



**February/March 2018**

Table of Contents

[*“The Cool Chemistry of Dry Ice”* 2](#_Toc503455343)

[*“Pain Relievers: How Do they Take Away Pain?”* 23](#_Toc503455360)

[*“Acidic Seas: How Carbon Dioxide is Changing the Oceans”* 48](#_Toc503455377)

[*“Eat the Wrapper?! Edible Solution for Wasteful Packaging”* 69](#_Toc503455394)

[*“Indigo: The ‘Blue’ in Blue Jeans”* 93](#_Toc503455411)

[About the Guide……………………………………………....…..…… 116](#_Toc503455428)

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**Teacher’s Guide**



**Teacher's Guide for**

### *“The Cool Chemistry of Dry Ice”*

**February/March 2018**

**Table of Contents**

[Connections to Chemistry Concepts 3](#_Toc503455505)

[Teaching Strategies and Tools 4](#_Toc503455506)

[Standards 4](#_Toc503455507)

[Vocabulary 4](#_Toc503455508)

[Reading Supports for Students 5](#_Toc503455509)

[Anticipation Guide 7](#_Toc503455510)

[Reading Strategies 8](file:///C:\Users\Bill\Documents\1%20OFFICE%20DOCUMENTS\CHEMATRS\2017-18%20CM%20TG\3%20February\TG%20Good%20to%20Go\2018%20%2002-03%20Feb-Mar%20TG%20Compilation.docx#_Toc503455511)

[Graphic Organizer 9](#_Toc503455512)

[Student Reading Comprehension Questions 10](#_Toc503455513)

[Answers to Student Reading Comprehension Questions 12](#_Toc503455514)

[Possible Student Misconceptions 14](#_Toc503455515)

[Anticipating Student Questions 15](#_Toc503455516)

[Activities 16](#_Toc503455517)

[References 18](#_Toc503455518)

[Web Sites for Additional Information 19](#_Toc503455519)

[About the Guide 22](#_Toc503455520)

# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Phase changes** | The transition directly from solid to gas is probably the least familiar of the phase changes. The examples of sublimation in this article provide familiar examples to tie this concept to the daily lives of students. |
| **Vapor pressure** | While studying sublimation, the article provides an example of the behavior of matter at the particle level as vapor pressure is increased. |
| **Intermolecular forces** | Information about dry ice from the Rohrig article can be used as a prime example when discussing the weak intermolecular forces present in dry ice that result in its sublimation upon increasing the energy of (i.e., heating) the solid carbon dioxide. |
| **Phase diagrams** | While studying phase change, the teacher can use the phase diagram and information in the Rohrig dry ice article to show how and why dry ice sublimates. |
| **Endothermic process** | As discussed in the Rohrig dry ice article, the commercial process for making dry ice relies on an endothermic change that results in the deposition of CO2 gas (directly) to CO2 solid. |
| **Triple point & critical temperature** | While studying solid, liquid, and gas phases of a substance, the CO2 phase-change diagram in the Rohrig article provides the opportunity to show that each phase of a substance is stable only in certain ranges of temperature and pressure, and to investigate the limits placed at the triple point and the critical temperature. |

# 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.

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.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in this issue:

Physical properties

States of Matter

Structural Formulas

pH

Oxidation & Reduction

Enzymes

Intermolecular forces

* Some of the articles in this issue provide information about carbon dioxide and its role in the environment.
* 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 consumer choices. Also, ask them if they have questions about some of the issues discussed in the articles.

# 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. 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.

*NEW! Instead of using the aforementioned anticipation guide, consider these ideas to engage your students in reading.*

* Ask students to list three things they already know about dry ice, including at least one safety precaution.
* As they read the article, they can compare what they knew (or thought they knew) to the information in the article.
* **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. 10-11):**  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.

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.

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.

“The Cool Chemistry of Dry Ice”, *ChemMatters*, February/March 2018

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Anticipation Guide

“A Close-up Look at the Quality of Indoor Air” (*ChemMatters*, April/May 2016 Issue)

**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. Dry ice is solid carbon dioxide. |
|  |  | 1. Dry ice melts at room temperature and pressure. |
|  |  | 1. Putting a piece of metal on top of dry ice will make it sublime more slowly. |
|  |  | 1. Carbon dioxide is a polar molecule. |
|  |  | 1. Dry ice was discovered by accident. |
|  |  | 1. Evaporation is an exothermic process, releasing energy to the surroundings. |
|  |  | 1. Making dry ice requires low pressure. |
|  |  | 1. Dry ice floats in water. |
|  |  | 1. One of the first uses of dry ice was to carbonate beverages. |
|  |  | 1. Inhaling the vapor from dry ice is dangerous. |

## Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

“The Cool Chemistry of Dry Ice”, *ChemMatters*, February/March 2018

**Directions**: ***As you read***, complete the graphic organizer below to describe sublimation.

|  |  |
| --- | --- |
| Definition | How to increase sublimation of dry ice (at least 2 ways)  sublimation |
| Why dry ice sublimes | Everyday examples  (not dry ice) |

Complete this graphic organizer to describe how to use dry ice safely, with the chemical reasons for each safety precaution.

|  |  |
| --- | --- |
| **Safety precaution** | **Why?** |
|  |  |
|  |  |
|  |  |

**Summary:** On the back of this paper, write one new thing you learned about dry ice that you would like to share with a friend.

## Student Reading Comprehension Questions

“The Cool Chemistry of Dry Ice”, *ChemMatters*, February/March 2018

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name

**Directions**: Use the article to answer the questions below.

1. What will you see if a piece of dry ice is left on the lab counter?
2. How do your wet clothes dry when hung outside in sub-freezing temperatures?
3. Give two factors that affect a substance’s tendency to sublimate.
4. Why does a piece of dry ice act like a puck on an air hockey table?
5. When pressed onto a piece of dry ice, why does a piece of metal (a) make a loud squealing noise and (b) increase the rate of sublimation?
6. Under what conditions of pressure and temperature will carbon dioxide exist as a liquid?

**Student Reading Questions, cont.**

“The Cool Chemistry of Dry Ice”, *ChemMatters*, February/March 2018

1. What are the conditions of pressure and temperature at the triple point of dry ice? (Use the phase diagram for CO2 to answer this question.)
2. What is the meaning of the term “critical temperature”, and what is the value of the critical temperature of CO2?
3. Why will the sublimation rate increase substantially when dry ice is placed in water?
4. What makes freezing an exothermic process?
5. Why does CO2 make an excellent fire extinguisher?
6. Use the table below to list the three safety precautions from the article and the possible consequences of each.

|  |  |
| --- | --- |
| **Safety Precaution** | **Possible Consequence(s)** |
|  |  |
|  |  |
|  |  |

## Answers to Student Reading Comprehension Questions

1. **What will you see if a piece of dry ice is left on the lab counter?**

*If a piece of dry ice is left on the lab counter, you will see it get smaller until it disappears, with no liquid left around it.*

1. **How do your wet clothes dry when hung outside in sub-freezing temperatures?**

*The liquid water on your clothes freezes to ice, then the ice sublimates, changing directly from solid ice to water vapor, leaving your clothes dry.*

1. **Give two factors that affect a substance’s tendency to sublimate.**

*A substance’s tendency to sublimate is affected by its vapor pressure and the forces of attraction among its particles. If the forces of attraction between particles are weak, as in dry ice, the substance will be more likely to change phases directly from solid to vapor.*

1. **Why does a piece of dry ice act like a puck on an air hockey table?**

*As a piece of dry ice sublimates, it becomes surrounded by CO2 gas that reduces the friction between the dry ice puck and the hockey table, so the puck glides on a cushion of CO2 gas just like an air hockey puck glides on air.*

1. **When pressed onto a piece of dry ice, why does a piece of metal (a) make a loud squealing noise and (b) increase the rate of sublimation?**

*A piece of metal*

1. *makes a loud squealing noise when pressed onto the dry ice, because, as the CO2 gas escapes, it makes the pressure fluctuate and the metal vibrates, causing the squealing sound as the gas escapes, and*
2. *increases the rate of sublimation because metals are good conductors of heat, so when pressed onto dry ice, the metal quickly releases heat energy to the ice, increasing the rate of sublimation.*
3. **Under what conditions of pressure and temperature will carbon dioxide exist as a liquid?**

*Carbon dioxide will exist as a liquid at a pressure of 5.1atm or greater and between –56.4 and 31 oC.*

1. **What are the conditions of pressure and temperature at the triple point of dry ice? (Use the phase diagram for CO2 to answer this question.)**

*From reading the phase change diagram, the pressure at the triple point is 5.1atm and the temperature is –56.7 oC.*

1. **What is the meaning of the term “critical temperature”, and what is the value of the critical temperature of CO2?**

*The critical temperature is the temperature where the vapor of a substance can no longer be liquefied by any amount of pressure. The critical temperature of CO2 is 31 oC, as shown in the phase diagram in the article.*

1. **Why will the sublimation rate increase substantially when dry ice is placed in water?** *The sublimation rate of dry ice will increase substantially when it is placed in water because water is a better heat conductor and denser than air so it will continuously release heat to the dry ice thus accelerating sublimation.*
2. **What makes freezing an exothermic process?**

*Freezing is an exothermic process because energy is released from the system to the surroundings.*

1. **Why does CO2 make an excellent fire extinguisher?**

*CO2 makes an excellent fire extinguisher because the CO2 is denser than air, so it sinks and displaces the air surrounding the fire, depriving the fire of oxygen.*

1. **Use the table below to list the three safety precautions from the article and the possible consequences of each.**

|  |  |
| --- | --- |
| **Safety Precaution** | **Possible Consequence(s)** |
| *Don’t touch dry ice.* | *Frostbite occurs from contact with the skin for more than a few seconds.* |
| *Don’t inhale dry ice; work in a ventilated area.* | *Too much CO2 in the blood may make the pH of the blood too acidic, which can be fatal; or it may cause asphyxia, due to depriving the body of O2.* |
| *Don’t put dry ice in a closed metal container.* | *As dry ice sublimates, pressure from the carbon dioxide gas may increase explosively.* |

# Possible Student Misconceptions

1. **“Yes, I’ve seen what happens when dry ice dropped in water forms a cloud. This must be a chemical change because a new substance—“fog”—forms.”** *Actually, dry ice undergoes a physical change when it sublimates from the solid to the gaseous state without first melting into a liquid. The same carbon dioxide is still present, it just undergoes a phase change to become a colorless gas. The fog is composed of a mixture of the sublimated carbon dioxide gas and the water vapor from the air that has been condensed into tiny fog-like droplets by the cold CO2 gas.*
2. **“I watched a demonstration of the “sublimation of iodine”. I thought this would be like dry ice, and extreme pressure would be required to melt it.”** *While solid iodine easily sublimates at room temperature or upon slight heating, it can be melted if the temperature is very carefully controlled to reach just above its normal boiling point (114 oC). Then the melt will quickly evaporate into its characteristic purple vapor.*
3. **“As the temperature rises, I think that all solids melt to become liquids first, and then boil to become gases.”** *No, some solids, like dry ice and mothballs (naphthalene), have intermolecular forces that are so weak that their vapor pressure is greater than atmospheric pressure, allowing the molecules to change from solid to gaseous states directly, without becoming a liquid—as long as the temperature is below the melting point of the substance****.***
4. **“Sublimation is just like evaporation, the substance becomes a gas.”** *While in both sublimation and evaporation the substance becomes a gas, each process reaches the gaseous state differently. During sublimation, a solid goes directly to the gaseous state (bypassing the liquid state); in evaporation, a liquid goes to the gaseous state.*
5. **“I don’t think that sublimation can be reversed.”** *Sublimation can be reversed. For example, water vapor in sub-freezing air will change directly into ice without becoming a liquid first, this is called deposition.*

# Anticipating Student Questions

1. **“Why does a punch bowl bubble when dry ice is added?”** *As the dry ice sublimates, the solid becomes carbon dioxide gas that bubbles out through the liquid punch as it leaves the liquid punch and enters the surrounding air.*
2. **“How do mothballs kill moths?”** *When solid mothballs sublimate, the resulting gas vapor contains insecticides that kill moth larvae. The larvae hatch from eggs left on garments by adult moths. Note: The Environmental Protection Agency (EPA) places restrictions on the sale of mothballs because their vapors can be harmful or toxic to humans and pets, as well.*
3. **“As dry ice sublimates in a bowl of warm water, why does the fog that forms stay near the bowl?”** *When dry ice is added to warm water it sublimates and the cold carbon dioxide gas cools the water vapor in the warm air, condensing it into suspended water droplets. The fog is a heavier-than-air mixture of water droplets and gaseous carbon dioxide that settles below the surrounding air, due to the greater density of CO2 relative to that of air.*
4. **“Can a gas change directly into a solid?”** *Yes. This change, considered the opposite of sublimation, is called deposition. For example, in sub-freezing temperatures, the water vapor in the air may change directly into ice without becoming a liquid as it forms an ice deposit on windows.*
5. **“Do all solids sublimate?”** *Yes, most solids will sublimate to some extent, especially at low pressures (under a vacuum); however, when the intermolecular forces are very strong, as in sodium chloride where its ions are bound tightly in lattices, sublimation will be unnoticeable. A few solids with weak intermolecular attractions such as dry ice, mothballs, and iodine (when gently heated) sublimate at room temperature and pressure.*

# Activities

**Labs and demos**

**Lab: finding the triple point of dry ice:** This microscale lab brings together the excitement of actually “seeing” carbon dioxide liquefy, and calculating the value for its triple point. (<http://bcpshelpdeskhighschoolscience.weebly.com/uploads/6/3/4/6/6346142/lab_-_how_sublime_ltf_triple_point.pdf>)

**Sublimation of iodine demonstration:** This activity should be done as a demonstration (best under a chemistry hood) due to the irritating iodine fumes that may escape. However, students will be amazed, as the purple iodine vapor forms beautiful crystals on a cold surface (deposition). (<https://lsa.umich.edu/content/dam/chem-assets/chem-docs/Sublimation%20of%20Iodine.pdf>)

**Simulations**

**“States of Matter (Inquiry based) Phase Change and Phase Diagrams”:**  This PhET simulation program includes an “Atomic Interactions” simulator. As students manipulate the atoms, the changing effects can be seen on a graph of the potential energy as a function of the distance between the atoms. (<https://phet.colorado.edu/en/contributions/view/3168>)

**Media**

**“Phase Diagrams” (12:35) video lesson:** This video compares phase diagrams of water and carbon dioxide, including a discussion of triple and critical points, as well as supercritical fluids. This program comes from a series of 8 KhanAcademy Videos on “States of Matter and Intermolecular Forces”; links to each are located in the left margin. (<https://www.khanacademy.org/science/chemistry/states-of-matter-and-intermolecular-forces/states-of-matter/v/phase-diagrams>)

**Terrific dry ice demos:** This Flinn Scientific video (10:30) not only demonstrates how to easily perform several demonstrations that explain concepts well beyond “gee-whiz” presentations, but it also explains the observations, using the structural formula and density of dry ice. (<https://www.youtube.com/watch?v=QhTekm5NdiE>)

**Lessons and lesson plans**

**“The sublimation of air freshener”:** This lesson plan from the British Royal Society of Chemistry (RSC) contains background information about the concept of sublimation for teacher use, to prepare students before, during, and after demonstrating this sublimation. Safety hazards are also given, as well as extension possibilities. (<http://www.rsc.org/learn-chemistry/resource/res00000404/the-sublimation-of-air-freshener?cmpid=CMP00005967>)

**“The Behavior of Atoms—Phases of Matter and the Properties of Gases”:** This is a well prepared, comprehensive *Annenberg Learner* unit lesson plan that includes the history and derivation of gas laws, shows and compares the difference between phase diagrams for water and carbon dioxide, and discusses physical changes at the particle level. The program includes items that could stand alone, such as a video (28:28) on drawing phase diagrams, an Interactive chemistry timeline, a unit guide, and a glossary. (<https://www.learner.org/courses/chemistry/text/text.html?dis=U&num=Ym5WdElUQS9NeW89&sec=YzJWaklUQS9NU289>)

# 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**](http://www.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)**

**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”*.**



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This article describes the 1997 Presidential Green Chemistry Challenge Award for designing polymer surfactants that reduce the surface tension of supercritical carbon dioxide. This increases the solubility and usefulness of CO2 as a dry-cleaning reagent. (Kirchoff, M. A Supercritical Clean Machine. *ChemMatters,* 2000, *18* (2) pp 13–15)

This article provides activities that are shown and described as a way to study the physical and chemical behavior of carbon dioxide. Students can use dry ice and/or vinegar and baking soda to prepare carbon dioxide gas to perform the experiments described by the diagrams. (Becker, B. A Pourable Green House Gas. *ChemMatters,* 2009, *19* (special edition 1), pp 10–11)

In the context of describing food for astronauts, this article does a nice job of explaining the process and advantages of freeze-drying food. The phase diagram for water is used to explain the process of sublimation for freeze-drying food. (De Antonis, K. Space Food. *ChemMatters,* 2009, *27* (4), pp 11–13)

The Teacher’s Guide for the article “From Fish Tank to Fuel Tank” in the April 2012 issue of *ChemMatters* explains the extraction of biodiesel from algae by a process using supercritical CO2 (sCO2) as the solvent to dissolve the biodiesel. This process is not only better for the environment but it extracts 100% of the biodiesel, in contrast to the use of flammable, toxic cyclohexane as the extraction solvent that retrieves only 95% of the biodiesel.

# Web Sites for Additional Information

**Sublimation**

This site uses structural diagrams to discuss the polarizability of various molecules and describes how this leads to different types and strengths of intermolecular forces between them. (<http://chemistry.bd.psu.edu/jircitano/IMforces.html>)

This site describes the industrial steps used to freeze-dry food and medicines, the various uses and reasons for freeze drying, and ways to do-it-yourself for backpacking food.

