



**April/May 2019**

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**Teacher’s Guide**



**Teacher's Guide for**

# “Celebrating Paper!”

**April/May 2019**

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### Tools and Resources

### Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Hydrogen bonds** | This article provides multiple examples where hydrogen bonds are important in both the formation and the properties of paper products. |
| **Covalent bonds** | As described in the article, paper towels use a polymeric cross-linker to form covalent bonds between cellulose fibers giving them greater strength when wet. |
| **Hydrophilic / Hydrophobic** | The cellulose used in paper is hydrophilic but can be treated with a sizing agent to make it more hydrophobic for special uses. |
| **Polymers** | The article explains that cellulose is a long-chain polymer of glucose units and provides an example of a natural polymer, cellulose. |
| **Amorphous** | Hemicelluloses and lignin are described in the article as being amorphous and contribute to paper’s flexibility. |
| **Crystalline** | Microfibrils in paper form hydrogen bonds to each other which results in rigid crystalline regions contributing to paper’s strength. |
| **Saccharides / Polysaccharides** | A sidebar in the article explains what sugars are, and gives an explanation of sugars, table sugar, and the polysaccharide, cellulose. |

### Possible Student Misconceptions

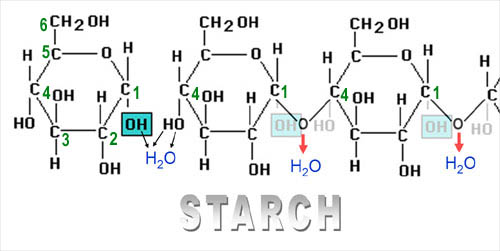
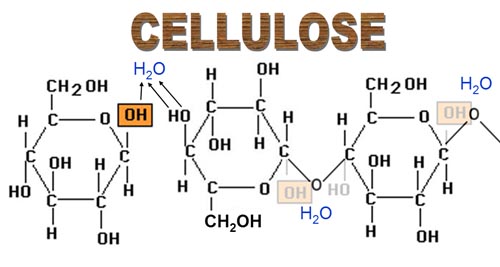
1. **“United States paper money is made of paper.”** U.S. “paper” money is not really made of paper! It is made of 75% cotton and 25% linen with a few colored silk fibers running through it. Paper, cotton, and linen all are primarily composed of cellulose fibers, but the fibers in cotton and linen are stronger than the cellulose fibers in paper. The cotton and linen used in U.S. money give the currency its unique look and feel, make the bills more durable and waterproof (if you forget and wash them in your pocket), and make the money harder to counterfeit.
2. **“Using paper products destroys trees and forests.”** Trees are the most popular source of cellulose fibers for paper products and, certainly, trees are killed when they are cut down for use. However, most trees used in paper production come from managed forests—places where trees that are cut down for use are replaced with seedlings that are either planted or grow naturally in their place. In the past 100 years, the forested land of the U.S. has remained constant at about 750 million acres. It is beneficial for the paper companies to manage the forests well to ensure that they have an adequate supply of raw materials for the future. The paper industry estimates that about 40% of all trees harvested in the U.S. are used for paper, with the remainder going for lumber and construction. The old practice of clear-cutting large swaths of land is not commonly used today in the paper industry.
3. **“Because paper can be easily recycled, there is no need to cut down new trees.”** It is true that paper can be recycled; however, the fibers in paper products cannot be recycled infinitely. Most paper fibers can only be used and recycled about 4–6 times before they become so short or damaged that they are no longer useful (think of washing a shirt until it falls apart). Paper manufacturers must use some new fibers in their products; the percent of new fibers required is dependent upon the specific paper product. Certainly, by recycling most of the paper used, the number of new fibers from trees is greatly reduced, but there will always be a need for new, replacement fibers even if demand for paper products remains at a constant level.
4. **“Printing is dead; electronic documents will soon replace all paper ones.”** Even in the “digital age”, there is a need for printed documents, and there will be for the foreseeable future. Electronic documents are certainly handy for many tasks, like for e-books, bills, bank statements, correspondence, email, and advertising. But many people prefer printed documents over electronic because they find it easier to read and comprehend printed material rather than electronic documents. Also, people who use electronic documents frequently print them for ease of reading and use or for long-term storage. Electronic documents have a useful place in the world, but printing is not dead, and paper documents have a useful place in most people’s lives, too.
5. **“All types of paper can, and should be, recycled.”** While it may be possible that all types of paper *can* be recycled, the better thought might be, “*Should* all types of paper be recycled?” The answer to that last question is, probably not. Most types of common paper can be, and are, recycled, such as newspapers, corrugated boxes, chipboard (cereal boxes), office (printer) paper, and junk mail. In 2015, paper products were the largest component (by weight) of US municipal solid waste, at 25.9%. Each person generates an average of 4.48 pounds of paper waste daily (<https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials>). Paper products had the highest recycling rate and accounted for about 67% (by weight) of all recycled materials in 2015. There are some types of paper that may be too expensive to successfully recycle, such as specialty papers with wax, foil, or plastic coatings; papers printed with oil-based inks; soiled papers (used pizza boxes, dirty napkins and paper towels); or even shredded papers, due to the shorter length and, thus, weakening of the paper fibers. Other types of paper that would be undesirable to recycle include toilet paper and disposable diapers. While people can always improve their recycling habits, U.S. citizens are doing a good job of recycling the appropriate types of paper.
6. **“It is better for the environment to recycle rather than to burn paper.”** The initial response from most people would be, yes, which is why paper recycling has a high participation rate in the U.S. Like many environmental issues, the accuracy of the answer is very complicated. Recycling paper certainly reduces the need to cut down new trees, energy used to produce virgin paper, the release of possible toxins (dioxin and metals used in inks) into the air, and the production of greenhouses gases from burning the paper. However, recycling paper is not as green as many people believe. Paper is dense and requires a lot of fuel to collect and haul it to recycling centers. The deinking process produces a toxic mess, and the amount of water used is greater than that used in producing virgin paper. Part of the energy used to produce virgin paper comes from burning the waste products (bark, etc.) from the trees. Much of the energy used to recycle paper comes from electricity, which may be generated from mining and burning coal. Either recycling or burning paper is preferable to throwing it away.

### Anticipating Student Questions

1. **“If paper is made of cellulose, and cellulose is made of the common sugar glucose, why can’t people digest paper?”** Cellulose and starch are similar polymers, both made of the repeating glucose monomer. The short answer why people can’t digest paper as they can starch is that humans don’t have the appropriate enzyme to break down the cellulose molecule. The primary difference between starch and cellulose is that the bonds between glucose monomers are not the same. The bonds between glucose molecules in starch are called alpha (α) linkages, and the bonds between glucose molecules in cellulose are called beta (β) (linkages. (See the diagrams below.)

