocean Acidification": This investigation of "the other carbon dioxide problem" involves the study of the long-term effects of carbon dioxide acidification on aquatic animals. Suggested materials include articles, discussion questions, videos, and a virtual (data based) lab exercise on sea urchins. https://serc.carleton.edu/eslabs/carbon/7b.html

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Acids and Bases: indicators, pH, titrations
- Equilibrium: Le Chatelier's Principle

Correlations to Next Generation Science Standards

This article relates to the following performance expectations and dimensions of the NGSS:

HS-PS1-6

Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

Disciplinary Core Ideas:

- PS1.B: Chemical Reactions
- ESS3.C: Human Impacts on Earth Systems

Crosscutting Concepts:

- Scale, Proportion, and Quantity
- Systems and System Models
- Stability and Change

Science and Engineering Practices:

- Analyzing and interpreting data
- Constructing explanations (for science) and designing solutions (for engineering)

Nature of Science:

- Scientific knowledge assumes an order and consistency in natural systems.

Correlations to Common Core State Standards

See how *ChemMatters* correlates to the **Common Core State Standards** at www.acs.org/chemmatters.

Teaching Strategies

Consider the following tips and strategies for incorporating this article into your classroom:

- **Alternative to Anticipation Guide:** Before reading, ask students if they have ever seen jellyfish, and where they live. Ask students what they think they know about the chemistry of the oceans, including the dissolved minerals and pH. Ask students how increasing CO_2 in the air might affect the chemistry of the ocean.
- As they read, students can find information to confirm or refute their original ideas. *Do not tell students the answers prior to reading.*
- After they read, ask students what surprised them about the article. Ask them what ideas they have about maintaining the pH balance of the oceans.
- There is an interesting ACS Reactions video (about 5 minutes long) that relates to some articles in this issue: "Space Mirrors and Other Weird Ways to Fight Climate Change." suggested in the video. https://youtu.be/9agoVDFJs8A
- Consider showing the video after the students have read "Mirror Reflections" and "How to Raise a Jellyfish." Ask students to think about the risks and benefits of the solutions to problems.

ChemMatters™
Demystifying Everyday Chemistry

Teacher's Guide

Mirror Reflections

December 2020

Table of Contents

Anticipation Guide

Name: _____

Directions: ***Before reading the article*****,** in the first column, write "A" or "D," indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.
As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Before mirrors were invented, some people used a volcanic glass to reflect light.
		2. Metals have delocalized electrons that enhance reflection of light.
		3. Sodium is a good metal to use for mirrors because it polishes well.
		4. The round mirrors used by dentists have silver in them to reflect light.
		5. Copper and gold produce tinted reflections.
		6. Older mirrors were made using an amalgam of tin and mercury to coat glass.
		7. When you look at an image of yourself in a mirror, you appear to be behind the mirror.
		8. Most low-cost mirrors today are made with steel.
		9. The mirror on the Hubble Space Telescope is coated with silver.
		10. The first silvered mirrors were made using silver nitrate and ammonia.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. List some of the first objects used as mirrors. What were the common traits of these objects?

2. What property do the best mirrors, which provide for a good reflection, have in common?

3. What does the term "luster" mean? What characteristic of metal atoms creates their luster?

4. Explain how metallic bonding occurs using delocalized electrons.

5. What is the chemical reaction that explains how silver tarnishes?

6. Is glass needed for a mirror? What is the reasoning for mirrors to have glass?

7. What happens when a metal is oxidized? What happens to the delocalized electrons in metals when oxidation occurs?

8. Explain, based on atomic bonding and structure, why nonmetal solids cannot create a reflection.

9. Why should a mirror be flat? What would happen to an image if the mirror is curved?

10. We say light is "reflected" (bounced off a mirror). That is technically incorrect. What happens to the photons of light when they come in contact with the atoms of the reflective surface?