(<https://science.howstuffworks.com/innovation/edible-innovations/freeze-drying.htm>)

**Deposition**

This site shows how the exothermicity of deposition provides the energy to produce safer (nonflammable) solid-state lithium-ion batteries for electric cars. (<https://arxiv.org/ftp/arxiv/papers/1709/1709.02918.pdf>)

The company Semi-Core’s Web site advertises “complete solutions for standard custom vacuum deposition”, describes many uses for physical vapor deposition (PVD), and contains links to more information about the process. PVD products include coatings to reduce friction for high performance moving parts, coating as rust repellants for metals, and alloys, including solar panels. (<http://www.semicore.com/what-is-pvd-coating>)

**Supercritical carbon dioxide—a cleaner energy source and a solvent**

This U.S. Department of Energy (DOE) Web page describes the development of efficient ways to replace fossil fuels with more efficient, “greener”, supercritical carbon dioxide (sCO2) as the working fluid (at room temperature) to convert its thermal energy to electrical energy. The sCO2 is “greener” because it isn’t a volatile organic compound (VOC), as described in this article (which also has nice graphs and schematics to accompany explanations of the process).(<https://energy.gov/under-secretary-science-and-energy/supercritical-co2-tech-team>)

This article from *Chemical Engineering* is an excellent summary of a 233-page report that includes a list of supercritical fluids, with the critical temperature and pressure given for each. A phase diagram of sCO2 is clearly explained, along with a discussion of its solubility, its use in extracting processes, and the limitations to its use. (<http://www.chemengonline.com/supercritical-co2-a-green-solvent/?printmode=1>)

**Vibration of metals**

This article does a nice job of using Bernoulli’s Principle and the ability of metals to conduct heat to explain the vibration and subsequent squealing of a metal spoon as it touches dry ice. (<https://sciencing.com/metal-scream-touches-dry-ice-7187818.html>)

“Cacophanies from Metal on Dry Ice” is from the *All Things Considered* National Public Radio (NPR) program. Note that sounds differ when a professional sound recordist tosses various types of metal on dry ice; both the script and the recorded sounds can be accessed on the sites below. Script: (<https://www.npr.org/templates/story/story.php?storyId=12309256>), sounds: (<https://www.npr.org/programs/all-things-considered/2007/07/27/13120894/>)

**Conflicting history of the discovery of dry ice**

The first version of the discovery of dry ice is the one in the Rohrig dry ice article.

Version 2: In 1823 while using pressure to liquefy various gases, Michael Faraday found that when a gas exceeded a certain temperature (critical temperature), no amount of pressure would liquefy it. During this study, Faraday is credited with the discovery of liquid carbon dioxide that to his surprise liquefied at a fairly low pressure (5.1 atm). (<https://books.google.com/books?id=04xk5M168nEC&pg=PA57&lpg=PA57&dq=Michael+Faraday+dry+ice&source=bl&ots=R1hDgX3oxY&sig=WxH5DSG8et07W5nE15Pu-igl8rA&hl=en&sa=X&ved=0ahUKEwjZ0q_h-ZPYAhXLPCYKHVhpBxkQ6AEIPTAI#v=onepage&q=Michael%20Faraday%20dry%20ice&f=false>)

Version 3: In 1835 the French scientist, Adrien-Jean-Pierre Thilorier used his award-winning compressor to liquefy and study the properties of carbon dioxide. Excerpts (translated on this site) from his fascinating biography include his description of the exciting, serendipitous discovery of dry ice. (<https://upclosed.com/people/adrien-jean-pierre-thilorier/>)

**How to make dry ice**

This article from “How Products are Made” is a good information source for the physical process and properties of dry ice, including manufacturing history and current production processes (note the incorrect caption on a schematic labeled as chemical reactions rather than physical processes or changes!). The information includes present use to slow bud growth in flower shops, and possible future uses: killing gophers in their holes and removing car dents. (<http://www.madehow.com/Volume-7/Dry-Ice.html>)

“How to make dry ice at home (or in the classroom)” is a step-by-step guide on how to use a compressed carbon dioxide fire-extinguisher to provide dry ice for experiments. Of course, it is usually much cheaper to purchase a block from an ice cream shop (frozen cakes), meat market, or another retail source. (<https://www.wikihow.com/Make-Dry-Ice>)

**Uses for dry ice**

A major supplier, Dry Ice Corp, suggests special effects for Halloween and provides an interesting list of unusual dry ice uses, including floor tile removal, sand-blasting, making root beer, and food preservation during electrical outages. There are also links to specifics, such as medical uses and how dry ice serves as a safe replacement for toxic cleaners. (<http://www.dryicecorp.com/dry-ice-applications/>)

In 2015, a British scientist proposed using the significant deposits of dry ice from the Mars polar ice caps as the power source for electrical generators for future Mars colonies. (<https://theconversation.com/how-energy-from-dry-ice-could-power-human-colonies-on-mars-38250>)

Although this may sound far-fetched, since it would require a considerable amount of dry ice, NASA has recently (2015) discovered at Mars’ south pole an underground deposit of dry ice of approximately 3,000 cubic miles, that augments the sizeable amounts already known to be on the surfaces of both poles. (<https://www.nasa.gov/mission_pages/MRO/news/mro20110421.html>)

**Safety precautions**

“Cool Science Experiments with Dry Ice” from Owl Education includes a good, basic list of precautions about how to use dry ice safely in the classroom. Several dry ice demonstrations, including “dry ice with dish soap” and “screaming metal,” are also located on this site. (<https://owlcation.com/stem/dryiceexperiment>)

Continental Carbonic, a manufacturer and distributor of dry ice, provides basic instructions for handling, storage, and ventilation for dry ice on their Web page. A click at the bottom of the page produces a two-page safety brochure in both English and Spanish. (<https://www.continentalcarbonic.com/dry-ice-safety.html>)

# About the Guide

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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>.



**Teacher's Guide for**

### *“Pain Relievers: How Do they Take Away Pain?”*

**February/March 2018**

**Table of Contents**

[Connections to Chemistry Concepts 24](#_Toc503436538)

[Teaching Strategies and Tools 25](#_Toc503436539)

[Standards 25](#_Toc503436540)

[Vocabulary 25](#_Toc503436541)

[Reading Supports for Students 26](#_Toc503436542)

[Anticipation Guide 28](#_Toc503436543)

[Reading Strategies 29](file:///C:\Users\Bill\Documents\1%20OFFICE%20DOCUMENTS\CHEMATRS\2017-18%20CM%20TG\3%20February\TG%20Good%20to%20Go\2018%20%2002-03%20Feb-Mar%20TG%20Compilation.docx#_Toc503436544)

[Graphic Organizer 30](#_Toc503436545)

[Student Reading Comprehension Questions 31](#_Toc503436546)

[Answers to Student Reading Comprehension Questions 33](#_Toc503436547)

[Possible Student Misconceptions 35](#_Toc503436548)

[Anticipating Student Questions 36](#_Toc503436549)

[Activities 37](#_Toc503436550)

[References 39](#_Toc503436551)

[Web Sites for Additional Information 41](#_Toc503436552)

[About the Guide 47](#_Toc503436553)

# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Catalysts** | NSAIDs reduce pain by reacting with enzymes (biological catalysts) that would normally produce the prostaglandins that cause the pain. Identifying enzymes as catalysts may be useful for students. |
| **Inhibitors** | Students may be familiar with catalysts which accelerate reactions, but they may be less familiar with the important role of inhibitors. Understanding the role of NSAIDs as chemical inhibitors may provide an important chemical lesson. |
| **Activation energy** | Cyclooxygenase-1 (COX-1) and cyclooxygenase-2 (COX-2) are examples of enzymes that accelerate the biochemical reaction of converting arachidonic acid into prostaglandins in the body. They do this by providing an alternate reaction path, with a lower activation energy, for the conversion reaction. |
| **Carboxylic acids** | Common carboxylic acids such as acetic or lactic acids are used as examples in teaching about organic acids. By comparing the carboxylic acid functional group on these with that of arachidonic acid, students could see the similarities and understand organic acids. |
| **Skeletal formulas** | Students can view the skeletal formulas used in the article to reinforce functional groups, single and double bonds, organic chemistry, and catalysts. The simplicity and ease of visualizing skeletal formulas, compared to either molecular or structural formulas, is emphasized. |
| **Reaction mechanisms** | By using the sequence of reactions required to convert arachidonic acid into prostaglandins, students can visualize how reaction mechanisms are dependent on precursors. Inhibiting any step prevents the reaction moving forward. |

# 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.

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.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in this issue:

Physical properties

States of Matter

Structural Formulas

pH

Oxidation & Reduction

Enzymes

Intermolecular forces

* 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 consumer choices. Also, ask them if they have questions about some of the issues discussed in the articles.

# 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. 29):**  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.

*NEW! Instead of using the aforementioned anticipation guide, consider these ideas to engage your students in reading.*

* Ask students to describe how they think painkillers work, then compare their ideas to the information in the article.
* Ask students what questions about painkillers they would like to have answered in the article.
* **Graphic Organizer (p. 30):**  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. 31-32):** 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.

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.

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.

“Pain Relievers: How Do They Take Away Pain?” *ChemMatters*, February/March 2018

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Anticipation Guide

“A Close-up Look at the Quality of Indoor Air” (*ChemMatters*, April/May 2016 Issue)

**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. When you injure yourself, pain is caused by chemicals released by your body. |
|  |  | 1. NSAIDs (non-steroidal anti-inflammatory drugs) stop production of chemicals that cause pain. |
|  |  | 1. Enzymes increase the activation energy of chemical reactions. |
|  |  | 1. Enzymes are needed for most chemical reactions in our bodies. |
|  |  | 1. All three common over-the-counter NSAIDs have the same chemical structure. |
|  |  | 1. The side effects of NSAIDs include bleeding. |
|  |  | 1. Aspirin is recommended for children and teens. |
|  |  | 1. The pain-relieving effect of all NSAIDs is the same. |
|  |  | 1. Unlike NSAIDs, acetaminophen contains nitrogen. |
|  |  | 1. Acetaminophen can help reduce swelling. |

## Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

“Pain Relievers: How Do They Take Away Pain?” *ChemMatters*, February/March 2018

|  |  |  |
| --- | --- | --- |
| **Chemicals** | **Examples** | ***What do they do?*** |
| **Prostaglandins** |  |  |
| **Enzymes** |  |  |
| **Competitive inhibitors (painkillers)** | 1. |  |
| 2. |  |
| 3. |  |

**Directions**: As you read the article, complete the graphic organizer below to describe the chemicals involved in producing and relieving pain.

**Summary:** On the back of this paper, write a short (15-18 words) one-sentence summary of the article.

“Pain Relievers: How Do They Take Away Pain?” *ChemMatters*, February/March 2018

## Student Reading Comprehension Questions

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name

**Directions**: Use the article to answer the questions below.

* 1. What does the acronym NSAID stand for?
  2. List three common NSAID medicines.
  3. What are prostaglandins?
  4. List five different roles that prostaglandins have in the body.
  5. What molecule is the source of all prostaglandins in the body?
  6. How do NSAIDs relieve pain in the body?

**Student Reading Comprehension Questions, cont’d**

“Pain Relievers: How Do They Take Away Pain?” *ChemMatters*, February/March 2018

* 1. Explain how NSAIDs act as competitive inhibitors.
  2. Analyze the chemical structures of the pain relievers in Figure 2, and describe how the ring structure is different in one of them.
  3. Why should teens and children avoid taking aspirin?

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 11. Complete the table below comparing the various painkillers. | | | | |
| **Property** | **Naproxen** | **Aspirin** | **Ibuprofen** | **Acetaminophen** |
| Is this an NSAID? (yes/no) |  |  |  |  |
| List side effects  (from article) |  |  |  |  |
| Longer lasting? (yes/no) |  |  |  |  |
| Treats swelling and clotting? (yes/no) |  |  |  |  |
| Treats pain and fever? (yes/no) |  |  |  |  |
| Inhibits prostaglandin formation? (yes/no) |  |  |  |  |
|  |  |  |  |  |

* 1. (a) What are enzymes, (b) how do they work, and (c) why are they important in our body?

## Answers to Student Reading Comprehension Questions

1. **What does the acronym NSAID stand for?**

*The acronym NSAID stands for* ***n****on-****s****teroidal* ***a****nti-****i****nflammatory* ***d****rug.*

1. **List three common NSAID medicines.**

*Three common NSAID medicines are naproxen, ibuprofen, and aspirin.*

1. **What are prostaglandins?**

*Prostaglandins are chemicals, released by injured cells, which trigger pain.*

1. **List five different roles that prostaglandins have in the body.**

*Five different roles that prostaglandins have in the body include*

* 1. *pain,*
  2. *swelling,*
  3. *fever,*
  4. *regulating blood pressure, and*
  5. *blood clotting.*

1. **What molecule is the source of all prostaglandins in the body?**

*All prostaglandins in the body come from the molecule arachidonic acid.*

1. **How do NSAIDs relieve pain in the body?**

*NSAIDs relieve pain in the body when they stop the production of prostaglandins by inhibiting the arachidonic acid pathway.*

1. **Explain how NSAIDs act as competitive inhibitors.**

*NSAIDs act as competitive inhibitors by competing with the arachidonic acid for cyclooxygenase and binding with the cyclooxygenase so the arachidonic acid cannot form prostaglandins.*

1. **Analyze the chemical structures of pain relievers in Figure 2, and describe how the ring structure is different in one of them.**

*The ring structure of the pain reliever naproxen is different than the others because it contains two rings, while the other three contain only one ring.*

1. **Why should teens and children avoid taking aspirin?**

*Teens and children should avoid taking aspirin because its use is linked to Reye's syndrome, which could cause life-threatening liver and brain swelling.*

1. **(a) What are enzymes, (b) how do they work, and (c) why are they important in our body?**
2. *Enzymes are biological catalysts,*
3. *they work by speeding up chemical reactions; they do this by providing a new path that lowers activation energy required, and*
4. *they are important in our body because without them, most chemical reactions in the human body would be very slow, if they’d happen at all.*
5. **Complete the table below comparing/contrasting these pain relievers.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ***Property*** | ***Naproxen*** | ***Aspirin*** | ***Ibuprofen*** | ***Aceta-minophen*** |
| ***Is this an NSAID? (yes/no)*** | ***yes*** | ***yes*** | ***yes*** | ***no*** |
| ***List side effects (from article)*** | ***digestive irritation and bleeding*** | ***digestive ulcers and bleeding*** | ***digestive irritation and bleeding*** | ***none listed in article*** |
| ***Longer lasting? (yes/no)*** | ***yes*** | ***no*** | ***no*** | ***no*** |
| ***Treats swelling and clotting? (yes/no)*** | ***yes*** | ***yes*** | ***yes*** | ***no*** |
| ***Treats pain and fever? (yes/no)*** | ***yes*** | ***yes*** | ***yes*** | ***yes*** |
| ***Inhibits prostaglandin formation? (yes/no)*** | ***yes*** | ***yes*** | ***yes*** | ***yes*** |

# Possible Student Misconceptions

1. **“Sometimes people must learn to live with pain.”** *Occasionally this may be true for some chronic cases; however, for the majority of people, there are many options for managing either acute or chronic pain. Of course, there are numerous pain medications such as the NSAIDs, but there are other medications (some, much stronger) as well. The choice of pain medication to use depends on the type and location of the pain, the severity of the pain, and the side effects of the medication. In addition to traditional medicine, other options for relieving pain include relaxation techniques, physical therapy, surgery, acupuncture, massage, and injections. While total elimination of pain may not always be possible, pain reduction or pain management is possible.*
2. **“Comparable injury produces similar pain in different people.”** *Pain is unique to each individual; it is multidimensional and based on physical and psychosocial factors. When people touch a hot object, they feel pain. However, the intensity of the pain and the perception of that pain varies with each individual. Factors such as the thickness of the skin, previous injuries to that part of the body, previous burns to that area, mental status, perception of the possible danger, previous prolonged pain, etc. cause highly individual pain responses.*
3. **“Pain does not physically damage the body, so it can be ignored.”** *Pain takes both an emotional and a physical toll on our bodies. Physically, pain can increase respiratory rate, blood pressure, heart rate, and muscle tension. Emotionally, pain (especially chronic pain) can produce feelings of frustration, resentment, and stress—all of which can affect attitudes, relationships, and activities. The physical effects of pain on the body can lead to fatigue, sleeplessness, and changes in appetite, which can all be damaging in the long term. Any pain that persists or intensifies should not be ignored.*

# Anticipating Student Questions

1. **“Is the saying 'No pain, no gain' true?”** *Many bodybuilders and athletes believe this myth, but there is no evidence to support it. Trying to build strength or muscles by exerting them to the point of pain is not wise. Also, the thought of working or pushing through pain is not accurate, either. Pain is an indication of damage to the body, and wise people heed that warning.*
2. **“Why does pain exist?”** *While pain is no fun, it has an important role in our lives. Pain is a defense mechanism that has evolved to alert us to injury. Our response to this pain allows us to protect our bodies from further damage. Because pain is an autonomic response (pain reflex), it allows us to react efficiently and quickly, avoiding additional injury. Pain is usually the quickest and most effective way of getting our attention and forcing us to modify our behavior accordingly.*
3. **“Can the use of pain medications lead to addictions?”** *There are many types of pain medications, and all medications carry some risk of use. Addictions can be either physical or psychological. The NSAIDs discussed in the article are not physically addictive, although they may cause other medical concerns if used for a prolonged time. However, pain medications like opioids are addictive. Physical addictions occur when the cells in the body need the substance to function, and withdrawal produces tremors, nausea, diarrhea, chills, and body aches. Psychological addictions are associated with the perceived need to use the substance. Sometimes people think they need a substance in order to fall asleep, but they can eventually fall asleep without the drug. It is possible that some people may develop a psychological dependency on any painkiller medication.*

# Activities

**Labs and demos**

**Lab synthesizing aspirin:** Students in a well-equipped high school laboratory can synthesize aspirin using the college general chemistry lab procedure, “Synthesis of Aspirin.” The procedure provides student information to synthesize, recrystallize, and test the purity of aspirin, which requires multiple classroom periods to complete; however, there are no instructor notes provided. (<http://www.chem21labs.com/labfiles/uky_gl04_lab.pdf>; link to supporting information: <https://genchemlab.wordpress.com/5-aspirin/>)

**Virtual lab on enzymes:** “Enzyme Lab–Virtual” provides students the opportunity to study the effects of substrate concentration and pH on the rate of an enzyme-catalyzed reaction. The site includes a student sheet for collecting data and analysis questions. (<https://www.biologycorner.com/worksheets/enzyme-lab-virtual.html>)

**Simulations**

**Simulation of enzyme activity and inhibitors:** The KScience Web site provides an animation of enzyme action and a student-controlled simulation, investigating the effects of the concentrations of enzymes, substrate, inhibitors, temperature, container size, and pH. (<http://www.kscience.co.uk/animations/anim_2.htm>) An independent student data sheet for the KScience simulation is located at <http://www.sennhs.org/ourpages/auto/2014/12/18/42764837/Enzyme%20Simulation%20Lab%20HON.pdf>.