In the diagram of a starch molecule below, the glucose monomers all have the same orientation and the α linkages are all below the plane of the glucose monomers, while in the diagram of the cellulose molecule, successive glucose monomers are flipped 180o, producing β linkages as the bonds that link successive monomers alternately form above and below the plane of the monomers.

This simple, but significant, difference in the structures requires different enzymes to break the alpha and beta linkages in these molecules. No vertebrate animal has the necessary enzyme to digest cellulose directly, but some animals (horses, cattle, sheep, and goats) have symbiotic bacteria in their guts that allow them to break down the cellulose (found in plants and grasses), benefitting both the bacteria and the animal. Even termites, known for destroying wood (made of cellulose), cannot digest cellulose without symbiotic bacteria.

*(*[*http://www.chemistryland.com/CHM107Lab/Exp03\_DetectOzone/OzoneLab/GlucoseMakesStarch.jpg*](http://www.chemistryland.com/CHM107Lab/Exp03_DetectOzone/OzoneLab/GlucoseMakesStarch.jpg)*)*

([*https://mybiochem.wordpress.com/tag/cellulose/*](https://mybiochem.wordpress.com/tag/cellulose/)*)*

1. **“When was paper invented?”** It is believed that the Chinese made the first true paper (thin sheets of macerated plant fibers) around 100 CE, and its manufacture spread to the Islamic world through the Silk Road during the 6th to 8th centuries. Papyrus and parchment were used in the Mediterranean and other areas of the world before then, but the pulping of the plant fibers and production of sheets (true paper) originated with the Chinese. The Chinese used the paper for writing and for religious art using woodblock printing.
2. **“How many different kinds of paper are there?”** The Web site <https://rbms.info/vocabularies/paper/th343.htm> lists over 80 types of paper, and many of them could have multiple subdivisions. Paper types can be organized by fiber patterns, method of manufacture, use (or not) of sizing, or by end use. Paper has myriad uses, from the more common ones such as writing, wrapping, boxes, facial tissues, and printed media, to less common uses that include magician’s flash paper, underwater paper, and thermochromic paper (changes color with heat). Some people believe that if the mind can dream it, there’s a paper that might achieve it!
3. **“Why does some paper tear better in one direction than another (e.g., newspaper)?”** As the wood fibers are deposited on a moving belt to form the paper, the long pulp fibers tend to line up in the direction of the belt’s travel. With the fibers mostly aligned in one direction, it gives the completed paper a grain, or direction of orientation. If the paper is torn with the alignment of the pulp fibers, then the paper tears more smoothly and evenly. However, trying to tear the paper perpendicular to that grain will result in a ragged pattern, as the tear goes against the direction of the fibers. Creasing the paper sharply will help the paper tear more evenly because it breaks the pulp fibers. Sometimes lightly dampening the paper crease with water will improve the tearing action because the water interferes with the hydrogen bonding between the fibers.
4. **“Why does paper wrinkle when it gets wet?”** Paper is composed of compressed cellulose fibers held together primarily by hydrogen bonds between the fibers. Water causes the compressed cellulose fibers to expand and breaks the hydrogen bonds between the compressed fibers, allowing them to separate. When the paper is wet, the expansion of the wet fibers shifts their location and places them in a different, wrinkled, arrangement. Also, as the water evaporates and hydrogen bonds reform between the fibers, the wrinkling sets up because the cellulose fibers are no longer compressed. Entropy also plays a role in this behavior, because the wrinkled paper has a lower energy state than a smooth, flat piece of paper.
5. **“Is it true that paper bags are more environmentally friendly than plastic bags?”** This is an excellent, but complex, question. Some localities are considering action regarding single-use plastic (polyethylene) shopping bags. Before the 1970s, most shopping bags were brown paper bags, but concern over cutting forests, plus other environmental factors, led to the development of the plastic bags used today. To fully answer the question requires analysis of multiple factors. Paper bags are a renewable resource and can be recycled like other paper products. Plastic bags are produced from petroleum, a non-renewable resource, but they can also be recycled. Paper bags are strong when manufactured from high virgin fiber content (from new trees), but much weaker when using recycled fibers. Plastic bags are typically produced from ethane, a by-product of natural gas extraction. The manufacture of paper bags requires four times the water and two to four times the energy that is required to produce plastic bags. In a complete life cycle analysis (LCA), most studies agree that plastic bags are more environmentally friendly. An important point lies in reusing either type of bag as many times as possible and then recycling it. Paper bags have a higher recycling rate than plastic bags, which may be why there are so many plastic bags in the environment. Also, the paper bags will break down more readily in the environment when wet and can decompose faster than the plastic bags that can litter the land. Good stewardship of either resource, reduction of littering, conscious reuse, and purposeful recycling efforts can allow either type of bag to fill needs in society. So, which is better? It depends on how the bags are used, reused, recycled, and their method of disposal. Perhaps the ultimate solution might be for consumers to use their own cloth or durable plastic bags for shopping, as many are starting to do. But those bring their own problems, such as bacterial contamination in the bags from the contents, and spills, especially from fresh meats if the bags are not cleansed properly and regularly.

### Activities

**Labs and demos**

**“Paper Making” lab:** In this lab for 9th to 12th graders, students start with used paper and process it to form new, recycled paper. It includes directions, helpful suggestions, and options for varying the paper composition. (<https://www.teachervision.com/print-making/paper-making>)

**“Biofuels: Cellulose Lab”:** This two-day lab uses paper pulp (shredded newspapers) as the starting material for the enzymatic conversion of cellulose into sugar for use as a biofuel. Materials provided include the student lab sheet, teacher guide, and additional teacher resources. (<https://eli.lehigh.edu/energy/instructional-sequence/day-21>)

**Simulations**

“**Hydrogen Bonds: A Special Type of Attraction”:** In this activity students manipulate temperatures while viewing the formation of hydrogen bonds among water molecules. Students can show the hydrogen bonds with dotted lines, show partial charges on the atoms, and use slow-motion animation. (<https://learn.concord.org/resources/769/hydrogen-bonds-a-special-type-of-attraction>)

**“Molecule Polarity”:** This PhET simulation allows students to investigate polarity, electronegativity, bonds, partial charges, and dipoles, which may assist them with comprehending the structure of cellulose and its interactions with water. (<https://phet.colorado.edu/en/simulation/molecule-polarity>)

**Media**

**“Chasing Paper” video (45:10):** This video from National Geographic examines the past, present, and future of paper in our lives. The video includes segments on modern paper manufacturing and toilet paper. (<https://www.youtube.com/watch?v=4K85aiiD_6I>)

