

ChemMatters™

Demystifying Everyday Chemistry

Teacher's Guide

December 2022

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December Teacher's Guide Introduction

Lesson Ideas

For all of the articles, encourage students to think about how science is done, how we know what we know, and how understanding chemistry relates to their lives. This month's "Open for Discussion" (page 4) is good for helping students understand the differences between observations and assumptions.

Teaching Ideas for this issue:

1. "Chemistry in Pictures" on page 2 shows a beautiful photo of a snowflake. Students may have heard the fascinating story of Snowflake Bentley, who was the first person to photograph snowflakes, because his story was made into a children's book popular in elementary schools. You can find more information about Bentley here: <https://snowflakebentley.com/> Ask students to compare how Bentley created his photographs compared to how the photo on page 2 was created.
2. "Open for Discussion" on page 4 describes an interesting lab activity to help students think more deeply about the differences between observations and assumptions. (You can [find the original lab module here](#), on page 40 of the Teacher's guide for IAC). Important topics related to the nature of science are introduced, including confirmation bias, the importance of questioning our assumptions, and how to base claims on evidence.
3. "Quick Read: Chewing Gum" on page 14 describes the many ingredients in chewing gum. There are two engaging ACS Reactions videos related to chewing gum that your students may find interesting:
 - o Gum + Chocolate = ????? (2:10) <https://youtu.be/baC4iuD4gGU> describes some solubility rules
 - o Does Gum Really Stay in Your Stomach for 7 Years? (3:25) https://youtu.be/R6R_V9xkAo describes some chemistry of the digestive process.
4. "What Can You Do with a Bachelor's Degree in Chemistry?" on pages 18 and 19 describes five diverse career paths for someone with a bachelor's degree in chemistry. After students read the article, ask students which career is most interesting to them and why.
5. Assign a team of students to read each feature article, then present what they learned in a podcast, PowerPoint or similar presentation, poster or brochure, or some other engaging format.
 - o Prior to reading the article, give students the Anticipation Guide for the article along with the graphic organizer and links to other information provided.
 - o Be sure to ask students to include information providing evidence for the claims made in the article.
6. Alternatively, students can create concept maps about the important concepts in the article they choose.

5E Lesson Ideas for individual articles:

Engage	Provide the Anticipation Guide, or ask a thoughtful question (see the individual Teacher's Guide for each article) to engage students in the reading. Students should record their initial ideas individually in pen so they can't be erased. Students can then discuss their initial ideas in small groups, or as a whole class.
Explore	Students read the article to discover more about the concepts in the article. During this phase, students will revisit their beginning ideas and record how the information in the article supports or refutes their initial ideas, providing evidence from the article.
Explain	Students answer questions and/or complete the graphic organizer provided for each article, then discuss their learning with their classmates. Students should recognize the evidence for the claims made in the articles, and how the evidence supports the claims.
Elaborate	Students can pose questions for further study. For most articles, there are related ACS Reactions videos students can watch to learn more about the concepts in the article. See the individual Teacher's Guide for each article to learn more. The videos are also listed below.
Evaluate	Students write a short summary of what they learned, describing how it connects to their lives. Students may also present their learning to their classmates or others.

Teacher's Guide

Sugar: 'White Gold,' Transforming America

December 2022

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This helps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.	
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Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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. Excessive sugar consumption is linked to increased risk of heart attack and stroke.
		2. Sugar cane was growing in America when the Europeans arrived.
		3. The boiling point of water on top of a mountain is greater than the boiling point of water in a pressure cooker.
		4. Two hundred years ago, sugar was concentrated and refined by using a series of increasingly smaller kettles called a sugar train.
		5. Norbert Rillieux, the inventor of the multiple effect evaporator, was educated in the United States.
		6. Sugar is a hydrocarbon.
		7. Glucose and sucrose are monosaccharides.
		8. Water can boil at room temperature if the pressure is low enough.
		9. Rillieux’s invention saved fuel in the process of sugar cane refining.
		10. The laws of thermodynamics were understood prior to the invention of the multiple effect evaporator.

Student Reading

Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. List some of the effects of consuming too much sugar.
2. What are some of the ideal conditions needed to grow sugar cane?
3. Describe the relationship between the boiling point of a liquid and the air pressure.
4. Assuming air pressure remains constant, what can also cause a liquid to boil at a higher boiling point?
5. What is the 1st law of thermodynamics?
6. List the steps Rillieux used to conserve energy in the sugar making process.
7. Even though outer space has a temperature near zero Kelvin (absolute zero, or about -273°C), water would exist only as a gas, and not a solid. Explain in terms of air pressure and boiling points.
8. Would it take longer to cook a pot of pasta in Denver, Colorado, or Lincoln Nebraska (or neither)? Explain.
9. Explain how pressure cookers are used to increase the speed of cooking foods.
10. Why does the concentration of sugar make the boiling point of the liquid higher?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

11. Colligative properties are physical properties of a liquid that change with the amount of solute (a dissolved substance) in it. Boiling point elevation is one example of a colligative property. Find some other examples, and explain how they work.
12. Research other minority scientists and write a brief biography on their discoveries as well as the challenges they had to face in their scientific pursuits.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe the history of sugar refining, the chemistry of sugar refining, and how sugar affects health.

