ChemMatters

Demystifying Everyday Chemistry

Teacher's Guide
October 2017

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Teacher's Guide

"A Toxic Dose of Water"

(October/November 2017 Issue)

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ChemMatters
Demystifying Everyday Chemistry

Teacher's Guide for

"A Toxic Dose of Water"

October/November 2017

Table of Contents

Connections to Chemistry Concepts

Chemistry Concept	Connection to Chemistry Curriculum
Ionic compounds	During the study of ionic compounds, use the information in this article to show how anions and cations play an essential role in maintaining the health of organisms.
Electrolytes	When discussing conductivity and ions in class, refer to how electrolytes like Na^+ are responsible for transmitting electrical impulses through the nervous system. In hyponatremia, low Na^+ can disrupt these signals.
Concentration units	While chemists usually describe solution concentrations in molarity (M), other units are also used (e.g., molality [*m*], parts per thousand [ppt], parts per million [ppm], etc.); and biologists often use percent by mass (g solute/100g water).
Energy of evaporation (Kinetic Energy of water molecules)	The endothermic phase change from liquid water (sweat) to gaseous water during evaporation requires energy sufficient to increase the kinetic energy of water molecules until the hydrogen bonds between the molecules break, removing heat from the body.

Teaching Strategies and Tools

Standards

- Links to **Common Core Standards for Reading**:
  ELA-Literacy.RST.9-10.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  ELA-Literacy.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).
  ELA-Literacy.RST.11-12.1: Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
  ELA-Literacy.RST.11-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*.

- Links to **Common Core Standards for Writing**:
  ELA-Literacy.WHST.9-10.2F: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
  ELA-Literacy.WHST.11-12.1E: Provide a concluding statement or section that follows from or supports the argument presented.

- Links to **Next Generation Science Standards**
  HS-LS1-2: Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
  - **Disciplinary Core Ideas:**
    - LS1.A: Structure and Function
  - **Crosscutting Concepts:**
    - Systems and system models
    - Scale, proportion, and quantity
  - **Science and Engineering Practices:**
    - Developing and using models
    - Constructing explanations and designing solutions
  - **Nature of Science:**
    - Scientific knowledge assumes an order and consistency in natural system

Vocabulary

Vocabulary and **concepts** that are reinforced in October 2017 issue:

- Equilibrium
- Solute and solvent
- Electrolyte
- Ions
- Lipids
- Osmosis
- Metallic and nonmetallic

- Igneous, sedimentary, metamorphic rocks
- Composting
- Aerobic and anaerobic
- Carcinogen
- Heavy metals
- Amalgam
- Polymerization
- Composites

Reading Supports for Students

The pages that follow include reading supports in the form of an Anticipation Guide, Reading Strategies, a Graphic Organizer, and Student Reading Comprehension Questions. These resources are provided to help students as they prepare to read and in locating and analyzing information from the article.

The borders on these pages distinguish them from the rest of the pages in this Teacher's Guide—they have been formatted for ease of photocopying for student use.

- **Anticipation Guide (p. 9:** The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

- **Graphic Organizer (p.10):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

  If you use the **Anticipation Guide** or **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

- **Student Reading Comprehension Questions (p. 11-12):** The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.

- **Additional Reading Supports:**
  - This issue supports the 2017 National Chemistry Week theme of “Chemistry Rocks!”
  - Most of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them in their personal lives.
  - Consider asking students to read “Open for Discussion: Sports Drinks” on page 4 to extend the information in “A Toxic Dose of Water” on pages 5-7.
  - The infographic on page 19 provides more information to support the article “Making Water Safe to Drink” on pages 14-16.
  - To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles.
  - You might also ask them how information in the articles might affect their health and/or consumer choices. Also ask them if they have questions about some of the issues discussed in the articles.
  - To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles. Some of the articles in this issue provide opportunities, references, and suggestions for students to do further research on their own about topics that interest them. The “Web Sites for Additional Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

Anticipation Guide

Directions: ***Before reading the article*****,** in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. 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. Cells can shrink or swell depending on the amount of water inside.
		2. Most of the water in our bodies is within our cells.
		3. The most plentiful positive ion inside our cells is sodium ion (Na^+).
		4. Potassium, sodium, and chloride ions move as freely as water between cells.
		5. Medications, including ibuprofen, can contribute to hyponatremia (too much Na+ inside the cell).
		6. Drinking too much water can dilute the Na^+ concentration in your blood.
		7. Sports drinks are unsafe for athletes to use in any amount in hot weather.
		8. The semipermeable membranes in our bodies are composed of lipids.
		9. Electrolyte solutions conduct electricity.
		10. The symptoms of dehydration and hyponatremia are the same.

Graphic Organizer

Name: ______________________________

Directions: ***As you read***, complete the graphic organizer below to compare different air pollutants.

What is it?	**How does it affect electrolyte balance?**
	What causes hyponatremia?

Osmosis

Summary: On the bottom or back of this paper, write a short email (about 3 sentences) to a friend who wants to know how drinking too much water can affect your body.

Student Reading Comprehension Questions

Directions: Use the article to answer the questions below.

Name

1. What was the cause of Zyrees's death?

2. What happened to Cynthia at mile 22 of the Boston Marathon?

3. What causes (a) dehydration, and (b) hyponatremia?

4. What happens when the amount of water inside body cells (intracellular) is (a) too low, or (b) too high?

5. Why is the constant exchange of water between intracellular and extracellular areas critically important?

6. (a) How do chemists usually report the concentration of a solution? (b) How is molarity defined?

Student Reading Comprehension Questions, cont.

7. Complete the following table: Use Table 1 and information in the article to identify the ion in each column that has the largest concentration, and state the ion's location (extracellular or intracellular).

Highest Concentration	Ion	Location
Cell (M)		
Blood (M)		

8. (a) Why is a cell membrane considered semipermeable? (b) What does the process of osmosis describe?

9. In addition to consuming too much water that can result in hyponatremia, what medications can play a role in bringing on this condition?

10. What happens when the sodium level in blood plasma falls below 0.135M?

11. What probably killed Zyrees and Cynthia?

12. Describe the symptoms of dehydration. Why is it especially important to watch for these?

Answers to Student Reading Comprehension Questions

1. **What was the cause of Zyrees's death?**
   The cause of Zyrees's death was consuming too much water.
2. **What happened to Cynthia at mile 22 of the Boston Marathon?**
   Cynthia passed out at mile 22 of the Boston Marathon (and died 3 days later of hyponatremia).
3. **What causes (a) dehydration, and (b) hyponatremia?**
   a. *Dehydration can be caused by not drinking enough water.*
   b. *Hyponatremia can be caused by drinking too much water.*
4. **What happens when the amount of water inside body cells (intracellular) is (a) too low, or (b) too high?**
   a. *When the water content inside body cells is too low, cells can shrink.*
   b. *When the water content inside body cells is too high, cells can swell and burst.*
5. **Why is the constant exchange of water between intracellular and extracellular areas critically important?**
   The constant exchange of water between intracellular and extracellular areas …"is critically important for hydration, nerve impulses, muscle function (including the heart) and pH level."
6. **(a) How do chemists usually report the concentration of a solution? (b) How is molarity defined?**
   a. *Chemists usually report the concentration of a solution in terms of molarity (M).*
   b. *Molarity is defined as the number of moles of solute divided by the volume of the resulting solution in liters.*
7. **Complete the following table: Use Table 1 and information in the article to identify the ion in each column that has the largest concentration, and state the ion's location (extracellular or intracellular).**

Highest Concentration	Ion	Location
Cell (M)	*K^+*	*Intracellular (within cells)*
Blood (M)	*Na^+*	*Extracellular (outside cells)*

8. **(a) Why is a cell membrane considered semipermeable? (b) What does the process of osmosis describe?**
   a. *A cell membrane is considered semipermeable because water molecules freely pass through the cell membrane, while movement of ions (Na^+, K^+, and Cl^-) is partially blocked.*
   b. *The process of osmosis "describes water molecules moving from an area of low-solute concentration to an area of high-solute concentration."*

9. **In addition to consuming too much water that can cause hyponatremia, what medications can play a role in bringing on this condition?**
   Medications that can play a role in bringing on hyponatremia include diuretics, antidepressants, Ecstasy, and painkillers such as ibuprofen.
10. **What happens when the sodium level in blood plasma falls below 0.135M?**
    When the sodium level in blood plasma falls below 0.135M, hyponatremia can occur.
11. **What probably killed Zyrees and Cynthia?**
    Zyrees and Cynthia probably drank too much water, which diluted the Na^+ concentration in their blood and, through osmosis, too much water rushed into their brain cells.
12. **Describe the symptoms of dehydration. Why is it especially important to watch for these?**
    Some signs or symptoms of dehydration are nausea, muscle weakness, dizziness and confusion.
    It is especially important to watch for these because the symptoms of dehydration are identical to those of hyponatremia.

Possible Student Misconceptions

1. **"While running, I need to be certain that my body stays hydrated, so I think of "more is better" and drink as much Gatorade as possible."** *Drinking as much as possible can be dangerous. Proper hydration is important, but consuming too much water, or fluids containing mostly water, too quickly, can lead to a sodium (Na^+) imbalance and hyponatremia.*
2. **"I've heard that all athletes can benefit from drinking sports drinks while exercising."** *Sports drink will not be beneficial until you have lost a considerable amount of Na^+ during a long hard workout, one that lasts for more than an hour; until then, water is probably sufficient.*
3. **"I read that 'carbo-loading' is important before a marathon."** *"Carbo-loading" is a running tradition. Runners flock to Italian restaurants for pasta the night before competition. It was believed that carbohydrate storage provided energy needed for long races. Studies now show that the best preparation for distance running is a healthy diet throughout the year and drinking water only when thirsty. For triathlon and longer events, eating salty snacks should be used to replenish Na^+—after a marathon or during a triathlon.*
4. **"My cousin told me that when running a marathon, I should hydrate before I am thirsty and continue to drink at least one cup of water every 30 minutes."** *This was the advice years ago, until it was discovered that one-third of the Boston Marathon runners had low sodium levels. The U.S. Track and Field Association have revised their guidelines and they now advise runners to skip regulated times to hydrate and just drink when they are thirsty.*
5. **"Since sports drinks contain electrolytes, drinking them should keep me from getting hyponatremia."** *Not necessarily. Sports drinks also contain a lot of water so the sodium in the drink is quite dilute. If you drink them too quickly, there will not be enough time for your body to process the additional water.*

Anticipating Student Questions

1. **"Does it matter which sports drink I choose?"** *Yes, sports drink ingredients differ. It is important to read the ingredient labels to determine which is best for you and for your activity level. Also, check with your health care provider if you are using prescription medications.*
2. **"Do sports drinks really work?"** *It is important to drink when you are thirsty, but drinking plain water will hydrate as well as sports drinks and it doesn't contain sugar. Endurance athletes need to replenish sodium ions lost in sweat. Eating potato chips can do this as well as sports drinks.*
3. **"When I run, I sweat a lot, so I need to keep hydrated, but I don't want to get hyponatremia. How can I hydrate safely?"** *Sports physicians recommend that you drink water when thirsty and snack on salty foods like potato chips or pretzels to replace sodium ions lost in sweat.*
4. **"What makes me feel thirsty?"** *The hypothalamus located in the brain has sensors that monitor the concentration of sodium in the blood. When the sodium concentration increases to a certain level because there is a lack of water, the brain sends thirst signals.*
5. **"How can taking Ecstasy increase the risk of hyponatremia?"** *Ecstasy disrupts the normal release of the hormone arginine vasopressin (ADH) from the brain. This is the hormone that signals the kidneys to either excrete water in the urine or absorb and keep it to prevent dehydration. Ecstasy increases the release of ADH. This signals the kidneys to retain water, which may lead to hyponatremia.*

Activities

Labs and Demos

"Electrolytes and Non-electrolytes" lab (1 class period): Students test the conductivity of various solutions including soda and Gatorade. This lab could be extended to include testing other sports drinks. (http://www.sciencegeek.net/Chemistry/chempdfs/Electrolytes.pdf)

"The Energy of Evaporation – A Lab Investigation" (45–50 min.): Students measure evaporation rates of water, acetone and isopropyl alcohol. This data and structural formulas are used compare and explain the strength of the intermolecular forces between molecules of each substance. (http://highschoolenergy.acs.org/content/hsef/en/how-can-energy-change/energy-of-evaporation/_jcr_content/toparticleparsys/columnsbootstrap/column1/acscontainer/containerPar/download/file.res/Teachers_Key.pdf)

Media

Two Khan Academy videos: These presentations are designed to enhance student understanding at the particle level. Videos are accompanied by complete text transcripts.

- "LeBron asks: "Why does sweat cool you down?" (5:39) A question from basketball star LeBron James leads to an explanation of molecular collisions, average kinetic energy of molecules, and phase changes involved in evaporative cooling. (https://www.khanacademy.org/science/biology/water-acids-and-bases/water-as-a-solid-liquid-and-gas/v/lebron-asks-why-does-sweating-cool-you-down)
- "Osmosis, Membranes and Transport" (8:03) Particle-level diagrams show osmosis through a semipermeable membrane as water moves from low to higher solute concentrations. (https://www.khanacademy.org/science/chemistry/states-of-matter-and-intermolecular-forces/mixtures-and-solutions/v/boiling-point-elevation-and-freezing-point-supression)

"Introduction to homeostasis", YouTube video (4:07) Students will enjoy this well-done, partially animated presentation that clearly explains homeostasis, the negative feedback loop, and how the hypothalamus controls the body's response to hot or cold in the outside environment. (https://www.youtube.com/watch?v=-W7kAyUQT0E)

Lessons and Lesson Plans

A debate, "Rise and Sell: The Energy Drink Business and What They're Really Offering" (90 min.) This lesson, with complete instructions, is designed for a debate class but would fit well as a chemistry debate. A major goal is for students to recognize beliefs and assumptions regarding energy drinks. (https://teachers.net/lessonplans/posts/4258.html)

Lesson plan for an experimental design, "Is Gatorade® the Only Source of Electrolytes?" (60–90 min.) Students are asked to consider Gatorade advertisements and plan an investigation designed to provide evidence of the presence of electrolytes. (http://alex.state.al.us/lesson_view.php?id=34677)

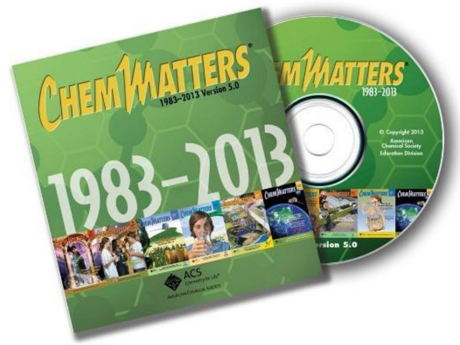
Projects and Extension Activities

Group research project and poster presentation: Students will identify the ingredients in a sports drink, determine the rationale for each addition and prepare a classroom poster that illustrates and describes the purpose of each chemical ingredient (beyond basic carbohydrates). This Web site (for teacher use only) may help in poster evaluation: (http://www.myhealthwire.com/news/diet-nutrition/345).