**“Intermolecular Forces” video (8:35):** The segment of this Khan Academy video from   
2:54–5:47 explains hydrogen bonding, using the water molecule as an example. (<https://www.khanacademy.org/science/biology/chemistry--of-life/chemical-bonds-and-reactions/v/intermolecular-forces-and-molecular-bonds>)

**Lessons and lesson plans**

**“The Science of Papermaking and Paper Recycling: A Research Experience for Teachers” lessons:** This site, while described as “for teachers”, provides three lab activities: Bleaching of Recycled Pulp, Flotation Deinking of Copy Paper, and Screening Experiment to Determine Yield of a Recycling Process, all with directions, extensions, and questions that may be adapted for classroom use in studying paper and its recycling. (<http://www.shodor.org/ssep/lessons/paperscience/index.html>)

**“Paper Recycling Experiments and Studies” lesson plans:** This Web site provides lesson plans, plus K–12 labs, activities, suggestions for science fair projects, and background information for making paper and recycling paper. (<https://www.juliantrubin.com/encyclopedia/environment/paperrecycling.html>)

**Projects and extension activities**

**“Measuring Paper Strength” activity:** This lab, which could be conducted at home using common items, or done at school, allows students to measure the strength of different papers. The lab also includes suggestions for extension experiments. (<https://cnr.ncsu.edu/fb/wp-content/uploads/sites/2/2014/04/testingpaper.pdf>)

**“Hand Papermaking” project:** Conventional methods of making paper actually recycle old paper, but this Web site provides numerous free articles with helpful advice for hand-making paper from plants. Readers will find the process challenging and will need to read carefully because the articles provide only general information with few details; however, sufficient information is included to inspire adventurous readers to tackle making raw paper. (<https://handpapermaking.org/?page_id=30>)

### References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles and Teacher’s Guides published from the first issue in October 1983 through April 2013.**

**The DVD is available from the ACS for $42 ($135 for a site/ school license) here:** [***http://www.acs.org/chemmatters***](http://www.acs.org/chemmatters)***.***



“Old News, New Paper” provides information on the processes of recycling newspaper, including de-inking, bleaching, and forming the paper. (Borchardt, J. Old News, New Paper. *ChemMatters*. 1993, *11* (2), pp 12–14)

“Sizing Up Paper” explains: controlling how different papers absorb moisture by using sizing, preserving papers, and the historical spread of paper across the world, as well as providing chemical structures for compounds discussed. (Ruth, C. Sizing Up Paper. *ChemMatters*. 1998, *16* (2), pp 10–12)

“The Money Makers” describes how paper currency is made, including the special paper, inks, printing, security measures, and counterfeiting. (Venere, E. The Money Makers. *ChemMatters*. 2003, *21* (1), pp 14–16)

This article includes an activity for using paper chromatography to separate water-based markers into their components. (Brownlee, C. Forensic Chemists: Solving Mysteries with Fascinating Science. *ChemMatters*. 2010, *28* (3), pp 17–19)

This “Open for Discussion” article examines whether paper or plastic bags are better for the environment. (Sitzman, B.; Goode, R. The Big Bag Battle. *ChemMatters*. 2014, *32* (1), p 5)

“It’s Not Easy Being Green—Or Is It?” explains a life cycle analysis (LCA) and explores the life cycles of disposable paper cups, shopping bags, and plastic water bottles. (Tinnesand, M. It’s Not Easy Being Green—Or Is It? *ChemMatters*. 2014, *32* (1), pp 12–13)

“Cellulosic Ethanol: A Fuel of the Future?” looks at the process of producing cellulosic ethanol from corn and other bio-sources. (Sherwood, J. Cellulosic Ethanol: A Fuel of the Future? *ChemMatters*. 2016, *34* (2), pp 16–18)

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“New Paper from Newspaper”, a *J. Chem. Educ.* Classroom Activity, provides a two-part student activity to a) make paper from old newsprint and answer questions about that paper, then b) use the finished paper in an art project. (Gettys, N.; Jacobsen, E First initial. New Paper from Newspaper. *J. Chem. Educ.*, 2001, *78* (11), p 1512A–1512B; <https://pubs.acs.org/doi/pdf/10.1021/ed078p1512A>. Note that this link takes you to a brief abstract only; the full article is available only to American Chemical Society members or subscribers to the journal.)

### Web Resources for More Information

**Paper manufacturing**

“Overview of Pulp and Papermaking Processes” provides an in-depth explanation of paper manufacturing.

(<http://kchbi.chtf.stuba.sk/upload_new/file/Miro/Proc%20problemy%20odovzdane%20zadania/Moln%C3%A1r/10_1002@9780470649657_ch2.pdf>)

This link is a shorter and less technical description of how paper is manufactured.

(<http://www.madehow.com/Volume-2/Paper.html>)

**The history of paper**

Follow this link for excellent information on the origin of, history of, and interesting facts about paper.

(<http://users.stlcc.edu/nfuller/paper/>)

**Products made from paper**

This site provides a list of products made from paper, organized by categories like office and school, household, medicine and technology, and more.

(<https://www.paperonweb.com/A1096.htm>)

This article, “10 Most Bizarre Uses of Paper in History”, might be a slight exaggeration, but the uses *are* unusual.

(<https://www.huffingtonpost.com/nicholas-a-basbanes/post_5940_b_4136654.html>)

**Paper recycling**

“Life-Cycle Assessment for Paper Products” is a report from a 1997 symposium examining the entire process for recycling certain paper products and the environmental impacts of paper use and recycling.

(<https://www.nap.edu/read/5734/chapter/9>)

Read this article for a concise, colorful, and informative overview of recycling paper products and an extensive list of reference links.

(<https://greentumble.com/how-is-paper-recycled-step-by-step/>)

**Types of paper**

This site lists different types of paper with a brief description of their composition, uses, or characteristics.

(<http://www.csun.edu/~pjd77408/DrD/resources/Printing/images03/20024.pdf>)

**Paper versus plastic bags**

The environmental impact of both paper and plastic bags is outlined in this article.

(<https://science.howstuffworks.com/environmental/green-science/paper-plastic1.htm>)

This site provides another discussion of the controversy of whether consumers should use paper or plastic bags in shopping.

(<http://www.yalescientific.org/2015/05/paper-vs-plastic-the-science-behind-the-national-shopping-controversy/>)

**Papermaking**

This web site is a compendium of many aspects of papermaking, but readers will find the categories and multiple links within “Fun and Art”, “Mini-encyclopedia”, and “Links: Paper Chemistry Sites” of particular interest.

(<https://projects.ncsu.edu/project/hubbepaperchem/>)

**Cellulose**

Cellulose was the ACS Molecule of the Week on January 19, 2009, and this link provides both structural and ball-and-stick formulas and a brief description of the compound.