11. What does your brain assume when you look at an object in a mirror? Why do letters and numbers look backwards then?

Student Reading Comprehension Questions, cont.

12. When you look into the front side of a spoon, you see an upside down image of yourself. Explain how that happens (think how light reflects). (Sketching a diagram of reflecting light waves would help answer this question.)

13. The best metals for reflection are silver, gold, and copper. (The article also mentions other metals, such as rhodium, aluminum, and sodium, can be used for mirrors.) What makes silver a better metal for mirrors than copper or gold (think absorbing/reflecting colors)?

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Conduct some research on two-way mirrors. How do they work? Use this explanation to explain why it is easier for someone to look inside a window as opposed to outside a window when it is dark outside.

2. Metals typically bond with oxygen when they oxidize. Silver, however, more readily bonds with sulfur to make Ag_2S. Why does sulfur oxidize with silver more readily than oxygen?

3. Tarnished silver is actually the compound Ag_2S. Commercial tarnish removers remove the layer of silver sulfide to bring back the shiny look of pure silver. Unfortunately, this procedure removes the silver completely, so over time the object decreases in mass. There is another procedure that chemically removes tarnish without removing any of the silver. What is this procedure? What is the reaction, and why is it effective?

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe metals that could be used for the reflective surface of mirrors. Include descriptive words from the article such as luster, oxidize, amalgam, volatile, and sublimation.

Metal	Advantage(s)	Drawback(s)
Chromium		
Sodium		
Rhodium		
Aluminum		
Mercury		
Silver		
Gold		

Summary: Write a short email to a friend describing what you learned about the chemistry of mirrors.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **List some of the first objects used as mirrors. What were the common traits of these objects?**
   Original objects used for mirrors include shiny stones, metals, and obsidian. All had shiny, smooth, flat surfaces that provided the reflection.

2. **What property do the best mirrors, which provide for a good reflection, have in common?**
   The best mirrors reflect the highest amount of incoming, or incident, light. This light will bounce back to form accurate images in a viewer's eyes.

3. **What does the term "luster" mean? What characteristic of metal atoms creates their luster?**
   Luster is how a surface interacts with light. The delocalized electrons in a metal move around and vibrate at the same frequency as the incident light.

4. **Explain how metallic bonding occurs using delocalized electrons.**
   In metals, electrons move around from atomic orbital to atomic orbital. These electrons are not fixed on one atom. They flow like an "electron sea."

5. **What is the chemical reaction that explains how silver tarnishes?**
   Silver will tarnish when it reacts with sulfur compounds in the air. Hydrogen sulfide (H_2S) is the most common molecule that silver reacts with. The reaction is: $2\ Ag + H_2S \rightarrow Ag_2S + H_2$.

6. **Is glass needed for a mirror? What is the reasoning for mirrors to have glass?**
   The reason for using glass is that glass is one of the smoothest substances we have. This keeps the thin metal (silver, aluminum, etc.) from forming any imperfections that would alter the reflective image.

7. **What happens when a metal is oxidized? What happens to the delocalized electrons in metals when oxidation occurs?**
   When a metal is oxidized, the metal gives up one or more of its valence electrons to a nonmetal (i.e. oxygen) to become a positive ion. The positive ion forms an ionic bond with the negative ion of oxygen. The loss of electrons from the metal means that there are no delocalized electrons around the metal (which in turn takes away the metal's reflective properties).

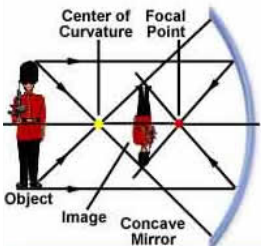
8. **Explain, based on atomic bonding and structure, why nonmetal solids cannot create a reflection.**
   Nonmetals bond through covalent bonding. These covalent bonds consist of shared electrons between two atoms. Because these valence electrons are shared, and not freely moving like delocalized electrons, they cannot reflect light like metals.