Design and advertise a new sports drink: Research possible formulas for known sports drinks. Design a sports drink with specialty ingredients. Use information about the additives you choose to convince your audience that your new drink is a "must-buy". Name the new drink and prepare an advertisement in the format of your choice (brochure, Prezi, video, live presentation, etc.).

References

The references below can be found on the *ChemMatters* 30-year DVD, which includes <u>all</u> articles published from the magazine's inception in October 1983 through April 2013; all available Teacher's Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site: http://ww.acs.org/chemmatters. Click on the "Teacher's Guide" tab to the left, directly under the "*ChemMatters Online*" logo and, on the new page, click on "Get the past 30 Years of *ChemMatters* on DVD!" (the icon on the right of the screen)



30* Years of *ChemMatters !

Available Now!

Selected articles and the complete set of Teacher's Guides for all issues from the past three years are available free online at the same Web site, above. Click on the "Issues" tab just below the logo, *"ChemMatters Online"*.

Consuming sports drinks is one way to restore electrolytes and sugar lost during endurance activities; however sports drinks are not beneficial for exercise under an hour. This article mentions athletes becoming dehydrated but not hyponatremic. (Graham, T. Sports Drinks: Don't Sweat the Small Stuff. *ChemMatters*, 1999, *17* (1), pp 11–13)

The "Drinking Bird" toy works similarly to the way evaporation of sweat cools the skin. Author Rohrig provides an explanation of how the toy works in this article. (Rohrig, T. The Amazing Drinking Bird. *ChemMatters,* 2005, *23* (3), pp 10–11)

This article discusses the ingredients in energy drinks, the physiological effects of each additive, and how the combined effect of several of the added substances may be harmful. (Rohrig, B. Are Energy Drinks Good for You? *ChemMatters*, 2008, *26* (4), pp 10–11)

Diagrams in this article compare normal cells (balanced osmolarity between interstitial and intracellular fluids) with shrunken cells and bursting cells (too much salt). (Eboch, C. Shaking out the Facts about Salt. *ChemMatters*, 2016, *34* (1), pp 11–13.)

Web Sites for Additional Information

Invention of sports drinks

Long before Gatorade, there was Glucozade. Rebranded as Lucozade, it is still the best selling sports drink in the UK. This site provides more of the history and backstory of this early sports drink. (http://www.campaignlive.co.uk/article/superbrands-case-studies-lucozade/232378?src_site=brandrepublic)

Concern over heat effects on University of Florida "Gators" football players prompted the production of Gatorade, designed to replace water, electrolytes and energy lost during practice and games. Find more about Gatorade here: https://www.gatorade.com/company/heritage.

Sports drink ingredients

While the basic composition of all sports drinks is the same, individual manufacturers add their own colors, flavors and preservatives. Ingredients of various drinks are listed on a table at this URL:
https://www.sportsdietitians.com.au/wp-content/uploads/2015/04/Sports-Drinks.pdf.

This Web site explains how to calculate the efficiency of oxidizing glucose for quick energy during sports. (http://www.tiem.utk.edu/~gross/bioed/webmodules/ATPEfficiency.htm)

Sports drinks vs energy drinks

When *Consumer Reports* magazine analyzed the caffeine content in 27 top-selling energy drinks available in U.S. markets, they found that many companies underestimated the amount of caffeine in their products, by as much as 20%. Results are published in a table at http://www.consumerreports.org/cro/magazine/2012/12/the-buzz-on-energy-drink-caffeine/index.htm.

Along with warnings about the effects of consumption of excess caffeine (sleeplessness, heart palpitations, headaches, nausea, jitters and death), the World Anti-doping Agency (WADA) has added caffeine to its Monitoring Program for 2017. (https://www.washingtonpost.com/news/early-lead/wp/2017/03/08/caffeine-could-be-headed-to-world-anti-doping-agencys-prohibited-substance-list/)

Sweat glands

This research paper published by the U.K. *Journal of the Royal Society* compares the activity of hunter-gatherers to modern athletes to explain our need for apocrine glands. These are the sweat glands that secrete an oily solution through hair follicles. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1281456/)

Eccrine glands, the major human sweat glands, secrete an odorless, water-based electrolytic fluid though pores all over the body. This site contains an illustration of sweat glands and discusses how sweat glands work. (http://health.howstuffworks.com/skin-care/information/anatomy/how-sweat-works2.htm)

Homeostasis

This site includes diagrams that illustrate how negative feedback loops reduce the effect of a stimulus, stabilize the system and return the system to homeostasis—the body's ability to maintain stable internal conditions necessary for survival (e.g., regulation of normal body temperature in response to hot or cold external stimuli), or response to changes in blood glucose levels. (https://www.khanacademy.org/science/biology/principles-of-physiology/body-structure-and-homeostasis/a/homeostasis)

This Rice University site describes the differences in (and confusion about) the terms: homeostasis, steady state, and chemical equilibrium. Definitions and examples of each situation is provided, including a description of the two major differences between homeostasis and equilibrium. (http://www.ruf.rice.edu/~bioslabs/studies/invertebrates/steadystate.html)

Thermoregulation

This Web site explains the role of the hypothalamus in regulating body temperature. Diagrams illustrate mechanisms to show how this is accomplished. (http://www.bbc.co.uk/schools/gcsebitesize/science/add_ocr_pre_2011/homeostasis/bodytemprev4.shtml)

This Web site describes the chemical composition of human sweat, our body's mechanism for regulating our internal temperature, including ion concentrations. (https://www.thoughtco.com/chemical-composition-of-human-sweat-or-perspiration-604001).

Balancing electrolytes

The University of Utah defines osmosis as the process responsible for maintaining the electrolytic balance in the body. This site provides a 25-page slide show of the osmotic balance in various types of animals: (http://www.sci.utah.edu/~macleod/bioen/be6000/notes/L17-osmotic-balance.pdf.

This site contains nice illustrations, plus a description of the three terms used to describe the concentration of a solution in comparison to the concentration of the interstitial fluid. (http://www.dummies.com/education/science/anatomy/the-cell-membrane-diffusion-osmosis-and-active-transport/.

Water's role in electrolyte balance

The focus of this chapter is on water's important physiological role in the transport of electrolytes and nutrients (biochemical molecules), maintaining osmotic and temperature balance, and as a medium for chemical reactions. Guidelines for determining the replenishment needs of weekend athletes, teens and children, videos on dehydration and osmosis and a link to U.S. Centers for Disease Control and Prevention (CDC) data are included. (https://2012books.lardbucket.org/books/an-introduction-to-nutrition/s11-nutrients-important-to-fluid-a.html#zimmerman_1.0-ch07_s01_s01_s01_n01)

Normal kidney function and its essential role in regulating the concentration of water in blood plasma are explained. A detailed diagram shows how the brain signals release of the hormone (ADH) to direct the process of adjusting the concentration of water excreted in the urine. (http://www.bbc.co.uk/schools/gcsebitesize/science/add_ocr_pre_2011/homeostasis/waterbalrev3.shtml)

Hyponatremia

This clear description of the causes of, and dangers present in, our "over-hydrated culture" includes a discussion of the physiological effects of drinking too much water. (https://www.scientificamerican.com/article/strange-but-true-drinking-too-much-water-can-kill/)

Emphasis is placed on overhydration presenting a greater risk than dehydration in this Web site. Discussion includes tips on how much liquid runners should drink, and the best times for runners to drink liquids. (https://runnersconnect.net/overhydration-dangers-drinking-too-much-water-while-running/)

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Connections to Chemistry Concepts

Chemistry Concept	Connection to Chemistry Curriculum
Properties of matter	The physical and chemical properties that are used to identify different minerals are an example of how these properties are used in geology.
States of matter	Igneous rocks begin in the liquid state and solidify upon cooling. The rate of cooling will affect the crystals that form and their size. This can be used to connect to the different states of matter.
Chemical bonding	The discussion of metallic and covalent bonding in mineral crystals can be used to supplement a unit on chemical bonding
Crystal lattice formation	The shape of the different mineral crystals provides an opportunity to discuss crystal lattices and lattice energy
Elements and compounds	Minerals are composed of compounds which are the source for the extraction of individual elements. Many elements were discovered through the analysis of minerals. This connection can be made while discussing elements and compounds.
Mixtures	Most rocks are solid mixtures of several minerals. These can be used as examples in classifying matter as pure substances or mixtures. Some rocks may fall under pure substances while most others would be classified as mixtures.
Chemical nomenclature	Many of the minerals have the familiar ionic formulas students write when learning about chemical nomenclature. These formulas can be used to demonstrate that many of the chemical names they are accustomed to have common mineral names as well.
Chemical formulas	The many chemical formulas used throughout this article could be used during lessons concerning the writing and meaning of chemical formulas.

Teaching Strategies and Tools

Standards

- Links to **Common Core Standards for Reading**:

  ELA-Literacy.RST.9-10.1. Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  ELA-Literacy.RST.9-10.5. Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).
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  ELA-Literacy.RST.11-12.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*.

- Links to **Common Core Standards for Writing**:

  ELA-Literacy.WHST.9-10.2F. Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
  ELA-Literacy.WHST.11-12.1E. Provide a concluding statement or section that follows from or supports the argument presented.

- In addition to the writing standards above, consider asking students to debate issues addressed in some of the articles. Standards addressed:

  ELA-Literacy.WHST.9-10.1B. Develop claim(s) and counterclaims fairly, supplying data and evidence for each while pointing out the strengths and limitations of both claim(s) and **counterclaims** in a discipline-appropriate form and in a manner that anticipates the audience's knowledge level and concerns.
  ELA-Literacy.WHST.11-12.1.A. Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that logically sequences the claim(s), counterclaims, reasons, and evidence.

- Links to **Next Generation Science Standards:**
  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**:
    - PS1.A: Structure and properties of matter
    - PS2.B: Types of Interactions

- **Crosscutting Concepts:**
  - Patterns
  - Structure and function
- **Science and Engineering Practices:**
  - Developing and using models
  - Planning and carrying out investigations
- **Nature of Science:**
  - Science addresses questions about the natural and material world

Vocabulary

Vocabulary and **concepts** that are reinforced in October 2017 issue:

- Equilibrium
- Solute and solvent
- Electrolyte
- Ions
- Lipids
- Osmosis
- Metallic and nonmetallic
- Igneous, sedimentary, metamorphic rocks
- Composting
- Aerobic and anaerobic
- Carcinogen
- Heavy metals
- Amalgam
- Polymerization
- Composites

Reading Supports for Students

The pages that follow include reading supports in the form of an Anticipation Guide, a Graphic Organizer, and Student Reading Comprehension Questions. These resources are provided to help students as they prepare to read and in locating and analyzing information from the article.

The borders on these pages distinguish them from the rest of the pages in this Teacher's Guide—they have been formatted for ease of photocopying for student use.

- **Anticipation Guide (p. 32):** The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

- **Graphic Organizer (p. 33):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

  If you use the aforementioned organizers 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

- **Student Reading Comprehension Questions (p. 34):** The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.

- This article supports the 2017 National Chemistry Week theme of "Chemistry Rocks!"

- To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles. The "Web Sites for Additional Information" section of the Teacher's Guide provides sources for additional information that might help you answer these questions.

- You might also ask them how information in the articles might affect their health and/or consumer choices. Also ask them if they have questions about some of the issues discussed in the articles. Some of the articles in this issue provide opportunities, references, and suggestions for students to do further research on their own about topics that interest them.

“Chemistry Rocks!” *ChemMatters*, October/November 2017 Issue

Anticipation Guide

Name ______________________________

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. 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. All known minerals are chemical compounds.
		2. Most rocks are mixtures of several minerals.
		3. Large crystals form quickly.
		4. All crystals are held together by metallic bonds.
		5. Halide minerals contain elements such as chlorine and fluorine from the halogen group on the Periodic Table.
		6. Rubies and sapphires are composed of the same mineral.
		7. Your fingernail has a hardness greater than talc.
		8. Minerals always leave a streak on unglazed porcelain that is the same color as the mineral.
		9. Sedimentary rocks are the most common rocks on Earth’s surface.
		10. Limestone and marble are both composed mainly of calcium carbonate, $CaCO_3$.

Name: ________________________________

Graphic Organizer

Directions: As you read the article, complete the graphic organizer below to describe rocks and minerals.

3	**New things you learned about rocks and minerals**	
2	**Ways a knowledge of chemistry can help you understand rock formation**	
1	**Question you have about rocks or minerals**	
Contact!	**How can an understanding of the chemistry of rocks and minerals affect your life?**	

Student Reading Comprehension Questions

Name: ______________________________

Directions: Use the article to answer the questions below.

1. How are rocks defined?

2. Give two examples of rocks composed of only one mineral.

3. How does the arrangement of atoms differ in crystals and glass?

4. What determines the type of bonding in a crystal?

5. Describe the type of bonding present in diamonds and the effect of this bonding.

6. Name five (5) properties used to identify minerals.

Student Reading Comprehension Questions, cont.

7. Fluorescence can be used to identify some minerals. When a mineral fluoresces, what is happening?

8. How does a streak test help distinguish two minerals with similar appearance?

9. Name the three types of rocks, and give an example of each type.

10. How is the formation of granite different from that of pumice?

11. How are metamorphic rocks formed?

12. Give an example of a metamorphic rock and the rock from which it originated.

Answers to Student Reading Comprehension Questions

1. **How are rocks defined?**
   A rock is defined as a mineral—"a naturally occurring inorganic solid with a definite chemical composition and ordered internal structure—or a mixture of several types of minerals."
2. **Give two examples of rocks composed of only one mineral.**
   Examples of two rocks that are composed of one mineral are pyrite and quartz.
3. **How does the arrangement of atoms differ in crystals and glass?**
   The arrangement of atoms in crystals is a regular repeating pattern; while in glass, the atoms have no orderly arrangement (it is amorphous).
4. **What determines the types of bonding in a crystal?**
   The types of bonds that exist in a crystal depend on the types of elements from which it is composed.
5. **Describe the type of bonding present in diamonds and the effect of this bonding.**
   Diamonds have many covalent bonds between the non-metallic carbon atoms; these involve the sharing of an electron pair between atoms. These bonds make diamond the world's hardest mineral.
6. **Name five (5) properties used to identify minerals.**
   The five properties that are used to identify minerals are:
   a. *luster,*
   b. *color,*
   c. *hardness,*
   d. *streaking, and*
   e. *fluorescence.*
7. **Fluorescence can be used to identify some minerals. When a mineral fluoresces, what is happening?**
   When a mineral fluoresces, it absorbs ultraviolet light and emits visible light.
8. **How does a streak test help distinguish two minerals with similar appearance?**
   A streak test can be used to distinguish two minerals with similar appearance when the marks they make when rubbed across a piece of unglazed porcelain are different colors. For example, the streak color for fool's gold is black, while that for actual gold is yellow.
9. **Name the three types of rocks, and give an example of each type.**
   The three types of rocks are:
   a. *igneous rocks, example: pumice or granite;*
   b. *sedimentary rocks, example: sandstone, coal, or limestone; and*
   c. *metamorphic rocks, example: marble or slate.*
10. **How is the formation of granite different from that of pumice?**
    The formation of granite is different from that of pumice in that granite forms underground as magma cools slowly. Pumice forms quickly when the magma is rapidly ejected into the atmosphere. Once in the atmosphere, gases escape from the rock creating a porous structure, making pumice one of the few rocks that floats.