**Simulation of enzymes and concentrations:** This simple simulation allows students to manipulate only the type of enzyme (anabolic or catabolic) and substrate concentration (high or low), but it may be useful to help students with the concept of enzymatic action. (<https://scratch.mit.edu/projects/32615728/>)

**Media**

**Video drawing skeletal structures:** “Drawing Skeletal Structures or Bond-Line Notations of Organic Molecules” (Organic Chemistry Basics) (14:53) clearly explains the process of drawing and interpreting skeletal structures for students who may be unfamiliar with these structures in the Hendricks-Sturrup article. (<https://www.youtube.com/watch?v=RP6AS7XVIC8>)

**Infographic of common painkillers:** The Compound Interest Web site contains the infographic "A Brief Guide to Common Painkillers", illustrating NSAID and opioid painkillers. In addition to the infographic, the site also includes brief information on these drugs. (<http://www.compoundchem.com/2014/09/25/painkillers/>)

**Lessons and lesson plans**

**Khan Academy lessons on enzymes:** *Introduction to Enzymes* is a lesson sequence that includes the video, "Introduction to Kinetics" (15:26), a reading activity, "Activation Energy," the video, "Enzymes" (8:12), another reading activity, "Enzymes and the Active Site," and a one-question assessment, "Practice: Enzymes and Activation Energy." (<https://www.khanacademy.org/science/biology/energy-and-enzymes/introduction-to-enzymes/v/introduction-to-kinetics>)

**Lab lessons on pain and pain reduction:** “No Pain, No Gain” is a complete teacher and student lesson for conducting a three-day activity on pain perception and reduction. The lesson from the National Association of Biology Teachers includes some useful line drawings and is an excellent lesson plan. (<https://www.nabt.org/files/galleries/09NLCAchp7.pdf> Note: The reference to the (optional) *NIH Image* computer program in the lesson is no longer available.)

**Projects and extension activities**

**Presentations on NSAIDs:** Divide students into four groups (aspirin, acetaminophen, ibuprofen, and naproxen) to research and prepare a visual (PowerPoint, poster, video, brochure, etc.) presentation on their NSAID drug. The presentations should include history, benefits, risks, uses, alternatives, and pharmacology/chemistry of their pain reliever.

**Research on Vioxx®:** Student can research why the effective COX-2 NSAID pain reliever Vioxx**®** was removed from sale in the U.S. in 2004. Students can compare the chemical structure, mode of action, side effects, and effectiveness of Vioxx**®** to the other common NSAIDs still in use.

**Lab experiments with aspirin:** "Experiments with Aspirin" is an AP or second-year high school lab activity that involves the synthesis and characterization of aspirin, the kinetics of the hydrolysis of aspirin, and the synthesis of copper(II) aspirinate and copper(II) salicylate. The article provides a generic description of the procedure, and the extensive supplemental material is accessed via an online link in the article. (<http://pubs.acs.org/doi/pdf/10.1021/ed077p354>)

# 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**](http://www.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)**

**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”*.**



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

Available Now!

This 1993 article on aspirin contains a nice diagram with chemical structures on salicylates. It also provides an activity testing different types of aspirin compounds in a simulated stomach with acidic, basic, and neutral solutions. (Marcella, G. Aspirin. *ChemMatters*, 1993, *11* (1), pp 4–7)

A 2004 article discusses pain, aspirin, NSAIDs, prostaglandins, and the mechanism of pain relief. This article also includes a brief history of aspirin and the other NSAIDs. (Kimbrough, D. The Aspirin Effect: Pain Relief and More. *ChemMatters*, 2004, *22* (1), pp 7–9)

The February 2004 Teacher's Guide for “The Aspirin Effect: Pain Relief and More" (above) provides background information on the discoveries of aspirin, acetaminophen, ibuprofen, naproxen prostaglandins, and cyclooxygenase.

This article about digestion has general information and two useful figures on how enzymes work by lowering activation energy. (Tinnesand, M. The Dog Ate My Homework. *ChemMatters*, 2006, *24* (2), pp 4–6)

This brief *Did You Know?* article, "Organic Chemistry/Proteins: New Type of Painkiller from Sea Snails," describes a new family of painkillers made from polypeptides. (Karabin, S. Organic Chemistry/Proteins: New Type of Painkiller from Sea Snails. *ChemMatters*, 2011, *29* (4), p 4)

This *ChemMatters* article includes an activity to test how quickly different pain relievers dissolve in an acidic solution simulating the stomach. The activity tests the brand-name NSAID pain relievers Motrin, Aleve, Tylenol plus aspirin. (Washam, C. Brand-Name vs. Generic Drugs. *ChemMatters*, 2013, *31* (1), pp 8–10)

Painkillers made from snake venom and a little more about sea snail painkillers is found in "Venoms: From Lethal to Life Saving." The painkiller made from snake venom may be as effective as morphine. (Haines, G. Venoms: From Lethal to Life Saving. *ChemMatters*, 2015, *33* (2), pp 13–15)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

This article describes an experiment to determine the ibuprofen concentration of an over-the-counter liquid-filled gelatin capsule. The procedure is for a first-year college chemistry course and would require access to a UV-Vis spectrometer. (Wheate, N, et. al. Determining the Ibuprofen Concentration in Liquid-Filled Gelatin Capsules to Practice Collecting and Interpreting Experimental Data, and Evaluating the Methods and Accuracy of Quality Testing. *J. Chem. Educ.*, 2017, *94* (8), pp 1107–1110; <http://pubs.acs.org/doi/10.1021/acs.jchemed.6b00955>. 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.)

The anti-inflammatory activity of freshly pressed extra-virgin olive oil is similar to that of ibuprofen. Details of the compound, oleocanthal, and its discovery are in this article. (Ritter, S. Olive Oil Compound Acts Like Ibuprofen. *Chem. Eng. News.*, 2005, *83* (36), p 15; <http://pubs.acs.org/doi/pdf/10.1021/cen-v083n036.p015a>. 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.)

Readers with access to a UV-Vis spectrometer can follow the procedure in this article to study the time release of acetaminophen from gel capsules. The article is suitable for first-year college and high school laboratories. (Smith, K., Cedillo, D. Determining the Mass and Time Release of Acetaminophen from Gel Capsules. *J. Chem. Educ.*, 2014, *91* (3), pp 437–439; <http://pubs.acs.org/doi/10.1021/ed400324k>. 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 from 1989, gives a thorough explanation of activation energy, and it clarifies some possible misconceptions associated with reaction mechanisms of catalyzed and uncatalyzed reactions. (Haim, A. Catalysis: New Reaction Pathways, Not Just a Lowering of the Activation Energy. *J. Chem. Educ.*, 1989, *66* (11), pp 935–937; <http://pubs.acs.org/doi/pdf/10.1021/ed066p935>. 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.)

*Chemical and Engineering News* published a cover story, "How Chemists Are Responding to the Opioid Epidemic," which contains sections on "Abuse-Deterrent Opioids: Worth the Cost and Effort?", "Powerful Detection Technology for Powerful New Street Drugs", and "Looking beyond Opioids for Safer Pain Relief". The graphics, information, and chemistry in these pieces provide insight into the troublesome problem of misuse of opioid pain relief drugs. (Nguyen, T; Hiolski, E; Halford, B. How Chemists Are Responding to the Opioid Epidemic. *Chem. Eng. News*, 2017, *95* (45), p 32–42; <https://cen.acs.org/articles/95/i45/chemists-responding-opioid-epidemic.html>; 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.)

# Web Sites for Additional Information

**Pain**

The *WebMD* Web site provides detailed information on pain types and causes. The article includes sections on "Acute and Chronic Pain," "Other Ways Pain Is Classified," "Pain Caused by Tissue Damage," and "Pain Caused by Nerve Damage." ([https://www.webmd.com/pain-management/guide/pain-types-and-classifications#1](https://www.webmd.com/pain-management/guide/pain-types-and-classifications%231))

"How Do Pain Relievers Work?" (4:13) on the *TED-Ed* Web site is a powerful video explaining pain, nociceptors, prostaglandins, competitive inhibitors, and more. It is a great companion piece to the Hendricks-Sturrup article. (<https://ed.ted.com/lessons/how-do-pain-relievers-work>)

**Arachidonic acid**

Body Nutrition publishes "Arachidonic Acid Benefits and Side Effects." The article examines arachidonic acid when it is used as a supplement by athletes to build muscle mass. However, caution must be used when consuming any supplement. (<https://bodynutrition.org/arachidonic-acid/>)

The role of arachidonic acid in forming the regulatory molecules called eicosanoids and their importance in homeostasis and inflammation is described and illustrated in "Paracrines Derived from Polyunsaturated Fatty Acids." (<https://courses.washington.edu/conj/membrane/arachidonic.htm>)

**Prostaglandins**

"Prostaglandins and Inflammation" provides a scholarly discussion of the mechanisms of prostaglandin formation and their roles in inflammation. In addition, prostaglandins are relevant in atherosclerosis and the article includes information on this topic. (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3081099/>)

The Society for Endocrinology hosts the Web page “You and Your Hormones,” which contains information on prostaglandins. The article is short and relatively easy to read. (<http://www.yourhormones.info/hormones/prostaglandins/>)

**Cyclooxygenase**

A slide presentation converted to a pdf document, "Cyclooxygenase and NSAIDs," highlights information on the relationship among cyclooxygenase enzymes, prostaglandins, and NSAIDs. The colorful presentation enhances the Hendricks-Sturrup article. (<http://www.albany.edu/faculty/cs812/bio366/Cyclooxygenase_ppt.pdf>)

Cyclooxygenase was a “Molecule of the Month” on the *Protein Data Bank* Web site. The article explains cyclooxygenase, prostaglandins, and how aspirin works with these materials. (<http://pdb101.rcsb.org/motm/17>)

**Nociceptors**

For a visual and textual explanation of pain and the role of nociceptors, see the University of Texas McGovern Medical School article, "Chapter 6: Principles of Pain." The article shows and discusses the types of nociceptors and factors that activate them, along with other information about pain. (<http://nba.uth.tmc.edu/neuroscience/s2/chapter06.html>)

"Nociceptors and the Perception of Pain" is a 153-page comprehensive explanation of the nociceptors. The eight chapters in the publication include "Introduction," "Chemical Mediators," "Neuropathic Pain," and "Pain in the Brain." (<https://cell.uchc.edu/pdf/fein/nociceptors_fein_2012.pdf>)

**NSAIDs**

The *Medical News Today* Web site provides the article, "NSAIDs: Examples, Side Effects, and Uses," which supplements the information in the Hendricks-Sturrup article. The article includes information on how NSAIDs work, precautions, side effects, and some fast facts on them. (<https://www.medicalnewstoday.com/articles/179211.php>)

For a thorough understanding of NSAIDs, readers can access "An Evidence-Based Update on Nonsteroidal Anti-Inflammatory Drugs". Although the article was published in 2007, it contains deeper content and extensive references. (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1855338/>)

**Safety of NSAIDs**

The Harvard Medical School provides additional information on the safety of taking NSAIDs in "Pain Relief: Taking NSAIDs Safely." The article contains information on NSAID cautions, tips for using them safely, and alternatives to NSAIDs. (<https://www.health.harvard.edu/pain/pain-relief-taking-nsaids-safely>)

Also from the Harvard Medical School is the article "10 Things You Should Know about Common Pain Relievers." Information on understanding the differences between NSAIDs and acetaminophen, over-the-counter pain relievers, and prescription NSAIDs are provided on the site. (<https://www.health.harvard.edu/pain/12-things-you-should-know-about-pain-relievers>)

**NSAID method of action**

The mechanism of action of NSAIDs is explained in "Pharmacology of NSAIDs". Visuals and a general explanation of the competitive inhibition by NSAIDs help readers understand the action of these drugs. (<https://pharmafactz.com/pharmacology-of-nsaids/>)

"Non-Steroidal Anti-inflammatory Drugs (NSAIDs)" is a 2002 article with a clinical explanation of NSAIDs and their mechanism of action. Additional information includes details on salicylates, profens, anthranilates, COX-2 inhibitors, and much more. (<http://www.auburn.edu/~deruija/nsaids_2002.pdf>)

**Information on Individual NSAIDs**

* **Aspirin**

The NIH Web site, MedlinePlus, has a consumer-friendly article for aspirin that contains information on why it is prescribed, how it is used, special precautions, side effects, and other information. To prevent overdoses of aspirin, a list of brand names of combined medicines containing aspirin is provided. (<https://medlineplus.gov/druginfo/meds/a682878.html>)

In addition to its use as a pain reliever, aspirin is widely used to reduce the risk of heart attack and stroke. The U.S. FDA supplies the article, "Aspirin for Reducing Your Risk of Heart Attack and Stroke: Know the Facts," to educate consumers on the risks and benefits of using aspirin. (<https://www.fda.gov/Drugs/ResourcesForYou/Consumers/BuyingUsingMedicineSafely/UnderstandingOver-the-CounterMedicines/SafeDailyUseofAspirin/ucm291433.htm>)

* **History of aspirin**

*Chemical and Engineering News* featured an article on aspirin in 2005 as part of “The Top Pharmaceuticals That Changed the World.” The article provides information on its then-current uses, classification as an NSAID, ancient origin in willow and myrtle trees, and its formulation by Felix Hoffman at Bayer into the modern form as we know it. (<https://pubs.acs.org/cen/coverstory/83/8325/8325aspirin.html>)

The Chemical Heritage Foundation published a history of aspirin titled, "Aspirin: Turn-of-the-Century Miracle Drug" in its summer, 2009 issue of *Distillations* magazine. The article highlights the 2,000-year history of salicylic acid and aspirin, and the chemical secrets of aspirin that were not uncovered until the 1970s. (<https://www.chemheritage.org/distillations/magazine/aspirin-turn-of-the-century-miracle-drug>)

* **Reye's Syndrome and aspirin**

The National Reye's Syndrome Foundation's Web site has links to a vast number of resources and links to further information on this disease. Links include "What Is Reye's Syndrome?", "After Reye's Syndrome," "The Aspirin Link," "Reye's and Teens," "Aspirin Lists," "Article Library," "Medical Library," "Video Library," and more. (<http://www.reyessyndrome.org/index.html>)

* **Acetaminophen**

The U.S. National Institutes for Health's (NIH) Web site, *MedlinePlus*, provides consumer-friendly information on acetaminophen, including health warnings, how it should be used, precautions, side effects, and much more. Because acetaminophen overdoses can easily occur due to the drug being combined with other medicines, a list of brand names of these combination products is provided. (<https://medlineplus.gov/druginfo/meds/a681004.html>)

The U.S. Food and Drug Administration (FDA) Web site has a page, “Acetaminophen Information,” with links to numerous articles for the safe use of this medication. (<https://www.fda.gov/Drugs/DrugSafety/InformationbyDrugClass/ucm165107.htm>)

* **Ibuprofen**

Similar to acetaminophen and aspirin, the MedlinePlus Web page has an article on ibuprofen for consumers. Again, warnings, usage, special precautions, side effects, and other information are supplied. The list of combined medicines containing ibuprofen is shorter but included. (<https://medlineplus.gov/druginfo/meds/a682159.html>)

“An Overview of Clinical Pharmacology of Ibuprofen" provides an in-depth explanation of ibuprofen. Since ibuprofen's introduction in 1969, it has been a popular analgesic, and this article looks at the pharmacology, applications, and adverse reactions. (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3191627/>)

* **Naproxen**

MedlinePlus continues with a page devoted to naproxen containing information similar to the other NSAIDs on warnings, why it's prescribed, usage, special precautions, side effects, and a short list of brand name combination drugs. (<https://medlineplus.gov/druginfo/meds/a681029.html>)

The Drugs.com Web site has its page devoted to naproxen with the tabs for information including "Overview," "Side Effects," "Dosage," "Professional," "Tips," and "Interactions." The "Professional" tab includes information on pharmacology, chemical structure and properties, excretion, and more. (<https://www.drugs.com/pro/naproxen.html>)

**Choosing an NSAID pain reliever**

*Business Insider* published a chart to help people determine which NSAID painkiller to take for a specific ailment or pain. The easy-to-use chart provides a "thumbs up" painkiller for problems including fever, headache, menstrual cramps, sore muscles, earaches, and toothaches. (<http://www.businessinsider.com/tylenol-vs-advil-vs-aleve-2015-5>)

"OTC: Taking the Pain Out of Choosing a Pain Reliever" from the UC San Diego Health Wed site offers six questions with discussions for selecting an effective OTC (over-the-counter) pain reliever. (<https://health.ucsd.edu/news/features/Pages/2016-12-21-otc-pain-relief-meds.aspx>)

**Opioid and narcotic pain relievers**

The U.S. FDA's Web site, "Opioid Medications," contains links to many articles related to opioid or narcotic medications used as painkillers. Links include: "Information on Opioid Medications," "Treating Pain," "Consumer Information," "FDA's Role in Preventing Opioid Abuse," and more. (<https://www.fda.gov/Drugs/DrugSafety/InformationbyDrugClass/ucm337066.htm>)

The Drugs.com Web site provides the article "Narcotic Analgesics" and a list of brand-name and generic-name narcotic analgesics. Click on the name of each of these drugs to link to additional information on that narcotic (opioid) drug. (<https://www.drugs.com/drug-class/narcotic-analgesics.html>)

**Pain relief alternatives**

"Natural Anti-inflammatory Agents for Pain Relief" includes a review of the literature about the pathways of inflammatory pain in the body, the potential side effects of NSAIDs, and commonly-used and clinically-studied natural alternatives to these drugs. Alternatives include the omega-3 essential fatty acids (in fish oil), white willow bark, turmeric, green tea, chili pepper, and others. (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3011108/>)

The Harvard Medical School's Web site discusses "8 Non-invasive Pain Relief Techniques that Really Work." These techniques include the use of cold or heat, exercise, physical therapy, mind-body techniques, massage, and others. (<https://www.health.harvard.edu/pain/8-non-invasive-pain-relief-techniques-that-really-work>)

**Activation energy**

A thorough explanation of activation energy, the Arrhenius Law, effects of enzymes, and Gibbs energy are found on the LibreTexts Chemistry site. Diagrams, formulas, problems, and solutions are on the site as well. (<https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Kinetics/Modeling_Reaction_Kinetics/Temperature_Dependence_of_Reaction_Rates/The_Arrhenius_Law/The_Arrhenius_Law%3A_Activation_Energies>)

The Study.com Web site's lesson, "Function of Enzymes: Substrate, Active Site, & Activation Energy," provides a lesson that is presented in a video, lesson text, and a quiz. Information in this lesson complements the discussion of enzymes and activation energy in the Hendricks-Sturrup article. (<http://study.com/academy/lesson/function-of-enzymes-substrate-active-site-activation-energy.html>; note that a free trial registration is required to access the content.)