9. **Why should a mirror be flat? What would happen to an image if the mirror is curved?**
   A mirror must be flat so that the light hitting the mirror will reflect at the correct angle, providing an accurate image. If the mirror is not flat, it will reflect the light at odd angles, creating a distorted reflection. An example of this is funhouse mirrors.

10. **We say light is "reflected" (bounced off a mirror). That is technically incorrect. What happens to the photons of light when they come in contact with the atoms of the reflective surface?**
When the photons of light hit the atoms in the mirror, they vibrate the electrons in them. The electrons then release the same amount of energy as the incident light, so the same color of light is released back to the viewer's eyes (so, instead of reflecting, the mirror is "recreating" the image). (Link for explanation: https://youtu.be/iE6I52Th9DE).

11. **What does your brain assume when you look at an object in a mirror? Why do letters and numbers look backwards then?**
Your brain still assumes you are looking at something directly ahead. It cannot distinguish light reflecting. Your eyes sees letters backwards because the mirror reflects the light at the same angle the mirror receives it. So your eyes see the reverse image. (A good visual is for kids to look at the writing on their t-shirts from the inside. That is what the mirror is receiving.) This website is a good source: https://science.howstuffworks.com/question415.htm

12. **When you look into the front side of a spoon, you see an upside down image of yourself. Explain how that happens (think how light reflects). (Sketching a diagram of reflecting light waves would help answer this question).**
Because of the curvature of the spoon, when light hits the spoon, the reflection happens at a much different angle. All these reflected light beams converge into a focal point, and then continue in their opposite directions, causing a flipped image. See the diagram below:



13. **The best metals for reflection are silver, gold, and copper. (The article also mentions other metals, such as rhodium, aluminum, and sodium, can be used for mirrors.) What makes silver a better metal for mirrors than copper or gold (think absorbing/reflecting colors)?**
When someone sees the color white, what they see is a reflection of all the colors of the visible spectrum. When someone sees a specific color, that means the object reflects just that color, but absorbs the others. In metals, the color silver is very similar to the color white. So silver will reflect all colors it absorbs. Gold and copper already reflect their respective colors, which will tint the colors of the original object.

Questions for Further Learning

1. **Conduct some research on two-way mirrors. How do they work? Use this explanation to explain why it is easier for someone to look inside a window as opposed to outside a window when it is dark outside.**
A two way mirror is a piece of glass that will reflect like a mirror on one side, but is transparent when looked through the other side. This works when one side of the glass is in a very well lit room, and the other side is in a dark room. In the lighted room, some of the light (and images) passes through to the other side, while some reflects back. On the dark side, you cannot see a reflection, because there is not enough light to reflect. This is also why it is hard to look out a window at night, but someone outside can see in easily.

2. **Metals typically bond with oxygen when they oxidize. Silver, however, more readily bonds with sulfur to make Ag_2S. Why does sulfur oxidize with silver more readily than oxygen?**
   Silver reacts with sulfur more readily than oxygen. The main reason is that sulfur compounds break down more quickly than oxygen when they come into contact with silver.

3. **Tarnished silver is actually the compound Ag_2S. Commercial tarnish removers remove the layer of silver sulfide to bring back the shiny look of pure silver. Unfortunately, this procedure removes the silver completely, so over time the object decreases in mass. There is another procedure that chemically removes tarnish without removing any of the silver. What is this procedure? What is the reaction, and why is it effective?**
   Another common way to remove tarnish is to rub the affected silver with aluminum foil. Aluminum is higher on the activity series, so it will replace the silver in the sulfide compound. Thus, no silver will be lost. The reaction for this is:

$$3\ Ag_2S(s) + 2\ Al(s) \rightarrow 6\ Ag(s) + Al_2S_3(s)$$

Graphic Organizer Rubric

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

Additional Resources

Labs and demos

Silver to Black - and Back: This activity allows students to remove tarnish from silver using the reaction of tarnish with aluminum. https://pubs.acs.org/doi/10.1021/ed077p328A