(<https://www.acs.org/content/acs/en/molecule-of-the-week/archive/c/cellulose.html>)

This infographic shows the cellulose in cotton fibers, with their hydrogen bonds, and how water can disrupt the hydrogen bonds between cellulose molecules.

(<https://www.compoundchem.com/wp-content/uploads/2017/03/The-Chemistry-of-Ironing.png>)

**Hydrogen bonding**

Students may refresh their knowledge of hydrogen bonding by reading this article, which includes charts and illustrations.

(<https://www.chemguide.co.uk/atoms/bonding/hbond.html>)

**Hydrophilic and hydrophobic**

This Web site explains the concepts of hydrophilic and hydrophobic compounds with useful pictures.

(<http://news.mit.edu/2013/hydrophobic-and-hydrophilic-explained-0716>)

**Polysaccharides**

This link explains various types of saccharides, including polysaccharides, plus a description of cellulose (with structural formula) and why it is different from amylose, a starch.

(<http://www.edinformatics.com/math_science/what_are_polysaccharides.htm>)

**House made of paper**

A curiosity, this house has typical wood framing, floors, and roof, but the walls and much of the furnishings are made of paper.

(<https://www.paperhouserockport.com/index.html>)

### Reading Supports

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 designed to help students prepare to read the article and then locate and analyze information from the article.

* **Anticipation Guide (p. 15):** 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.

**Or** consider the following ideas to engage your students in reading:

**Celebrating Paper!**

* Before reading, ask students what kinds of paper they can think of, and why we need so many kinds of paper. Ask students to think about how different kinds of paper are different chemically. As they read the article, students should record information they find interesting and the differences in types of paper.
* **Graphic Organizer (p. 16):** 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. 17-18):** 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 Resources for More Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

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

### Anticipation Guide

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. The composition of most paper comes from tree fibers. |
|  |  | 1. Cellulose is the most abundant natural polymer. |
|  |  | 1. Both the length and width of wood fibers depends on the type of tree it comes from. |
|  |  | 1. Cellulose is hydrophilic (“water-loving”). |
|  |  | 1. Hydrogen bonding holds toilet paper together. |
|  |  | 1. Cellulose, sugars, and starches are carbohydrates. |
|  |  | 1. Sturdy paper such as mail envelopes have hydrophilic compounds added to them. |
|  |  | 1. Recycling facilities must separate the different types of paper prior to recycling. |
|  |  | 1. Paper towels have fewer covalent bonds than toilet paper. |
|  |  | 1. Natural paper is bright white. |

### Graphic Organizer

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

**Directions**: As you read, complete the graphic organizer below to compare different ingredients in paper. The last row refers to a hydrapulper, which is explained in the article.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **What is it?** | **Structure** | **Properties** | **Interesting fact** |
| **Cellulose** |  |  |  |  |
| **Wood fibers** |  |  |  |  |
| **Microfibrils** |  |  |  |  |
| **Sizing agents** |  |  |  |  |
| **Hydrapulper** |  | *How does it work?* | |  |

**Summary:** In the space below, or on the back of this paper, write a short sentence (20 words or less) summarizing the article.

### Student Reading Comprehension Questions

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

Name

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

* 1. In the table below, list three properties and a use for each that make paper useful for humans.

|  |  |
| --- | --- |
| **Property** | **Use** |
|  |  |
|  |  |
|  |  |

* 1. What are three characteristics of tree fibers that provide paper’s versatility?
  2. Complete the table below regarding types of wood fibers.

|  |  |  |  |
| --- | --- | --- | --- |
| **Type of  wood fiber** | **Source** | **Length  of fiber** | **Use** |
|  |  |  |  |
|  |  |  |  |

* 1. What force binds the long polymeric chains of cellulose to each other, forming rigid crystalline regions?
  2. What is the composition of tree cell walls?
  3. (a) Define hydrophilic, and (b) explain what effect this property has on cellulose.

**Student Reading Comprehension Questions, cont.**

* 1. Why do some paper products, like toilet paper, come apart easily in water?
  2. How does a hydrapulper work to help recycle paperboard products?
  3. (a) What are sizing agents used on paper, and (b) how do they work?
  4. What is done to paper towels to make them (a) strong, and (b) absorbent?
  5. What substance is added to printer paper to make it appear brighter or whiter?

**Critical-Thinking Questions**

***Write your answers on another piece of paper if needed.***

* 1. Cellulose is a polysaccharide found in plants, while glycogen is a polysaccharide found primarily in animals. Research and then prepare a table comparing the composition and structure of cellulose and glycogen, including their monomers, bonding links, strengths, solubilities, sources, and uses.

1. The article mentions, but it does not completely describe, holocellulose, cellulose, and hemicellulose. Research and explain the composition and relationships among these three components.

### Answers to Reading Comprehension Questions

1. **In the table below, list three properties and a use for each that make paper useful for humans.**

|  |  |
| --- | --- |
| **Property** | **Use** |
| Can be clean and bright | For writing notes |
| Can be tough | To form shipping boxes |
| Can be soft and absorbent | To wipe noses |

1. **What are three characteristics of tree fibers that provide paper’s versatility?**

Three characteristics of tree fibers that provide paper’s versatility are

1. strength,
2. flexibility, and
3. the ability to bond to each other.
4. **Complete the table below regarding types of wood fibers.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Type of  wood fiber** | **Source** | **Length  of fiber** | **Use** |
| Longer | Evergreen trees | 3–5 mm | Reinforce paper |
| Shorter | Deciduous trees | 1.2 mm | Make paper smooth |

1. **What force binds the long polymeric chains of cellulose to each other, forming rigid crystalline regions?**

Hydrogen bonds are the forces binding the cellulose chains to each other and forming rigid crystalline regions.

1. **What is the composition of tree cell walls?**

Tree cell walls are composed of multiple layers of microfibrils, which are composed of cellulose

1. **(a) Define hydrophilic, and (b) explain what effect this property has on cellulose.**
2. The term hydrophilic means “water-loving”.
3. The effect of cellulose absorbing water is that it softens the fiber wall, and the wall becomes more flexible.
4. **Why do some paper products, like toilet paper, come apart easily in water?**

Some paper products, like toilet paper, have only hydrogen bonds acting between the cellulose chains. So, water can get between the hydrophilic cellulose chains and break the hydrogen bonds, allowing the fibers to disperse.

1. **How does a hydrapulper work to help recycle paperboard products?**

A hydrapulper helps to recycle paperboard products by vigorously mixing the paperboard with water—like a big blender—which allows the fibers to easily separate from each other for cleaning and re-use.