**Enzymes**

The Royal Society of Chemistry has an excellent Web site, *Enzymes*, with the subsections: "Function and Structure," "How Enzymes Work," "Factors Affecting Catalytic Activity of Enzymes," "Immobilized Enzymes," and "Test Your Knowledge." The explanations and illustrations are simple and clear. (<http://www.rsc.org/Education/Teachers/Resources/cfb/enzymes.htm>)

"The Virtual Laboratory: Enzyme Assay" is a more complex activity than “Enzyme Lab–Virtual” in the Labs and Demos section above. The Enzyme Assay lab allows students to manipulate the effects of pH, time, enzyme quantity, temperature, and substrate concentration for five different enzymes with the results graphed and the ability to export the virtual data to Excel for further manipulation. (<http://www.ucl.ac.uk/~ucbcdab/enzass/enzymass.htm>)

**Inhibitors**

The LibreText Chemistry Web page presents "Drugs as Enzyme Inhibitors," which complements the Hendricks-Sturrup article very well. Penicillin is used as an example of an inhibitor interfering with the action of an enzyme similar to the action of NSAIDs. (<https://chem.libretexts.org/Textbook_Maps/Organic_Chemistry_Textbook_Maps/Map%3A_Organic_Chemistry_(Bruice)/31%3A_The_Organic_Chemistry_of_Drugs%3A_Discovery_and_Design/31.07%3A_Drugs_as_Enzyme_Inhibitors>; note: readers may need to register for free to access some information.)

The Khan Academy supplies a great lesson, "Enzyme Regulation." The content explains cofactors and coenzymes; reversible, irreversible, competitive, and noncompetitive inhibitors; allosteric enzymes; and feedback inhibition, with diagrams and text. (<https://www.khanacademy.org/science/biology/energy-and-enzymes/enzyme-regulation/a/enzyme-regulation>)

**Skeletal formulas**

"Drawing Organic Molecules" provides readers with reviews on molecular formulas, structural formulas, and skeletal formulas. Text and diagrams help readers understand the purpose for each and a discussion of how to decide which formula to use. (<http://www.chemguide.co.uk/basicorg/conventions/draw.html>)

Newcastle University in the United Kingdom shares a colorful and simple guide to skeletal formulas. "Basic Guide to Skeletal Formulae" is a quick way to review or learn about these types of organic formulas. (<http://www.ncl.ac.uk/media/wwwnclacuk/schoolofchemistry/files/C1-basicguidetoskeletalformula_000.pdf>)

# About the Guide

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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>.



**Teacher's Guide for**

### *“Acidic Seas: How Carbon Dioxide is Changing the Oceans”*

**February/March 2018**

**Table of Contents**

[Connections to Chemistry Concepts 49](#_Toc503455705)

[Teaching Strategies and Tools 50](#_Toc503455706)

[Standards 50](#_Toc503455707)

[Vocabulary 50](#_Toc503455708)

[Reading Supports for Students 51](#_Toc503455709)

[Anticipation Guide 53](#_Toc503455710)

[Reading Strategies 54](file:///C:\Users\Bill\Documents\1%20OFFICE%20DOCUMENTS\CHEMATRS\2017-18%20CM%20TG\3%20February\TG%20Good%20to%20Go\2018%20%2002-03%20Feb-Mar%20TG%20Compilation.docx#_Toc503455711)

[Graphic Organizer 55](#_Toc503455712)

[Student Reading Comprehension Questions 56](#_Toc503455713)

[Answers to Student Reading Comprehension Questions 58](#_Toc503455714)

[Possible Student Misconceptions 60](#_Toc503455715)

[Anticipating Student Questions 61](#_Toc503455716)

[Activities 62](#_Toc503455717)

[References 64](#_Toc503455718)

[Web Sites for Additional Information 65](#_Toc503455719)

[About the Guide 68](#_Toc503455720)

# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Greenhouse effect** | The study of the electromagnetic spectrum provides a good opportunity to investigate where the specific wavelengths involved in the greenhouse effect are located on the EMS and to consider their role in global warming and its impact on the health of coral reefs. |
| **Molecular polarity** | The slow acidification of the oceans from increased CO2 in the atmosphere shows the relatively low solubility of the gas due to its molecular structure and lack of polarity. |
| **Equilibrium** | The chemical equations in this article can be used to explain how human activities that produce CO2 emissions can set up a chain of equilibrium reactions that can do immeasurable harm to aquatic life. |
| **Limiting reagent** | Carbonate in the oceans is an example of a limiting reagent in coral and mollusk shell-forming reactions. |
| **Common Ion effect** | The common ion effect can be used to explain how dissolved atmospheric CO2 sets up equilibriums that consume available CO32 – ions, increasing the ocean’s acidity that inhibits the formation of coral and shellfish structures. |
| **Weak acids** | The effect of weak acids on coral reefs exposed to acidic seas can be used as an example of how even weak acids can cause environmental destruction. |
| **pH scale** | While a change in pH from 8.2 to 8.1 may not seem significant, its effects on ocean life can be devastating, and it suggests an increasingly acidic ocean. |

# 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.

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.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in this issue:

Physical properties

States of Matter

Structural Formulas

pH

Oxidation & Reduction

Enzymes

Intermolecular forces

* Some of the articles in this issue provide information about carbon dioxide and its role in the environment.
* 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 consumer choices. Also, ask them if they have questions about some of the issues discussed in the articles.

# 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. 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.

*NEW! Instead of using the aforementioned anticipation guide, consider these ideas to engage your students in reading.*

* Ask students to describe the importance of coral reefs around the world, and how we can protect them.
* As they read, ask students to add to the list they began before reading.
* **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.

|  |  |  |
| --- | --- | --- |
| **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. 56-57):** 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.

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.

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.

“Acidic Seas: How Carbon Dioxide is Changing the Oceans”, *ChemMatters*, February/March 2018

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Anticipation Guide

“A Close-up Look at the Quality of Indoor Air” (*ChemMatters*, April/May 2016 Issue)

**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. Unhealthy corals are faded and crumbling. |
|  |  | 1. Coral reefs make up 10% of the earth’s surface. |
|  |  | 1. Without carbon dioxide, the earth would be cold and inhospitable. |
|  |  | 1. When corals are stressed, they expel algae they need for food. |
|  |  | 1. Most of the carbon dioxide in seawater forms bicarbonate ion (HCO3-). |
|  |  | 1. When carbon dioxide from the atmosphere dissolves in ocean water, the pH of the ocean is lowered. |
|  |  | 1. Increased carbon dioxide in the ocean helps shells form more readily. |
|  |  | 1. Ocean water is slightly acidic. |
|  |  | 1. About one-fourth of ocean species live in coral reefs. |
|  |  | 1. Coral reefs around the world are affected equally by ocean acidification. |

## Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

“Acidic Seas: How Carbon Dioxide is Changing the Oceans”, *ChemMatters*, February/March 2018

**Directions**: As you read, complete the graphic organizer below to describe the effect of carbon dioxide on the world’s oceans.

|  |  |  |
| --- | --- | --- |
| 3 | **Ways carbon dioxide is affecting the oceans** |  |
| 2 | **Reasons we should be concerned about ocean life** |  |
| 1 | **Number or statistic from the article that surprised you (and why)** |  |
| Contact! | **What can you do to reduce the impact of carbon dioxide on the world’s oceans?** |  |

“Acidic Seas: How Carbon Dioxide is Changing the Oceans”, *ChemMatters*, February/March 2018

## Student Reading Comprehension Questions

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name

**Directions**: Use the article to answer the questions below.

1. Complete the following table to describe unhealthy signs of and threats to ocean coral.

|  |  |
| --- | --- |
| **Signs of Unhealthy Coral** | **Threat Responsible for Those Signs** |
|  |  |
|  |  |

1. Give two reasons why researchers are concerned about the health of coral reefs that make up less than 1% of the Earth’s surface.
2. What causes ocean warming and acidification?
3. Why is the term “greenhouse effect” misleading when used to describe ocean warming and acidification?
4. How do (a) greenhouses and (b) atmospheric gases trap heat?
5. Why are human activities that release carbon dioxide into the atmosphere causing concern?

**Student Reading Comprehension Questions, cont.**

“Acidic Seas: How Carbon Dioxide is Changing the Oceans”, *ChemMatters*, February/March 2018

1. What happens after warm oceans cause stressed corals to expel the symbiotic algae living in their tissues?
2. How does the water chemistry change as carbon dioxide gas is dissolved in the ocean water?
3. What does a drop in ocean pH from 8.2 to 8.1 mean?
4. How do coral reefs help protect the shore during storms?
5. What are two economic risks of ocean acidification?
6. According to the author, what two things will ocean scientists in the future need to understand?

## Answers to Student Reading Comprehension Questions

1. **Complete the following table to describe unhealthy signs of and threats to ocean coral.**

|  |  |
| --- | --- |
| **Signs of Unhealthy Coral** | **Threat Responsible for Those Signs** |
| *faded colors* | *stress from warming ocean water* |
| *weakening or crumbling* | *acidic ocean water decreases the ability of coral to obtain materials needed for their growth* |

1. **Give two reasons why researchers are concerned about the health of coral reefs that make up less than 1% of the Earth’s surface.**

*Researchers are concerned about the health of coral reefs because*

* 1. *they play a crucial role in the ocean ecosystem and*
  2. *they provide shelter for perhaps a quarter of the ocean’s species.*

1. **What causes ocean warming and acidification?**

*Ocean warming and acidification are caused by an increase in carbon dioxide (and other gases) in the atmosphere.*

1. **Why is the term “greenhouse effect” misleading when used to describe ocean warming and acidification?**

*The term greenhouse effect is misleading because, while both atmospheric gases and a greenhouse produce higher temperatures, they work in different ways.*

1. **How do (a) greenhouses and (b) atmospheric gases trap heat?**
   * + - 1. *Light from the sun passes through the glass roof of the greenhouse to heat plants and the ground inside the greenhouse. These objects then emit infrared radiation, that is, heat. This thermal energy is trapped in the greenhouse, keeping the building warm.*
         2. *“Heat radiates from Earth toward space. Some of this heat is trapped by greenhouse gases in the atmosphere.”*
2. **Why are human activities that release carbon dioxide into the atmosphere causing concern?**

*Human activities are increasing the amounts of greenhouse gases such as carbon dioxide in our atmosphere. These gases trap extra heat, causing Earth’s temperature to rise, leading to environmental changes such as melting glaciers and ice sheets and warming our oceans.*

1. **What happens after warm oceans cause stressed corals to expel the symbiotic algae living in their tissues?**

*After the coral expels the symbiotic algae living in its tissues, the coral loses its major source of food, turns white or very pale, and is more susceptible to disease.*

1. **How does the water chemistry change as carbon dioxide gas is dissolved in the ocean?**

*As shown in the first equation on page 11, gaseous carbon dioxide [CO2 (g)] dissolves in ocean surface water to produce aqueous carbon dioxide [CO2) (aq)]. Then, in the second equation, the CO2 (aq) reacts with water to form unstable carbonic acid [H2CO3 (aq)] that immediately dissociates adding a hydrogen ion (H+) (aq) that increases the acidity of the water.*

1. **What will happen if man continues to release carbon dioxide into the atmosphere?**

*A drop in ocean pH from 8.2 to 8.1 shows that continuing to release carbon dioxide at the current rate will result in the oceans’ continuing increase in acidity.*

1. **How do coral reefs help protect the shore during storms?**

*Coral reefs help protect the shore during storms by blocking and deflecting some of the energy of ocean waves, meaning that water between the shore and the reef is calmer.*

1. **What are two economic risks of ocean acidification?**

*Economic risks of ocean acidification include*

* 1. *harming fish and shellfish that humans eat, and*
  2. *eliminating commercially valuable species of fish.*

1. **According to the author, what two things will ocean scientists in the future need to understand?**

*Future ocean scientists will need to understand*

*how pollution, warming, and ocean acidification affect marine life, and*

*how to develop ways to reduce atmospheric carbon dioxide and its impact on oceans.*

# Possible Student Misconceptions

1. **“I heard that hurricanes are the major cause of ocean coral reef destruction.”** *Although hurricanes may cause some mechanical damage (i.e., breaking up the coral), ocean corals actually receive benefits from summer hurricanes. These storms alleviate thermal stress on corals by absorbing thermal energy from surface water, churning the ocean to bring cooler water from the depths up to the surface, and by shading (think cloud cover) the ocean surface from the sun.*
2. **“I read that the ocean dissolves about 26% of the carbon dioxide released by human activities such as fossil fuel burning. So, I assume that we really don’t need to worry about environmental damage due to carbon dioxide.”** *Much of the carbon dioxide released into our atmosphere is dissolved by oceans. Yet during the absorption process, the seawater becomes increasingly acidic, harming corals and other aquatic species.*
3. **“I’ve been to the Virgin Islands, where the coral reefs are beautiful, so I think that current risks are probably exaggerated. They’ll be fine if we just reduce the atmospheric carbon dioxide a bit.”** *Actually, the risks to coral reefs are probably underestimated because the data show that ocean warmth and acidity are not the only stresses placed on the coral reefs. They also face damage from other factors, such as water pollution, stronger storms, and overfishing.*
4. **“Since coral reefs are complex and a part of a whole reef system, they can probably resist environmental changes such as bleaching and acidic oceans.”** *Although the coral reef ecosystems are very complex, they are seldom able to resist a combination of the severe stress of warming oceans and the loss of their calcium shells due to ocean acidity.*
5. **“When you touch a coral, it seems like a big colorful rock. Are they actually ancient fossils, or just chunks of minerals?”** *Although corals may appear to be non-living minerals, fossils or rocks, coral reefs are composed of marine animals that attach their exoskeletons to underwater rocks and shipwrecks. They have tentacles with stingers that they can use to capture and then eat tiny fish and zooplankton (small floating sea animals).*

# Anticipating Student Questions

1. **“Why can’t damaged coral reefs just replenish themselves by forming more shells?”** *In some cases, damaged coral reefs can rebuild, but severe stressing caused by a combination of several environmental situations such as acidified and warmer ocean water, pollution and excessive tourism causes slower growth and interferes with polyp reproduction.*
2. **“What is the composition of a coral reef?”** *A coral reef is composed of thin layers of a calcium carbonate base. Millions of tiny coral polyps that feed on plankton and algae form a living mat over this skeleton and add the beautiful shapes and colors of the reef.*
3. **“Why are healthy corals so colorful?”** *The skeletons of most corals are white because they are composed of calcium carbonate, a white-colored compound. The brilliant colors of coral reefs come from the tiny algae that live inside their tissues. These pigments are visible through the clear polyp body of the corals.*
4. **“How many different types of coral are there?”** *There are* approximately 2,500 species of coral. About 1,000 of these form hard shells and build coral reefs; the others are soft shelled.
5. **“Is ocean acidification the only danger to coral reefs?”** *No, evidence shows that, in addition to ocean acidification, the complex interaction of various environmental stresses working at the same time causes greater damage than acidification alone.*

# Activities

**Labs and demos**

**13 hands-on experiments on ocean acidification:** The European Project on Ocean Acidification (EPOCA) asked leading European scientists to design labs for 10–18 year-olds. Lab titles include: “Atmospheric Carbon Dioxide Can Produce Ocean Acidity” and “pH Regulation of Seawater”: The Role of Carbonate (CO32–) and bicarbonate (HCO3–)”; links take you to complete directions, materials, and equipment diagrams, plus sample data. (<http://www.epoca-project.eu/index.php/what-do-we-do/education/educational-activities/hands-onexperiments.html>)

**Demo: “Ocean Acidification in a Cup”:** Short videos illustrate the concept and the demo using vinegar, baking soda, and acid/base indicator. Consider this extension: note the destruction shown when seashells (or eggshells) are submerged in increasingly acidic water (like the sea butterfly experiment shown on page 12 of the Hale “Acidic Seas” article). (<https://www.exploratorium.edu/snacks/ocean-acidification-in-cup>)

**Simulations**

**“CO2, Shell Building and Ocean Acidification”:** Produced by the Woods Hole Oceanographic Institution, this simulation uses chemical reactions to show where organisms must use energy to expel hydrogen ions (H+) from bicarbonate ions (HCO32–) to release carbonate ions (CO3–2) needed for shell building. Under the “Multimedia” box on the right side of the project page, click on the “Interactive” clamshell icon for the simulation (requires Adobe Flash). (<http://www.whoi.edu/ocean-acidification/>)

**Media**

**“Ocean Acidification” video (3:01):** This terrific video uses cartoon characters as molecules and ions to demonstrate the consequence of excess carbon dioxide in oceans, including reduction of carbonate ions and shell destruction. The program accompanied by lesson plans and activities is produced by the Smithsonian National Museum of Natural History (NMNH); the video is from *The Alliance* (between the American and the German chemical societies) *for Climate Education*. (<http://ocean.si.edu/ocean-acidification>)

**PBS video (8:50) “Coral Reefs”:** Excellent photography shows the formation and structure of different types of coral reefs. The text describes how coral reefs provide food and shelter for aquatic life and the process of bleaching that leads to their death. (<https://ca.pbslearningmedia.org/resource/bfe7f0ea-8cd1-4392-aed6-1708cd9edf0e/coral-reefs/?#.WhXyTXmWxjo>)

**NOVA video (4:07), “What is Ocean Acidity?”:** After a short description of how carbon dioxide dissolved in ocean water changes water’s chemistry, this excellent video uses structural formulas of the molecules and ions to show the series of five reactions given in the Hale article and explains that the carbonate ion is the limiting reagent required to form calcium carbonate shells for aquatic life. (<https://ca.pbslearningmedia.org/resource/nvls-sci-acidification/what-is-ocean-acidification/?#.WhXrBXmWxjo>)

**Lessons and lesson plans**

**“Effect of Acidification on Coral Reefs” (two-50-minute class periods):** This multi-section lesson plan produced by Gustavus/Howard Hughes Medical Institute Outreach Program includes readings, a hands-on lab with pre-lab, student questions, and a video. See a list of links at the end for additional resources. (<https://gustavus.edu/events/nobelconference/2012/teachers/files/EffectofAcidificationonCoralReefs_000.pdf>)

**Inquiry lesson—why do we explore? (two 45-minute class periods):** “Ocean Health”, a lesson based on exploration and research from the NOAA ship Okeanos, asks, “What factors tend to resist changes in ocean pH?” Students seek answers during a hands-on laboratory activity; the site contains thorough answers to questions and lab preparations that include how to make artificial sea water, with supplementary links provided for the teacher. (<http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/09offbase>)

**Projects and Extension Activities**

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

**“Slowing Down an Amplifying Greenhouse Effect” project:** This site provides an evaluation and risk/benefit study of technologies designed to reduce atmospheric carbon dioxide. The project includes student research, articles to read, a NOVA video, and questions to address. (<https://serc.carleton.edu/eslabs/carbon/lab8.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**](http://www.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)**

**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”*.**



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

Available Now!