11. **How are metamorphic rocks formed?**
    Metamorphic rocks are formed when igneous or sedimentary rocks are subjected to high temperature and pressure deep underground, causing a change in the rock. The metamorphic rock is typically harder and stronger than the rock from which it originated.
12. **Give an example of a metamorphic rock and the rock from which it originated.**
    Slate is an example of a metamorphic rock, it begins as shale and is changed into slate. Marble is another example of a metamorphic rock. It begins as limestone and is changed into marble.

Possible Student Misconceptions

1. **"All rocks contain minerals."** *This is almost, but not quite, correct. Rocks are defined as consolidated material composed of one or more minerals. However, obsidian which is volcanic glass, is one of the few rocks that is not composed of minerals. Glass is an amorphous solid without a defined chemical composition or structure. Minerals, on the other hand, are crystalline solids that have a definite chemical composition and structure.*
2. **"Diamonds are made from coal."** *This misconception is still taught in many science classrooms. Two observations can be used to support the idea that diamonds are not metamorphosed from coal. Coal is a product of the metamorphosis of ancient land plants. Diamonds that have been dated are much older than the Earth's first land plants so this seems to disprove that diamonds could be formed from the high pressure and heat treatment of coal. A second observation is that coal seams occur as horizontal or nearly horizontal layers of rock while diamonds are found in vertical pipes of igneous rocks. Therefore, it seems that diamonds formed in another way. Geologists believe diamond deposits were formed in the mantle and brought to the surface through volcanic activity. The high pressure and temperature that are required for diamond formation occurs only in some places in the mantle 90 miles below Earth's surface. Coal veins are generally no more than 2 miles from the surface. The carbon source for diamonds is most likely carbon that was trapped in Earth's interior during formation. A second way diamonds can be formed is during the subduction of one plate under another during plate tectonic processes. A third way diamonds are formed is when an asteroid impacts the Earth. Small diamonds have been discovered near asteroid impact sites. More information about diamond formation can be found here: http://geology.com/articles/diamonds-from-coal/.*

Anticipating Student Questions

1. **"Why are the minerals with transition metals so colorful?"** *The factor that separates transition metals from the other elements on the periodic table is the filling of the d orbitals in this group of elements. In the absence of d orbitals, or when all the d orbitals become filled (e.g., zinc), colorful compounds are not observed because the energy changes that take place in these elements as they bond with others falls outside the energy associated with visible light, and the only color that is seen is white. When transition elements bond with ligands in mineral formation, the electrons in the d orbitals are used. As d orbitals become bonding orbitals, energy is absorbed as some change to lower-energy positions and some to higher-energy positions. This energy change generally occurs in the wavelengths associated with the energy of the visible light spectrum, resulting in a colored compound. For example, if the energy that was absorbed by the promotion of the d orbital to a bonding orbital falls in the yellow frequency, then the color we see is the color opposite yellow on the color wheel—blue. A more thorough explanation using Crystal Field Theory can be found here: https://chemistry.stackexchange.com/questions/4667/why-do-transition-elements-make-colored-compounds.*
2. **"Why are diamonds the hardest rocks?"** *Diamonds are incredibly hard because of the structure their carbon atoms assume while forming under extreme conditions of heat and pressure 140 to 150 kilometers beneath the earth's surface. The bonding network in diamonds is responsible for their hardness. Diamonds are composed of carbon atoms that are covalently bonded to four other carbon atoms, forming a tetrahedron. The strength and quantity of these covalent bonds give diamonds their hardness.*
3. **"What minerals are in the precious stones like emeralds, rubies, and sapphires that are used in jewelry?"** *Emeralds are gem quality specimens of the mineral beryl, $Be_3Al_2(SiO_3)_6$. Trace amounts of chromium or vanadium in the mineral cause it to develop a green color. Rubies and sapphires are both made of the mineral corundum, Al_2O_3. Chromium impurities give rubies their characteristic red color, while trace amounts of iron and titanium give the corundum the characteristic blue color of sapphires. Purple amethysts are a variety of quartz, SiO_2. The purple color is due to trace amounts of iron that has been irradiated. Opals are hydrous silicon dioxide, $SiO_2 \bullet nH_2O$. The silicon dioxide in opals is amorphous—without a definite crystalline arrangement.*
4. **"What gives the gemstones their specific colors?"** *Gemstones are made from basic minerals that by themselves are not very colorful. The trace amounts of some of the transition metal elements that are incorporated into the crystalline structure of the stone give the gemstones their specific colors. Trace amounts of chromium or vanadium make emeralds green. Chromium impurities make rubies red, trace amounts of iron and titanium make sapphires blue, while irradiated iron is responsible for the purple color of amethysts.*
5. **"What type of rocks are formed from the lava that slowly oozes out of a volcano?"** *When lava slowly oozes from a volcano, igneous rocks are formed. The structure of these rocks is different from the igneous rocks that form underground, though they may have the same chemical composition. Rocks that harden at the surface have smaller and finer crystals, looking more homogeneous in appearance. Rhyolite is the primary rock that forms from lava extruded from a volcano. It is similar in chemical composition to granite but with much smaller crystals. If the lava is very gaseous, then pumice might be formed (though most pumice is associated with lava that is expelled rapidly into the air). If the lava oozing*

from the volcano cools quickly, it develops an amorphous internal structure like the glassy obsidian.

6. **"Are those giant crystals shown in the photo in the Rohrig article real, or are they 'Photo-shopped'? And why are the men all wearing orange jumpsuits?"** Yes, the crystals are real. They were formed in mineral-saturated water over the course of more than 500,000 years, deep underground at extremely high temperatures. A mining company pumped the water out in order to extract minerals containing metals and discovered the cave. An average temperature of 50 ^{o}C (~122 ^{o}F) and 100% humidity in the mine require that explorers in the cave wear special suits to keep them cool, to prevent their succumbing to the extreme conditions. Even so, they can only stay in the cave for a short time (90 minutes, max).

Activities

Labs and Demos

Mineral Identification Stations Lab: In this lab, students rotate through six stations, 1.Color and Streak, 2.Moh's Hardness tests, 3.Mass and Density, 4.Chemical Composition Tests for Carbonates, 5.Crystal Structure Examination, and 6. Special properties. Handouts in pdf form for student note and activity worksheets are provided, as well as the lesson's PowerPoint presentation with notes for the teacher. (http://sciencespot.net/Media/MineralIDLab.pdf)

Crystallization of supersaturated sodium acetate demonstration: This demonstration of the instant crystallization of a supersaturated solution of sodium acetate contains many lessons that can be applied to crystal formation. If done in the flask as written in the linked procedure, the students can see the crystals and feel the exothermic nature of the reaction by looking through and touching the flask. If the demonstration is done by slowly pouring the sodium acetate solution into a beaker containing a few crystals of sodium acetate in the bottom, you can build a tall, free-standing crystal mass that looks like the stalagmites in caves.
(https://www.flinnsci.com/supersaturated-sodium-acetate-solution/dc91215/ or https://projects.ncsu.edu/project/chemistrydemos/Thermochem/SatNaOAc.pdf)
A YouTube video of these demonstrations can be found here:
https://www.youtube.com/watch?v=nvHrXr5Jajg.

Percent composition of lime in limestone labs: In this classroom laboratory experiment, students compare limestone samples by their lime (CaO) content. Two procedures are available in the referenced activity book: the first one, "How much Lime is in Limestone?" (pp 10–12, or the second one, "Are All Limestones Created Equal?" (pp 33–34).
(http://www.wvgs.wvnet.edu/www/geoeduc/adaptiveactivities.PDF)

Simulations

How the speed of cooling of volcanic rock is affected by different variables: Five different variables that affect the rate of cooling of molten lava are tested in these virtual lab activities. Students explore and record data for the effects of size, surface area, grain size, composition, and composition of the surrounding rock on the speed of cooling. (http://www.esta-uk.net/cooling/)

Rock cycle animation: From flowing lava back to the melting of metamorphic rock, this animation has various items students can click on to see real life examples of what is being animated.
(http://www.classzone.com/books/earth_science/terc/content/investigations/es0602/es0602page02.cfm?chapter_no=investigation)

Media

***World of Chemistry*'s video, "The Chemistry of Earth":** (28:40) This video discusses the process of rock formation and composition. The chemistry of the rocks and the uses of the minerals obtained from them is the primary focus. (http://www.learner.org/vod/vod_window.html?pid=810)

Annenberg's *Earth Revealed* "Minerals" episode: (28:54) A video about the minerals in rocks and how and why geologists study them is the theme of this segment of the *Earth Science* series, *Earth Revealed*.
(http://www.learner.org/vod/vod_window.html?pid=323)

Lessons and Lesson Plans

The geology of building stones: A set of five lessons with activities guide the student to explore the geology of the three rock types as found in a variety of building stones. The fifth activity "How Long Will My Gravestone last?" involves a field trip to a local graveyard where the students examine the headstones. Each lesson and activity can be done as a stand-alone lesson, allowing the teacher to choose one activity or all five. The link is to the index of pdfs. Look for "Building Stones 1", which gives an overview of the series. (http://www.earthlearningidea.com/English/Earth_Materials.html)

"Mineral Experts": Four independent lessons, titled "Mineral Experts" 1, 2, 3, and 4 engage the student in different aspects of minerals. Each stand-alone lesson is accompanied with an activity. "Mineral Expert 1" is an introduction to mineral identification; "Mineral Expert 2" explains the tests used to identify minerals; while "Mineral Expert 3" is about minerals encountered in everyday life; and "Mineral Expert 4" is about why you should recycle your mobile phone. This might lead the students to start a school-wide phone recycling drive as an independent project. (http://www.earthlearningidea.com/English/Earth_Materials.htm)

"Lessons from The Life Cycle of a Mineral Deposit" handbook: This is a teacher's handbook, containing extensive geology background information for the teacher and several activities for students. Of particular interest to enhance the *ChemMatters* article might be Activity 5—"Extracting Metal (Cu) from a Rock" (page 14), Activity 7—"The Mineral Talc or 'Rocks on Your Face'" (page 17), or Activity 8—"Make your Own Toothpaste" (page 18). (https://pubs.usgs.gov/gip/2005/17/gip-17.pdf)

Projects and Extension Activities

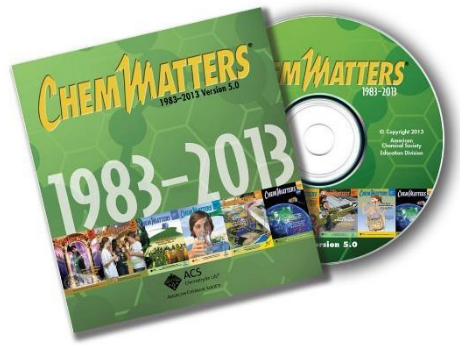
Making Crystals: Students can make crystals in class to observe over several days, or this can be assigned as an optional at-home project. Instructions for an activity that has the students compare the difference between crystals grown with a granulated sugar solution to those grown with a powdered sugar solution can be found here: http://spark.ieee.org/2014-issue-1/the-surface-area-effect/, with accompanying pdf files here: http://tryengineering.org/sites/default/files/lessons/sugarnano_0.pdf.
Two other sites with instructions for growing crystals at home or in class are: https://www.scientificamerican.com/article/bring-science-home-crystals/ and https://www.thoughtco.com/growing-a-big-alum-crystal-602197.

Starting a rock collection: The information at this United States Geological Survey site will give students enough information to get started on a rock collection. Students could collect rocks and display them, as either an individual or in groups. (https://pubs.usgs.gov/gip/collect1/collectgip.html)

"Sand or Rock? Finding out from 1000 km", using the physical properties of substances to identify them: This NASA activity could be assigned as an at-home project to students as individuals or to work on in groups. Students collect temperature data and graph it to compare the warming curves of sand vs. rock. (https://saturn.jpl.nasa.gov/legacy/files/Sand_Or_Rock.pdf)

References

The references below can be found on the *ChemMatters* 30-year DVD, which includes <u>all</u> articles published from the magazine's inception in October 1983 through April 2013; all available Teacher's Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site: http://ww.acs.org/chemmatters. Click on the "Teacher's Guide" tab to the left, directly under the "*ChemMatters Online*" logo and, on the new page, click on "Get the past 30 Years of *ChemMatters* on DVD!" (the icon on the right of the screen)



***30* Years of *ChemMatters* !**

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Selected articles and the complete set of Teacher's Guides for all issues from the past three years are available free online at the same Web site, above. Click on the "Issues" tab just below the logo, *"ChemMatters Online"*.

The chemistry of Mars' rocks is presented, as well as the way the samples were analyzed. Author Stone discusses some of the findings from the NASA spacecraft *Pathfinder* and its robotic rover *Sojourner* and includes a sidebar with an informative discussion about basalt. (Stone, C. Clues from a Far Planet. *ChemMatters,* 1998, *16* (2), pp 7–9)

Good explanations of volcanic rock formation from magma are presented in this article on volcanoes. (Rohrig, B. Volcanoes—Forecasting the Fury. *ChemMatters,* 1999, *17* (4), pp 12–13)

Cave and sinkhole formation is the major topic of this article. The solubility of limestone, $CaCO_3$, in the formation of caves and sinkholes is discussed. (Kimbrough, D. Caves: Chemistry Goes Underground. *ChemMatters,* 2002, *20* (2), pp 7–9)

For students particularly interested in diamonds, this article contains good information about diamonds and how they compare to graphite. (Sicree, A. Graphite vs. Diamond, Same Element but Different Properties. *ChemMatters,* 2009, *27* (3), pp 13–14)

Since talc is discussed in the Rohrig "Chemistry Rocks" article, students may find this article on mineral makeup interesting, as the makeup is made primarily from talc and mica powders. (Andrew, J. The Makeup of Mineral Makeup. *ChemMatters,* 2010, *29* (1), pp 16–17)

This article explains that the iridescence of opals can be attributed to the size and arrangement of internal silica particles. Some other silicates and their structures are also presented. (Argentine, C. Opals Playing with Color and Light. *ChemMatters,* 2013, *31* (3), pp 17–19)

The Teachers Guide for the above article contains considerable background information on rock formation, silicates, opals, gemstones, and minerals.

Lots of information on the internal bonding structure of diamonds can be found in this article. Also, there is considerable information on how fabricated diamonds are produced, followed by a comparison of natural vs manmade diamonds. (Eboch, C. An Explosion of Diamonds. *ChemMatters,* 2014, *32* (1), pp 14–16)

The Teacher's Guide for "An Explosion of Diamonds" above contains a copy and explanation of Moh's Hardness Scale, the classification scheme used to rate diamonds as gems, as well as several pictures illustrating the process of manufacturing diamonds. Under "Labs and Activities" there are links to crystal growing activities, as well as a "Teacher's Guide for Mineral Education Activities" produced by the US Geologic Society.