1. **(a) What are sizing agents used on paper, and (b) how do they work?**
2. Sizing agents used in paper are organic molecules that are hydrophilic on one end and hydrophobic on the other.
3. The hydrophilic end of the sizing agent covalently binds with cellulose during the drying process, with the hydrophobic end facing out toward the surface of the paper—which helps to slow down the absorption of water by the paper.
4. **What makes paper towels (a) strong, and (b) absorbent?**
5. Paper towels have polymeric cross-linkers added to form covalent bonds between the cellulosic fibers, so that water can enter the structure without the fibers separating from each other, making them strong.
6. At the same time, the amount of bonding in paper towels is limited. This keeps the density low, so lots of internal spaces are available for liquids to flow into, making them absorbent.
7. **What substance is added to printer paper to make it appear brighter or whiter?**

Calcium carbonate (CaCO3), mined as marble or chalk or prepared synthetically, can be added to paper to make it appear brighter or whiter.

**Critical-Thinking Questions**

1. **Cellulose is a polysaccharide found in plants, while glycogen is a polysaccharide found primarily in animals.** Research and then prepare a table comparing the composition and structure of cellulose to glycogen, including their monomers, bonding links, strengths, solubilities, sources, and uses.

|  |  |  |
| --- | --- | --- |
|  | **Cellulose** | **Glycogen** |
| **Monomer** | Glucose | Glucose |
| **Bonding link** | Beta linkage (β(1-4) glycosidic bonds) | Alpha linkage (α(1-4) glycosidic bonds) |
| **Strength** | Stronger than glycogen | Much weaker than cellulose |
| **Solubility** | Insoluble in water | Soluble in water |
| **Source** | Plant cell walls | Animal and fungi |
| **Use** | Structural strength | Energy storage |

1. **The article mentions, but it does not completely describe, holocellulose, cellulose, and hemicellulose. Research and explain the composition and relationships among these three components.**

Holocellulose is the total polysaccharide component of wood and other woody materials. It is composed of the cellulose plus the hemicellulose in a plant. Cellulose is an unbranched polysaccharide composed of only glucose monomers with beta-linkages. Hemicellulose is a much shorter, branched polysaccharide that is composed of many different sugar monomers including glucose, xylose, mannose, and galactose. Hemicellulose serves to connect microfibrils together. So, cellulose and hemicellulose are two different polysaccharides that, together, comprise holocellulose (from Greek *holos* “whole” or “total” + cellulose).



**Teacher's Guide for**

### “Fighting Frizz: How Chemistry Solved a Bad Hair Day”

**April/May 2019**

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## Tools and Resources

### Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Intermolecular forces** | The discussion of sodium lauryl sulfate’s action in water supports lessons about hydrogen bonds and polar and nonpolar attractive forces between molecules. |
| **Acids and bases** | The structural formula of glycolic acid, the principal ingredient in the Lubricity shampoo, can be used when talking about organic acids. The effect of the acid on hair provides a practical application of acids in commercial products. |
| **Oxidation and reduction** | The formaldehyde used in keratin treatments can be used as an example of a reducing agent. The definition of reducing agent in the article supports lessons on oxidation and reduction, as does the reaction of breaking and re-forming disulfide bonds in hair, illustrated in Figure 1. |
| **Organic chemistry** | During a unit on organic chemistry, the molecules discussed in the article provide examples of an aldehyde, an organic acid, and long-carbon-chain alkyl groups (found in surfactants). |
| **Green chemistry** | To emphasize green chemistry principles throughout the school year, you can point out to students that Clark was concerned that his product should be safe and contain safe ingredients. |
| **Biochemistry** | The discussion of disulfide bonds in hair keratin can be used while teaching about these bonds in proteins. Also, the explanation of quinoa protein being spliced into segments of hair provides an example of engineered protein repair. |
| **Engineering & problem-solving** | Clark’s trial and error process, employed while developing the anti-frizz shampoo, provides an example of product engineering and problem-solving while teaching about those components of scientific discovery. |

### Possible Student Misconceptions

1. **“Hydrogen bonding occurs when hydrogen is bonded to another atom on the same molecule. Like the hydrogen atoms bonded to oxygen in a water molecule.”** Students often develop a misunderstanding about hydrogen bonds. Some will label the bond between hydrogen and oxygen in a water molecule as a hydrogen bond. Literally, it *is* a hydrogen bond, just not the one chemists are referring to when they talk about *hydrogen bonding*. It is important to emphasize that a “hydrogen bond” is an electrostatic attraction between neighboring molecules. When hydrogen is covalently bonded to a highly electronegative element, the hydrogen electron is attracted to the more electronegative element, exposing the positive charge of the hydrogen nucleus. The exposed hydrogen nucleus is attracted to the negatively charged electrons of an oxygen, nitrogen, or fluorine atom in neighboring molecules, causing an attraction between and an alignment of the two molecules. This type of bonding is illustrated with dashes between the hydrogen atoms of a water molecule and an oxygen atom in a sulfate group of sodium lauryl sulfate in the article insert, “How Shampoo Cleans Your Hair”.
2. **“Intermolecular forces are the forces within a molecule.”** Sometimes students may interpret intermolecular forces as the forces that hold an individual molecule together. Perhaps “inter” is being heard as “inner”. You may be able to help students with this by using the example of the “***inter*state highways**” that connect one state to neighboring states, emphasizing the prefix *inter*-. “Intermolecular forces” then, are the attractions that connect one molecule to neighboring molecules. Attractions between the atoms *in* the molecule are the *intra*molecular forces and are stronger than forces between molecules.
3. **“Keratin treatments contain formaldehyde.”** Technically, keratin treatments do not contain formaldehyde, as formaldehyde is a gas. However, they may contain compounds that, when exposed to water, react to release formaldehyde. The formaldehyde-producing compounds often found in keratin treatments are methylene glycol, formalin, methanol, and methanediol. Products that contain some of these compounds could accurately advertise themselves as formaldehyde free. Formalin is formaldehyde dissolved in water, with methanol added to prevent polymerization. Glyoxylic acid can be used to replace formalin (see #4 below), though treatments that use glyoxylic acid last for only two to three months, while the treatments that use the more toxic ingredients last four to six months.
4. **“Keratin treatments are hair-straightening treatments.”** Keratin treatments and hair-straightening treatments are two different processes.

Hair-straightening treatments are similar to permanents. In this type of treatment, the hair is soaked with ammonium thioglycolate, which breaks the disulfide bonds in the hair. With the hair relaxed, it is then straightened with a flatiron and a solution of hydrogen peroxide is added that encourages the disulfide bonds in the hair to reform while the hair is straight. A hair-straightening treatment is permanent for the hair that is treated. As the hair continues to grow outward from the follicle, however, it will “grow in” with its original curliness, creating an awkward line between the curly hair and the straight hair.