Silver Test Tube Holiday Ornament: In this lab, students will carry out a reduction reaction in order to create a silver-plated test tube that can be used as a holiday ornament. https://teachchemistry.org/classroom-resources/silver-test-tube-holiday-ornament

Metallic Bonding & Magnetics: In this demonstration students will observe how electrons flow through a metal in an example of metallic bonding. Using tubes made of different metal materials as well as one made of plastic, in combination with a rare earth magnet (neodymium magnet) the teacher will demonstrate how electrons will flow freely through a metal and create a magnetic field. https://teachchemistry.org/classroom-resources/metallic-bonding-magnetics

Simulations/Videos

Why do I look upside down in a spoon? https://youtu.be/prWjk8UlRPs

How does light bounce off a mirror? https://youtu.be/iE6I52Th9DE

How do two-way mirrors work? https://youtu.be/4kKL32opewI

Aluminum Video https://teachchemistry.org/classroom-resources/aluminum-video

Lesson Plans

Observing Properties of Metals – observe different metals and learn about fundamental properties of elements and alloys. https://teachchemistry.org/classroom-resources/observing-properties-of-those-marvelous-metals

Informational Website

Chemistry world tarnish explanation
https://www.chemistryworld.com/news/simulations-solve-mystery-of-why-silver-tarnishes/3010299.article#/

Infographic: Making Silver mirrors
https://www.compoundchem.com/2017/09/06/silver-mirror/

Compound Interest: Removing tarnish
https://www.compoundchem.com/2013/12/16/removing-tarnish-silver/

Chemistry of Silver Tarnish & Solutions | Educational Innovations
http://blog.teachersource.com/2014/01/18/chemistry-of-tarnished-silver/

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Atomic Structure: electrons
- Chemistry Basics: physical properties
- States of Matter: sublimation
- Electrochemistry: redox reaction

Correlations to Next Generation Science Standards

This article relates to the following performance expectations and dimensions of the NGSS:

HS-PS1-1.
Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-ETS1-3.
Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraint, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- PS1.A: Structure and Properties of Matter
- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Patterns
- Structure and Function

Science and Engineering Practices:

- Obtaining, evaluating, and communicating information

Nature of Science:

- Scientific knowledge assumes an order and consistency in natural systems.

Correlations to Common Core State Standards

See how *ChemMatters* correlates to the **Common Core State Standards** at www.acs.org/chemmatters.

Teaching Strategies

Consider the following tips and strategies for incorporating this article into your classroom:

- **Alternative to Anticipation Guide:** Before reading, what they think is on the back of mirrors.
  - As they read, students can find information to confirm or refute their original ideas.
  - After they read, ask students what they learned about making mirrors.
- There is an interesting ACS Reactions video (about 5 minutes long) that relates to some articles in this issue: “Space Mirrors and Other Weird Ways to Fight Climate Change.” suggested in the video. https://youtu.be/9agoVDFJs8A
  - Consider showing the video after the students have read “Mirror Reflections” and “How to Raise a Jellyfish.” Ask students to think about the risks and benefits of the solutions

Mirror Mysteries

A variety of materials and methods have been used over the years to make mirrors. Five of the more common ones are listed below, but each letter has been randomly substituted with another letter of the alphabet. The letter substitutions are the same for each word. Can you identify all the materials and methods to make mankind's magnificent mirrors?

(Starting hint: Q stands for U and Y stands for M)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
												Y								Q					

Materials		***Methods***	
DOUBLE		WZUODNOAX	
ZVDOIOTA		TYTUXTYTPOZA	
XUTDD		LULFPEZWUTPOAX	
YLEFQEC		DQVUOYTPOZA	
TUQYOAQY		BTFQQY ILWZDOPOZA	

Mirror Mysteries – Answer Key

A variety of materials and methods have been used over the years to make mirrors. Five of the more common ones are listed below, but each letter has been randomly substituted with another letter of the alphabet. The letter substitutions are the same for each word. Can you identify all the materials and methods to make mankind's magnificent mirrors?