	Historical Significance	Chemistry Involved
Sugar cane		
Sugar train		
Multiple Effect Evaporator		
Sources of sugar prior to sugar refining process		

	How are they related?	Examples
Boiling point & Vapor pressure		
Sugar & Carbohydrates		
Sugar & Health		

Summary: On the back of this sheet, write three things you learned about the history of sugar refining from the article.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. List some of the effects of consuming too much sugar.
Some of the effects of consuming too much sugar are high blood pressure, inflammation, weight gain, and diabetes.
2. What are some of the ideal conditions needed to grow sugar cane?
Rich, fertile soil and consistently warm temperatures are needed to grow sugar cane. This makes the Caribbean and southern states the most common areas for growing sugar cane.
3. Describe the relationship between the boiling point of a liquid and the air pressure.
The boiling point of a liquid is when the liquid molecules have enough energy to overcome the competing air pressure and break away from the surface of the liquid. The lower the air pressure, the lower the boiling point, because the liquid needs less energy to break through the lower air pressure.
4. Assuming air pressure remains constant, what can also cause a liquid to boil at a higher boiling point?
Another way to increase the boiling point is to add a dissolved substance (a "solute"). This solute causes the liquid to keep from boiling at its regular temperature.
5. What is the 1st law of thermodynamics?
The first law of thermodynamics states that energy is neither created nor destroyed. It is just converted into different forms.
6. List the steps Rillieux used to conserve energy in the sugar making process.
Rillieux used steam instead of wood fire to heat and power his machine. The hot steam was passed through closed tubes throughout the apparatus to provide constant heat during the entire process. He was also able to trap any heat escaping the machine, and diverted it to other areas. This eliminated the need to create more fires for additional sources of energy. He also lowered the pressure inside the apparatus, which allowed the liquid to boil off at a lower temperature.
7. Even though outer space has a temperature near zero Kelvin (absolute zero, or about $-273\text{ }^{\circ}\text{C}$), water would exist only as a gas, and not a solid. Explain in terms of air pressure and boiling points.
Even though space is very cold, the pressure is almost zero (no air pressure). With no air pressure to keep a substance together in the liquid phase, the liquid molecules will easily separate into gaseous vapor particles and scatter throughout space.
8. Would it take longer to cook a pot of pasta in Denver, Colorado, or Lincoln Nebraska (or neither)? Explain.
Pasta takes longer to cook in Denver, because of the higher altitudes. In these higher altitudes, the air pressure is much lower, so the water to cook the pasta boils at a temperature below $100\text{ }^{\circ}\text{C}$. Because of the lower cooking temperature, the pasta needs longer to become fully cooked.
9. Explain how pressure cookers are used to increase the speed of cooking foods.
A pressure cooker is a sealed cooking vessel that increases the pressure inside as the food is heated. The high pressure keeps the water the food is cooking in at a much higher temperature (a temperature typically higher than the boiling point of water). This high temperature allows the food to cook faster.

10. Why does the concentration of sugar make the boiling point of the liquid higher?

Sugar (or any dissolved substances) causes the boiling point of a liquid to increase. This is because of the attraction of the sugar molecules to the water molecules. The sugar molecules attracted to the water molecules hold them in the liquid phase, thus preventing them from releasing as a gas. More energy is needed to break these attractions and allow the water to convert to gas.

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 and Teaching Strategies

Additional Resources

❖ Labs and demos

- Changing the Boiling Point of Water
<https://teachchemistry.org/classroom-resources/changing-water-s-boiling-point>
- Changing the Freezing Point of Water
<https://teachchemistry.org/classroom-resources/sweet-salty-and-cold-as-ice>

❖ Simulations

- Effects of Solutes on Boiling and Freezing Points
<https://teachchemistry.org/classroom-resources/simulation-activity-the-effect-of-solutes-on-boiling-and-freezing-point>

❖ Lessons and lesson plans

- Boiling Point Infographic
<https://www.compoundchem.com/2016/03/22/boiling-point/>
- Candy Making Infographic
<https://www.compoundchem.com/2014/10/21/chemistryofcandy/>
- Natural Sweeteners Infographic
<https://cen.acs.org/food/Periodic-Graphics-Natural-sweeteners/98/i32>
- History of Norbert Rillieux
<https://teachchemistry.org/classroom-resources/norbert-rillieux-thermodynamics-and-chemical-engineering>

❖ Projects and extension activities

- Designing an Effective Respiratory Mask: <https://teachchemistry.org/classroom-resources/designing-an-effective-respiratory-cloth-mask>
- Tie Dye: <https://teachchemistry.org/classroom-resources/tie-dye>
- Video- Layered Fabrics in Heat Resistance: <https://teachchemistry.org/classroom-resources/ingenious-this-sandwich-will-save-your-life-in-an-arc-flash-video-questions>

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students where sugar is found in their diet, and how white table sugar is produced. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about sugar refining and how sugar relates to good health.