In keratin treatments, a serum containing keratin is applied to the hair after the disulfide bonds have been relaxed with a solution containing formalin or a similar reducing agent. Many solutions used for the relaxing step contain compounds that give off the gas formaldehyde as the hair dries. Formaldehyde is a suspected carcinogen, so some treatments use glyoxylic acid to relax the hair. But, as mentioned in question #3 above, these treatments don’t provide as long-lasting results as the treatments that use the formaldehyde-forming compounds. After the hair has been coated with keratin serum, it is treated with a flat iron that activates the keratin, laminating it to the strands of hair. The keratin wears off with time, so the hair slowly resumes its original curliness. With keratin treatments, the hair maintains more of its original shape; it is just more manageable and holds a straighter style between washes.

1. **“Hair is composed of living cells that can repair themselves with the use of the right product.”** Reading the claims of many of the hair products on the market may give consumers the impression that hair is a living organism. Several ingredients in shampoos are listed as nutrients and, indeed, include some vitamins and minerals. However, hair is nonliving material just like fingernails. The only living portion of hair is the follicle in the scalp. Hair has no biochemical activity and hence is considered dead. To grow healthy hair requires *consuming* a diet with adequate protein, vitamins, and minerals—not just layering them on the hair surface.
2. **“Air drying is healthier for hair than blow drying.”** While blow drying causes more damage to hair’s surface, air drying can create damage deeper within the strands. The strands of hair swell when they get wet. When they remain swollen for the two hours it typically takes hair to air-dry, the pressure put on the delicate proteins that hold the hair intact can damage the strand’s internal structures. The best way to dry your hair is to blot it with a towel and let it partially air dry before using a hair dryer, set on a low-temperature setting, to finish drying your hair. (<https://www.prevention.com/beauty/hair/a20442345/the-healthiest-way-to-dry-your-hair/>)
3. **“You should brush your hair 100 strokes per day.”** Brushing benefits your hair by distributing the oils, located near the hair follicles, throughout the hair. But you do not need to brush your hair 100 strokes every day to maintain healthy hair. Too much brushing is actually bad for your hair. Brushing can create friction on hair leading to cuticle damage, breakage, and frizz. You should only brush your hair enough to get the tangles out and smooth it out when needed. A wide-tooth comb or a brush with soft bristles is the best tool to use for hair maintenance.

### Anticipating Student Questions

1. **“How do permanents for curling your hair differ from hair-straightening treatments and keratin treatments?”** Permanents for curling hair involve the same chemicals as those used in straightening hair. The difference between the two treatments lies in how the hair is shaped when the ammonium thioglycolate, a reducing agent, is applied to the hair. The ammonium thioglycolate relaxes the hair by breaking the disulfide bonds between the hair’s keratin molecules. In a perm (or “permanent wave”), the hair is wrapped on curlers when the ammonium thioglycolate is applied, while with hair straightening, the hair is pressed between the plates of a heated flat iron to restructure the hair into a straighter shape. The next step in both processes is the application of an oxidizing agent such as hydrogen peroxide to the hair, to reconstitute the disulfide bonds so that the hair will maintain the desired shape. Keratin treatments use a compound to relax the disulfide bonds in the keratin in order to allow more keratin to be added to the hair. A hot flat iron is then used to laminate this keratin into the hair strands. Keratin treatments are believed to be safer for the hair, since the natural structure of the hair is not being altered as drastically and more protein is being added to the hair.
2. **“In the hair-straightening treatments, why does the hair bond in a straightened shape?”** In hair-straightening treatments, the hair bonds in a straightened shape, because it is physically pulled and arranged into that shape while the disulfide bonds in the strands of hair are broken as hydrogen ions are added across the broken bond. This is referred to as relaxing the hair. Once the hair is in the desired straightened shape, hydrogen peroxide is placed on the hair. This causes the hydrogen to be removed from the sulfur in the cysteine molecules of the keratin, so that the disulfide bonds within the hair can reform, keeping hair straightened.

**Hair Relaxing Step**

Keratin-S--S-keratin + 2 HS-CH2CO2NH4 --> –HO2CH2CS-SCH2CO2H

curly hair ammonium thioglycolate + 2 NH3 + 2 HS-keratin

relaxed hair

**Hair Rebonding Step**

2 Keratin-SH + H2O2 --> Keratin-S--S-keratin + 2 H2O

relaxed hair straightened hair

(<https://is.muni.cz/el/1431/podzim2013/C3804/The_chemistry_of_perming___rebonding.pdf>)

1. **“What is the purpose of the heat used in a keratin treatment?”** Heat is used in the keratin treatments to laminate the added keratin onto the surface of the hair, similar to how a laminating machine seals the plastic film over and around a poster or piece of paper.
2. **“What exactly is the purpose of hair conditioners? How do they work?”** Conditioners reduce the friction between hair strands, which makes brushing and combing easier, thereby avoiding additional damage to the hair. It also improves the feel, appearance, and manageability of hair. Some conditioners also contain sunscreens to protect the hair during exposure to the sun. There are a lot of electrostatic attractions involved in the chemistry of hair conditioning. The cysteine molecules that compose keratin are mildly acidic. When hair is washed, these molecules lose hydrogen atoms, become deprotonated, creating a negative charge in the cuticles. As like charges oppose each other, this makes the cuticles stand up. Conditioners are mildly acidic and contain positively charged quaternary ammonium compounds that can attach to the hair via electrostatic attractions. The negatively-charged cuticles become neutral as they bond with either the quaternium cations or the hydrogen ions from the acid in the conditioner, and they lay flat, tight against one another. The quaternium cations have a long hydrocarbon backbone that lubricates the surface of each hair and facilitates hair combing. This surface coating of cationic groups that repel each other results in hair that resists tangling. <https://en.wikipedia.org/wiki/Hair_conditioner>
3. **“Some of my friends are only using conditioner to wash their hair. It’s called   
   co-washing. What does that do for your hair?”** Co-washing is where you skip the shampoo and wash your hair with conditioner to avoid stripping the natural oils from the hair. It allows natural oils to cleanse and condition the hair and scalp, and some think this is healthier. After using only conditioner, hair is not fluffy or fly away and is easier to control. Some say their hair feels softer and silkier from using only conditioner. The “down side” is that the hair feels dull and heavy and sometimes may have a musky smell. If too much oil collects around the hair follicle, the hair will not grow as fast. This practice works best for people with thick, coarse, dry, or curly hair.
4. **“How can defects in the hair cuticle be negatively charged?”** Damaged cuticles usually have hydrogen atoms that have been knocked off of the cysteine molecules that make up hair keratin. Losing a hydrogen atom causes the molecule to become negatively charged. Cysteine molecules are mildly acidic and, when hair is washed, these groups deprotonate, leaving a negative charge.
5. **“Are shampoos and conditioners bad for the environment?”** Shampoos and conditioners have many ingredients that can prove harmful to sea life, plants, and people. Once these chemicals get into the water system and into the air we breathe, it is not long until they can be detected within wildlife and humans. Waste-water treatment plants are not equipped to remove most of these chemicals from the water, so they find their way into our drinking water. Some of the most problematic chemicals are shown in the table below.