Web Sites for Additional Information

Basic geology—a "gold mine" for teachers

This site provides a plethora of information pertaining to geology. In the left-hand margin, you will find topographical and geologic maps for each state. The Web site also provides additional teacher resources. (http://geology.com/)

The *Science Daily* Web site contains current research related to rocks. There are several interesting articles about geology current events linked in this Web site. (https://www.sciencedaily.com/search/?keyword=rocks#gsc.tab=0&gsc.q=rocks&gsc.page=1)

Rock formation

Further information on the rock cycle and rock formation is available at this Web site. Several links to *Universe Today* articles that could be used for further reading assignments can be found at the end of this article. (https://www.universetoday.com/46594/how-are-rocks-formed/)

While the initial focus of this Web site is quartz content in rocks, it also gives a great deal of information on rock formation. Several chemical equations illustrate the different types of rock formation. (http://www.quartzpage.de/gen_rock.html)

Minerals

This site contains extensive lists of minerals with their pictures. The "MINERALS", "GEMSTONES", "RESEARCH", and "VIDEOS" tabs at the top of the Web site reveal great information for the teacher or student; clicking on the "RESEARCH" tab gives information on mineral formulas. (http://www.minerals.net/MineralMain.aspx) (http://www.minerals.net/resource/Chemical_Properties.aspx)

One can find extensive and in-depth information about minerals at this Wikipedia site. Sections on nomenclature and mineral chemistry contain good information about element substitution and polyhedral complexing in minerals. (https://en.wikipedia.org/wiki/Mineral)

Crystals and crystallization

This site provides information about the chemical process of crystallization. The information provided is not limited to geological processes, but they are mentioned. (https://en.wikipedia.org/wiki/Crystallization)

This Web site contains an explanation and definition of crystallization. At the end of the article are several links to instructions for growing crystals as well as some troubleshooting tips for when crystals are not growing as expected. (https://www.thoughtco.com/definition-of-crystallize-605854)

Moh's hardness scale

The primary focus of this Web site is Moh's hardness scale and how to use it in testing for a rock's hardness. An extensive list of minerals and their respective hardness ratings is hyperlinked to a site that contains pictures, as well as the chemical formulas for the different minerals. (http://geology.com/minerals/mohs-hardness-scale.shtml)

This graph is a nice visualization of mineral bonding and the resultant hardness of the mineral. A two-paragraph explanation accompanies the graphic. (http://www.gly.uga.edu/railsback/Fundamentals/HardnessTrends29IIL.pdf)

Streak tests

This Web site contains instructions on performing streak tests on minerals. (http://geology.com/minerals/streak-test.shtml)

The Mineralogic Society of America's "Mineral Identification Keys" can be accessed at this Web site. It provides several tables that contain the streak and hardness results for many minerals. (http://www.minsocam.org/msa/collectors_corner/id/mineral_id_keytia.htm)

Chemical bonding in rocks

This site contains explanations of metallic bonding as a function of low electron density and mobility. (https://en.wikipedia.org/wiki/Metallic_bonding)

The Britannica Web site provides a good explanation of chemical bonding as it applies to minerals in geology. (https://www.britannica.com/science/crystal/Types-of-bonds)

Gemstones

This is the homepage for an eleven-chapter book about gems, titled *The Geology of Gems*. Six labs, including one on Identification of minerals, are available on the Web site. (http://geologycafe.com/gems/index.html)

Beautiful pictures accompany a tremendous amount of information on a multitude of gemstones. Some stones have more information represented on the site than others. (http://geology.com/gemstones/)

Diamonds

This Web site provides extensive information about diamonds, including mineral descriptions, diamond mining, locations of diamonds on Earth, and myth-busting information on how diamonds are formed. There is also information on synthetic diamonds. (http://geology.com/diamond/)

This entry in the *Gem Encyclopedia* contains information about diamond as a gemstone. It explains how diamonds are graded and provides a world map depicting the locations of diamond mines. (https://www.gia.edu/diamond)

The Naica cave ("Cave of the Crystals") in Mexico

The Geology Page Web site contains a section describing the huge selenite (gypsum, $CaSO_4 \bullet 2H_2O$) crystals that exist in the Naica underground cave in Chihuahua, Mexico. The site contains beautiful still photos of the crystals, as well as a video (4:53) of the cave. (http://www.geologypage.com/2016/06/cave-of-crystals-giant-crystal-cave.html)

There is an extensive Naica Web site, devoted entirely to the caves (there are several at various depths), that contains a series of 30 beautiful photos, several different videos, and descriptions of the research that is ongoing at the geologic site. This site is mostly in Spanish, so it would be useful for Spanish-speaking students. (http://www.naica.com.mx/english/internas/interna1.htm)

ChemMatters
Demystifying Everyday Chemistry

Teacher's Guide

"Compost: Your Trash, Nature's Treasure"

(October/November 2017 Issue)

http://www.acs.org/chemmatters

ACS
Chemistry for Life®

ChemMatters
Demystifying Everyday Chemistry

Teacher's Guide for

“Compost: Your Trash, Nature's Treasure”

October/November 2017

Table of Contents

ACS Chemistry for Life®

Connections to Chemistry Concepts

Chemistry Concept	Connection to Chemistry Curriculum
Chemical reactions	Teachers can use examples of composting for some decomposition reactions and relate biochemical processes to chemical reactions.
Reaction rates	The reaction rate of composting organic materials is partially dependent upon the particle size of the organic material and the temperature. Incorporating these concepts into a discussion of factors affecting reaction rates may provide a different perspective for some students.
Thermodynamics	The heat energy produced from the decomposition reactions occurring during both aerobic and anaerobic composting are significant. Pictures of compost piles in cool weather producing enough heat to see condensing water vapor rising from them may be interesting for students. The heat produced during composting is an important product and factor in composting.
Environmental chemistry	Students may not understand the impact on greenhouse gases and global climate change that rotting food wastes in landfills and composting food wastes in commercial anaerobic digesters may have on the environment. The methane and carbon dioxide gases formed during anaerobic and aerobic composting are classified as greenhouse gases and may be generated in significant quantities.
Organic chemistry	Composting can produce a variety of organic compounds. Most students will not be familiar with the organic acids or amines that can be formed during composting. Connecting the malodor from improper composting to organic acids like butanoic (butyric) or hexanoic (caproic) acid, or to ammonia and various amines, could help students make connections between organic compounds and their properties, including odor.

Teaching Strategies and Tools

Standards

- Links to **Common Core Standards for Reading**:
  ELA-Literacy.RST.9-10.1. Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  ELA-Literacy.RST.9-10.5. Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).
  ELA-Literacy.RST.11-12.1. Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
  ELA-Literacy.RST.11-12.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*.

- Links to **Common Core Standards for Writing**:
  ELA-Literacy.WHST.9-10.2F. Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
  ELA-Literacy.WHST.11-12.1E. Provide a concluding statement or section that follows from or supports the argument presented.

- Links to **Next Generation Science Standards**
  HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
  HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.
  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**:
      - LS2.B: Cycles of matter and energy transfer in ecosystems
      - PS1.B: Chemical reactions
      - ETS1.C: Optimizing the design solution
    - **Crosscutting Concepts:**
      - Cause and Effect
      - Systems and System Models
      - Energy and Matter
    - **Science and Engineering Practices:**
      - Developing and using models
      - Planning and carrying out investigations
      - Constructing explanations and designing solutions

Nature of Science:

- Scientific knowledge assumes an order and consistency in natural systems

Vocabulary

Vocabulary and **concepts** that are reinforced in the October/November 2017 issue:

- Equilibrium
- Solute and solvent
- Electrolyte
- Ions
- Lipids
- Osmosis
- Metallic and nonmetallic
- Igneous, sedimentary, metamorphic rocks
- Composting
- Aerobic and anaerobic
- Carcinogen
- Heavy metals
- Amalgam
- Polymerization
- Composites

Reading Supports for Students

The pages that follow include reading supports in the form of an Anticipation Guide, Reading Strategies, a Graphic Organizer, and Student Reading Comprehension Questions. These resources are provided to help students as they prepare to read and in locating and analyzing information from the article.

The borders on these pages distinguish them from the rest of the pages in this Teacher's Guide—they have been formatted for ease of photocopying for student use.

- **Anticipation Guide (p. 54):** The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

- **Graphic Organizer (p. 55):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

  If you use the aforementioned organizers 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

- **Student Reading Comprehension Questions (p. 56):** The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.

- Most of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them in their personal lives.

- To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles.

- You might also ask them how information in the articles might affect their health and/or consumer choices. Also ask them if they have questions about some of the issues discussed in the articles.

- The Background Information in the *ChemMatters* Teachers Guide has suggestions for further research and activities.

"Compost: Your Trash, Nature's Treasure", *ChemMatters*, October/November 2017 Issue

Anticipation Guide

Name ______________________________

Directions: ***Before reading the article***, in the first column, write "A" or "D," indicating your agreement or disagreement with each statement. 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. Organic waste produces gaseous air pollutants whether it exposed to air or not.
		2. So far, we have not figured out how to use the methane produced in landfills to generate electricity.
		3. Composting helps reduce methane emissions.
		4. Aerobic composting produces carbon dioxide, water vapor, and compost which can be used to enrich soil in gardens.
		5. Two types of bacteria commonly found in organic waste grow best at different temperatures.
		6. The heat generated by bacterial reaction in a compost pile can kill disease-causing bacteria and weed seeds.
		7. Backyard composting is best done with both plant and animal matter.
		8. Bacteria in compost grow best when there is about 20-25 times as much carbon as nitrogen in the food waste.
		9. Composting can help mitigate climate change.
		10. Some large cities have municipal composting programs.

Graphic Organizer

Name: ______________________________

Directions: ***As you read***, complete the graphic organizer below to describe the differences between aerobic and anaerobic composting.

Aerobic Composting	Anaerobic Composting

Similarities of both types of composting

Summary: On the back of this paper, explain the meaning of the title of the article in 20 words or less.

“Compost: Your Trash, Nature's Treasure”, *ChemMatters*, October/November 2017 Issue

Student Reading Comprehension Questions

Directions: Use the article to answer the questions below.

____
Name

1. What are the four common chemical elements comprising organic wastes?

2. List four products of the decomposition of organic waste under anaerobic conditions.

3. What is the source of 15.4% of human-related annual methane emissions?

4. What is composting?

5. How does anaerobic composting work?

6. What are the end results of aerobic composting?

Student Reading Comprehension Questions, cont.

7. What is the favored option for composting (a) food waste, and (b) yard waste?

8. Which type of aerobic bacteria grows best at moderate temperatures?

9. Generally, biological organisms need a ratio of 25:1 of which two elements?

10. List two factors that affect the aerobic composting process.

11. Why is it not wise to use wastes like dog and cat feces in a backyard composting pile?

Answers to Student Reading Comprehension Questions

1. **What are the four common chemical elements comprising organic wastes?**
   Four common elements comprising organic wastes are carbon, hydrogen, oxygen, and nitrogen.
2. **List four products of the decomposition of organic waste under anaerobic conditions.**
   Four products of the anaerobic decomposition of organic wastes are methane, carbon dioxide, organic acids, and ammonia.
3. **What is the source of 15.4% of human-related annual methane emissions?**
   Landfills are the source of 15.4% of human-related annual methane emissions.
4. **What is composting?**
   Composting is the microbial breakdown of organic materials into simpler components which can be used to fertilize soil.
5. **How does anaerobic composting work?**
   Anaerobic composting works similarly to the way a landfill works. First, the waste is ground up. Then these chunks are placed in a closed container called a digester. In there, anaerobic microbes digest the organic matter, producing methane and a slurry called digestate.
6. **What are the end results of aerobic composting?**
   The end results of aerobic composting are carbon dioxide, water vapor, and a dark organic material called compost.
7. **What is the favored option for composting (a) food waste, and (b) yard waste?**
   f. The favored option for composting food waste is an anaerobic digester.
   g. The preferred process for composting yard waste is aerobic composting.
8. **Which type of aerobic bacteria grows best at moderate temperatures?**
   Mesophilic aerobic bacteria grow best at moderate temperatures.
9. **Generally, biological organisms need a ratio of 25:1 of which two elements?**
   Generally, biological organisms need a 25:1 ration of carbon to nitrogen.
10. **List two factors that affect the aerobic composting process.**
    Two factors that affect the aerobic composting process are
    a. *the temperature of the compost pile, and*
    b. *the right amounts of carbon and nitrogen.*
11. **Why is it not wise to use wastes like dog and cat feces in a backyard composting pile?**
    Dog and cat feces should not be used in a backyard composting pile because the compost pile may not be large enough to generate enough heat to kill disease-causing organisms like worm eggs.

Possible Student Misconceptions

1. **"Composting is smelly and attracts pests."** *When backyard composting is done properly there are no offensive odors or pests. The odors and pests are typically associated with people attempting to compost inappropriate materials, including pet feces, meat scraps, and fatty or oily foods. The solid end product of aerobic composting is a dark-brown or black solid that has an earthy odor.*
2. **"Composting takes too long."** *The composting reactions are an example of factors affecting reaction rates. Composting can be completed in about six weeks—if the pile is properly turned and aerated to provide oxygen (remember, it's aerobic!), if the pile is at optimal temperatures and contains the correct ratio of brown and green starting reactants, and if the material to be composted is smaller in particle size. Otherwise, it can take more than a year to compost naturally.*
3. **"Composting is too complicated!"** *Compost happens. It is a natural biological reaction which occurs without human intervention. However, with human assistance, the composting process can be accelerated and the final compost product can be useful. While there are ideal conditions, ratios of materials, and other factors to consider, it is not an exact science. Just jump in and get started.*

Anticipating Student Questions

1. **"I live in the middle of the city. Can I still compost?"** *Yes! A compost pile can take up as little as a 3 foot x 3 foot x 3 foot volume. So even small city yards can have a productive compost pile. Of course, a larger area will allow composting of more material. Commercial composting containers designed for city or condo living can be purchased that are easily used. Even if you live in a large apartment complex with no individual yard space, the apartment management may be open to beginning a composting pile for the residents—but be sure to ask permission before starting.*
2. **"I heard of composting using earthworms. Would it help to add earthworms to my compost pile?"** *Composting using earthworms is certainly an effective technique. However, the process of earthworm (vermiculture) composting and backyard (aerobic) composting are very different. The traditional backyard composting pile gets too hot from the decomposition reaction for the earthworms. So, it is not advisable to add earthworms to your compost pile. If you would like more information on vermiculture, please see https://www.treehugger.com/green-food/vermicomposting-and-vermiculture-worms-bins-and-how-to-get-started.html.*
3. **"If anaerobic composting releases greenhouse gases including methane and carbon dioxide, is it bad for the environment to compost?"** *Great question; but it is very complex! Certainly, methane and carbon dioxide gases contribute to global greenhouse conditions. However, we must consider what would have been the end products if the materials had not been composted; would those products have been more detrimental? Using large anaerobic composting digesters, the methane can be captured and used productively rather than releasing it into the environment. One must also consider the fuel used to run the digester (diesel or methane), the distance the organic matter is hauled (transportation exhausts), and the end use of the compost. Sequestering the carbon in the solid organic compost is beneficial rather than the carbon dioxide formed by decomposition or burning being released into the air. Most scientist believe that composting is preferable to other alternatives; however, the merits must be weighed on a case-by-case basis.*

Activities

Labs and Demos

Composting lab: For the 2003 Earth Day observance, ACS published "Chemistry and Compost", providing background and a lab activity for students in grades 8–12 on composting, with instructional notes for the teacher and student procedures. Students prepare and compare bioreactors for several waste materials. (https://www.acs.org/content/dam/acsorg/greenchemistry/education/resources/chemistry-and-compost.pdf)