The Teacher’s Guide for the April 2009 *ChemMatters* article on algal blooms contains some interesting information about the adverse effect of ocean acidity on the ability of clownfish larvae to locate coral reefs through “tasting” (smelling).

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

"Compound Interest" is a blog created by Andy Brunning, a chemistry teacher in the UK, who uses his site to post graphics that he designs to highlight and explain the uses, reactions, and impacts of everyday chemicals. His choice of carbon dioxide for the infographic in the link below produced a perfect fit for the topic of this Acidic Seas article: note that the three columns on the graphic focus on how atmospheric carbon dioxide affects pH, the subsequent chemical reactions that produce acidic seas, and the results of ocean acidification.

([http://www.compoundchem.com/wp-content/uploads/2017/01/Carbon-Dioxide-and-Ocean-Acidification.png)](http://www.compoundchem.com/wp-content/uploads/2017/01/Carbon-Dioxide-and-Ocean-Acidification.png)

All of the chemistry infographics he has created are posted on the *Learn Chemistry* Web page of the Royal Society of Chemistry Web site at [http://www.rsc.org/learn-chemistry/resource/listing?Keyword=KCN00000015&reference=compoundinterest#](http://www.rsc.org/learn-chemistry/resource/listing?Keyword=KCN00000015&reference=compoundinterest).

# Web Sites for Additional Information

**Characteristics and development of ocean corals**

This article from the Smithsonian NMNH contains excellent photos of ocean corals with details of their structure and formation, including the symbiotic relationship between coral reefs and the colorful algae that grow within the reef structure, and a description of the reproductive behavior of coral polyps, accompanied by photos and a short video (2:10) of polyps spawning. Current work at the Smithsonian’s Caribbean research station is described and illustrated.

(<http://ocean.si.edu/corals-and-coral-reefs>)

The Coral section of The “Marine Life Photography of Hawaii and Beyond” site has a “Coral Index” of 25 pictures of species of coral, a physical description of each type, and other facts such as the location of colonies (country, depth in the ocean, ocean temperature, etc.). (<http://www.marinelifephotography.com/corals/corals.htm>)

**Endangered ocean coral**

The World Wildlife Federation (WWF) explains why ocean corals are considered an endangered species, one whose survival goes beyond simply conserving their habitat. The site provides a map\*, suitable for PowerPoint or whiteboard displays, showing the worldwide location of coral reefs, in warm and in cold waters, and a brief description of each of the major threats to coral reefs and their inhabitants; many listed threats also contain a WWF link to a more extensive description of that threat.

(<http://wwf.panda.org/about_our_earth/blue_planet/coasts/coral_reefs/>)

\*This is a link to a clearer enlargeable view of the warm/cold map listed above. The author (Hugo Ahlenius) gives permission for classroom use if his URL and name are given credit. (<https://farm1.staticflickr.com/734/32357568885_5c8f0d1551_o.jpg>)

*The Conversation,* published by the University of Australia, discusses the scale and reasons for the massive loss of coral from the Great Barrier Reef, and embedded links take you to maps of coral loss. (<https://theconversation.com/how-will-the-barrier-reef-recover-from-the-death-of-one-third-of-its-northern-corals-60186>)

**Ocean warming**

In this article, ocean warming is described as “the most powerful evidence of global warming” due to the release of heat-trapping gas emissions as fossil fuels are burned. Excellent charts and graphs appropriate for classroom use show how the rate and depth of ocean warming are increasing due to the oceans’ absorption of 2/3 of the excess heat trapped by greenhouse gas emissions.

(<https://insideclimatenews.org/news/03102017/infographic-ocean-heat-powerful-climate-change-evidence-global-warming>)

The International Union for Conservation of Nature and National Resources (IUCN), based in Switzerland, has prepared an extensive (560 pages) report, *Explaining Ocean Warming: Causes, Scale, Effects and Consequences*. On the premise of ocean warming as the “greatest hidden challenge of our generation,” sections of this document report on the impacts and effects of ocean warming on various marine organisms, their habitats, and ecosystems.

(<https://portals.iucn.org/library/sites/library/files/documents/2016-046_0.pdf>)

**Ocean acidification**

This URL takes you to a clear explanation of the carbonate/bicarbonate buffer system that includes chemical equations, and a diagram that is suitable for classroom use. (<http://strippolichemistry.weebly.com/uploads/9/7/8/2/9782140/the_carbonate_buffering_system.pdf>)

“Ocean Chemistry” from the *ACS Science Toolkit* uses five equations to thoroughly and clearly explain the ocean carbonate buffer system, using Le Châtelier’s principle to discuss ocean pH and equilibrium shifts as additional environmental carbon dioxide is absorbed by the ocean and places a stress on the system. The margin presents an easy demonstration; this article is appropriate for student reading.

(<https://www.acs.org/content/acs/en/climatescience/oceansicerocks/oceanchemistry.html>)

**The greenhouse effect**

This National Aeronautics and Space Administration (NASA) site on “Global Climate Change,” includes an explanation of how the greenhouse effect has always warmed the planet, but that recent human activities have led to dramatic increases in the amounts of greenhouse gases released to the atmosphere. This is an amazing site that includes several articles based on NASA research, with interactive videos and suggestions of ways to mitigate climate change. (<https://climate.nasa.gov/causes/>)

“Threats to Coral Reefs” (due to climate change) contains an “Infographic” that could easily be shown and discussed in class. The text lists threats to coral reefs by climate change and describes ways that people can help reduce their contributions to ocean warming due to their activities.

(<https://oceanservice.noaa.gov/facts/coralreef-climate.html>)

**Loss of coral reefs**

On this site, *National Geographic* studied the effects of dredging the seafloor to expand Australian ports to accommodate large tankers. The Great Barrier Reef suffered as huge plumes of sediment from the seafloor blocked sunlight, thus preventing algal photosynthesis, the source of food and energy for coral reefs.

(<https://news.nationalgeographic.com/news/2014/07/140716-australia-coral-reef-dredging-sediment-disease-environment-ocean/>)

Oceana, an international organization devoted to the protection of the oceans, reports that coral reefs serve as the first line of defense against strong tropical storms for coastal communities. This article describes the economic and humanitarian necessity of careful worldwide monitoring of human activities to obtain targeted data as the basis for developing programs to reduce global threats to coral reefs.

(<http://oceana.org/marine-life/marine-science-and-ecosystems/coral-reef>)

**Recovery of coral reefs?**

According to a report in *LiveScience* of a study led by James Gilmore at the Australian Institute of Marine Science, published in *Journal of Science*, researchers were amazed to watch the recovery of a bleached coral reef; self-regeneration was not expected, nor was healing in years rather than decades. This article explains the scientific findings and what they suggest for the care of the environment.

(<https://www.livescience.com/28440-coral-reefs-can-regenerate.html>)

This BBC article contains beautiful photography, including a short (1:03) underwater video of corals. “The Corals that came back from the Dead” explains coral death from bleaching and provides possible explanations for their recovery.

(<http://www.bbc.com/earth/story/20140916-the-corals-that-come-back-from-the-dead>)

**New approaches to coral reef research**

The open access paper *Frontiers in Marine Science,* March 2016, contains excellent illustrations suitable for the classroom. Findings of the Duke University Nicholas Institute suggest that multiple stressors interact in complex ways leading to more rapid and stronger negative effects on coral ecosystems.

(<https://nicholasinstitute.duke.edu/ocean/publications/multiple-stressors-and-ecological-complexity-require-new-approach-coral-reef-research>)

The Marine Institutes of Australia, Florida, and Hawaii are working on an approach to restoring coral reef colonies through genetic research by attempting to grow hardy corals—ones that will resist ocean warming—in their labs and then implant them at sea. However, this work creates ethical questions regarding the use of selective breeding techniques. (<https://www.nytimes.com/2017/09/20/climate/coral-great-barrier-reef.html>)

**International efforts to stem ocean acidification**

*The Monaco Declaration*—2008: A group of 155 scientists from 26 countries reviewed the threats to the marine ecosystem posed by chemical changes in the ocean due to increasing worldwide carbon dioxide emissions. In an effort to prevent further damage, they launched initiatives to improve understanding and communications between scientists and economists and policymakers. (<http://www.fpa2.org/pdf/declaration_monaco.pdf>)

This United Nations (UN) slideshow covers the conference details: (<http://www.un.org/depts/los/consultative_process/ICP14_Presentations/HILMI_ICP_Presentation.pdf>)

*Paris Agreement*—2017: Representatives from 197 nations met to address the common cause of combating climate change and adapting to its effects through development of the UN Framework on Climate Change; 170 of the nations ratified the agreement to reduce their carbon dioxide emissions, with the ultimate goal of reducing emissions to reach climate neutrality (net zero carbon footprint) by the end of the century. (<http://unfccc.int/2860.php>)

# About the Guide

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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>.



**Teacher's Guide for**

### *“Eat the Wrapper?! An Edible Solution for Wasteful Packaging”*

**February/March 2018**

**Table of Contents**

[Connections to Chemistry Concepts 70](#_Toc503456609)

[Teaching Strategies and Tools 71](#_Toc503456610)

[Standards 71](#_Toc503456611)

[Vocabulary 71](#_Toc503456612)

[Reading Supports for Students 72](#_Toc503456613)

[Anticipation Guide 74](#_Toc503456614)

[Reading Strategies 75](file:///C:\Users\Bill\Documents\1%20OFFICE%20DOCUMENTS\CHEMATRS\2017-18%20CM%20TG\3%20February\TG%20Good%20to%20Go\2018%20%2002-03%20Feb-Mar%20TG%20Compilation.docx#_Toc503456615)

[Graphic Organizer 76](#_Toc503456616)

[Student Reading Comprehension Questions 77](#_Toc503456617)

[Answers to Student Reading Comprehension Questions 79](#_Toc503456618)

[Possible Student Misconceptions 81](#_Toc503456619)

[Anticipating Student Questions 82](#_Toc503456620)

[Activities 84](#_Toc503456621)

[References 86](#_Toc503456622)

[Web Sites for Additional Information 88](#_Toc503456623)

[About the Guide 92](#_Toc503456624)

# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Chemical bonding** | During a unit on chemical bonding, you can use the example of the divalent linkages of calcium ions to sodium alginate in Ooho! spheres to show one type of ionic bonding. |
| **Intermolecular forces** | You can use the examples of hydrogen bonding in the agar gels of LOLIWARE, and the London dispersion forces that link the tiny fibers together in edible paper in a discussion about intermolecular forces. |
| **Polymers** | In teaching about polymers, the starches used in edible paper, as well as the polysaccharides in agar used for LOLIWARE, can serve as examples of the use and action of polymers. |
| **Ions** | When a divalent calcium ion replaces a monovalent sodium ion in sodium alginate multiple alginate ions are linked together in a more complex compound that becomes a gel. This can be used as an example when discussing ionic reactions. |
| **Limiting reagents** | In a discussion about limiting reactants, you can use the description of the spherification process to ask students to determine the limiting reactant in the process as it is presented. The reaction only occurs in the presence of alginate, and the reaction is stopped by removing the spheres from the alginate solution. |
| **Biochemistry** | Since humans lack the enzymes to digest cellulose but can digest starch, the use of amylose and amylopectin molecules in making edible paper could be discussed in a biochemistry unit where these molecules are studied. |

# 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.

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.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in this issue:

Physical properties

States of Matter

Structural Formulas

pH

Oxidation & Reduction

Enzymes

Intermolecular forces

* Some of the articles in this issue provide information about carbon dioxide and its role in the environment.
* 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 consumer choices. Also, ask them if they have questions about some of the issues discussed in the articles.

# 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. 75):**  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.

*NEW! Instead of using the aforementioned anticipation guide, consider this idea to engage your students in reading.*

Ask students if they can provide examples of edible packaging they have used.

* **Graphic Organizer (p. 76):**  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.

|  |  |  |
| --- | --- | --- |
| **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. 77-78):** 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.

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.

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.

“Eat the Wrapper?! An Edible Solution for Wasteful Packaging”, *ChemMatters*, February/March 2018

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Anticipation Guide

“A Close-up Look at the Quality of Indoor Air” (*ChemMatters*, April/May 2016 Issue)

**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. Edible skins are made of organic molecules from food including oranges and chocolate. |
|  |  | 1. There is currently no way to protect edible skins from surface contamination. |
|  |  | 1. Compostable materials can be broken down by fungi and bacteria. |
|  |  | 1. Edible, compostable drinking cups made of agar have been developed. |
|  |  | 1. Making new plastic water bottles requires oil that could be used to generate electricity. |
|  |  | 1. Gel water spheres that you bite into are one possible solution to the plastic water bottle problem. |
|  |  | 1. Calcium ions can form three bonds linking alginate molecules together. |
|  |  | 1. The packaging waste added to landfills has gone down substantially since 2005. |
|  |  | 1. Edible paper is made of starch, not cellulose, so that it is digestible. |
|  |  | 1. Principles from molecular gastronomy can help solve the food packaging waste problem. |

## Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

“Eat the Wrapper?! An Edible Solution for Wasteful Packaging”, *ChemMatters*, February/March 2018

**Directions**: ***As you read***, complete the graphic organizer below to compare different forms of edible packaging.

|  |  |  |
| --- | --- | --- |
|  | **How they are made** | **Chemicals involved** |
| ***Edible skins*** |  |  |
| ***Edible cups*** |  |  |
| ***Water spheres*** |  |  |
| ***Edible cupcake paper*** |  |  |

**Summary:** On the back of this paper, use your knowledge of chemistry to write a short email to a friend explaining why you would or would not use edible packaging.

## Student Reading Comprehension Questions

“Eat the Wrapper?! An Edible Solution for Wasteful Packaging”, *ChemMatters*, February/March 2018

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name

**Directions**: Use the article to answer the questions below.

1. What is molecular gastronomy?
2. Give three reasons why WikiCell is an attractive alternative to traditional food packaging.
3. What inspired Chelsea Briganti and Leigh Ann Tucker to create LOLIWARE?
4. How does agar form a gel suitable for making cups?
5. What makes LOLIWARE cups capable of holding soda without dissolving?
6. Out of the 50 billion plastic water bottles disposed of in the United States, how many are recycled? Show your work.

**Student Reading Comprehension Questions, cont.**

“Eat the Wrapper?! An Edible Solution for Wasteful Packaging”, *ChemMatters*, February/March 2018

1. Why are many skeptical about the widespread use of edible packaging?
2. How do calcium ions help form Ooho! edible water spheres?
3. What materials are used to make edible paper?
4. If cellulose and starch are both natural polymers, why is starch used instead of cellulose to make edible baking paper?
5. In 2013 alone, how much food packaging ended up in landfills?
6. Besides edible food wrappers, cite three other examples mentioned in the article that involve the development of compostable and biodegradable materials to replace food packaging.

## Answers to Student Reading Comprehension Questions

1. **What is molecular gastronomy?**

*Molecular gastronomy is "the study of the physical and chemical transformations of ingredients that occur when cooking food.”*

1. **Give three reasons why WikiCell is an attractive alternative to traditional food packaging**.