(Starting hint: Q stands for U and Y stands for M)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
T	**V**	**F**	**I**	**L**	**K**	**X**	**N**	**O**	**M**	**R**	**U**	**Y**	**A**	**Z**	**W**	**J**	**E**	**D**	**P**	**Q**	**B**	**H**	**S**	**C**	**G**

Materials		***Methods***	
DOUBLE	**SILVER**	WZUODNOAX	**POLISHING**
ZVDOIOTA	**OBSIDIAN**	TYTUXTYTPOZA	**AMALGAMATION**
XUTDD	**GLASS**	LULFPEZWUTPOAX	**ELECTROPLATING**
YLEFQEC	**MERCURY**	DQVUOYTPOZA	**SUBLIMATION**
TUQYOAQY	**ALUMINUM**	BTFQQY ILWZDOPOZA	**VACUUM DEPOSITION**

ChemMatters™
Demystifying Everyday Chemistry

Teacher's Guide

Can a Vaccine End the Pandemic?

December 2020

Table of Contents

Anticipation Guide

Name: _____

Directions: ***Before reading the article*****,** in the first column, write "A" or "D," indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.
As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. Most infants receive a vaccine for hepatitis B shortly after birth.
		2. Smallpox was the first disease treated by vaccination.
		3. Your skin is part of your immune system.
		4. Vaccines introduce part of a whole virus to make your body produce antibodies specific for the virus.
		5. All vaccines work the same way.
		6. COVID-19 is the first viral disease that has kept children home.
		7. Vaccines may contain formaldehyde.
		8. Some multi-dose vaccines contain the same amount of mercury as that in a 3-oz can of tuna.
		9. Aluminum phosphate is added to some vaccines to prevent unwanted bacteria and fungi growth.
		10. Smallpox has been eradicated due to the use of vaccines.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. What does a vaccine do for a person?

2. How did Dr. Edward Jenner's method differ from what the Chinese doctors had been doing to try to help people fight off smallpox?

3. Which part of the immune system can be "trained" using vaccines?

4. Why does giving you the virus in the form of a vaccine help you fight off the virus that you might eventually be exposed to?

5. What is the difference between an antigen and an antibody?

6. Formaldehyde is a compound used as a preservative in funeral homes. Why are tiny amounts of this compound included in a vaccine?

7. The three major parts of the coronavirus are the viral envelope, which is made of proteins, the spike proteins that cover the viral envelope, and the RNA that is inside the viral envelope.
    a. Which part of the virus is responsible for the reproduction of more virus particles?

    b. Which part of the virus is responsible for getting it into a human cell?

8. Make an analogy for a virus and use it to describe each of the four main strategies used to produce vaccines. (You do not have to consider what it will do in the body, only how it relates to the virus itself.)

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Watch the video using the link at the end of the article.
    a. The virus responsible for the COVID-19 pandemic is in a class of viruses, called coronaviruses, that our bodies have had prior exposure to. Why does this help to speed the development of a vaccine for this most recent virus?

    b. At what point in your exposure to a virus are you considered to be infected?

    c. What is the role of the spike protein on the SARS CoV-2 virus?

    d. Why is knowledge of the specific structure and shape of the spike protein on a coronavirus important to scientists that are working on a vaccine for that virus?

2. Choose one of the four vaccine strategies and explain how putting that type of vaccine in your body is different from infecting the body with the virus you are trying to fight.

3. Consider the doctors that originally worked with the smallpox virus. Write an experimental question, along with a hypothesis, that may have guided:
    a. the Chinese doctors.
    b. the English doctor, Edward Jenner.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe what you learned about vaccines.