Anaerobic decomposition of organic matter lab: "Biogas from Biomass" and "A Methane Generator" are two student lab activities with suggested variations for research and numerous student materials. One possible modification to the labs would be to use Mylar balloons in place of latex balloons for collecting the methane/biogas because other sites report better results when using Mylar balloons due to gas permeability with latex. (http://energysafekids.org/ugi/wp-content/uploads/2013/11/Esk-Biogas-From-Biomass-131104.pdf)

Simulations

Composting virtual lab: Students control three parameters of home composting: brown to green balance, water concentration, and number of compost turns per month, and an efficiency meter rates how well the chosen parameters worked to produce compost. The Web site contains sidebar directions where teachers could use the activity as a virtual lab; but for high school students, it may work best as a simulation. (http://www.glencoe.com/sites/common_assets/science/virtual_labs/ES01/ES01.html)

Media

Composting PowerPoint: "Compost" (51 slides) presents the science of composting as chemistry and physics subsections (and a biotic section that is not labeled as such). Mesophilic and thermophilic phases of composting are discussed, and several charts and graphs, as well as pictures, complement the presentation. (https://ic.ucsc.edu/~cshennan/envs133/lecture_notes/compostPresentation08.ppt)

Composting infographics: The Visually Web site provides numerous infographics related to composting. Titles include "How to Compost in Your Apartment", "Composting 101—What's In, What's Out?", "Mining Black Gold: The Comprehensive Guide to Composting", "Chart—Things to Compost", and many more. (https://visual.ly/tag/composting)

Lessons and Lesson Plans

Composting lessons and activities: *Do the Rot Thing: A Teacher's Guide to Compost Activities* is a 68-page guide with high school level activities, including an introductory activity, four different composting activities, three worm composting activities, and four projects to help inform others about composting.
(http://www.cvswmd.org/uploads/6/1/2/6/6126179/do_the_rot_thing_cvswmd1.pdf)

Classroom composting: *Composting in the Classroom: Scientific Inquiry for High School Students* is a 126-page book published by Cornell University that includes sections on "The Science of Composting", "Composting Bioreactors and Bins", "Getting the Mix Right", "Monitoring the Composting Process", "Compost Properties", "Compost and Plant Growth Experiments", and "Composting Research". Suggestions for numerous classroom activities and research opportunities are provided throughout the publication.
(http://cwmi.css.cornell.edu/compostingintheclassroom.pdf)

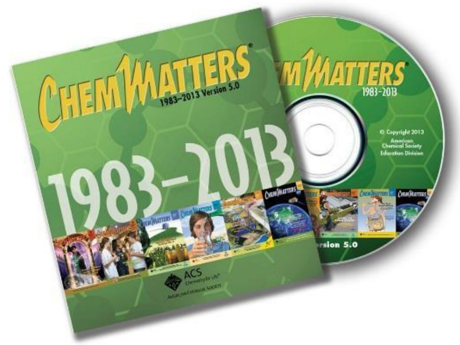
Projects and Extension Activities

Student research ideas for composting: Cornell University suggests ideas for research about composting in "Ideas for Student Research Projects", which include compost ingredients, microorganisms, compost physics, worm composting, and effects of compost on plant growth. There is very little support provided, so students and teachers must design and collect data on their own. (http://compost.css.cornell.edu/ResearchIdeas.html)

Build a classroom or home bioreactor: The Cornell University composting Web site details "Building a Two-Can Bioreactor", for use at home or in a classroom, from a 32-gallon and a 20-gallon plastic garbage can. Students could build and operate the bioreactor at school, use the leachate and compost produced in a garden, and test variations on the design.
(http://compost.css.cornell.edu/garbagecans.html)

References

The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine's inception in October 1983 through April 2013; all available Teacher's Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site: http://ww.acs.org/chemmatters. Click on the "Teacher's Guide" tab to the left, directly under the "*ChemMatters Online"* logo and, on the new page, click on "Get the past 30 Years of *ChemMatters* on DVD!" (the icon on the right of the screen)



30* Years of *ChemMatters !

Available Now!

Selected articles and the complete set of Teacher's Guides for all issues from the past three years are available free online at the same Web site, above. Click on the "Issues" tab just below the logo, *"ChemMatters Online"*.

Instead of using plastic bags made from petroleum (which do not decompose readily), scientist are researching the use of polylactic acid (PLA) synthesized from corn for a bioenvironmentally-degradable polymer that can be composted. The article discusses how a variety of PLA products can be better for the environment because they will break down or compost in landfills. (Black, H. Putting a High Grade on Degradables. *ChemMatters*, 1999, *17* (2), pp 14–15)

A more recent article from April 2010, "Plastics Go Green", updates the use of plant-based plastics including polylactic acid (PLA) to replace petroleum-based polymers and includes an activity for making your own compostable plastic with cornstarch. One section of this article is devoted to composting bioplastics and discusses the compostable PLA plastic. (Washam, C. Plastics Go Green. *ChemMatters*, 2010, *28* (2), pp 10–12)

The April 2012 Teacher's Guide for "Microbes and Molasses: A Successful Partnership" Includes information on composting as a simple method of bioremediation in the "Background Information" "More on bioremediation" section. The "In-Class Activities" section of the article includes links to the breakdown (composting) of motor oil, starch, and anaerobic fermentation.

The process of co-composting is important for managing huge volumes of cattle manure throughout the world. This article describes working with various animal manures, as well as municipal solid waste, and sludge from waste water treatment. Anwar, J.; et al. Characterization and Recycling of Organic Waste after Co-Composting—A Review. *Journal of Agricultural Science.* 2015, *7* (4), pp 68–79.

This publication reviews the existing literature on compost leachates, including the chemical and physical properties of the leachates, and provides a discussion of the chemical and physical properties of the composting feedstocks, the compost, and the compost leachate. A brief summary of the biochemical processes occurring in composting, and environmental considerations are included in the report. (Chatterjee, N.; et al. *Chemical and Physical Characteristics of Compost Leachates—A Review*. Washington State University: Puyallup, WA, 2013). This publication is also available online at https://www.wsdot.wa.gov/research/reports/fullreports/819.1.pdf.

Web Sites for Additional Information

Composting at home

The U.S. Environmental Protection Agency (EPA) provides information for "Composting at Home". Sub-sections include “Composting Basics”, “Benefits of Composting”, and “How to Compost at Home”. (https://www.epa.gov/recycle/composting-home)

The Home Composting Made Easy Web site contains sections on "Why Compost”, “Setting up Your System", "Composting Basics", "How to Compost", "Compost Problems", plus "Links & Resources". Sub-sections within these sections provide readers with information, pictures, and practical suggestions.
(http://www.homecompostingmadeeasy.com/compostsystems.html)

Composting at school

Cornell Composting is a bonanza of information, activities, and references centered on composting. The introduction page includes links to "Science and Engineering", "Composting in Schools", and "Composting Fact Sheets". (http://compost.css.cornell.edu/index.html)

“Composting for Students and Teachers” is a Web page from the US Composting Council with resources and descriptions of links for further information on various aspects of composting. Not all activities are aimed at high school, but many are appropriate.
(https://compostingcouncil.org/composting-for-teachers-and-students/)

Composting food wastes

Charles Vigliotti plans to use New York City food waste to fuel his private anaerobic composter on Long Island. He started with aerobic composting techniques, but the volume of waste as well as the odors and pests have convinced him to build a multi-million dollar anaerobic facility to process food wastes. (https://www.nytimes.com/2017/02/15/magazine/the-compost-king-of-new-york.html?_r=0)

The U.S. EPA has a robust composting Web site, "Reducing the Impact of Wasted Food by Feeding the Soil and Composting". This site has information on backyard composting, as well as organizational, business, and community composting. (https://www.epa.gov/sustainable-management-food/reducing-impact-wasted-food-feeding-soil-and-composting)

The problems of food waste

Why is nutritious food being thrown out? "Farm to Landfill: The Cost of Food Waste in America" hopes to enlighten readers on why 40% of the food that is produced in the U.S. is never consumed. (http://www.huffingtonpost.com/entry/farm-to-landfill-the-cost-of-food-waste-in-america_us_57c56101e4b0c936aababbed)

"Food Wastage Footprint: Impacts on Natural Resources" is a report from the Food and Agriculture Organization (FAO) of the United Nations that details the environmental impact of wasted food along the entire food chain for the world. The carbon and water footprints of food production are addressed in the extensive report. (http://www.fao.org/docrep/018/i3347e/i3347e.pdf)

Municipal solid food waste

Municipal Solid Waste (MSW) Composting Fact Sheets is a part of the wealth of resources on the Cornell Composting Web site. The seven fact sheets in this series include "Physical Processing", "Biological Processing", "Strategies for Separating Contaminants", "Potential Effects of Heavy Metals on Plants and the Environment", "Issues in Risk Assessment", "Issues in Policy and Regulation", and "Key Aspects of Compost Quality Assurance/Composting Resources". A "Composting Glossary" is included on the Web site as an extra. (http://compost.css.cornell.edu/MSWFactSheets/msw.fs.toc.html)

Overview of Food Waste Composting in the U.S. presents a comprehensive overview of the quantity, sources, and challenges of dealing with food waste in the U.S. Different methods of processing the wasted food are described, with examples of places where the methods are in use. (http://www.seas.columbia.edu/earth/wtert/sofos/Ulloa_Food%20Waste%20Composting_EEC_July2008.pdf)

The chemistry of composting

"Basic Principles of Composting" is a 12-page publication from the Louisiana State University Agricultural Center that explains the chemical factors involved in composting, including oxygen, temperature, moisture, nutrients, pH, and time. Equations for determining the optimal mix of carbon, nitrogen, and water are provided. (http://seafood.oregonstate.edu/.pdf%20Links/Basic-Principles-of-Composting-LSU.pdf)

"Compost Quality Analysis" provides information from the analysis of common home-produced compost in the United Kingdom. The chemical characteristics of home compost are thoroughly discussed, charted, and analyzed in the two-year study. (http://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/environmental-and-water-resource-engineering/ecwm/phase-1/Section-6.PDF)

Methane

"Main Sources of Methane Emissions" provides an overview of the sources of the potent greenhouse gas methane in our environment. Pie charts of human and natural sources of methane clarify the problem. The issue of methane from landfills and wastes is addressed. (https://whatsyourimpact.org/greenhouse-gases/methane-emissions)

"Greenhouse Gases and the Role of Composting: A Primer for Compost Producers" is a factsheet from the U.S. Composting Council. This publication looks at the relationship between composting and greenhouse gases, including methane. (https://compostingcouncil.org/wp-content/uploads/2016/05/GHG-and-Composting-a-Primer-for-Composters-final.pdf)

ChemMatters

Demystifying Everyday Chemistry

Teacher's Guide

"Making Water Safe to Drink"

(October/November 2017 Issue)

http://www.acs.org/chemmatters

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Chemistry for Life®

ChemMatters
Demystifying Everyday Chemistry

Teacher's Guide for

"Making Water Safe to Drink"

October/November 2017

Table of Contents

Connections to Chemistry Concepts

Chemistry Concept	Connection to Chemistry Curriculum
Types of reactions: double replacement reactions	Precipitation reactions such as those involving heavy metal ions in water treatment are good examples of these reactions.
Chemical nomenclature	Trihalomethanes (by-products of water disinfection by chlorine gas) can provide a nomenclature challenge for students (tri=3, halo= halogen).
Heavy metals	The study of heavy metals can include a brief discussion of their toxic effects, the need to remove them from drinking water, and the processes water treatment plants use to accomplish that task.
Solubility/precipitation	Precipitation of heavy metal ions by water treatment plants is a great example of compounds that have low solubility.
Solubility and the common ion effect	While studying solubility, the information in this article provides examples of its pH dependence. Consider the chemical equation in the article showing the formation of $Ni(OH)_2(s)$. If additional hydroxide ions (OH^-) are added (the solution is kept basic), the reaction will shift to the product, forming more precipitate.
Acid strength	During the acid/base unit, you can use the information in this article to discuss hypochlorous acid (HOCl). Although a weak acid ($K_a = 3.0 \times 10^{-8}$), it is strong enough to kill bacteria and viruses once it passes through bacterial cell walls and viral protein coats.
pH	Removal of heavy metals by precipitation provides a real world example of the importance of the pH of water. The hydroxide (OH^- and bicarbonate (HCO_3^-) anions are effective bases because they are soluble in acidic solutions. In water treatment the pH of the water must be adjusted to basic (above pH of 7) for precipitation to occur.

Teaching Strategies and Tools

Standards

- Links to **Common Core Standards for Reading**:
  ELA-Literacy.RST.9-10.1. Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  ELA-Literacy.RST.9-10.5. Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).
  ELA-Literacy.RST.11-12.1. Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
  ELA-Literacy.RST.11-12.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*.

- Links to **Common Core Standards for Writing**:
  ELA-Literacy.WHST.9-10.2F. Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
  ELA-Literacy.WHST.11-12.1E. Provide a concluding statement or section that follows from or supports the argument presented.

- Links to **Next Generation Science Standards**
  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**:
    - PS1.A: Structure and properties of matter
    - PS1.B: Chemical reactions
    - ETS1.B: Developing possible solutions
  - **Crosscutting Concepts:**
    - Structure and function
    - Cause and effect: Mechanism and explanation
    - System and system models
  - **Science and Engineering Practices:**
    - Planning and carrying out investigations
    - Constructing explanations and designing solutions
  - **Nature of Science:**
    - Science addresses questions about the natural and material world.

Vocabulary

Vocabulary and **concepts** that are reinforced in the October/November 2017 issue:

- Equilibrium
- Solute and solvent
- Electrolyte
- Ions
- Lipids
- Osmosis
- Metallic and nonmetallic
- Igneous, sedimentary, metamorphic rocks
- Composting
- Aerobic and anaerobic
- Carcinogen
- Heavy metals
- Amalgam
- Polymerization
- Composites

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- This issue supports the 2017 National Chemistry Week theme of "Chemistry Rocks!"

- Most of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them in their personal lives.

- The infographic on page 19 provides more information to support the article “Making Water Safe to Drink” on pages 14-16.

- To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles.

- You might also ask them how information in the articles might affect their health and/or consumer choices. Also ask them if they have questions about some of the issues discussed in the articles.

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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. 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. The most common waterborne disease is due to strains of *E. coli.*
		2. Chlorination and ozone are used to kill bacteria and viruses in water.
		3. Drinking water comes only from underground aquifers.
		4. At water treatment plants, the pH of water is adjusted to be acidic so that pipes do not corrode.
		5. Heavy metals can be precipitated out of water by adding compounds such as $NaOH$ or CaO.
		6. The use of chlorine for disinfecting water can produce harmful by-products.
		7. The EPA regulates only about 10 contaminants in drinking water.
		8. EPA regulations are based on scientific data.
		9. One part per billion is the same as 1 mg/L.
		10. Many contaminants are introduced into drinking water through human actions.

Graphic Organizer

Name: ______________________________

Directions: ***As you read***, complete the graphic organizer below to describe the chemical reactions involved in treating the contaminants found in drinking water.