- More lesson planning resources about Norbert Rillieux's life and his invention of the multiple effect evaporator can be found at <https://teachchemistry.org/classroom-resources/norbert-rillieux-thermodynamics-and-chemical-engineering>

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Separating mixtures
- Intermolecular forces
- Molecular structure
- Boiling point

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 constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- PS.1.A: Structure and Properties of Matter
- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Cause and effect
- Energy and matter
- Systems and system models

Science and Engineering Practices:

- Constructing explanations (for science) and designing solutions (for engineering)

Nature of Science:

- Science is a human endeavor.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teacher's Guide

Leaves of Three, Let It Be

December 2022

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Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.	
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Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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. Poison ivy grows better in areas where there is less CO ₂ .
		2. Poison ivy remains green all year round.
		3. Birds and deer like poison ivy seeds.
		4. Poison ivy is in the same family as cashews and mangos.
		5. Urushiol, the chemical in poison ivy that causes a rash, contains only carbon, hydrogen, and oxygen.
		6. Urushiol has a nonpolar hydrocarbon tail.
		7. More than 90% of the population is allergic to poison ivy.
		8. Your skin is coated with nonpolar oils.
		9. Many things can transfer urushiol oil.
		10. There is clinical evidence that repeated exposure to poison ivy reduces sensitivity to its allergic effects.

Student Reading

Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. What is the most common allergic reaction in the United States?
2. Poison ivy does not impact all organisms in the same way. Name two organisms that find poison ivy useful and two organisms that are irritated by poison ivy.
3. Name four members of the anacardiaceae family.
4. How long can urushiol remain potent outside of a plant?
5. Name two cells responsible for the human body's immune response to urushiol.
6. In which seasons are people more likely to get poison ivy? Why might that be the case?
7. What role does polarity play in enabling urushiol to enter the epidermis?
8. What function might urushiol serve in plants?
9. Name the three elements that compose a catechol.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

10. Describe three ways that increasing levels of CO₂ in the environment impact poison ivy.
11. Explain how the structure of the hydrocarbon tail of catechols in urushiol impacts the severity of an allergic response.
12. Describe the difference between a polar molecule and a nonpolar molecule.
13. Beginning with lymphocytes and ending with macrophages, describe the steps of the immune response at the cellular level when urushiol reaches the second layer of human skin.
14. Review the article's list of possible remedies for rashes caused by poison ivy. Select one method, research it, and explain the chemistry involved in the remedy. For instance, research and explain how the ingredients in a corticosteroid impact an allergic reaction.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to explain the chemistry of poison ivy and how to protect yourself.

	Chemistry Involved
Urushiol	<i>Include structural formula</i>
Other sources of urushiol	
What causes the itching	
How the urushiol is transferred from the plant to you	
How the rash develops	
How to treat the rash	
How to protect yourself	

Summary: On the back of this sheet, explain what you learned in a short email to a friend who is highly allergic to poison ivy.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. What is the most common allergic reaction in the United States?
Poison ivy is the most common allergic reaction in the United States.
2. Poison ivy does not impact all organisms in the same way. Name two organisms that find poison ivy useful and two organisms that are irritated by poison ivy.
Deer and birds find poison ivy useful as food while guinea pigs and some primates are irritated by poison ivy.
3. Name four members of the anacardiaceae family.
Mangos, cashews, poison ivy, poison oak.
4. How long can urushiol remain potent outside of a plant?
Urushiol can be potent for up to five years after being transferred from a plant.
5. Name two cells responsible for the human body's immune response to urushiol.
T-cells and macrophages are two cells responsible for the human body's immune response to urushiol.
6. In which seasons are people more likely to get poison ivy? Why might that be the case?
People are more likely to get poison ivy in spring and summer. This may be because people spend more time outside in spring and summer.
7. What role does polarity play in enabling urushiol to enter the epidermis?
Urushiol and the oils on human skin have the same polarity, which allows urushiol to mix with the oils and enter the epidermis.
8. What function might urushiol serve in plants?
Urushiol may help plants ward off microbial infections.
9. Name the three elements that compose a catechol.
The elements included in a catechol are carbon, hydrogen, and oxygen.
10. Describe three ways that increasing levels of CO₂ in the environment impact poison ivy.
Increasing levels of CO₂ cause poison ivy to grow faster, increase in biomass, and produce urushiols that have higher degrees of unsaturation.
11. Explain how the structure of the hydrocarbon tail of catechols in urushiol impacts the severity of an allergic response.
The longer the alkyl chain or an increase in the number of double bonds increases the severity of the allergic reaction.
12. Describe the difference between a polar molecule and a nonpolar molecule.
A nonpolar molecule has charges that are evenly dispersed but a polar molecule has charges that are separated. Nonpolar molecules are hydrophobic while polar molecules are hydrophilic.