|  |  |
| --- | --- |
| Compound | Action |
| Sodium laureth sulfate | This surfactant in shampoos is a skin irritant in humans and a mutagen in some wildlife. |
| Ammonium chloride | This is a respiratory and eye irritant. |
| Methylchloroisothiozolinone | This antibacterial, antifungal preservative is a skin irritant, an allergen, and a toxin to the immune system. |
| Parabens | These compounds have been linked to breast cancer. |
| Triclosan | This antibacterial agent is toxic to aquatic life and has been found in the bodies of fish and in human breast milk. |
| Phthalates | This family of 120 industrial chemicals interferes with hormones and is associated with reproductive problems in men and wildlife. These substances also show bioaccumulation. |

Some of the compounds in shampoos and conditioners, as well as other personal hygiene products, emit volatile organic compounds (VOC’s) when exposed to the air. These create a “personal plume” that follows a person out the door in the morning. VOCs in the presence of sunlight react with nitrogen oxides in the air to form ozone, a type of pollution regulated because of its effects on air quality and human health. Decamethylcyclopentasiloxane, or D5 siloxane for short, is one of these compounds added to products like shampoos, lotions, deodorants, and hair gels, to make them feel smooth and silky. Recently, environmental researchers from the University of Colorado found evidence of air pollution caused by these volatile organic compounds. They detected a spike of siloxane in the air during the morning rush hour. Thinking that it must be coming from automobile exhaust, the scientists conducted isolated tests on automobile exhaust but did not find siloxane present. Since the spike in siloxane occurred during the morning rush hour, a time where many people have just finished using many of their personal-care products, the scientists hypothesized that the source of the pollutants they detected was the “personal plumes’ of VOCs. Environmentally-friendly products use plant oils and natural fragrances in place of the many petroleum products currently found in the majority of personal hygiene products. (<https://www.sciencedaily.com/releases/2018/04/180430131828.htm>)

### Activities

**Labs and demos**

**“Soap vs Shampoo Surfactant Lab”:** In this engineering lab, students make their own shampoo and soap and then conduct tests for pH, viscosity, surface tension, and the ability to form suds for each product in different water environments. This activity can be simplified by having students use commercial soaps and shampoos, rather than make their own. (<https://www.teachengineering.org/activities/view/usm_surfactant_activity1>)

**“Intermolecular Forces and Physical Properties” demos:** Using alcohol, acetone, and water, the teacher discusses differences in polarity, intermolecular forces, surface tension beading, and miscibility of each liquid, while demonstrating the phenomenon. A demonstration of the polarity differences of blue food coloring and red food coloring provides a strong visual of molecular preferences based on polarity. (Access is restricted to AACT members, but the article will be available for free until June 1, 2019, at <https://teachchemistry.org/classroom-resources/intermolecular-forces-and-physical-properties>.)

**Media**

**“How Does Shampoo Work?” video (3:38):** This ACS *Reactions* video discusses the ingredients in shampoos, especially the sulfates, and describes their action in cleaning hair. (<https://www.acs.org/content/acs/en/pressroom/reactions/videos/2016/how-does-shampoo-work.html>)

A sequel to the above video, **“What Happens if You Stop Washing Your Hair?” (3:15),** gives information about the ingredients in conditioners and discusses the “no poo” craze called   
co-washing, where people skip the shampoo and just wash their hair with conditioner. (<https://www.youtube.com/watch?v=aTRZ-Up1iWA>)

**“Hair Styling Products: A Scientific Combination”, video (4:23):** A Loreal product scientist discusses the development of hair products that create different effects on the hair. The research centers on using polymers to create the company’s different products. (<https://www.youtube.com/watch?v=5WnkDK8SAI4>)

**Lessons and lesson plans**

**“Bad Hair Days? Chemistry to the Rescue”:** This site contains extensive background information for teaching a unit about proteins that uses the physical and chemical composition of hair, as well as the chemistry of perms and hair-straightening treatments, as a vehicle to deliver the lessons. The lessons include demonstrations, a mini-lab, a lab investigation using hair samples, and instructions for the students to make a foldable about hair treatments. (<https://teachers.yale.edu/curriculum/viewer/initiative_11.05.04_u>)

**“The Chemistry of Hair Care”:** The activities in this lesson are planned to help students answer the central question, “How does understanding the chemistry of hair care, including the role of pH, help in the development of better hair-care products?” In this three-part lesson, students measure the pH of different shampoos, analyze the effects of acidic and basic solutions on strands of hair, and read and answer questions about the chemistry of hair.

(<http://sciencenetlinks.com/lessons/the-chemistry-of-hair-care/>)

**Projects and extension activities**

**“Exploring Intermolecular Forces”:** This activity includes teaching notes and diagrams and could be used as an inquiry lab prior to teaching intermolecular forces. Students grade the cleaning effectiveness of substances based on the results of several analyses. (Access is restricted to AACT members, but the article will be available for free until June 1, 2019, at <https://teachchemistry.org/classroom-resources/exploring-intermolecular-forces>.)

**“Are Designer Shampoos Worth It?” project:** This site provides an idea and a structure for students to complete a longer-term experiment with hair-care products. Students recruit volunteers to use a variety of products and provide strands of hair for the student researchers to test and analyze under a microscope in order to determine the efficacy of each hair product.

(<https://www.education.com/science-fair/article/designer-shampoos/>)

### References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles and Teacher’s Guides published from the first issue in October 1983 through April 2013.**

**The DVD is available from the ACS for $42 ($135 for a site/ school license) here:** [***http://www.acs.org/chemmatters***](http://www.acs.org/chemmatters)***.***



In “pH and Hair Shampoo”, author Baxter discusses the effects of pH on the three different types of bonds—disulfide, salt bridge, and hydrogen—found in hair, and how their effects apply in the manufacture of shampoos and rinses. (Baxter, R. pH and Hair Shampoo. *ChemMatters.* 1983, *1* (2), pp 8–9)

This article provides illustrations of bonding changes that occur in hair during a perm that are useful in explaining what happens at the cellular and molecular level when various chemicals are applied to hair to relax and reshape it. (Baxter, R. Permanent Waves. *ChemMatters.* 1993, *11* (2), pp 8–11)

This article presents an overview of several hair products and how the chemicals they contain interact with hair protein to achieve the desired effect. (Fruen, L. Natural, Braided, Bleached, Colored, Straight, and Curly Hair…Thanks to Chemistry. *ChemMatters.* 2008, *26* (3), pp 15–17)

The Teacher’s Guide to the October 2008 *ChemMatters* article above contains instructions for making a hair hygrometer.