3	**New things you learned about making vaccines**	
2	**Additives that may be added to vaccines, and why they are needed**	
1	**Question you have about vaccines**	
Contact!	**How does an understanding of chemistry help you make decisions about your health?**	

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **What does a vaccine do for a person?**
   A vaccine helps the immune system to fight off certain infections or diseases.

2. **How did Dr. Edward Jenner's method differ from what the Chinese doctors had been doing to try to help people fight off smallpox?**
   The Chinese doctors were using discharges from infected people to introduce the same virus into people as they were trying to prevent. Dr. Jenner used a similar, but not the same, virus and introduced it into people to see if it would stave off the intended virus.

3. **Which part of the immune system can be "trained" using vaccines?**
   The adaptive immune system, because it is more specific to the foreign substances in the body and adapts to remove or fight them.

4. **Why does giving you the virus in the form of a vaccine help you fight off the virus that you might eventually be exposed to?**
   It gives your body a chance to build up some immunity before you get infected, so it can fight it off faster.

5. **What is the difference between an antigen and an antibody?**
   An antigen is a substance or molecule that triggers an immune response. An antibody is produced by the body in response to the antigen so it can recognize the antigen, bind to it, and prevent it from doing its damage.

6. **Formaldehyde is a compound used as a preservative in funeral homes. Why are tiny amounts of this compound included in a vaccine?**
   Formaldehyde is a molecule which can inactivate a virus, making it unable to replicate.

7. **Three major parts of the coronavirus are the viral envelope, which is made of proteins, the spike proteins that cover the viral envelope, and the RNA that is inside the viral envelope.**
   a. **Which part of the virus is responsible for the reproduction of more virus particles?**
      RNA. When the RNA is released into a human cell, the cell treats it like any other RNA and ends up replicating many more viruses that eventually burst out of the cell to go infect new cells.
   b. **Which part of the virus is responsible for getting it into a human cell?**
      The spike protein. It binds with a receptor molecule on the outside of a cell, allowing it to then merge with the lipid membrane and deliver its contents to the inside of the cell.

8. **Make an analogy for a virus and use it to describe each of the four main strategies used to produce vaccines. (You do not have to consider what it will do in the body, only how it relates to the virus itself.)**
   Answers will vary. Look for understanding of how the vaccine component is different from the "live" virus.

Questions for Further Learning

1. **Watch the video using the link at the end of the article: bit.ly/Reactions-Vaccine**
   a. **The virus responsible for the COVID-19 pandemic is in a class of viruses, called coronaviruses, that our bodies have had prior exposure to. Why does this help to speed the development of a vaccine for this most recent virus?**
   Since our immune system has been exposed to similar types of molecules, it has already developed antibodies and a mechanism to fight it. Scientists do not have to start at the beginning of the process if they already know a lot about how the virus works and have already developed similar vaccines. The hope is that they can build on the framework of what has already been tested, thus saving a lot of time.
   b. **At what point in your exposure to a virus are you considered to be infected?**
   When the viral RNA has entered one of your cells.
   c. **What is the role of the spike protein on the SARS CoV-2 virus?**
   To find the receptor on the outside of the cell, starting the infection process.
   d. **Why is knowledge of the specific structure and shape of the spike protein on a coronavirus important to scientists that are working on a vaccine for that virus?**
   Understanding the structure can give scientists possible avenues for designing a vaccine molecule that prevents the spike protein from doing its job.

2. **Choose one of the four vaccine strategies and explain how putting that type of vaccine in your body is different from infecting the body with the virus you are trying to fight.**
   Weakened: These are very similar to the actual virus, but scientists have found a way to modify the part of it that allows replication inside your cells. If it doesn't make more viruses, it does not progress the infection.
   Inactive: These are also very similar to the actual virus, but scientists have completely inactivated its ability to replicate, while keeping the parts that trigger the immune response.
   Subunit: Sometimes a particular part of the virus is responsible for starting the infection process. In this case, it may be possible to use only that part of the virus, like a particular protein, rather than the full virus and RNA.
   Piggyback: Use a known and harmless virus to inject RNA or DNA into the human cell in the same way as an infection, but the injected nucleic acid will contain the genetic code for a specific part of the virus. This is similar to the subunit strategy, but the molecule is made in the cell, rather than added to the vaccine.