13. Beginning with lymphocytes and ending with macrophages, describe the steps of the immune response at the cellular level when urushiol reaches the second layer of human skin.

When urushiol reaches the second layer of skin, lymphocytes send cytokines to inform the body to send macrophages to attack the antigens.

14. Review the article's list of possible remedies for rashes caused by poison ivy. Select one method, research it, and explain the chemistry involved in the remedy. For instance, research and explain how the ingredients in a corticosteroid impact an allergic reaction.

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.

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4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
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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 and Teaching Strategies

Additional Resources

❖ Labs and demos

- [Solubility and Compound Type](#) - In this lab students test the solubilities of unknown substances that are polar, nonpolar, or ionic. This lab can help students understand how urushiol enters the skin.
- [Modeling Bond Polarity](#) - This hands-on activity provides students with the opportunity to create model representations of polar and non-polar bonding, which can help them understand the chemistry involved in allergic reactions to poison ivy.

❖ Lessons and lesson plans

- [Insect Herbivores and Plants](#) - By exploring the pages on this site, students can learn more about the various chemicals that plants can produce for protection.
- [The Immune System](#) - This HHMI Biointeractive lesson plan includes videos, simulations, and readings to help students understand the parts of the immune system as well as the functions associated with the immune response.

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 are allergic to poison ivy, how they think the rash develops, how they protect themselves, and how they treat a poison ivy rash. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about how chemistry can help us understand allergic reactions to poison ivy.
- After students have read and discussed the article, ask students what they would like to share with friends and family about why poison ivy produces a rash, and how they can protect themselves.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Solutions
- Intermolecular forces
- Molecular structure

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.

Disciplinary Core Ideas:

- PS.1.A: Structure and Properties of Matter

Crosscutting Concepts:

- Cause and effect
- Structure and function

Science and Engineering Practices:

- Obtaining, evaluating, and communicating information

Nature of Science:

- Scientific knowledge is based on empirical evidence.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teacher's Guide

What is Dental Enamel?

December 2022

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Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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. Sugar contributes to dental enamel damage.
		2. Dental enamel protects dentin and pulp, both of which are soft.
		3. Dental enamel contains calcium and phosphorus, in addition to carbon, hydrogen, and oxygen.
		4. The outer layer of dental enamel is about a millimeter thick.
		5. The molecules in inner dental enamel are arranged to provide strength and avoid cracks in the enamel.
		6. Magnesium is needed for strong enamel.
		7. Dental plaque that is scraped off your teeth by the hygienist is mostly minerals.
		8. Acid produced by bacteria weakens tooth enamel.
		9. Brushing your teeth with fluoride toothpaste can make your teeth stronger.
		10. Your teeth can last for more than a hundred years.

Student Reading

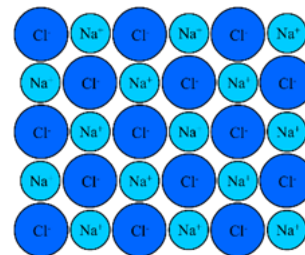
Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

- For compounds classified as apatites, answer the following questions:
 - What is the major cation? _____
 - What is the major anion? _____
 - If the above two ions were the only components of the compound, what would be its chemical formula? _____
 - What is the total positive charge in one formula unit of an apatite compound? _____
 - What are the sign and magnitude of the charge an ion must have in order to complete the generic formula for an apatite by filling in the "X"? Explain your answer.
- Determine the percent composition for each **ion** in hydroxyapatite. Show your calculations.
- What is the percentage of oxygen in a sample of hydroxyapatite?
- One characteristic of simple ionic compounds is that they are brittle, due to their very regular crystalline structures. This means that a sample of an ionic compound is more likely to fracture into pieces when a force is applied than to simply deform and change shape.

- Using the model of sodium chloride, NaCl, explain why a force on one part of the crystal would easily cause a fracture to spread along a line all the way to the other side of the crystal.



- Explain how the crystal structure of hydroxyapatite in tooth enamel prevents these fractures from causing the enamel to crack away from the teeth.
- Though tooth enamel is primarily made from hydroxyapatite, small amounts of some magnesium salts are also found between the various formations of the irregular crystals. These salts appear to add to the mechanical strength and quality of the enamel. List the name and chemical formulas for the anions of the magnesium salts that are found within the hydroxyapatite.
 - What is in the plaque that the dentist scrapes from your teeth when you get a dental cleaning?
 - Sugar is not considered a corrosive substance, but we are always warned that sugar will ruin our teeth. Describe the role of sugar in tooth decay.
 - Explain why the fluoride ion, commonly added to either water or toothpaste, helps to make your teeth more resistant to decay. Write the chemical formula for the substance most responsible for this effect.