Contaminant	Why is this a problem?	Chemicals used for treatment	Possible problems posed by treatment
Viruses and Bacteria			
Heavy Metals			
Pesticides, carcinogens, and endocrine disruptors			

Summary: On the back of this paper, summarize the important issues related to water treatment in a sentence (20 words or less).

Student Reading Comprehension Questions

Directions: Use the article to answer the questions below.

____
Name

1. Which water contaminants should concern us?

2. Which diseases associated with untreated water come (a) from bacteria and (b) from viruses?

3. Give two reasons why it is difficult to track viral infections to contaminated water.

4. How does chlorine gas kill bacteria and viruses?

5. List two ways that ozone kills bacteria and viruses.

6. Name two major advantages of using ozone over chlorine as a disinfection technique.

Student Reading Comprehension Questions, cont.

7. In the water-treatment process, explain (a) how and (b) why the pH is adjusted near the end of the purification process.

8. How can heavy metals present at the source of the drinking water be removed?

9. In the precipitation reaction given in the article, what is the formula of the precipitate?

10. What is an unintended hazard of using chlorine as a disinfection agent?

11. Describe two ways that heavy metals get into the water supply

12. How can water purification plants reduce heavy metals that leach from the linings of pipes?

Answers to Student Reading Comprehension Questions

1. **Which water contaminants should concern us?**
   Water contaminants that should concern us include bacteria, viruses, parasites, heavy metals, pesticides and carcinogens.
2. **Which diseases associated with untreated water come from (a) bacteria and (b) viruses?**
   a. *Bacterial diseases associated with untreated water include dysentery, typhoid, cholera, botulism and legionella.*
   b. *Viral diseases associated with untreated water include hepatitis A and SARS.*
3. **Give two reasons why it is difficult to track viral infections to contaminated water.**
   It is difficult to track viral infections to contaminated water because
   a. *people may not associate their illness with drinking water.*
   b. *SARS mimics flu symptoms, and some viral infection symptoms may take several days to appear.*
4. **How does chlorine gas kill bacteria and viruses?**
   Chlorine gas forms a weak acid called hypochlorous acid (HOCl) when added to water. Bacterial cell walls are negatively charged; the weak acid is electrically neutral, so it passes through cell membranes, chemically attacks lipids in cells walls, and destroys the enzymes and structures in bacterial and viral cells.
5. **List two ways that ozone kills bacteria and viruses.**
   Ozone kills germs by
   a. *breaking through the cell membranes (and interfering with the work of their enzymes) to destroy bacteria.*
   b. *diffusing through the protein coats of viruses, damaging their ribonucleic acid.*
6. **Name two major advantages of using ozone over chlorine as a disinfection technique.**
   The two advantages ozone has over chlorine are that
   a. *ozone must be made on site because it is highly reactive and does not last long. Chlorine cannot be produced on site and has to be shipped or stored as a gas or as bleach, and*
   b. *fewer unintended reactions occur in the water being cleaned with ozone.*
7. **In the water-treatment process, explain (a) how and (b) why the pH is adjusted near the end of the purification process.**
   a. *The acidity is adjusted by adding lime (calcium oxide, CaO) near the end of the purification process.*
   b. *The pH is adjusted to ensure that the pH of the water remains basic as it leaves the municipal plant to prevent acidity from corroding metallic water-distribution pipes.*
8. **How can heavy metals present at the source of the drinking water be removed?**
   Heavy metals present at the source of the drinking water can be removed in the water treatment facility by precipitation reactions.
9. **In the precipitation reaction given in the article, what is the formula of the precipitate?**
   In the chemical reaction given in the article, the precipitate's formula is $Ni(OH)_2(s)$.
10. **What is an unintended hazard of using chlorine as a disinfection agent?**
    An unintended hazard of using chlorine as a disinfection agent is the formation of trihalomethanes, especially chloroform ($CHCl_3$); all are suspected carcinogens.

11. **Describe two ways that heavy metals get into the water supply.**
    a. *When groundwater comes into contact with soil or rocks that contain high concentrations of arsenic, the water dissolves some of the metal.*
    b. *Heavy metals enter the drinking system by leaching from the linings of pipes in the distribution system.*
12. **How can water purification plants reduce heavy metals that leach from the linings of pipes?**
    Water purification plants can reduce heavy metals that leach from the linings of pipes by adding corrosion inhibitor compounds to the water.

Possible Student Misconceptions

1. **"My uncle says that when water runs swiftly over rocks it is cleaned for drinking."** *When water runs swiftly over rocks it may be cleaned of visible debris, but this does not remove microscopic parasites such as giardia, commonly found in backcountry streams or lakes. Giardia causes mild to severe intestinal problems that can last for weeks.*
2. **"To avoid all contaminants, I'll just drink distilled water!"** *Yes, distilled water is pure water (only molecules of H_2O), so you will not be drinking any contaminants. Yet, this is not a healthy choice. Tap water contains minerals that catalyze reactions in your body and ions that are essential in the transmission of the nerve impulses, keep your heart beating, and maintain the balance of water in your cells and blood plasma.*
3. **"I read that one billion people in the world don't have enough water, so I am worried that the world must be running out of water."** *Running out of water globally is a major misconception because all of the water present when the world was formed is still here. Unfortunately, water is not evenly distributed; there are droughts in some areas and floods in others. Much of the earth's water is located where it is not easily accessible—in deep lakes, jungle rivers, polar ice caps—and some of our water is polluted.*
4. **"I always drink bottled water because it is purer than tap water."** *This depends upon the source of the bottled water. It may come from municipal sources that are the same as tap water, or spring water sources containing impurities such as heavy metal contaminants from rocks and the ground.*
5. **"My Mom says that drinking six to eight glasses of water every day will keep me healthy."** *Yes drinking water is important, but the amount depends upon the weather and how much you sweat, your height, weight, muscle mass and the food that you eat. Your diet can supply much of your water needs. Actually drinking too much water can lead to water intoxication, hyponatremia. If you perspire excessively and drink so much water that your body's sodium level drops, your brain cells may swell, leading to death. (Read the Larter article, "A Toxic Dose of Water", in this* ChemMatters *issue.)*

Anticipating Student Questions

1. **"Does boiling water eliminate all contaminants?"** *Boiling water kills bacteria, viruses and parasites because the heat destroys the structure and denatures the proteins of living organisms. However it does not remove toxic chemicals and heavy metals from water.*
2. **"I live in Southern California where we don't have enough water. There is plenty of water in the ocean so why doesn't the government just build plants to remove the salt from ocean water?** *Desalination is used to remove salt from ocean water, producing drinking water, but this process is very expensive because much electrical energy is required to evaporate the water. Desalination may negatively affect coastal water quality if effluent containing a high concentration of salt, sediment and marine organism debris is not cleaned and adjusted to the salinity, pH and temperature of the area where it is discharged.*
3. **"Why was the water in Columbia, S.C., Flint, MI, and Baltimore, MD unsafe to drink?"** *Updated infrastructure in all three of these cities was lacking. In Columbia, lead was leached from corroded pipes that serve homes, and floods destroyed two canals, releasing bacteria into the water system. In Baltimore, drinking fountain pipes leached lead. To save money, Flint changed its water supply to the Flint River, but corrosion controls were not implemented, so lead and E. coli were released from corroded supply lines.*
4. **"How is ozone produced at water treatment facilities?"** *Most water treatment facilities use the Corona Discharge method to produce ozone. A spark of high voltage electricity is sent through a flow of oxygen, the electricity splits the diatomic O_2 into singlet oxygen atoms that combine with other O_2 molecules to form O_3. This is similar to the way ozone is produced by lightning or ultraviolet radiation in the upper atmosphere.*
5. **"Since the symptoms are similar, how can I tell if I have SARS or the flu?"** *Both SARS and the flu begin with high fevers and may include symptoms of pneumonia, such as a cough, difficulty breathing, or shortness of breath. SARS is very rare, but there are laboratory tests that can help with identification. However these are not reliable in the early stages of infection.*
6. **"I've read about how much of our water stays in underground compartments called aquifers. Why don't we just inject them with disinfection materials to kill bacteria and viruses?"** *You are correct when you say that much of our water is stored underground, but aquifers are underground areas of porous rock that absorb and transmit water. The underground water is always naturally flowing and picking up new bacteria and viruses as it moves underground and eventually reaches the surface, where it will mix with possibly contaminated surface water. So, water in aquifers would still require disinfection when it reaches the surface.*

Activities

Labs and Demos

Lab activity, "Solar Still Challenge": The challenge to build a solar still was developed for the International Year of Chemistry (IYC 2011). The activity uses household materials and provides complete instructions for the teacher. Since this was a global challenge, students were invited to contribute water quality data from their experiment to an on-line international map. Links on this site also take you to salinity and acidity experiments. (http://water.chemistry2011.org/web/iyc/experiments)

"Precipitation and Solubility Chemistry Laboratory" (1 class period): This micro-lab experiment was designed for high school honors students. The material includes pre- and post-lab questions, laboratory procedures (using well-plates) plus safety and waste management instructions. (http://nshs-science.org/chemistry/make_handout.php?course=820&%20path=common&%20handout=CLH-precipitation_reactions)

Simulation

"Precipitate Reactions": These simulations use animations of ionic reactions at the particle level to show the formation of precipitates (requires *Flash Player* app). (http://preparatorychemistry.com/precipitation_flash.htm)

Media

"The Water Treatment Process" video (3:20): This video takes the viewer through a municipal water treatment plant illustrating the removal of metals, flocculation, filtration, pH adjustment, activated carbon filtration and disinfection by ozone and chlorination. (https://www.youtube.com/watch?v=9z14l51ISwg)

Two YouTube videos on the Flint water crisis, from CNN:

a. "Here's How Flint's Water Crisis Happened" (4:29): This video shows how political decisions led to changing the city's water supply to the Flint River and the subsequent rulings that precipitated the dangerous pollution crisis. (https://www.youtube.com/watch?v=nTpsMyNezPQ)
b. "Flint Water Crisis 2017" (8:51): this video shows some of the cognitive and behavioral problems displayed by children affected by drinking water containing high levels of lead. Teachers and health care personnel are shown working with young children to diagnose signs of lead poisoning and find ways to teach children with subsequent brain disorders. (https://www.youtube.com/watch?v=3-hVMjgzEiI)

Lessons and Lesson Plans

"Water Quality" (six 50-min. class periods) and "Water Quality Testing" lab activity (1-2 hours): This very thorough 5E (Engage, Explore, Explain, Extend, Evaluate) lesson plan is designed for students to study their local water quality and the effects of water pollutants. Complete information is given, including handouts for students and grading rubrics for teachers. (http://www.learnnc.org/lp/editions/criticalthinking/6650)

"Precipitates": Complete instructions, material list, questions and guidance for the teacher for each of the 5 E parts of the lesson are given. Although "Reacting Two Compounds to Form a Precipitate", University of California, Irvine (UCI), was designed for 8th grade, it can be easily adapted for high school chemistry students.
(http://www.cfep.uci.edu/cspi/docs/lessons_secondary/precipitate%20Lab.pdf)

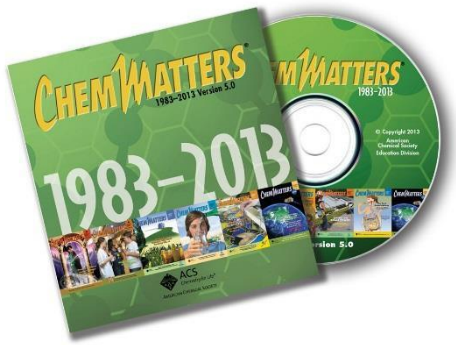
Projects and Extension Activities

"Neo- Malthusian vs Anti-Malthusian", a debate: Students will prepare for and then debate these two opposing views of the relationship between population size and resource consumption with the focus on water. Following a short written explanation, a video (8:26) located on this Web site describes the two viewpoints, shows pertinent graphs, provides data to support each view and gives clear instructions as focus for this debate. (http://share.nanjing-school.com/dpgeography/patterns-and-change-core-unit/sl-patterns-and-change-4-resource-consumption/1-patterns-of-resource-consumption/neo-malthusian-vs-anti-malthusian/)

"Water Filtration Challenge", laboratory activity (1–2 hours): This is a National Aeronautics and Space Administration/Jet Propulsion Laboratory (NASA/JPL) engineering challenge for students, grades 5–12. Students are presented with the challenge to clean waste water and given materials to build, test, and measure the performance of their filtration device; analyze the data collected; and use this information to work toward an improved filtration design. Complete teacher instructions are included on this site: https://www.jpl.nasa.gov/edu/teach/activity/water-filtration-challenge/.

References

The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine's inception in October 1983 through April 2013; all available Teacher's Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site: http://ww.acs.org/chemmatters. Click on the "Teacher's Guide" tab to the left, directly under the "*ChemMatters Online*" logo and, on the new page, click on "Get the past 30 Years of *ChemMatters* on DVD!" (the icon on the right of the screen)



30* Years of *ChemMatters !

Available Now!

Selected articles and the complete set of Teacher's Guides for all issues from the past three years are available free online at the same Web site, above. Click on the "Issues" tab just below the logo, *"ChemMatters Online"*.

Chemical reactions for the formation of hypochlorous acid (HOCl) from chlorine gas and water are given showing that as the pH changes, the size of the chemical symbols in the HOCl equilibrium increases or decreases to illustrate the amount of hydrogen ion (H^+) present. You may find this an effective way to present acidity changes to students. (Tanis, D.; Dombrink, K. Swimming Pool Chemistry. *ChemMatters*, 1983, *1* (2), pp 4–5)

This article presents a chemical engineering problem and describes the chemistry involved in developing a practical process for removing arsenic from personal drinking water in a non-industrialized region of India. (Brownlee, C. The Quest for a Clean Drink. *ChemMatters*, 2008, *26* (2), pp 4–6)

This article describes how bioremediation was used to remove toxic perchloroethylene (PCE), discarded by dry cleaning facilities, from the drinking water. The author shows and explains the chemical redox reactions that occur when bacteria decompose PCE to ethylene gas. (Argentine, C. Microbes and Molasses: A Successful Partnership. *ChemMatters*, 2012, *30* (2), pp 9–11)

Author Dingle provides details on both the chemistry and the political problems that led to high levels of lead in the drinking water of Flint, Michigan. Pictures of corroded pipes, accompanied by chemical equations, provide a good oxidation/corrosion lesson. (Dingle, A. The Flint Water Crisis. *ChemMatters*, 2016, *34* (4), pp 5–8)

Web Sites for Additional Information

Safe Drinking Water Act (SDWA)

The "Clean Water Enforcement Act" (1972) set wastewater standards for industry and, since then, the U.S. Environmental Protection Agency (EPA) has monitored the quality of water from livestock and poultry feeding operations, storm drains, oil spills and waste water treatment plants. Links on this Web site provide additional information. (https://www.epa.gov/laws-regulations/summary-clean-water-act)

In 1974 the U.S. EPA enacted SDWA to protect public health by setting limits for natural and manmade contaminants in public drinking water and, in 1996, the law was expanded to include protection of drinking water at its source (e.g., rivers, lakes, reservoirs, springs and groundwater wells). History and details of the SDWA can be found here: https://www.epa.gov/sites/production/files/2015-04/documents/epa816f04030.pdf.