*Three reasons that WikiCell is an attractive alternative to traditional food packaging are:*

1. *it has no known negative environmental impacts,*
2. *it shields food from bacterial contamination, and*
3. *it provides extended shelf life for food.*
4. **What inspired Chelsea Briganti and Leigh Ann Tucker to create LOLIWARE?**

*Briganti and Tucker were inspired to create LOLIWARE as a solution to the wasteful consumption of plastic cups at parties and other gatherings—the problem of 25 billion plastic cups ending up in landfills and never decomposing.*

1. **How does agar form a gel suitable for making cups?**

*In hot water, agar is in solution as random coils and can be poured into molds for shaping. As the agar solution cools, agar gels due to the formation of hydrogen bonds that cross-link galactin chains. Further cooling leads to a firmer gel that can be dried to make cups.*

1. **What makes LOLIWARE cups capable of holding soda without dissolving?**

*LOLIWARE is capable of holding soda without dissolving because soda is served cold and the cups are only water soluble at near-boiling temperatures of 95–100 °C.*

1. **Out of the 50 billion plastic water bottles disposed of in the United States, how many are recycled? Show your work.**

*Out of the 50 billion plastic water bottles disposed of in the United States, 23% or 12 billion are recycled. There are two ways this answer can be calculated from the information in the article*

*50 billion plastic water bottles used*

*– 38 billion bottles in landfills*

*12 billion bottles recycled*

*Or*

*50 billion bottles used x 23 bottles recycled = 11.5 billion bottles recycled,*

*100 bottles used*

*rounded to 2 significant figures = 12 billion bottles recycled*

1. **Why are many skeptical about the widespread use of edible packaging?**

*Many are skeptical about using edible packaging because it could get contaminated as it passes from hand to hand during the shipping and storage journey. To keep it germ-free would require using some external packaging, thus completely negating the “packaging-free” mission.*

1. **How do calcium ions help form Ooho! edible gel water spheres?**

*“Calcium ions are divalent and can thus form two bonds. A single calcium ion from calcium lactate can form a bond between two sodium alginate molecules, effectively linking them together. As calcium ions join the alginate molecules, a solid gel sphere forms around the water in the bath.”*

1. **What materials are used to make edible paper?**

*Edible paper is usually produced with rice or tapioca, both of which contain large amounts of starch.*

1. **If cellulose and starch are both natural polymers, why is starch used instead of cellulose to make edible baking paper?**

*Starch is used to make edible paper rather than cellulose because humans lack enzymes to digest cellulose, but they do have the enzymes required to digest starch.*

1. **In 2013 alone, how much food packaging ended up in landfills?**

*In 2013 the U.S. Environmental Protection Agency reported that 36,720 tons of food packaging ended up in landfills.*

1. **Besides edible food wrappers, cite three other examples mentioned in the article that involve the development of compostable and biodegradable materials to replace food packaging.**

*Three other examples in the article that involve the development of compostable and biodegradable materials to replace traditional food packaging are:*

1. *Eco-Products offers plates, cups, bowls, and flatware that can be composted to rapidly degrade and used to enrich soil.*
2. *Ecovative introduced compostable packaging made from mycelium from mushrooms.*
3. *“Cellulose, starches, and polyesters produced by bacteria can also be used to make biodegradable plastic bags and wrappings.”*

# Possible Student Misconceptions

1. **“Water bottles and plastic bags decompose in landfills over time.”** *Plastic has only been around commercially a little over 70 years and nearly all of it is still present in the environment. It is unknown how long it will take for plastic to decompose but it is longer than this. Some sources state 1000 years, while others report a more modest 400 years. This is a long lifetime for something like food packaging that fulfills its purpose in a matter of hours to a couple of years. Recently some plastics have been made to decompose when exposed to sunlight. However, plastic buried deep within a landfill or in the ocean does not get enough light exposure to decompose.*
2. **“Food packaging is there only to make the food look good, to sell more of it.”** *From a marketing standpoint, you are exactly right. How a product looks to the consumer will definitely influence whether they purchase it. There would be no need to use tinted cellophane that makes meat look redder if the attractiveness of a product did not matter. However, that same cellophane also protects the meat from germs. The most important purpose of packaging is to extend the shelf life of the food it contains by preventing its premature exposure to microorganisms and the oxygen and humidity in the air. Oxygen is required for many of the reactions that cause food to spoil. Another purpose of packaging is to protect the product from physical damage. Bags of chips are filled with air to keep the chips from getting crushed. Packaging serves as the container for products like milk that must have it. Packaging is primarily for cleanliness, protection, and convenience, but it also provides a place for marketing.*
3. **“Everybody is recycling these days, so food packaging doesn’t typically get to landfills anyway. So, why worry about it?”** *Actually, everyone is not recycling. In the U.S. alone, 22% of materials added to landfills come from food packaging waste. A recent global study cited by* National Geographic *shows that in the past 60 years, 8.3 billion metric tons of plastic has been produced. Of that, 6.3 billion metric tons has become plastic waste. Only nine percent has been recycled. Food packaging materials do not account for all discarded plastic, but they represent a portion that consumers can reduce. The United States recycles less than any developed nation. Europe recycles 30% of its plastics and China recycles 25%, but recycling in the U.S. has remained at 9% since 2012. The majority of plastic waste has ended up in landfills. Some of it is finding its way into the oceans, where it either sinks to the bottom, washes up on shores, or remains floating in vast gyres of waste, mid-ocean. Plastic waste is hazardous to the wildlife that consumes it, or that gets caught in it. Beyond that, microscopic plastic fibers can now be found in the majority of drinking water throughout the world. In a global study of drinking water, 84% of the samples contained plastic fibers. 94% of the U.S. samples contained plastic fibers, while 72% of the European water samples contained plastic fibers. There were also more fibers per sample found in the U.S. samples compared to those in other countries. The physiological problems associated with plastic in the food chain is unknown at this time. Any efforts we can make to contain plastic’s presence in our environment could be to our advantage.* (<https://news.nationalgeographic.com/2017/07/plastic-produced-recycling-waste-ocean-trash-debris-environment> and <https://www.theguardian.com/environment/2017/sep/06/plastic-fibres-found-tap-water-around-world-study-reveals>)

# Anticipating Student Questions

1. **“The article states, “Entrepreneurs and scientists want to apply the principles of molecular gastronomy”. What are the principles of molecular gastronomy?** *The principles of molecular gastronomy are simply the principles of scientific inquiry. Experimentation in molecular gastronomy starts in the kitchen, where chefs study how food tastes and behaves under different temperatures, pressures, and other scientific conditions. The same principles that guide the “scientific method” are utilized by cooks and scientists practicing molecular gastronomy. Many of the tools and equipment that are used look as though they belong in a chemistry lab. Some food scientists use infrared spectroscopy to determine the structure of various food molecules in order to decide how to blend them for a specific taste experience. These same principles are used as scientists experiment with food to produce edible packaging.*
2. **“Could edible packaging be detrimental to my health?”** *It is unlikely that the materials used in edible packaging will be detrimental to your health. The materials used in making the packaging are already molecules that are in the human diet. Actually, we may have more to worry about the health effects of current plastic packaging made from petroleum products. It has been shown that some compounds like bisphenol A and phthalates leak into the food that is stored in plastics made with them. Due to recent regulations in some U.S. states, Canada, and European countries, most children’s cups and bottles are made of plastic that is BPA-free. Even plastic-lined paper used to wrap hamburgers may leach chemicals into our food. It is not yet known what the effects on human health of these chemicals associated with plastics might be, but some hypothesize that they may contribute to infertility, obesity, breast cancer, prostate cancer, heart disease, and diabetes.* *(*<https://www.choice.com.au/food-and-drink/food-warnings-and-safety/plastic/articles/plastics-and-food>*)*
3. **“Why have an edible skin if you still have to wrap the food in cellophane to protect it from germs?”** *Some of the edible wrappers that are being developed can be washed, just like you would wash the edible skin of an apple or grape before eating them. For those items that would require additional disposable packaging, hopefully, that packaging will be biodegradable as well. Some of the edible packaging actually extends the shelf life of the product because it is not permeable to oxygen. Oxygen is responsible for adverse changes in many foods, changing their flavor or speeding up their decay. With decreased exposure to oxygen, foods last longer and taste fresher.*
4. **“How are plastic bottles recycled?”** *Once collected, the plastic bottles are sorted according to the type of plastic they contain. At this point, they undergo several cleaning and further sorting steps before they are shredded into flakes. The flakes are then washed and can be sold as is or melted into pellets or roll stock to be made into more plastic products. Using recycled plastic stock reduces the amount of carbon consumed, as well as the amount of plastic that is landfilled. A video of this process can be found here:* <https://makezine.com/2011/06/16/how-plastic-bottles-are-recycled-video/>.
5. **“How big are the Ooho! water spheres, and how much water can they hold?”** *The Ooho! water spheres can be made to hold various volumes but are generally small, since they do not have a lid. Typically, the ideal volume is one sip to a few sips, depending on the application. At a marathon, the size might be 50 mL, while at a place like Starbucks, it might be 150 mL. The marketing idea for the Ooho! spheres is that they can be made on the spot in a machine similar to a coffee-making machine.*
6. **“How do you make edible paper?”** *Edible paper is made by creating a slurry with rice and potato flours and water. The slurry is spread into a thin layer and dried in an oven, microwave, or air-dried. Some edible paper has been produced using seaweed.*
7. **“What about current recycling programs—aren’t they working to keep things out of landfills?”** *Current recycling programs do keep some packaging out of landfills, but only a small portion of packaging makes it to the recycler. A lot of other countries seem to be doing a better job at recycling than the U.S. The U.S. population is not well educated about recycling, nor disciplined to recycle. Plus, facilities that collect recyclable materials are not evenly distributed geographically. For a recycling program to work well, there has to be an easy and convenient way to properly dispose of recyclable materials, and there must be a market for the recycled material. It also has to be cheaper to use stock from recycled goods than to make the packaging from its raw ingredients. Many plastics cannot be recycled, and those that can are subject to fluctuating markets. Plastic bags are a good example. They can be recycled, but the cost of recycling them is often more than it costs to make new bags from scratch, especially when the price of oil (the raw material for this plastic) is low. A lot of bags that are sent to a recycling facility end up being incinerated as a result. But at least that keeps them out of landfills and waterways.*

# Activities

**Labs and demos**

**“Molecular gastronomy in the science classroom”:** Three applications of spherification are used to teach about acid-base reactions, chemiluminescent redox reactions, and thermal convection in a reaction with a thermochromic effect. Instructions and videos are supplied for each activity, any/all of which could be used as a class lab activity or as a teacher demonstration. (<http://www.scienceinschool.org/content/molecular-gastronomy-chemistry-classroom>)

**“Juice Balls: The Science of Spherification”:** The information for this lab to make juice balls, which could be done in the classroom or assigned as a home project, is organized under tabs labeled Background, Materials, Procedure, and Make it Your Own. The instructions contain a short video that shows how the juice spheres are made. (<https://www.sciencebuddies.org/science-fair-projects/project-ideas/FoodSci_p074/cooking-food-science/juice-balls-science-of-spherification#summary>)

**Media**

**Video (2:02)—Making a food coating from milk casein:** This short, ACS-sponsored video shows the production of a food film made from casein. While it may best be used for dairy products and items already containing milk to protect people with milk allergies, the film could also be sprayed on breakfast cereal to prevent soggy cereal. (<https://www.youtube.com/watch?v=wt32GgQGTcI&feature=youtu.be>)

A Fox interview (4:51) with the scientists developing this casein film can be found here: <https://www.youtube.com/watch?v=0K_udXd-rx4>.

**Video (3:50)—“How to Make an Edible WATER ‘BOTTLE’”:**  The presenter provides instructions on how to make water spheres like the ones referenced in the Bricker-Anthony article. This video could be used as a resource for making water spheres in class, or at home as an enrichment activity. (<https://www.youtube.com/watch?v=YLjzsfgk198>)

**Motivational video (3:55)—reducing plastic consumption:**  “Open Your Eyes”, from the Plastic Pollution Coalition, seeks to educate and motivate people to use less plastic. This could be shown to initiate a discussion about the need for finding solutions to the waste plastic problem. (<http://www.plasticpollutioncoalition.org/>)

**Lessons and lesson plans**

**Using techniques from molecular gastronomy in class:**  This lesson plan gives instructions for a class of high school students to explore molecular gastronomy by making olive oil powder and juice spheres. The instructions are well written and the plan provides suggestions for discussion questions, as well as ideas for further exploration.

(<https://fromseedtoshelf.files.wordpress.com/2015/12/dowd2.pdf>)

**Molecular gastronomy unit plan:**  Students explore molecular gastronomy while studying basic chemistry content knowledge in this 13-lesson unit that uses NGSS and Understanding by Design principles and culminates in a snack food competition. All teacher materials and student materials are provided. (<https://sites.google.com/a/wgu.edu/instructional-portfolio-mg-engineering/kindergarten>)

A copy of the paper describing this lesson plan, presented at an ASEE’s conference can be found here: <file:///C:/Users/Owner/Downloads/the-recipe-for-a-gourmet-snack-ngss-nae-and-steam-fundamental%20(1).pdf>.

**Projects and extension activities**

**Making edible paper in class or at home:**  This site contains a simple recipe for an edible paper that uses rice flour, potato starch, salt, and water. This could be a fun activity to do in class or at home and could become an open inquiry activity by challenging the students to experiment with the amounts of each ingredient to determine its role in the quality of the final product. (<https://makezine.com/projects/make-edible-paper-3-easy-steps/>)

**Design a new edible wrap:**  Divide the students into small design groups to come up with creative, yet reasonable uses for edible packaging. For example, they may suggest mustard flavored paper napkins for the big hot pretzels sold in the mall. As a follow-up activity, you could assign them the task of researching their idea to see if it is currently being developed.

**Sponsor a school-wide recycling campaign:** Challenge students to launch a recycling campaign to educate their schoolmates about the need to reduce the amount of plastic in the environment and the amount of waste going to landfills. They might make posters to hang on the wall throughout the school, serve as guest speakers in other classes to present public service announcements, write a thought-for-the-day to be read over the intercom during schoolwide announcements, or sponsor a school-wide recycling challenge. If your school does not have a recycling program, the students may want to meet with the principle to try to start one.

# 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**](http://www.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)**

**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”*.**



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

Available Now!

Author Brian Rohrig explores the chemical factors that affect food spoilage, while presenting several types of food packaging, from oxygen-permeable films to steel cans. At the end of the article is a set of four experiments students can conduct that compare a 16-oz. aluminum can and a 16-oz. plastic bottle for chill factor, size, amount of material, and strength. (Rohrig, B. Food Packaging—Wrapping up Freshness. *ChemMatters*, 2000, *18* (3), pp 9–11)

The October 2000 Teacher’s Guide to the above article contains a description of the different plastic-packaging materials. There are also instructions for performing a demonstration of the small amount of material in a Styrofoam® cup that involves “dissolving” cups in acetone.

In her article "Edible Wraps—Safe, Strong, and Delicious", author Mahoney addresses the research aspect of developing edible packaging. She discusses polymers and compares plant-derived polymers vs petroleum-derived polymers, and the hydrophilic nature of edible food wraps. (Mahoney, M. Edible Wraps—Safe, Strong, and Delicious. *ChemMatters*, 2003, *21* (2), pp 14–16)

The April 2003 Teacher’s Guide to the above article gives information about the amount of food packaging found in landfills, as well as information about plastic recycling processes and more information about edible wraps and biodegradable plastics. Suggestions for student activities include research reports, keeping a list of the types and amounts of packaging they discard at school and at home, and searching for examples of packaging “waste”.

The following issues of *ChemMatters* contain articles about recycling packaging materials, should you want to pursue that aspect of environmentally-friendly actions.

* Author Borchardt presents the chemistry of paper recycling. (Borchardt, J. Old News, New Paper. *ChemMatters* 1993, *11* (2), pp 12–14)
* An article about PET recycling presents the process of recycling plastic from soft drink bottles. The insert “Making and Unmaking of PET” within the article provides the overall chemical equation for this process. (Plummer, C. PET Recycling: “It’s Not Easy Getting New Shirts from Old Bottles”. *ChemMatters* 1994, *12* (3), pp 7–9)
* Poverty in India drives its populace to recycle nearly every piece of plastic they can find. The article discusses the process of how plastic is recycled in India. (Husband, T. Recycling to Survive. *ChemMatters* 2011, *29* (1), pp 5–7)
* Another article from author Husband presents the chemistry and social impact of aluminum recycling in India. (Husband, T. Recycling Aluminum: A Way of Life or a Lifestyle? *ChemMatters* 2012, *30* (2), pp 15–17)
* Author Tinnesand shows that the answer to the question “paper or plastic?” is not so simple when the energy required to produce each type of material is taken into consideration. Tinnesand, M. It’s Not Easy Being Green—Or Is It? *ChemMatters* 2014, *32* (1), pp 12–13)
* In the article “Recycling Plastic Bags”, author DeAntonis discusses the chemistry of making plastic bags and the process of recycling them. (DeAntonis, K. *ChemMatters* 2017, *35* (2), pp 8–9)

# Web Sites for Additional Information

**Edible packaging**

The *National Geographic* blog article “Food Packaging: Have Your Cake and Eat the Wrapper, Too” outlines several innovations in edible food packaging, including LOLIWARE and WikiCell. Links in the article make it easy to find more information on each innovation. (<http://theplate.nationalgeographic.com/2015/07/21/food-packaging-have-your-cake-and-eat-the-wrapper-too/>)

The article “This Indonesian Company Turns Seaweed into Edible & Biodegradable Packaging” contains information about the products being made by EvoWare, as well as a video (1:45) about these products as told by its founder. (<https://www.treehugger.com/clean-technology/company-turns-seaweed-edible-biodegradable-packaging.html>)

The *Seattle Times* article “Could edible packaging solve three environmental food problems?” discusses some of the types of edible packaging that are currently reaching the marketing stage, and how they may solve some environmental problems. Ecovative and Ooho! are both mentioned. (<https://www.seattletimes.com/life/food-drink/could-edible-packaging-solve-three-environmental-food-problems/>)

**WikiCell**

Information about eating the wrapper, liquid-proof skin, protecting the environment, hygiene, and a biodegradable future is just a click away on this infographic about WikiCell packaging. (<http://viewer.zmags.com/publication/8473aceb#/8473aceb/10>)

A short (1:40) video produced by *Al Jazeera* gives information about WikiCell packaging in the style of an infomercial. It could be used in class to support the *ChemMatters* article. (<http://www.aljazeera.com/programmes/earthrise/2013/10/how-it-works-edible-packaging-201310885639197443.html>)

**LOLIWARE**

Since LOLIWARE is presented in the Bricker-Anthony article, students might enjoy seeing this short, commercial-like video (0:57)about this product after they have read about it. (<https://www.youtube.com/watch?v=Fzdzuzg0d10>)

**Ooho! water spheres**

While this site does not provide a lot of technical information, it does provide the names and pictures of the team of young people behind the Ooho! water spheres. It might be motivational for students to see the young developers behind this product coming out of a lab in England. (<http://www.oohowater.com/>)

**Ecovative—mushroom-based packaging**

The ECOVATIVE Web site contains a wealth of information about their mycelium products. They also have an education link with several articles they have written about the experiments they conduct to test and develop their product. It is a good example of engineering design development. (<https://www.ecovativedesign.com/>)

**Bioplastics**

The article“Biopolymer Materials and Technologies Flourish” in the trade journal *Packaging World* lists several new options for biodegradable packaging materials that are being developed. The author gives extensive information about several polymers made by blending plant-based materials with petroleum-based products. (<https://www.packworld.com/article/sustainability/bioplastics/biopolymer-materials-and-technologies-flourish>)

“The Truth about Bioplastics” discusses the pros and cons of the new bioplastics. The authors present the downside to manufacturing bioplastics, including that not all bioplastics are biodegradable, land used to grow raw materials for bioplastics could be used for food production, and when bioplastics break down in landfills, they produce the greenhouse gas methane; and they also contaminate the recycling stream when they are mistaken for PET. (<https://phys.org/news/2017-12-truth-bioplastics.html>)

**Molecular gastronomy**

This Wikipedia entry for “Molecular Gastronomy” gives the history of this discipline developed by two academics, Nicholas Kurti and Hervé This in 1980. Though it is a recent term, cooks and scientists from the 1800s are cited for their contributions to this discipline. (<https://en.wikipedia.org/wiki/Molecular_gastronomy>)

Many chemistry concepts are increasingly used in the kitchen to provide novel gastronomical experiences. The article “Molecular Gastronomy: A New Emerging Scientific Discipline” contains extensive scientific explanations of food preparation, as well as the human sensual experience of enjoying it; the article would make a great resource if you are planning a unit on food chemistry. (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2855180/>)

A commentary by one of the originators of the term ‘molecular gastronomy, Hervé This, is an interesting read. This conducted volumes of inquiries into wives’ tales and legends that surrounded certain cooking regimens. He expounds on some of his work in this commentary: <http://www.kitchen-theory.com/wp-content/uploads/2011/10/Herve-This-PDF.pdf>.