3. **Consider the doctors that originally worked with the smallpox virus. Write an experimental question, along with a hypothesis, that may have guided:**
   a. **The Chinese doctors.**
   b. **The English doctor, Edward Jenner.**
   Answers will vary. The difference will be that the Chinese doctors were using the exact virus, while Jenner was using a different one that was similar.

Graphic Organizer Rubric

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

Additional Resources

Labs and demos

Spreading Diseases: In this activity, students model how a virus spreads through a group. Demonstration similar to the one found at the following website to show how easily a virus can be transmitted. There are many variants of this demonstration. Some use a gel that glows under black light to track where the gel shows up after some activity. Others like this one use a non-contact version where students have water in cups and use any chemical that changes pH to represent the virus. All cups are later tested with phenolphthalein. https://www.sciencelearn.org.nz/resources/192-spreading-diseases

Simulations

"Solve the Outbreak" CDC Interactive Game: Get clues, analyze data, solve the scenario, and save lives! In this app, you get to be the Disease Detective. https://www.cdc.gov/mobile/applications/sto/web-app.html

Lessons and lesson plans

"The Vaccine Makers Project" Full lesson plans: Find 12 complete lesson plans covering the human immune system, disease and vaccination, biomedical research and animals, and how diseases spread. https://vaccinemakers.org/lessons

Projects and extension activities

Research one of the prior pandemics and describe the progression of the pandemic and how it finally ended.

Play a card game called "VaxCards". http://www.vaxcards.com/rules
The following description from the website explains why this should not be a touch subject.

- This game was created by doctors for a few simple reasons.
  - To educate kids and parents about vaccination and infectious diseases
  - To provide a fun way to achieve this education, and
  - To provide a reward for vaccination that kids want!
- Vaccination should not be a touchy subject, and we hope this game will start the conversation for those who are hesitant and make the process easier for parents and children to get educated about the diseases vaccines protect us from.

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Molecules & Bonding: Molecular structure

Correlations to Next Generation Science Standards

This article relates to the following performance expectations and dimensions of the NGSS:

HS-ETS1-3

Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraint, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Cause and Effect: Mechanism and explanation
- Structure and Function

Science and Engineering Practices:

- Constructing explanations (for science) and designing solutions (for engineering)
- Obtaining, evaluating, and communicating information

Nature of Science:

- Scientific knowledge assumes an order and consistency in natural systems.

Correlations to Common Core State Standards

See how *ChemMatters* correlates to the Common Core State Standards at www.acs.org/chemmatters.

Teaching Strategies

Consider the following tips and strategies for incorporating this article into your classroom:

- **Alternative to Anticipation Guide:** Before reading, ask students if how they think a vaccine against COVID-19 might work, and what might be in it.
- As they read, students can find information to confirm or refute their original ideas.
- After they read, ask students what they learned about how vaccines are developed.
- An excellent video (about 5 minutes long) that complements the information in the article is the ACS Reactions video: “Could a mRNA Vaccine End the Pandemic?” (also link on p. 18) https://youtu.be/gDY8pH6OWBc . This could be shown before or after reading the article.

About the Teacher's Guide

Teacher's Guide team editors Dusty Carroll, Scott Hawkins, Matt Perekupka, and Jennifer Smith created the Teacher's Guide article material. Susan Cooper prepared the anticipation, reading guides, and connections to standards.

Christine Suh (Managing Editor), Emily Abbott (Administrative Editor), and Lis Gallegos (Production Editor) coordinated the production and development of the Teacher's Guides.
E-mail: chemmatters@acs.org

Subscribe to *ChemMatters* magazine or purchase back-issues of the magazine at www.acs.org/chemmatters.