The following are appropriate for AP Chemistry or for an advanced chemistry class.

- The phosphate ion is a relatively strong base. Write a net ionic equation that shows how an acid would react with phosphate ions if there were an equimolar proportion of each.

10. Draw a Lewis structure for the phosphate ion, including formal charges.
- Identify the total number of resonance structures needed to describe this molecular ion. ____
 - Describe the molecular polarity of this molecular ion.
 - Estimate the O-P-O bond angle for this molecular ion. ____

11. Write the hydrolysis reaction equation that occurs when one phosphate ion reacts with one water molecule.

- Draw a Lewis structure for the conjugate acid of the phosphate ion in this reaction.

Compound	Value of K_{sp}
$\text{Ca}_5(\text{PO}_4)_3\text{OH}$	4.34×10^{-26}
CaHPO_4	8.42×10^{-12}
$\text{Ca}_3(\text{PO}_4)_2$	1.01×10^{-3}

- The K_{sp} values above are for various calcium and phosphate compounds. Use the K_{sp} values to explain why acid coming into contact with hydroxyapatite can be destructive.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

Hydroxyapatite is an example of a double salt.

12. Find the chemical formulas for other double salts, such as dolomite and alum.
13. Determine uses for these double salts.
14. Explain how the properties of the double salt are more favorable for a given use than either of the single cation-anion combinations would be on its own.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe the chemistry and structure of dental enamel.

Chemicals	Formula	Importance to dental enamel
Hydroxyapatite		
Magnesium fluoride		
Magnesium carbonate		

Structure	Description (in your words)	Importance to dental enamel
Aprismatic enamel		
Rods		
Hydroxyapatite microcrystals		

Summary: On the back of this sheet, write a one-sentence summary (18 words or less) of the article.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. For compounds classified as apatites, answer the following questions:

- What is the major cation? Ca^{2+}
- What is the major anion? PO_4^{3-}
 - If the above two ions were the only components of the compound, what would be its chemical formula? $\text{Ca}_3(\text{PO}_4)_2$
- What is the total positive charge in one formula unit of an apatite compound? **+10**
- What are the sign and magnitude of the charge an ion must have in order to complete the generic formula for an apatite by filling in the "X"? Explain your answer.
-1. Five calcium ions make up +10 charge. Three phosphate ions make up -9 charge. An ionic compound must have a neutral charge.

2. Determine the percent composition for each **ion** in hydroxyapatite. Show your calculations.

Ca- 40.078 g/mol; P- 30.974 g/mol; O- 15.999 g/mol; H- 1.008 g/mol

Ca^{2+} : $200.390/502.307 \times 100 = 39.9\%$

PO_4^{3-} : $284.910/502.307 \times 100 = 56.7\%$

OH^- : $17.007/502.307 \times 100 = 3.4\%$

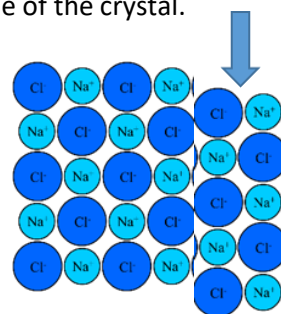
3. What is the percentage of oxygen in a sample of hydroxyapatite?

$207.987 \text{ g O} / 502.307 \text{ g compound} \times 100 = 41.4\% \text{ oxygen}$

4. One characteristic of simple ionic compounds is that they are brittle, due to their very regular crystalline structures. This means that a sample of an ionic compound is more likely to fracture into pieces when a force is applied than to simply deform and change shape.

- Using the model of sodium chloride, NaCl, explain why a force on one part of the crystal would easily cause a fracture to spread along a line all the way to the other side of the crystal.

If a force is applied, it will push like charges to be much closer together than they are in the original crystal. Since the crystal structure is very rigid, most of the ions in line with the force would be shifted. Since this would cause all ions to be closer to other ions with like charges, the overall repulsion would quickly allow the fracture to travel down the line of alternating charges, and split along the plane.



- Explain how the crystal structure of hydroxyapatite in tooth enamel prevents these fractures from causing the enamel to crack away from the teeth.

In hydroxyapatite, the ions are not arranged in one large perfectly crystalline structure. There are areas of crystallinity that are somewhat randomly oriented. In this less regular arrangement, both the energy and the direction of a fracture will be limited to the portion of the structure that is in a very regular arrangement. Once the line of fracture meets a different arrangement, the energy can spread in multiple directions and the dislocation of ions would no longer cause them to shift to a repulsive position. This less regular arrangement allows forces to be applied in

many directions without a net effect in any one direction that would cause a piece of the structure to fracture away from the tooth.