Waterborne pathogens

This site contains details about *Escherichia coli* (*E. coli*) bacteria, including its importance to living systems and the harmful effects of the *E. coli* O157:H7 strain. This O157:H7 strain can serve as an indicator of human and animal waste contamination in drinking water supplies. (http://www.freedrinkingwater.com/water-contamination/ecoli-bacteria-removal-water.htm)

Two Centers for Disease Control and Prevention (CDC) sites provide information on waterborne pathogens. One provides detailed information about the viral infection Severe Acute Respiratory Syndrome (SARS), its transmission and symptoms. (https://www.cdc.gov/sars/about/faq.html), and the second lists waterborne pathogens (bacterial and viral), their route of transmission, preventative measures, and death rates from major outbreaks. (https://www.cdc.gov/nceh/vsp/training/videos/transcripts/water.pdf)

Municipal disinfection—chlorine

In addition to the gaseous form, this Web site lists the types of dry and liquid chlorine used in municipal plants and the environmental factors that determine chlorine's effectiveness. The site shows how to calculate contact (retention) time, the time required from chlorine's introduction to the production of safe drinking water. (http://www.water-research.net/index.php/water-treatment/tools/chlorination-of-water)

This Web site provides information about harmful by-products of chlorine disinfection. A graph displays trihalomethane (THM) formation as a function of chlorine contact time; another graph shows how organic carbon concentration influences the formation of THMs; and a table lists by-products from various disinfection techniques. (http://www.lenntech.com/processes/disinfection/byproducts/disinfection-byproducts.htm)

Municipal disinfection—ozone

This site discusses, explains, and provides a list of the advantages and disadvantages of municipal use of ozone to disinfect drinking water. A schematic, “Automatic Ozone Injection, Filtration, and Recirculation of Iron, Manganese”, illustrates the method used to filter (remove) metal oxide precipitates formed during ozonation. (http://www.water-research.net/index.php/ozonation)

Although ozone is an unstable molecule with a half-life of only 30 seconds, it is a strong oxidizing agent that forms the free radical OH*. A description of how OH* leads to harmful by-products and ways to control their formation are provided at: (https://www.wwdmag.com/microfiltration/strategies-minimizing-ozonation-products-drinking-water)

Municipal water treatment process

This site describes primary, secondary and tertiary municipal water treatment. In the Wood-Black article diagram, the first four steps are designed to reduce THM formation by removing organic material before chlorine is added (step 5). (http://www.filtronics.com/blog/tertiary-treatment/stages-in-typical-municipal-water-treatment/)

Students can use the map on this U.S. EPA site and click on their state and water district to retrieve a local Customer Confidence Report (CCR) that shows the level of contaminants in their water. The CCR lists the source of their water, and the Web site contains links to frequently asked questions (FAQs). (https://ofmpub.epa.gov/apex/safewater/f?p=136:102)

Heavy metals

This manuscript describes the sources, toxicity and carcinogenicity of heavy metals in our environment. Detailed focus is on arsenic, cadmium, chromium, lead and mercury, and the potential for exposure in water, air and soil. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4144270/)

Research describes a novel approach to removal of heavy metal ions from waste and ground water using a reusable metal chelator that forms metal complexes removable by filtration. A graph on this site shows how pH is a critical factor in successful removal. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4355739/)

Pesticides

The National pesticide Information Center (NPIC) site has prepared this fact sheet on pesticides in drinking water. Sections include: how pesticides enter drinking water, health effects from pesticides and what is being done to remove them from drinking water. (http://npic.orst.edu/factsheets/drinkingwater.pdf)

In municipal water treatment, activated carbon and filtration are usually used to remove pesticides, because chemical treatments may degrade synthetic molecules forming harmful by-products. Fenton’s oxidation reaction is one of the most effective treatments, the chemistry of which is shown here: http://www.pjoes.com/pdf/10.4/207-212.pdf)

Endocrine disruptors and carcinogens

This site reports data collected during a study of water released from wastewater treatment plants and the monitoring of Minnesota's rivers and lakes for endocrine-active compounds. Sampling methods and analysis of the effects on fish are described. (https://www.pca.state.mn.us/sites/default/files/lrp-ei-1sy11.pdf)

Recognizing the possible carcinogenicity of pesticides and endocrine disruptors, the European Union (E.U.) proposed a list of criteria to define endocrine disruptors. This article discusses the politics involved when environmental groups, the pesticide industry, and E.U. member countries work toward an agreement on the regulation of these compounds. (https://www.euractiv.com/section/energy-environment/news/eu-experts-agreeoncriteria-for-endocrine-disrupting-chemicals-in-pesticides/)

ChemMatters
Demystifying Everyday Chemistry

Teacher's Guide

"Dental Fillings: A Reaction in Your Mouth"

(October/November 2017 Issue)

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ACS Chemistry for Life®

ChemMatters
Demystifying Everyday Chemistry

Teacher's Guide for

Dental Fillings: A Reaction in Your Mouth

October/November 2017

Table of Contents

Connections to Chemistry Concepts

Chemistry Concept	Connection to Chemistry Curriculum
Alloys	Some students may have silver-colored dental amalgam fillings, or at least they have heard about them. Connecting this common dental material (containing mixtures of mercury, silver, tin, and/or copper) to alloys can provide an example other than the common steel, brass, and bronze examples used in class.
Polymers	Students may be familiar with common polymers, including polyester, cellulose, and polyethylene, but they may not know that white-colored, composite dental resins are a commonly-used and very strong polymer. Understanding how polymers form from monomer units and how they are useful in our lives (including less familiar polymers like those in dentistry) may be insightful for students.
Covalent bonding	In addition to the traditional study of covalent bonds in hydrocarbons, students may better relate to the covalent bonds formed during polymerization of composite resins in their dental fillings. Often thought of as weaker bonds, covalent bonds can create large and strong molecules capable of withstanding the tremendous forces (275 pounds) in a human bite.
Polar molecules	The hydrophobic polymer in composite dental resins and the hydrophilic silica-based glass provide teachers with an opportunity to discuss the polarity of molecules and why those polar charges occur, using the example of students' dental fillings. In particular, the hydroxyl groups in both the composite resin silica-based glass reinforcement material and the silanes used as a coupling agent provide opportunities for understanding polar molecules and their interactions.
Chemical properties and reactivity	A discussion of why gold was used in the past as a dental filling could lead students into a discussion of chemical properties and reactivity. Why was copper not used, or iron? The characteristics which make dental amalgam or composite resins preferable as dental fillings over gold could include costs, hardness, non-reactivity, availability, aesthetics, etc.
Materials science	The development of composite resins for dental fillings in the 1990s is an example of materials science at work. Moving from gold, to amalgam, to composites illustrates the process of material science research to meet the needs of humans by modifying the materials around them for better lives.

Teaching Strategies and Tools

Standards

- Links to **Common Core Standards for Reading**:
  ELA-Literacy.RST.9-10.1. Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  ELA-Literacy.RST.9-10.5. Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).
  ELA-Literacy.RST.11-12.1. Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
  ELA-Literacy.RST.11-12.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*.

- Links to **Common Core Standards for Writing**:
  ELA-Literacy.WHST.9-10.2F. Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
  ELA-Literacy.WHST.11-12.1E. Provide a concluding statement or section that follows from or supports the argument presented.

- Links to **Next Generation Science Standards**
  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**:
        - LS1.A: Structure and function
        - PS1.A: Structure and properties of matter
        - ETS1.B: Optimizing the design solution
    - **Crosscutting Concepts:**
        - Systems and system models
        - Stability and change
        - Structure and function
    - **Science and Engineering Practices:**
        - Asking questions (for science) and defining problems (for engineering)
        - Obtaining, evaluating, and communicating information
    - **Nature of Science:**
        - Scientific knowledge is based on empirical evidence.
        - Scientific knowledge assumes an order and consistency in natural systems

Vocabulary

Vocabulary and **concepts** that are reinforced in the October/November 2017 issue:

- Equilibrium
- Solute and solvent
- Electrolyte
- Ions
- Lipids
- Osmosis
- Metallic and nonmetallic
- Igneous, sedimentary, metamorphic rocks
- Composting
- Aerobic and anaerobic
- Carcinogen
- Heavy metals
- Amalgam
- Polymerization
- Composites

Reading Supports for Students

The pages that follow include reading supports in the form of an Anticipation Guide, Reading Strategies, a Graphic Organizer, and Student Reading Comprehension Questions. These resources are provided to help students as they prepare to read and in locating and analyzing information from the article.

The borders on these pages distinguish them from the rest of the pages in this Teacher's Guide—they have been formatted for ease of photocopying for student use.

- **Anticipation Guide (p. 8):** The Anticipation Guide helps to engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

- **Graphic Organizer (p. 9):** The Graphic Organizer is provided to help students locate and analyze information from the article. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher, if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the article. The use of bullets helps them do this.

  If you use the aforementioned organizers 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

- **Student Reading Comprehension Questions (p. 10):** The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.

- This issue supports the 2017 National Chemistry Week theme of "Chemistry Rocks!"

- Most of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them in their personal lives.

- To help students engage with the text, ask students which article engaged them most and why, or what questions they still have about the articles.

- You might also ask them how information in the articles might affect their health and/or consumer choices. Also ask them if they have questions about some of the issues discussed in the articles.

- The Background Information in the *ChemMatters* Teachers Guide has suggestions for further research and activities.

“Dental Fillings: A Reaction in Your Mouth”, *ChemMatters*, October/November 2017 Issue

Anticipation Guide

Name ______________________________

Directions: ***Before reading the article*****,** in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. 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
		11. About half of the high school students in the U. S. have tooth decay.
		12. Amalgam dental fillings contain mercury and other metals.
		13. Composite resins, which are white, are used for dental fillings today.
		14. Monomers have the same properties than the polymers they form.
		15. Polymerization to form dental resins begins spontaneously when molecules of the monomer are present.
		16. Blue light is used by dentists to trigger polymerization.
		17. The polymer in dental resins attracts water.
		18. Hydroxyl (OH^-) groups are attracted to water.
		19. Dental resins are reinforced with silica-based glass.
		20. Composite-resin fillings include dyes to match a patient’s tooth color.

Graphic Organizer

Name: ______________________________

Directions: ***As you read***, complete the graphic organizer below to describe what you learned about the chemistry of composite resin dental fillings.

Composite Resin Dental Fillings	
Why are they used?	
What is the role of polymerization in creating the fillings?	
Why is blue light used?	
Why are particles of silica-based glass added to the dental resin?	
How do coupling agents help create the dental resin?	

Summary: On the back of this paper, use information from the article to write a tweet (140 characters or less) about dental resins.

“Dental Fillings: A Reaction in Your Mouth”, *ChemMatters*, October/November 2017 Issue

Student Reading Comprehension Questions

Directions: Use the article to answer the questions below. ______________________________
Name

1. What fraction of high school students in the United States have tooth decay?

2. List five desirable characteristics of an ideal dental filler for sealing a tooth.

3. What are three common types of dental fillings?

4. What are three drawbacks to the use of silver (amalgam) fillings?

5. Provide four advantages of using composite resin fillings.

6. What is one example of a thoroughly cross-linked polymer that is one big molecule?

Student Reading Comprehension Questions, cont.

7. What are free-radicals?

8. Explain why dental resins are poured in thin layers until the cavity is filled.

9. Why is a coupling agent included in dental resins?

10. Identify the two parts of composite materials. For dental resin, what material is used for each of these two composite parts?

11. Dental resin composites contain materials that are hydrophobic and hydrophilic. What do these two terms mean?

12. Name three actions students can take to prevent tooth decay.

Answers to Student Reading Comprehension Questions

1. **What fraction of school students in the United States have tooth decay?**
   Approximately half of high school students in the United States have tooth decay.
2. **List five desirable characteristics of an ideal dental filler for sealing a tooth.**
   Five desirable characteristics of an ideal dental filler for sealing a tooth include:
   a. it must be soft and malleable when applied,
   b. it must harden once in place,
   c. it must be resistant to chewing,
   d. it must be chemically stable, and
   e. it must be biocompatible.
3. **What are three common types of dental fillings?**
   Three common types of dental fillings are
   a. gold,
   b. amalgam, and
   c. composite resins.
4. **What are three drawbacks to the use of silver (amalgam) fillings?**
   Three drawbacks to the use of silver or amalgam fillings are
   a. the filling is unattractive in the mouth,
   b. the amalgam does not stick to the tooth, so extra healthy tooth must be removed to anchor the amalgam, and
   c. there are concerns about mercury in the amalgam leaking from the filling.
5. **Provide four advantages of using composite resin fillings.**
   Four advantages of using composite resin fillings are
   a. they match the tooth color,
   b. they are soft and easily applied,
   c. they solidify quickly to a hard solid, and
   d. they last a long time.
6. **What is one example of a thoroughly cross-linked polymer that is one large molecule?**
   One example of a thoroughly cross-linked polymer that is one big molecule is a resin bowling ball.
7. **What are free radicals?**
   Free radicals are molecules that have unpaired electrons.
8. **Explain why dental resins are poured in thin layers until the cavity is filled.**
   Dental resins are poured in thin layers until the cavity is filled because the blue light used to induce polymerization of the resin can only travel a few millimeters into the filling. Therefore, the resin must be poured in layers to allow each layer, exposed to the blue light, to properly polymerize and harden.
9. **Why is a coupling agent included in dental resins?**
   A coupling agent is included in dental resin because the polymer is hydrophobic and the silica-based glass is hydrophilic. The coupling agent is needed to bond the polymer to the silica.
10. **Identify the two parts of a composite materials. For dental resin, what material is used for each of these composite parts?**
    The two parts of a composite material are the matrix and the reinforcement (or filler). In dental resin, the matrix is the polymer and the reinforcement material (or filler) is the silica.

11. **Dental resin composites contain materials that are hydrophobic and hydrophilic. What do these two terms mean?**
    The term hydrophobic means that the material does not mix with water. The term hydrophilic means that the material attracts water.
12. **Name three actions students can take to prevent tooth decay.**
    Three actions that students can take to prevent tooth decay include
    a. limiting the consumption of sugar and carbohydrates,
    b. brushing and flossing daily, and
    c. seeing a dental hygienist regularly.