**Molecular gastronomy “recipes”**

If you are ready to explore molecular gastronomy, this site provides recipes, plus tutorials on the methods employed. There is a section on both spherification and reverse spherification. The site contains multiple links to a host of recipes, as well as a link to purchase a kit of common supplies. (<http://www.molecularrecipes.com/molecular-gastronomy/>)

**Waste disposal and landfill statistics**

The Environmental Protection Agency links the results of their studies on this Web site. From Table 1 in the “2014 Factsheet”, the most recent report published, it can be seen that out of 33.25 million tons of plastic waste generated, only 3.17 million tons were recycled. (<https://www.epa.gov/smm/advancing-sustainable-materials-management-facts-and-figures-report>)

“Toward a Plastic-Free Future”, published in *Earth Island Journal,* December 2017, emphasizes that simply recycling plastic is not enough. The article cites many of the statistics compiled for the United Nations Environment Program that project the level of plastic pollution by 2050:  **“**By 2050 there will be more plastic in the oceans than fish.” (<http://www.earthisland.org/journal/index.php/elist/eListRead/tquidoward_a_plastic-free_future/>)

**Global initiatives to reduce plastic waste**

The Web site *Verdict* reports on a recent meeting of the United Nations Environment Assembly where several nations joined the initiative to eliminate the use of plastics (e.g.,Kenya has recently banned the manufacture and use of plastic bags).The article presentseight alternatives to plastic that were discussed at the Assembly. (<https://www.verdict.co.uk/plastic-pollution-environment-ministers-pledged-zero-tolerance-alternatives/>)

This report contains a discussion of six of the latest innovations in solving the plastic waste problem, one example of which is that Coca-Cola Bottling Company and IKEA are two companies that are promoting plant-based packaging. Two short videos are embedded in the article, as well as a link to an on-demand webinar. (<https://www.edie.net/news/8/Edible-packaging-and-ocean-plastic-trainers--the-best-innovations-to-combat-the-plastics-problem/>)

**Short video clips about various edible packaging products**

* This short video (1:06), from the Fox News segment “Chew on This”, reports on WikiFoods yogurt pearls: <http://video.foxnews.com/v/3625503179001/?#sp=show-clips>.
* This short clip (3:42) about edible cutlery illustrates the difficulty in marketing a new product. (<https://www.youtube.com/watch?v=r4Cc5zmy0eY>)
* Coffee drinkers might enjoy learning about edible coffee cups. (1:30) (<https://www.youtube.com/watch?v=5jVx1teP0p8>)
* Saltwater Brewery has solved the problem of the sea turtle whose growth has been restricted by a trashed six-pack ring. Edible six-pack rings produced by the brewery can be safely eaten by aquatic wildlife. (1:52) ( <https://www.youtube.com/watch?v=-YG9gUJMGyw>)

**Infographic about edible packaging**

An infographic that contains pictures and basic information about several types of edible packaging that are being introduced to the marketplace can be found here: <http://www.rrpackaging.co.uk/blog-article/examples-of-edible-and-biodegradable-packaging>.

**Spherification**

The article “The Science of Spherification”, besides giving a brief history of this process, discusses the effect of pH on spherification, as well as the effect of the calcium salt chosen. The material could be used on PowerPoint slides for classroom use, or as extra reading material for students who want more information. (<https://www.chefsteps.com/activities/the-science-of-spherification>)

**Health concerns from environmental plastic**

The *Guardian* reports on a global study of plastic in drinking water, showing that 83% of the global samples contained microscopic plastic particles; 94% of the U.S. samples contained plastic fibers, and 72.2% of European samples contained plastic fibers. The article contains a graphic of a world map with the percentages of water samples studied that contained plastic. (<https://www.theguardian.com/environment/2017/sep/06/plastic-fibres-found-tap-water-around-world-study-reveals>)

“Not-so-Fantastic-Plastic” is an article about the chemicals in plastic that can leach out of containers into the food stored in them and the prospective health problems this may cause. The article contains a good chart of the different plastics and how they are used. (<https://www.choice.com.au/food-and-drink/food-warnings-and-safety/plastic/articles/plastics-and-food>)

# 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.

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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>.



**Teacher's Guide for**

### *“Indigo: The ‘Blue’ in Blue Jeans”*

**February/March 2018**

**Table of Contents**

[Connections to Chemistry Concepts 94](#_Toc503456830)

[Teaching Strategies and Tools 95](#_Toc503456831)

[Standards 95](#_Toc503456832)

[Vocabulary 95](#_Toc503456833)

[Reading Supports for Students 96](#_Toc503456834)

[Anticipation Guide 98](#_Toc503456835)

[Graphic Organizer 100](#_Toc503456837)

[Student Reading Comprehension Questions 101](#_Toc503456838)

[Answers to Student Reading Comprehension Questions 103](#_Toc503456839)

[Possible Student Misconceptions 104](#_Toc503456840)

[Anticipating Student Questions 105](#_Toc503456841)

[Activities 106](#_Toc503456842)

[References 108](#_Toc503456843)

[Web Sites for Additional Information 110](#_Toc503456844)

[About the Guide 115](#_Toc503456845)

# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Hydrogen bonding** | Hydrogen bonding is often associated with the water molecule. This article provides another practical context for hydrogen bonding that you can use in class, the binding of indigo to fibers, as a cause for the fading of blue denim clothing. |
| **Multiple bonds/ Conjugated bonds** | The alternating single and double bonds (conjugated system) in the indigo molecule allow it to absorb light energy. Indigo is an example of a chromophore with a conjugated system of multiple bonds. |
| **Electron transitions** | Electrons in the indigo molecule absorb light energy and move from ground state to an excited state and provide a different context for students to understand electron transitions. |
| **Oxidation-reduction reactions** | The process of extracting and using indigo dyes is a series of oxidation and reductions reactions. Some students may relate to this concept with greater interest, with the practical and visual oxidation and reduction reactions involved in the transition between blue-colored indigo and the yellowish-white indigo white. |
| **Properties of light** | The colors of dyed clothing are related to the wavelengths and frequencies of light energy both absorbed and released. The indigo molecule absorbs light in the 613 nm wavelength range but the item appears bluish in color due to the reflected wavelength of visible light. |
| **Solubility** | Because indigo is insoluble in water, it cannot easily be used in that form as a dye. However, converting it, by oxidation, to indigo white makes the dye soluble in water and able to react to color fibers. |

# 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.

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.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in this issue:

Physical properties

States of Matter

Structural Formulas

pH

Oxidation & Reduction

Enzymes

Intermolecular forces

* 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 consumer choices. Also, ask them if they have questions about some of the issues discussed in the articles.

# 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. 99):**  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.

*NEW! Instead of using the aforementioned anticipation guide, consider this idea to engage your students in reading.*

Ask students to describe why blue jeans have been popular for more than a hundred years, and how their color might relate to chemistry.

* **Graphic Organizer (p. 100):**  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.

|  |  |  |
| --- | --- | --- |
| **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. 101-102):** 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.

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.

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.

“Indigo: The ’Blue’ in Blue Jeans", *ChemMatters*, February/March 2018

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Anticipation Guide

“A Close-up Look at the Quality of Indoor Air” (*ChemMatters*, April/May 2016 Issue)

**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. More than a billion pairs of jeans were sold around the world in 2015. |
|  |  | 1. Indigo dye penetrates the cloth’s threads. |
|  |  | 1. The woad plant that natural indigo dye comes from has bright blue flowers. |
|  |  | 1. Indigo absorbs orange light and reflects purplish-blue light. |
|  |  | 1. Indigo white molecules are oxidized in air to produce blue indigo. |
|  |  | 1. The blue color of jeans slowly fades because the indigo is attached to the cloth by weak intermolecular forces. |
|  |  | 1. Indigo is soluble in water. |
|  |  | 1. The person who first synthesized indigo in a laboratory won the Nobel Prize. |
|  |  | 1. The first mass-production synthesis of indigo used a chemical from coal. |
|  |  | 1. Today indigo is usually produced using chemicals from petroleum. |

## Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

“Indigo: The ’Blue’ in Blue Jeans", *ChemMatters*, February/March 2018

**Directions**: As you read the article, complete the graphic organizer below to describe what you learned about the chemistry of indigo dye.

|  |  |  |
| --- | --- | --- |
| ***Problem*** | ***Solution*** | ***Chemicals involved*** |
| ***How to get indigo dye from the woad plant*** |  |  |
| ***How to use indigo (which is insoluble) to dye cloth*** |  |  |
| ***How to synthesize indigo*** |  |  |
| **Summary**: On the back of this paper, write a tweet (280 characters or less) about indigo, based on what you learned from reading the article. | | |

“Indigo: The ’Blue’ in Blue Jeans", *ChemMatters*, February/March 2018

## Student Reading Comprehension Questions

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name

**Directions**: Use the article to answer the questions below.

1. How much indigo is produced annually?
2. What improvement to denim jeans did Jacob Davis make during the 1870s?
3. How is indigo different from other natural dyes in binding to fibers?
4. What is the name, color, and source of the compound in woad plants from which indigo is formed?
5. How does the indoxyl (formed from indican in woad plants) finally form indigo and turn a blue color?
6. Describe a chromophore and its typical chemical structure.

**Student Reading Comprehension Questions, cont.**

“Indigo: The ’Blue’ in Blue Jeans", *ChemMatters*, February/March 2018

1. Why does indigo look purplish-blue in color if it absorbs orange light?
2. What are the attractive forces that bind indigo white to cellulose molecules?
3. Explain the chemistry of why the blue color of jeans slowly fades with wear and washing.
4. Who was the German scientist who discovered a synthetic synthesis for indigo in the late 1800s?
5. What is the starting chemical used in the modern production of indigo?
6. How is the ring structure of aniline different from that of naphthalene?

## Answers to Student Reading Comprehension Questions

1. **How much indigo is produced annually?**

*Each year, about 20 million kilograms of indigo is produced.*

1. **What improvement to denim jeans did Jacob Davis make in the 1870s?**

*In the 1870s, Jacob Davis improved denim jeans by using copper rivets at points of strain, such as pocket corners and the base of the button fly.*

1. **How is indigo different from other natural dyes in binding to the fibers?**

*Indigo is different from other natural dyes because it binds externally to the fibers, rather than penetrating the fibers directly, like most natural dyes.*

1. **What is the name, color, and source of the compound in woad plants from which indigo is formed?**

*The compound in woad plants from which indigo is formed is indican, which is a colorless compound found in the plant tissues.*

1. **How does the indoxyl (formed from indican in woad plants) finally form indigo and turn a blue color?**

*The indoxyl formed from indican in woad plants finally forms indigo and turns a blue color when the indoxyl is stirred to mix with air, and oxygen oxidizes the indoxyl to form indigo.*

1. **Describe a chromophore and its typical chemical structure.**

*A chromophore is a region in a molecule, usually containing alternating double and single bonds, that produces color.*

1. **Why does indigo look purplish-blue in color if it absorbs orange light?**

*Indigo looks purplish-blue because the human eye sees indigo's complementary color, not the orange color of light that it absorbs.*

1. **What are the attractive forces that bind indigo white to cellulose molecules?**

*The chemical forces that bind indigo white to cellulose molecules are hydrogen bonds.*

1. **Explain the chemistry of why the blue color of jeans slowly fades with wear and washing.**

*The blue color of jeans slowly fades with wear and washing because the indigo dye is bonded to the surface of the fibers with hydrogen bonds, intermolecular bonds, which are weaker than chemical bonds. Thus, some indigo molecules separate from the fibers with each laundering, and the blue color slowly fades.*

1. **Who was the German scientist who discovered a synthetic synthesis for indigo in the late 1800s?**

*The German scientist, Adolf von Baeyer, discovered a synthetic synthesis for indigo in the later 1800s.*

1. **What is the starting chemical used for the modern production of indigo?**

*The starting chemical used for the modern production of indigo is naphthalene.*

1. **How is the ring structure of aniline different from that of naphthalene?**

*The ring structure of aniline and naphthalene are different in that aniline is composed of a single ring and naphthalene is composed of a double ring.*

# Possible Student Misconceptions

1. **“Only seven spectral colors exist (red, orange, yellow, green, blue, indigo, and violet—‘ROY G BIV’).”** *The number of spectral colors is unlimited, and humans can see hundreds of colors. The colors we see and identify are dependent upon physiological, psychological, and cultural factors.*
2. **“Levi Strauss invented denim jeans.”** *Levi Strauss owned a wholesale dry goods store in San Francisco during the California Gold Rush. The miners needed durable work clothes that would not easily rip or tear. Denim clothing was popular, but would sometimes rip at stress points such as pockets and the crotch. Jacob Davis, a Nevada tailor and one of Strauss’s customers, had an idea to add copper rivets to strengthen those stress points and reduce rips. Davis needed a business partner to help patent and produce his improved denim jeans, and Strauss agreed. Their patent was granted on May 20, 1873. So, while denim jeans existed prior to Levi Strauss, the blue jeans worn today started with the partnership between Davis and Strauss. (*[*https://www.smithsonianmag.com/smithsonian-institution/the-origin-of-blue-jeans-89612175/*](https://www.smithsonianmag.com/smithsonian-institution/the-origin-of-blue-jeans-89612175/)*)*
3. **“The color (that we see) of an object is due to the color absorbed.”** *The color of an object that humans see is due to the colors absorbed by the object, as well as the colors it reflects. An apple appears red in color because most of the colors of the visible spectrum are absorbed by the apple pigments, leaving primarily red wavelengths of light reflected and received by the eyes. The red color of an apple is not due just to red light being reflected, it is also influenced by other wavelengths that are reflected, giving rise to various hues of red.*
4. **“Because hydrogen bonds are weak, they must not be****very important.”** *While intermolecular hydrogen bonds are certainly weaker than chemical bonds like ionic or covalent, they are nonetheless very important. Hydrogen bonds are the primary force adhering indigo to clothing fibers. In addition, hydrogen bonds are responsible for holding the double helix strands of DNA together, joining H2O molecules together to form liquid water—or even ice, and many other important roles. The strength of the attraction does not parallel its importance.*

# Anticipating Student Questions

1. **“I heard that the color indigo was being removed from the seven colors of the rainbow. Is this true?”** *Isaac Newton first set the colors of the rainbow, and he named seven colors—including indigo. School children learn the colors as ROY G BIV. Many people believe that the number seven has significance and it is associated with completion or perfection such as seven days per week, seven notes in the diatonic music scale, and the seven seas. Newton may have identified indigo as a primary color to round out the number of colors defined in the rainbow. There are some who omit indigo when painting or depicting a rainbow. Many people have difficulty distinguishing indigo from blue or purple which may lead to its omission. However, ROY G BIV is still in use and indigo has its place in the rainbow.*
2. **“When I mix red and green paint, I make brown paint, but when I mix red light and green light, I get yellow light. Why?”** *Color theory can be complex. There are two aspects to color theory: additive (light) and subtractive (pigment). In light (additive), the presence of all colors forms white; but in pigments (subtractive), the presence of all colors forms black. Pigment colors (subtractive color theory) are more intuitive because we experience them frequently in daily life. Light colors (additive) are less intuitive because we work with light colors less, and light is different than mixing physical substances. For a full explanation, please see* [*http://ux1.eiu.edu/~cfadd/3050/Ch17Color/ToC.html*](http://ux1.eiu.edu/~cfadd/3050/Ch17Color/ToC.html)*.*
3. **“How is natural indigo chemically different from synthetic indigo?”** *There is no chemical difference between natural and synthetic indigo. A chemical does not change its chemical or physical properties based upon whether it is extracted from natural sources or synthesized in a laboratory. There ARE some differences between them, though, that are inherent in their methods of production. Some of these differences between natural and synthetic indigo (or any chemical) are costs of production, sources of reactants, energy and time required to produce, safety in production, and wastes formed.*

# Activities

**Labs and demos**

**Lab synthesizing indigo dye:**  "The Chemistry of Dyes, Part I: The Synthesis of Indigo Dye" provides complete student background theory and procedures for students to synthesize indigo dye. The lab procedure prompts students to complete a data table, complete with calculations, limiting reactant, percent yield, and cost per pound; however, no teacher support is included. (<http://faculty.trinityvalleyschool.org/pricep/Chem/labs/indigo>)

**Microscale lab synthesizing indigo dye:**  The student lab procedure in "The Microscale Synthesis of Indigo Dye" from the Royal Society of Chemistry requires only 10 minutes to complete, and includes chemical structures for the indigo synthesis reactions. Note though, that there are no teacher resources, student questions, or extensions provided. ([http://www.rsc.org/learn-chemistry/resource/res00000560/the-microscale-synthesis-of-indigo-dye#!cmpid=CMP00000575](http://www.rsc.org/learn-chemistry/resource/res00000560/the-microscale-synthesis-of-indigo-dye%23!cmpid=CMP00000575))

**Simulations**

**Simulation of seeing colors:** "The Colors of Light" from PhET is a 30-minute activity to accompany the simulation, "Color Vision," which allows students to manipulate colors of light and color filters to explore how color is perceived by the human eye and brain. Registering for a free account is required to access the student activity materials but not the simulation. (<https://phet.colorado.edu/en/simulation/color-vision>)

**Activity modeling hydrogen bonds:** This *JCE Classroom Activity* prompts students to use K'Nex toy components and Velcro to model hydrogen bonding. Instructor information, possible student answers, plus the student activity sheet are all included, along with student questions to expand the lesson. (<http://pubs.acs.org/doi/pdf/10.1021/ed082p400A>. 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.)