5. Though tooth enamel is primarily made from hydroxyapatite, small amounts of some magnesium salts are also found between the various formations of the irregular crystals. These salts appear to add to the mechanical strength and quality of the enamel. List the name and chemical formulas for the anions of the magnesium salts that are found within the hydroxyapatite.

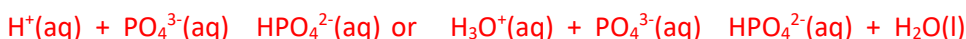
Fluoride, F^-

Carbonate, CO_3^{2-}

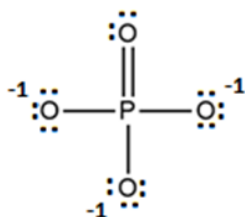
6. What is in the plaque that the dentist scrapes from your teeth when you get a dental cleaning?
The plaque is mostly bacteria, with about 30-40% of it being carbohydrates and proteins from our saliva.
7. Sugar is not considered a corrosive substance, but we are always warned that sugar will ruin our teeth. Describe the role of sugar in tooth decay.
Sugar, itself, does not cause the harm. Sugar is, however, readily used as nutrient for bacteria. When the bacteria metabolize the sugar, acids are produced, which can break down the enamel of the tooth.
8. Explain why the fluoride ion, commonly added to either water or toothpaste, helps to make your teeth more resistant to decay. Write the chemical formula for the substance most responsible for this effect.
When fluoride is present, some of the hydroxyapatite can convert into fluorapatite, which is more resistant to acids than the hydroxyapatite.

The following are appropriate for AP Chemistry or for an advanced chemistry class.

9. The phosphate ion is a relatively strong base. Write a net ionic equation that shows how an acid would react with phosphate ions if there were an equimolar proportion of each.



10. Draw a Lewis structure for the phosphate ion, including formal charges.

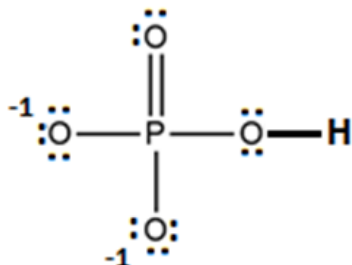


- a. Identify the total number of resonance structures needed to describe this molecular ion.
4 total resonance structures (double bond could be in each of the four positions)
- b. Describe the molecular polarity of this molecular ion.
This ion would be nonpolar, because it has four equivalent P-O bonds symmetrically arranged into a tetrahedron, leaving zero dipole moment.
- c. Estimate the O-P-O bond angle for this molecular ion.
The tetrahedral angle is approximately 109.5° .

11. Write the hydrolysis reaction equation that occurs when one phosphate ion reacts with one water molecule.



a. Draw a Lewis structure for the conjugate acid of the phosphate ion in this reaction.



Compound	Value of K_{sp}
$\text{Ca}_5(\text{PO}_4)_3\text{OH}$	4.34×10^{-26}
CaHPO_4	8.42×10^{-12}
$\text{Ca}_3(\text{PO}_4)_2$	1.01×10^{-3}

b. The K_{sp} values above are for various calcium and phosphate compounds. Use the K_{sp} values to explain why acid coming into contact with hydroxyapatite can be destructive.

Hydroxyapatite has a very low K_{sp} value, meaning it is largely insoluble. If an acid protonates the phosphate, like in the above reaction, that converts the phosphate into hydrogen phosphate. Hydrogen phosphate, in the presence of calcium is significantly more soluble than phosphate in the presence of calcium, as the K_{sp} for CaHPO_4 is about 14 orders of magnitude greater than that for hydroxyapatite. Since phosphate is a relatively strong base (K_b is approximately 1×10^{-2}), phosphate would readily protonate in the presence of an acid, and the hydroxide from hydroxyapatite would protonate to form water, thus converting some amount of the hydroxyapatite into the more soluble calcium hydrogen phosphate compound.

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 and Teaching Strategies

Additional Resources

❖ Labs and demos

- Investigate the equilibrium of hydroxyapatite to show how acid shifts the solubility equilibrium to dissolve more of it.
- Explore the acid/base equilibrium and solubility equilibrium of calcium phosphate or just the acid/base equilibrium of just the phosphate ion, using sodium phosphate.
- Determine the chemical formula for a double salt, like Alum, through a series of chemical reactions and separations.
- Students create their own double salts by dissolving two salts and crystallizing by evaporation. They can then investigate how the physical properties differ between the individual salts and the double salt.