Possible Student Misconceptions

1. **"My friend said that I need to have the silver-colored (amalgam) fillings in my teeth removed so I don't get mercury poisoning."** *The U.S. Food and Drug Administration (FDA) advises that if the fillings are in good condition and there is no tooth decay below the filling then there is no need to replace the amalgam fillings with new ones. The unnecessary removal and replacement of amalgam fillings can lead to loss of healthy tooth structure and possible exposure to additional mercury vapor in the process of removal.*
2. **"I heard that silver fillings can cause Alzheimer's disease"** *"According to the best available scientific evidence, there is no relationship between silver dental fillings and Alzheimer's… Public health agencies, including the FDA, the U.S. Public Health Service and the World Health Organization, endorse the continued use of amalgam as safe, strong, inexpensive material for dental restorations." (http://www.alz.org/alzheimers_disease_myths_about_alzheimers.asp)*
3. **"Sugar causes tooth cavities."** *Sugar can be contribute to dental cavities, but other culprits include carbohydrates such as pasta, breads, fruits, beans, and desserts. However, it's not the sugar or the carbohydrates that cause the actual dental decay and cavities. It is, instead, the acids produced as waste by bacteria in the mouth as they digest these sugars and carbohydrates that cause the cavities. It is important to remove these acids from the teeth by rinsing, brushing, and flossing teeth at least twice a day so the acids do not accumulate and eat away at the teeth.*

Anticipating Student Questions

1. **"How long can the fillings in my teeth last?"** *Different types of dental fillings have different durabilities. Typically, cast gold fillings can last at least 10–15 years, or longer, with proper care. The amalgam (silver) fillings can last at least 10–15 years. The composite resin fillings are less durable and last at least five years, but they may not last as long if used in large cavities or on chewing surfaces of the teeth.*
2. **"What causes cavities in my teeth?"** *Tooth decay or a cavity is caused by the reaction of acids on teeth. The acids are produced as a waste by bacteria in the mouth digesting foods, especially sugars and starches, and changing them into the acids. The bacteria, saliva, food, and resulting acids form a very sticky substance called plaque which sticks to the teeth. This plaque accumulates most commonly on the back molars, around the gum line, and around the edges of dental fillings. The acids trapped in the plaque (which builds up on teeth within 20 minutes after eating) erode the enamel of the tooth and creates holes called cavities (also called dental caries).*
3. **"If mercury is toxic, why is it used in dental fillings?"** *About half of the dental amalgam in a silver-colored filling is made of mercury. The mercury is used to dissolve and bind the other metals (silver, tin, and copper) into a strong and stable filling. Mercury's unique property of being a liquid metal at room temperature makes it easy to form the durable amalgam filling at room temperature, which is safe for the patient. All of the credible scientific evidence reviewed by the FDA, and the clinical studies conducted in adults and children above age 6 and adults, have found no links between dental amalgam fillings and health problems.*

Activities

Labs and Demos

Dental chemistry lab: Students design their own experiment to investigate the effects of fluoride treatment on teeth using sodium fluoride solution and marble chips or eggshells as a substitute for teeth. "Dental Chemistry Analogy" from Terrific Science includes student materials and extensive instructor notes. (http://www.terrificscience.org/lessonpdfs/03DentalChem.pdf)

Simulations

Simulation of condensation and hydrolysis reactions: *Biomolecules* contains a simple simulation activity, “Building and Breaking Biomolecules”, where students can build and label a simple dimer molecule through a condensation (or dehydration synthesis) reaction and follow with a hydrolysis reaction. (https://dlc.dcccd.edu/biology1-3/functional-groups-and-biomolecules)

Animated simulation of condensation and hydrolysis: "Condensation and Hydrolysis – Cengage" provides a simple, clear audio and visual representation of both condensation and hydrolysis reactions with organic molecules.
(http://www.cengage.com/biology/discipline_content/animations/reaction_types.html)

Media

Infographic of "The Chemistry of Dentistry": This infographic illustrates the topics of “Tooth Decay”, “Fluoride Versus Tooth Decay”, “Fillings and Composites”, and “Teeth Whitening”.
(http://cen.acs.org/articles/94/i24/Periodic-Graphics-chemistry-dentistry.html)

PowerPoint on dental materials: This 52-slide presentation, "Restorative and Esthetic Dental Materials", discusses amalgams, composite resins, glass ionomers, gold alloys, porcelain, and other dental materials. Indications for use, concerns, preparation, and application of these materials is provided.
(http://www.csi.edu/facultyAndStaff_/webTools/sites/Bowcut58/courses/552/ch43.ppt)

Video of dental cavity formation: "What Is a Cavity?" (6:45) shows the formation of a dental cavity. The video discusses the biotic conditions responsible for dental acid formation through animation. (https://www.youtube.com/watch?v=hTK0iua4tNA&t=119s)

Lessons and Lesson Plans

Dentistry polymers lesson: The Royal Society of Chemistry publishes an eight-page lesson, "Polymers in Everyday Things—Dentistry", with background information on different types of dental fillings but focusing on dentistry polymers. The lesson includes a four-page worksheet for students but has no teacher support materials.
(http://www.rsc.org/Education/Teachers/Resources/Inspirational/resources/3.1.2.pdf)

Lesson plan for metal alloys: A sequence of lessons for studying metal alloys is structured with reading, videos, and a summary task for students, with aluminum alloys. The Web site also includes links to lessons on ceramics, polymers, and composites, all of which are other types of materials used in dentistry. (https://www.e-education.psu.edu/matse81/node/2140)

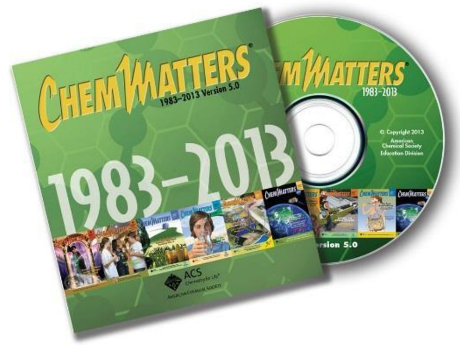
Projects and Extension Activities

Dental science fair projects and experiments: Suggestions for science fair projects and experiments, including natural substances for whitening teeth, amalgam toxicity, effectiveness of different teeth cleaners on bacteria, the effect of acids on amalgam, and how teeth are affected by fluoride and acids are provided at http://www.juliantrubin.com/fairprojects/medicine/dentistry.html.

Teaching dental health to elementary students: Dental health is typically taught to students in early elementary grades. High school students could develop and teach lessons for elementary students using content, demonstrations, and experiments similar to those at https://www.deltadentalnj.com/kidsclub/kids_experiments.html.

References

The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine's inception in October 1983 through April 2013; all available Teacher's Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site: http://ww.acs.org/chemmatters. Click on the "Teacher's Guide" tab to the left, directly under the "*ChemMatters Online*" logo and, on the new page, click on "Get the past 30 Years of *ChemMatters* on DVD!" (the icon on the right of the screen)



***30* Years of *ChemMatters* !**

Available Now!

Selected articles and the complete set of Teacher's Guides for all issues from the past three years are available free online at the same Web site, above. Click on the "Issues" tab just below the logo, *"ChemMatters Online"*.

"Toothpaste", a complementary *ChemMatters* article to the Pistoi dental fillings article, includes the chemical reactions for the demineralization of dental enamel, a discussion of pH and acids produced by oral bacteria, and suggestions for preventing tooth decay. While the 1986 article is in black and white only, the chemistry and content are accurate and useful. (Yohe, B. Toothpaste. *ChemMatters*, 1986, *4* (1), pp 12–13)

"Tooth Decay: A Delicate Balance" is a wonderful companion to the Pistoi dental fillings article, providing a discussion of the acids that cause tooth decay and the equilibrium (and Le Châtelier's Principle) occurring to reverse that decay. The article provides details about acids, bases, buffers, and equilibrium associated with tooth decay. (Warmflash, D. Tooth Decay: A Delicate Balance. *ChemMatters*, 2015, *33* (3), pp 8–10)

The Teacher's Guide for "Tooth Decay: A Delicate Balance" (see above) supplies in-depth information on tooth structure, the chemistry of tooth decay, fluoride tooth treatments, dental fillings, tooth decay prevention, amalgam, and composite dental fillings. Additional activities and Web links to these same topics are included.

"Brush Up on Toothpaste!" explains how to reduce or prevent dental fillings through the chemical and physical action of toothpaste. Demineralization of tooth enamel from bacterial acids, biofilms, and the physical act of brushing teeth are detailed in this excellent supporting article. (Brown, V. Brush Up on Toothpaste! *ChemMatters*, 2017, *35* (1), pp14–15)

The Teacher's Guide for "Brush Up on Toothpaste!" (see above) provides additional content on tooth decay, oral bacteria, demineralization and remineralization of teeth, and the components of toothpaste, all of which complement the dental fillings article. Additional Web links, references, and a lab related to tooth decay are also supplied.

Five assessment questions for college general chemistry (adaptable for high school use) applied to fluorine compounds in dentistry are provided in this article. Chemistry concepts covered by the questions (with answers supplied) are: stoichiometry, concentration units, resonance, geometry of polyatomic ions, bond length, and bond order. (Pinto, G. Fluorine Compounds and Dental Health: Applications of General Chemistry Topics. *J. Chem. Educ.*, 2009, *86* (2), pp 185–187; http://pubs.acs.org/doi/pdf/10.1021/ed086p185. Note that this link takes you to a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal.)

This article reviews the chemistry of dental materials from past issues of the *Journal of Chemical Education*. Topics included in the review are toothpaste, dental restoration, and amalgams. (Williams, K. Behind the Scenes at the Toothpaste Aisle: The Chemistry of Dental Materials. *J. Chem. Educ.*, 2010, *87* (10), pp 1007–1008; http://pubs.acs.org/doi/abs/10.1021/ed1004992. Note that this link goes to a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal.)

Safety concerns of dental amalgams and identifying appropriate biomarkers for measuring the exposure to mercury from the amalgams are reported in this article summarizing U.S. Food and Drug Administration hearings. (Erickson, B. FDA Revisits Dental Amalgams. *Chem. Eng. News*, 2011, *89* (5), pp 40–41; http://pubs.acs.org/doi/abs/10.1021/cen-v089n005.p040. Note that this link provides a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal.)

Web Sites for Additional Information

Dental history timeline

The American Dental Association provides a *History of Dentistry Timeline,* with subsections on “Ancient Origins”, “The Beginnings of a Profession—Middle Ages”, “The Development of a Profession—18th Century”, “Advances in Science and Education—19th Century”, and “Innovations in Techniques and Technology—The 20th Century”. (http://www.ada.org/en/about-the-ada/ada-history-and-presidents-of-the-ada/ada-history-of-dentistry-timeline)

Tooth decay

The chemistry of tooth decay is explained in "Sugar and Tooth Decay". Chemical structures are used to illustrate the conversion of sucrose into lactic acid as it applies to tooth decay. (http://chemistry.elmhurst.edu/vchembook/548toothdecay.html)

A clinical description of tooth decay is provided in "Microbiology of Dental Decay and Periodontal Disease". The article discusses the bacterial aspects of tooth decay and the role of *Streptococcus mutans*. (https://www.ncbi.nlm.nih.gov/books/NBK8259/)

Comparing types of dental fillings

"Types of Fillings" compares the advantages and disadvantages of the common dental fillings of amalgam, composite resin, cast gold, ceramics, and glass ionomers. (http://www.colgate.com/en/us/oc/oral-health/procedures/fillings/article/types-of-fillings)

"Dental Health and Tooth Fillings" contains numerous links on the Web site listing the advantages and disadvantages (including durability, aesthetics, and expense) of cast gold, amalgam, composite, and other dental fillings. ((http://www.webmd.com/oral-health/guide/dental-health-fillings)

Gold fillings

"Gold in Dentistry: Alloys, Uses, and Performance" explains how 70 tons of gold are used annually in dentistry. The current uses of gold and newer techniques, including electroforming, are explained, along with suggestions for future development. (https://link.springer.com/article/10.1007/BF03215496)

A 1981 article, "Dental Gold Alloys: Composition, Properties, and Applications", discusses the properties of gold that have led to its wide use in dentistry. The chemical and physical properties of different gold alloys used in a variety of dental applications are explained. (https://link.springer.com/article/10.1007/BF03214598)

Amalgam fillings

The U.S. Food and Drug Administration's Web site, "About Dental Amalgam Fillings", discusses amalgam fillings, their benefits and risks, the use of mercury in the amalgams, and whether existing amalgam fillings should be removed. (https://www.fda.gov/medicaldevices/productsandmedicalprocedures/dentalproducts/dentalamalgam/ucm171094.htm)

"Dental Amalgam: An Update" reviews the history and the future of this common dental filling. Topics discussed in the article include its durability, toxicity, composition, and several variations on the traditional amalgam. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3010024/)

Composite resin fillings

"New Materials to Take a Bite out of Tooth Decay" explains the shift in dental fillings from gold and amalgam to polymer composite resins. Newer techniques for dental repairs, such as biomaterials and cavity-arresting alternatives, are included. (http://cen.acs.org/articles/94/i31/New-materials-take-bite-tooth.html)

"Composite Materials: Composition, Properties, and Clinical Applications" provides an in-depth look at dental resin composites. Methacrylate polymers with different fillers are analyzed for their advantages and disadvantages in various dental applications. (https://www.sso.ch/fileadmin/upload_sso/2_Zahnaerzte/2_SDJ/SMfZ_2010/SMfZ_11_2010/smfz_11_2010_research1.pdf)

Glass ionomers

Glass ionomers are dental cements that bond to teeth and release fluoride for a long time and can be used as dental fillings when paired with appropriate fillers. The advantages and disadvantages of glass ionomers are described in "A Review of Glass Ionomer Restorations in the Primary Dentition". (https://www.cda-adc.ca/jcda/vol-65/issue-9/491.html)

"20 Tips for Using Glass Ionomers" shows pictures of teeth being repaired with glass ionomers (GI). While written as for dentists, the publication provides insight into how and why GI can be used for dental restoration. (http://www.aacd.com/proxy/files/Students%20and%20Faculty/20%20tips%20Glass%20Ionomers.pdf)

Curing composite resins with blue light

"The Physics of Light Curing and its Clinical Implications" is a brief description of how light curing works in dental composite resins. Both older ultraviolet devices and newer LED lights are discussed. (https://www.dentalaegis.com/cced/2011/08/the-physics-of-light-curing-and-its-clinical-implications)

"Cure Mechanisms in Materials for Use in Esthetic Dentistry" is a technical explanation of how dental resins are cured (or hardened) using heat, light, or self-cure techniques. Chemical structures and reactions are included in the article. (https://www.researchgate.net/publication/221799494_Cure_mechanisms_in_materials_for_use_in_esthetic_dentistry)

Bis-GMA

One of the most common composite dental resins is Bis-GMA (Bisphenol A glycidylmethacrylate). This Web site provides a technical chemical compound summary for this substance and links to Web sites and publications where Bis-GMA is cited. (https://pubchem.ncbi.nlm.nih.gov/compound/Bis-gma)

The toxicity and causes of degradation of composite dental resins, including Bis-GMA, are described in "Release and Toxicity of Dental Resin Composite". This technical article concludes that newer composites are safer when used appropriately, but more studies are needed to understand the biocompatibility of these resins. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3532765/)

About the Guide

Teacher's Guide team leader William Bleam and editors Pamela Diaz, Steve Long and Barbara Sitzman created the Teacher's Guide article material.
E-mail: bbleam@verizon.net

Susan Cooper prepared the anticipation and reading guides.

Terri Taylor, *ChemMatters* Teacher's Guide interim editor, coordinated production and prepared the Microsoft Word and PDF versions of the Teacher's Guide.
E-mail: chemmatters@acs.org

Articles from past issues of *ChemMatters* and related Teacher's Guides can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013, along with all the related Teacher's Guides since they were first created with the February 1990 issue of *ChemMatters*.

The DVD also includes Article, Title, and Keyword Indexes that cover all issues from February 1983 to April 2013. A search function (similar to a Google search of keywords) is also available on the DVD.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558. Purchase information can also be found online at http://tinyurl.com/o37s9x2.