**Media**

**Video explaining intermolecular forces, including hydrogen bonding:** "Intermolecular Forces" (8:35) from the KhanAcademy reviews all of the types of intermolecular forces, with diagrams. The explanation of hydrogen bonding begins at 2:54 in this video. (<https://www.khanacademy.org/science/biology/chemistry--of-life/chemical-bonds-and-reactions/v/intermolecular-forces-and-molecular-bonds>)

**Video of blue jeans:** The ACS Reactions video "How Do Jeans Get Blue?" (3:06) is a quick history of jeans and the chemistry of indigo. This video is targeted to students. (<https://www.youtube.com/watch?v=kiMBFKwnxzI&t=1s>)

**Lessons and lesson plans**

**Lesson on light and color:** The PBS LearningMedia lesson "Light and Color" is targeted for grades 6-12 and includes a 3:55 video clip, a background essay, discussion questions, and education standards to instruct students about the relationship between light photons and visible color. ([https://aetn.pbslearningmedia.org/resource/lsps07.sci.phys.energy.lightcolor/light-and-color/#.WibFW0qnFhE](https://aetn.pbslearningmedia.org/resource/lsps07.sci.phys.energy.lightcolor/light-and-color/%23.WibFW0qnFhE))

**Lesson on colors of light and pigments:**  Although "Physics of Light: Light, Energy, and Color" is a lesson for light and solar cells, the lesson also includes detailed information on color, with specific background information on the electromagnetic spectrum, light absorption and reflection, and why we see color related to pigments. A general procedure using red and green gummy bears and red and green lasers, plus review questions and analysis, are provided for teachers to develop their student lesson aligned with NGSS. (<http://thesolararmy.org/wp-content/uploads/2014/12/Physics-Revisions-High-School-Lesson-Plan-Final.pdf>)

**Projects and extension activities**

**Synthesizing and using an azo dye:** The Royal Society of Chemistry publishes "The Microscale Synthesis of Azo Dyes", providing student directions and reactions with the chemical structures, to prepare a red azo dye from aniline and use the dye on a piece of cotton fabric. No teacher support or detailed safety guidelines are included. (<http://www.rsc.org/learn-chemistry/resource/res00000559/the-microscale-synthesis-of-azo-dyes>)

**Synthesizing and dyeing with indigo and comparing it to alizarin red S dye:** "Chemistry of Blue Jeans: Indigo Synthesis and Dyeing" involves preparing and using indigo dye and comparing it to a mordant dye, alizarin red S. Extensive background information, procedures with chemical structures, and a testing procedure for comparing the dyes is included; however, teachers should carefully consider whether the chemicals required, the procedures, and the safety of the project are appropriate for their teaching environment. (<https://scilearn.sydney.edu.au/fychemistry/labmanual/e04.pdf>)

# 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**](http://www.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)**

**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”*.**



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

Available Now!

This 1986 article contains a large section on dyes extracted from plants, including indigo. The article also provides a sidebar on chromophores with chemical structures (Wood, C. Natural Dyes. *ChemMatters*, 1986, *4* (4), pp 4–8)

Also in the 1986 issue is a short article on denim blue jeans providing a brief history of Levis Strauss jeans and how the traditional blue denim cloth is manufactured. (Robson, D. Blue Jeans. *ChemMatters*, 1986, *4* (4), p 9)

In the “Matter of Fact” feature of the *ChemMatters* October 1998 issue, a student asked, "Why are blue jeans so blue?" The one-page answer complements the present Deakin and Cooper article about indigo. (Becker, R. As a Matter of Fact: Why are blue jeans so blue? *ChemMatters*, 1998, *16* (3), p 16)

This article contains a sidebar on the discovery of mauve, the first synthetic dye that was produced from aniline and other chemicals. (Hersey, J; Helzel, C. Graphene: Your Colorful Food. *ChemMatters*, 2007, *25* (1), pp 12–15)

For an excellent explanation and more information on hydrogen bonding, including illustrations, please see this article about paintballs. (Rohrig, B. Paintball! Chemistry Hits Its Mark. *ChemMatters*, 2007, *25* (2), pp 4–7)

Read this *ChemMatters* article for additional information and pictures about the chemistry of dyes. Information on chromophores and a brief sidebar on tie-dyeing may also be of interest. (Wood, C. The Art and Chemistry of Dyes. *ChemMatters*, 2009, *27* (1), pp 13–15)

This *ChemMatters* article discusses food colors and it includes illustrations of chemical ring structures with alternating single and double bonds (conjugation, as in chromophores). The article also contains a graphic (Figure 4) illustrating colors produced by absorbed and transmitted light. (Rohrig, B. Eating with Your Eyes: The Chemistry of Food Colorings. *ChemMatters*, 2015, *33* (3), pp 5–7)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

In 1930, the *Journal of Chemical Education* included a thorough biography of Adolf von Baeyer (1835–1917) that contains photographs, summaries of his discoveries and chemical syntheses, and collaboration with other scientists. (Henrich, F. Adolf von Baeyer (1835-1917).   
*J. Chem. Educ.*, 1930, *7* (6), pp 1231–1248; <http://pubs.acs.org/doi/pdf/10.1021/ed007p1231>. 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 1983 article provides additional background information about, and chemical structures for, indigo. It includes more details on the synthetic manufacture of this dye. (Fernelius, W; Renfrew, E. Indigo. *J. Chem. Educ.*, 1983, *60* (8), pp 633–634; <http://pubs.acs.org/doi/pdf/10.1021/ed060p633>. 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.)

ACS members or subscribers to *J. Chem. Ed.* can read about the microscale synthesis of indigo from *o*-nitrobenzaldehyde in this article. The article also provides the chemical reaction, illustrated with the chemical structures. (McKee, J; Zanger, M. A Microscale Synthesis of Indigo: Vat Dyeing. *J. Chem. Educ.*, 1991, *68* (10), pp A242–A243; <http://pubs.acs.org/doi/pdf/10.1021/ed068pA242>. Note that this article is only available to American Chemical Society members or subscribers to the journal.)

This is a short article on the indigo dye in blue jeans. It discusses the color-addition and color-removal chemistry involved in dyeing and then fading the color to produce the worn look. (Wolf, L. Blue Jeans. *Chem. Eng. News*, 2011, *89* (43), p 44; <http://pubs.acs.org/doi/10.1021/cen-v089n043.p044>. 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. It is also available for free access at <https://pubs.acs.org/cen/science/89/8943sci3.html>.)

This book is filled with pictures, research, and the history of indigo. The cultural impact of indigo, as well as dyeing techniques from ancient to more modern times, is presented. (Balfour-Paul, J. *Indigo: Egyptian Mummies to Blue Jeans*; Firefly Books: Richmond Hill, ON, 2011.)

Beautiful photographs highlight indigo and its place in world history and culture. This book references the Balfour-Paul book (above) and is considered a companion piece. (Legrand, C. *Indigo: The Color that Changed the World*, 1st ed.; Thames & Hudson: New York, NY, 2013.)

# Web Sites for Additional Information

**Indigo**

Additional history and background information on indigo, including many photographs with indigo-dyed fabrics, are located at <http://facweb.cs.depaul.edu/sgrais/indigo.htm>.

**History of indigo**

The University of Minnesota Web site article "Indigo in the Early Modern World" briefly describes the history of indigo from about 2500 B.C. through the 1700s. (<https://www.lib.umn.edu/bell/tradeproducts/indigo>)

Indigo was a valuable crop in the U.S. southern states during the 18th century. The *South Carolina Encyclopedia* Web site published the article, "Indigo", and the site has links to related information and historical documents, including the use of slave labor in the production of indigo. (<http://www.scencyclopedia.org/sce/entries/indigo/>)

**Indigo problems**

*Popular Science* reports in 2013 on "The Problem with Indigo." The short article describes the problem of pollution in Bangladesh and China from the dye industry and the use of indigo and mordants. ([https://www.popsci.com/blog-network/techtiles/problem-indigo#page-2](https://www.popsci.com/blog-network/techtiles/problem-indigo%23page-2))

"Blue Jeans: Environmental Aspects and Opportunities to Reduce the Environmental Impact" is a 2013 report commissioned by the International Solid Waste Association. It examines the history, manufacturing, environmental impact (including climate), and opportunities to reduce the environmental impact of blue jeans made from cotton and treated with indigo and other chemicals. (<http://www.iswa.org/index.php?eID=tx_iswaknowledgebase_download&documentUid=3184>)

**Indican (soluble indigo)**

The University of California Berkeley provides “A Green Solution to Blue Denim” Web site, with tabs for "Project Blue Jeans" that includes an introduction to the problem of indigo dyeing of three billion pairs of jeans annually, using biosynthesis to produce indigo, and harnessing recombinant technology to produce indican. Additional information, including details on these and other components of making the use of indigo more environmentally friendly, is provided, along with photographs and reactions. (<http://2013.igem.org/Team:Berkeley>)

**Levi Strauss**

The Biography.com Web site includes an article on the life of Levi Strauss. The article begins with his birth in 1929 in Germany, immigrating to the U.S., his success with the birth of blue jeans, and concludes with his death in 1902. (<https://www.biography.com/people/levi-strauss-9496989>)

The Levi Strauss & Co. Web site also highlights their founder in a link, "A full biography of Levi Strauss," located at the bottom of their Web page, titled "Our Story." Additional links are provided at the bottom of the Web page to other articles, videos, and recommended readings. (<http://www.levistrauss.com/our-story/>)

**Jacob Davis**

One of the links at the bottom of the “Our Story” Web page on the Levi Strauss & Co. Web site takes you to "A biography of Levi Strauss's business partner, Jacob Davis," where a bulleted list of information on the life of Davis can be obtained. (<http://www.levistrauss.com/wp-content/uploads/2014/01/Jacob-Davis-His-Life-and-Contributions1.pdf>)

Another brief biography of Davis is supplied by the *History of Jeans* Web site. A partial copy of U.S. Patent No. 139121 granting Strauss and Davis ownership of the copper rivets in jeans is included. (<http://www.historyofjeans.com/jeans-inventor/jacob-w-davis/>)

**Blue jeans**

An interesting infographic, "Chemistry of Levi's," along with a short explanation, is located at <https://jameskennedymonash.wordpress.com/2014/07/31/why-are-jeans-blue-new-infographic-chemistry-of-levis/>.

A Web site, *History of Jeans*, is a fun site to read about all things jeans. Tabs on the site include history, inventors, facts, and making jeans. (<http://www.historyofjeans.com/>)

**Adolf von Bayer**

*The New World Encyclopedia* Web site details the life and accomplishments of Johann Friedrich Wilhelm Adolf von Baeyer, the noted organic chemist who won the Nobel Prize in Chemistry in 1905. (<http://www.newworldencyclopedia.org/entry/Adolf_von_Baeyer>)

The *Nobel Prize* Web site also has a page devoted to von Baeyer, recognizing his award in chemistry in 1905. The site contains links to information about von Baeyer for facts, biography, his 15 nominations for the Nobel Prize, and other resources. (<https://www.nobelprize.org/nobel_prizes/chemistry/laureates/1905/baeyer-facts.html>)

**Chromophores**

The University of Western Ontario has a slideshow converted to pdf, "Colours and Chromophores," which explains color theory, electron energy-level transitions, and chromophores, using diagrams, pictures, and text. (<https://instruct.uwo.ca/chemistry/2223/downloads/chromphores.pdf>)

This site is a succinct but complete explanation of chromophores, the different types, their role in human eyes, and other applications for them. (<http://www.innovateus.net/science/what-chromophore>)

**Glycosides / glycosidic bonds**

The Khan Academy supplies a video, "Glycoside Formation" (10:42), explaining the formation and mechanisms of glycosides at a collegiate level. (<https://www.khanacademy.org/test-prep/mcat/chemical-processes/nucleic-acids-lipids-and-carbohydrates/v/carbohydrate-glycoside-formation-hydrolysis>)

**Oxidation and reduction reactions**

The "What Is a Redox Reaction?" article by Khan Academy is a straight-forward lesson (or review) of oxidation and reduction reactions. The lesson includes example practice questions for engagement, balancing simple redox reactions, and some practice problems to balance. (<https://www.khanacademy.org/science/chemistry/oxidation-reduction/redox-oxidation-reduction/a/oxidation-reduction-redox-reactions>)

Khan Academy also provides a video, "Introduction to Redox Reactions" (10:53), which follows the article referenced above. The video illustrates assigning oxidation numbers, oxidation and reduction half-reactions, electron transfers, and balancing redox reactions. (<https://www.khanacademy.org/science/chemistry/oxidation-reduction/redox-oxidation-reduction/v/oxidation-reduction-or-redox-reactions>)

**Hydrogen bonds**

The LibreTexts Web site has a lesson, "Hydrogen Bonding," which is a clear explanation of simple and more complex examples of hydrogen bonding. The text is supplemented with diagrams and examples of hydrogen bonding found in nature. (<https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Physical_Properties_of_Matter/Atomic_and_Molecular_Properties/Intermolecular_Forces/Specific_Interactions/Hydrogen_Bonding>)

"Hydrogen Bonding" is a useful resource from the Purdue Chemistry Department. This concise and colorful lesson is an effective review of hydrogen bonding and its physical consequences. (<https://www.chem.purdue.edu/gchelp/liquids/hbond.html>)

**Intermolecular forces (IMFs)**

Boise State University provides a jigsaw activity (see explanation below) to help students learn about different intermolecular forces. Four student groups each study one of the intermolecular forces: London dispersion forces, induced dipole, dipole-dipole, and hydrogen bonds; the site provides links for more information, videos, and extension learning. In a jigsaw activity, each student becomes an expert on one aspect of a topic and teaches that topic to others in their group/class until all students have taught and learned all aspects. (<http://edtech2.boisestate.edu/lindabennett1/502/Bonds%20and%20IMFs/bonding%20jigsaw.html>)

The Khan Academy Web site has a valuable lesson, "Intramolecular and Intermolecular Forces," explaining each of these types of attraction. The portion focusing on IMFs includes dipole-dipole, hydrogen bonding, and London Dispersion forces, all clearly illustrated and explained. (<https://www.khanacademy.org/test-prep/mcat/chemical-processes/covalent-bonds/a/intramolecular-and-intermolecular-forces>)

**Color**

"Additive and Subtractive Color Mixing" is an informative article on the ColorBasics.com Web site. Additional tabs on the Web site take readers to information on color temperatures, history of color science, human eyesight, and numerous other items that may be of interest. (<http://www.colorbasics.com/AdditiveSubtractiveColors/>)

Eastern Illinois University provides a robust Web site, “Color and Vision,” that explains the complexities of understanding color addition and color subtraction (see Anticipating Student Questions, number 2, above). Additional tabs on the site address Color and Wavelength," "Dispersion and Spectra," "Rainbows," and "Color Vision", plus a summary and homework with answers. (<http://ux1.eiu.edu/~cfadd/3050/Ch17Color/ToC.html>).

**Electron excitation by light**

A Web site at Michigan State University publishes "Visible and Ultraviolet Spectroscopy,” which presents information and illustrations on the visible light spectrum, color, and conjugated pi-electron systems often found in chromophores. The site provides a diagram explaining electron transitions and relates these to UV and visible absorption spectra. (<https://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/spectrpy/uv-vis/spectrum.htm>)

Another explanation of light causing electron excitation comes from LibreTexts. "What Causes Molecules to Absorb UV and Visible Light" contains clear diagrams showing the electron energy-level changes with light absorption and relates the changes to chromophores. (<https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Spectroscopy/Electronic_Spectroscopy/Electronic_Spectroscopy_Basics/What_Causes_Molecules_to_Absorb_UV_and_Visible_Light>)

**Conjugated bond systems**

A simple review of the chemistry of double covalent-bond formation is found at <https://www.chemguide.co.uk/atoms/bonding/doublebonds.html>.

Chromophores use alternating double and single bonds in a conjugated system, and this video, "Conjugated Pi Bonds" (13:53), explains and illustrates conjugated systems. (<https://www.youtube.com/watch?v=QJ_Z91bqfk0>)

**Aniline**

Aniline was the reactant von Baeyer used to synthesize indigo. Additional information on the synthesis, uses, derivatives, history, and toxicology of aniline is located at <http://www.toxipedia.org/display/toxipedia/Aniline>.

*Scientific American* published an excerpt from the book *Toms River: A Story of Science and Salvation* that tells the history of how William Henry Perkin revolutionized the dye industry using aniline. Aniline was a precursor in synthesizing numerous dyes in the latter 1800s, and Toms River, NJ, became an EPA Superfund site in 1983 due to vat dye manufacturing wastes. (<https://www.scientificamerican.com/article/toms-river-excerpt-on-aniline-dye/>)

**Naphthalene**

A fact sheet from the U.S. Environmental Protection Agency provides information about the hazards, uses, sources, and health effects of naphthalene. (<https://www.epa.gov/sites/production/files/2016-09/documents/naphthalene.pdf>)

A more reader-friendly article from the National Pesticide Information Center shares a general fact sheet containing an explanation of naphthalene, products that use it, how it works, symptoms of exposure, effects in the environment, and more. (<http://npic.orst.edu/factsheets/naphgen.html>)

# 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.

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Terri Taylor, *ChemMatters* Teacher’s Guide interim editor, coordinated production and prepared the Microsoft Word and PDF versions of the Teacher’s Guide.

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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*.

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