❖ Lessons and lesson plans

- ChemMatters article, Oct. 2016: “How Sue Became a Rock Star” talks about the role of hydroxyapatite in fossils

❖ Projects and extension activities

- Research how hydroxyapatite is being used in tissue engineering to aid bone regeneration.
- Research other organisms where hydroxyapatite, or other calcium phosphates, are significant structure components. (e.g. fish bones, corals, eggshells)

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 had dental cavities, and why cavities might form in your teeth. Ask them what dental enamel might be made from, and how durable it is. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students how chemistry and physics help explain how strong their dental enamel is.
- After students have read and discussed the article, ask students how they can protect their teeth and how the information in the article informs their decision.
- This article relates somewhat to the Quick Read article on page 14: Chewing Gum. This article describes the many ingredients in chewing gum, including sweeteners. Students may investigate the pros and cons of the sweeteners used to flavor chewing gum.
- On a first-year chemistry level, this would fit nicely into a unit on chemical formulas, when students are just learning about moles and molar mass.
- On an advanced, or AP level, there are a lot of acid/base and solubility equilibrium applications possible here. It can also be used during a bonding unit, or a unit addressing intermolecular and other interparticle forces in different types of substances (ionic, molecular, metallic, network)

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Physical properties
- Acids
- pH

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.

Disciplinary Core Ideas:

- PS.1.A: Structure and Properties of Matter

Crosscutting Concepts:

- Cause and effect
- Structure and function

Science and Engineering Practices:

- Constructing explanations (for science) and designing solutions (for engineering)

Nature of Science:

- Science addresses questions about the natural and material world.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teacher's Guide

The Chemistry of Deception

December 2022

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Activate students' prior knowledge and engage them before they read the article.	
<u>Reading Comprehension Questions</u>	39
These questions are designed to help students read the article (and graphics) carefully. They can help the teacher assess how well students understand the content and help direct the need for follow-up discussions and/or activities. You'll find the questions ordered in increasing difficulty.	
<u>Graphic Organizer</u>	41
This helps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.	
<u>Answers</u>	42
Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.	
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Here you will find additional labs, simulations, lessons, and project ideas that you can use with your students alongside this article	
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Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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. Lemon juice was used by German spies during World War I to send secret messages.
		2. Milk, fruit juices, and human body fluids have all been used to send secret messages.
		3. Revolution spies in George Washington’s time developed a new type of invisible ink.
		4. Tannic acid contains iron.
		5. Tannic acid is found in tea, coffee, chocolate, and bitter other foods.
		6. Cellulose is a polysaccharide.
		7. Incomplete combustion of carbon compounds produces carbon dioxide.
		8. German spies used an antiseptic containing silver to create invisible ink.
		9. Ultraviolet (UV) light has a longer wavelength than the light we can see.
		10. Invisible UV inks must be viewed with a UV light.

Student Reading

Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. What common citrus fruit was used in early spy missions to create invisible messages? What did the reader have to do to reveal the hidden secret?
2. Discuss the chemical composition of the “magical white ink” used by George Washington during the American Revolution. Explain how the ink was “developed” so the recipient could read the message.
3. Explain the process of chelation. Discuss a real world use of chelation in the medical field.
4. Explain how lemon juice browns faster when subjected to heat than the paper it is written on.
5. The Germans' secrets for developing silver invisible ink were unfortunately lost over time. Discuss the process French scientists derived to reveal messages written with silver based invisible ink.
6. How do ultraviolet invisible inks work?
7. The article mentions electrolysis as a means of developing secret messages written with silver invisible ink. Discuss electrolysis and some common uses of electrolysis.
8. A portion of the electromagnetic spectrum is shown on page 17. Discuss the wavelength, frequency, and uses of 3 of the 7 types of electromagnetic radiation on the diagram at the top of the page.
9. The article discusses how bonds in the tannic acid structure resonating between single and double bonds affect energy absorption and thus are responsible for the color of the compound. Resonating single and double bonds causes electrons to be “delocalized” inside the molecule. Define delocalized electrons and list some properties associated with molecules containing delocalized electrons.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

10. War, despite its horrors, often accelerates progress and innovation. Many of the technologies we enjoy today were invented in a time of war due to a nation trying to secure victory. Make an infographic discussing at least 5 technologies or innovations that were developed or invented during a time of war.
11. Now it's your turn! Attempt to make an encrypted message using either a mysterious alphabet, pattern, or invisible ink. If invisible ink supplies are available such as lemon juice or other chemicals be sure to follow safety precautions presented by your teacher. Give your message to a friend or partner with instructions on how to "develop" the message. If you create a message using a pattern, mysterious alphabet, puzzle, or other technique, give your message to a friend or partner and see if they can crack the code! Please keep the hidden messages appropriate and kind!

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe how invisible inks work.

Type of Invisible Ink	Chemicals (or ingredients) involved	How the message is made visible
Milk		
Magical White Ink		
Lemon Juice		
Silver Invisible Ink		
Ultraviolet Invisible Ink		

Summary: On the back of this sheet, write a short email (3-4 sentences) to an older relative describing what you learned about invisible inks.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. What common citrus fruit was used in early spy missions to create invisible messages? What did the reader have to do to reveal the hidden secret?
Lemons, lemon juice, were used to create invisible messages by the Germans in World War 1. The invisible message could be revealed by applying heat to the paper, darkening the ink.
2. Discuss the chemical composition of the “magical white ink” used by George Washington during the American Revolution. Explain how the ink was “developed” so the recipient could read the message.
Tannic acid was the primary component of the magical white ink. The ink could be developed using Iron (II) Sulfate which darkened the message through a process called chelation.
3. Explain the process of chelation. Discuss a real world use of chelation in the medical field.
Chelation involves organic molecules surrounding a metal atom by bondings at several points. Chelation is used by doctors to extract heavy metals from the body.
4. Explain how lemon juice browns faster when subjected to heat than the paper it is written on.
Lemon juice contains simple sugars and acids that combust more rapidly than the complex polysaccharides that are found in paper.
5. The Germans' secrets for developing silver invisible ink were unfortunately lost over time. Discuss the process French scientists derived to reveal messages written with silver based invisible ink.
The message was placed in a medium of silver nitrate with a reducing agent which serves as an electron donor. Electricity is applied to the medium which causes silver metal to be plated where the message was written making it visible. The process is known as electrolysis.
6. How do ultraviolet invisible inks work?
Ultraviolet light is not visible to the human eye. Ultraviolet markers can be used to write a message that can only be read when exposed to ultraviolet light which will cause the message to glow with fluorescent light.
7. The article mentions electrolysis as a means of developing secret messages written with silver invisible ink. Discuss electrolysis and some common uses of electrolysis.
Answers may vary. Example answer: Electrolysis is the process of using electricity to drive a nonspontaneous process or chemical reaction, particular redox reactions. Electrolysis can be used to plate metals on other metals for various purposes or products.
8. A portion of the electromagnetic spectrum is shown on page 17. Discuss the wavelength, frequency, and uses of 3 of the 7 types of electromagnetic radiation on the diagram at the top of the page.
Answers may vary. Example answer: X-rays have a wavelength of 10^{-8} to 10^{-12} meters and a frequency of 10^{16} to 10^{20} hertz. X-rays can be used to take images of bones and hard tissue inside the body.
9. The article discusses how bonds in the tannic acid structure resonating between single and double bonds affect energy absorption and thus are responsible for the color of the compound. Resonating single and double bonds causes electrons to be “delocalized” inside the molecule. Define delocalized electrons and list some properties associated with molecules containing delocalized electrons.

Delocalized electrons are electrons in a molecule that are not associated with a single atom or covalent bond. They are able to flow or move within the molecule. Delocalized electrons give molecules the ability to conduct electricity and/or be malleable, such as metals.

10. War, despite its horrors, often accelerates progress and innovation. Many of the technologies we enjoy today were invented in a time of war due to a nation trying to secure victory. Make an infographic discussing at least 5 technologies or innovations that were developed or invented during a time of war.

Answers may vary. Examples are radar, penicillin, computers.

11. Now it's your turn! Attempt to make an encrypted message using either a mysterious alphabet, pattern, or invisible ink. If invisible ink supplies are available such as lemon juice or other chemicals be sure to follow safety precautions presented by your teacher. Give your message to a friend or partner with instructions on how to "develop" the message. If you create a message using a pattern, mysterious alphabet, puzzle, or other technique, give your message to a friend or partner and see if they can crack the code! Please keep the hidden messages appropriate and kind!

Answers may 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.
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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 and Teaching Strategies

Additional Resources

❖ Labs and demos

- Investigating Ink Lab Activity
<https://teachchemistry.org/classroom-resources/investigating-black-ink>
- Homemade Invisible Ink Activity
<https://teachchemistry.org/classroom-resources/top-secret>

❖ Lessons and lesson plans

- Electrolysis Lesson
<https://teachchemistry.org/classroom-resources/exploration-of-electrolytic-cells>
- Delocalized Electrons and Material Science Article
<https://teachchemistry.org/periodical/issues/may-2022/bringing-materials-chemistry-into-the-teaching-of-bonding>

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 used invisible ink to send secret messages. Also ask them who might find invisible ink useful, and how invisible inks might work. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about the varieties of invisible inks.
- After students have read and discussed the article, ask students what they learned about invisible ink and how it relates to other subjects, including history.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Physical properties
- Molecular structure
- Chemical change
- Electrolysis

Correlations to Next Generation Science Standards

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

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Disciplinary Core Ideas:

- PS.1.A: Structure and Properties of Matter
- PS.1.B: Chemical Reactions
- ETS1.B: Developing Possible Solutions

Crosscutting Concepts:

- Cause and effect
- Energy and matter
- Structure and function

Science and Engineering Practices:

- Constructing explanations (for science) and designing solutions (for engineering)

Nature of Science:

- Science is a human endeavor.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).