Author Bruzek writes about how surfactant molecules in shampoos clean hair, using several diagrams of the cleaning process to illustrate her work. There is a full-page graphic about sodium lauryl sulfate following the article that could be used as a poster. (Bruzek, A. Shampoo: From Lab to Shower. *ChemMatters*. 2014, *32* (3), pp 17–18)

The Teacher’s Guide to the October 2014 *ChemMatters* article above contains additional information on the function and safety of the chemicals used in shampoos and conditioners. Recipes for students to use to make their own shampoo are included, as well as links to additional recipes and instructions.

This article contains information about parabens in regards to their safe use in personal care products. (Gmurczyk, M. Parabens: A Source of Concern. *ChemMatters*. 2015, *33* (2), pp 8–9)

Triclosan, an antibacterial agent that is added to many shampoos, soaps, toothpastes, and lotions, may interfere with some hormones, as well as alter the normal bacterial flora. This article reviews some of the recent reports on this substance. (Harper, K. Bacteria Buster Triclosan Kills Bacteria but Is It Safe? *ChemMatters*. 2015, *33* (4), pp 13–15)

The Teacher’s Guide to the December 2015 *ChemMatters* article above includes extensive information and links to the various studies, both human and environmental, that have been conducted about triclosan.

### Web Resources for More Information

**Hair-care documentary**

“Horizon: Hair Care Secrets” (58:38) is a documentary about hair care, not only about the chemistry of the products used for its maintenance but also the use of hair transplants and dyes to counter the natural changes that occur in hair over time.

(<https://vimeo.com/209603274> )

**Keratin treatments**

“The Everything Guide to Keratin Treatments” describes the difference in hair-straightening techniques. The site discusses keratin treatments, where keratin is bonded to hair; chemical relaxers, which are like permanents; and Brazilian blowouts, which are temporary.

(<https://www.thecut.com/2018/05/everything-to-know-about-keratin-treatments.html>)

“8 Things to Know About Keratin Treatments” describes the chemistry of these treatments and addresses the use of compounds that produce formaldehyde when heated in—treatments that claim to be formaldehyde free. It also explains some chemistry of glyoxylic acid alternatives. (<https://www.allure.com/story/keratin-hair-smoothing-treatment-how-to>)

**Permanent hair-straightening**

This site explains the difference between hair-straightening and keratin treatments.

(<https://www.stylecraze.com/articles/hair-smoothing-vs-hair-straightening/#gref>)

In “Hair Straightener”, the author addresses the chemistry behind the Brazilian blowout, the Japanese thermal straighteners, and the alkaline-relaxer hair treatments. (<https://cen.acs.org/articles/88/i45/Hair-Straighteners.html>)

**Shampoo surfactants**

“How Shampoo Works” contains information on shampoo as well as a brief (1:10) video about busting four shampoo myths.

(<https://www.thoughtco.com/how-shampoo-works-607853>)

This entry (“Shampoo”) in *How Products are Made* goes through the steps involved in producing a shampoo. It discusses in detail the purpose of each of the ingredients used to make shampoo.

(<http://www.madehow.com/Volume-3/Shampoo.html>)

**Hair conditioners**

Besides relating the history of conditioners and how they are classified, this site contains a good list of conditioner ingredients and their function:

<https://en.wikipedia.org/wiki/Hair_conditioner>.

How does hair conditioner work? Explains the chemistry involved in hair conditioners and conditioning shampoos.

(<https://scienceline.org/2014/01/how-does-hair-conditioner-work/>)

**Recipes to make your own shampoo or conditioner**

This site gives ten different recipes for making your own shampoo, even including one for a no poo shampoo.

(<https://www.instructables.com/id/Homemade-Shampoo/>)

Use simple ingredients from your kitchen or garden to make six hair conditioners.

(<https://food.ndtv.com/beauty/6-natural-hair-conditioners-for-every-hair-type-you-can-make-at-home-1810325>)

**Environmental impact of shampoo and conditioners**

Scientists from the University of Colorado, while studying air pollution, discovered a spike in the VOC siloxane in the atmosphere during morning “rush hour”, possibly from personal-care products such as shampoos, lotions, and deodorants.

(<https://inhabitat.com/your-shampoo-and-deodorant-cause-as-much-pollution-as-your-daily-commute/>)

“Polluting the Water with Toothpaste, Shampoo, and Drugs” addresses the pollution of water with household chemicals found in soaps, shampoos, cleaning agents, and drugs. Many of these compounds have not been thoroughly studied and are not required to be removed from drinking water.

(<http://www.invw.org/2012/09/12/new-pollutants-1313/>)

**Lubricity Web site**

Not only is Alden’s and Dr. Clark’s story retold on this site, but the chemistry of the product they developed is also presented.

(<https://lubricitylabs.com/pages/the-lubricity-system>)

**General hair-care chemistry**

“Better Hair Through Chemistry” is an article written for high school students that discusses the chemistry of hair and several types of hair products. It addresses the hydrogen bonds and disulfide bonds found in hair and explains how they are affected by changes in pH.

(<http://www.exploratorium.edu/exploring/hair/>)

“Hair Cosmetics, An Overview” reviews the ingredients and action of shampoos, conditioner, hair-straightening products, and hair dyes. The Brazilian keratin treatment is also reviewed.

(<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4387693/>)

## Reading Supports

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 designed to help students prepare to read the article and then locate and analyze information from the article.

* **Anticipation Guide (p. 36):** 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.

**Or** consider the following ideas to engage your students in reading:

**Fighting Frizz: How Chemistry Solved a Bad Hair Day**

* Before reading, ask students to think about what is meant by a bad hair day and how the weather can affect hair. Ask the students what chemical and physical properties hair products might have that would help prevent a bad hair day.
* As they read, students should record information they find interesting and look for solutions to frizzy hair problems.
* **Graphic Organizer (p. 37):** 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. 38-39):** 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 Resources for More Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

### Anticipation Guide

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

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Many keratin treatments contain formaldehyde. |
|  |  | 1. A formaldehyde molecule has three carbon atoms. |
|  |  | 1. A carcinogen is a substance that can cause cancer. |
|  |  | 1. Surfactants, the cleansing ingredient in shampoos, are both hydrophilic (“water-loving”) and hydrophobic (“water-fearing”). |
|  |  | 1. The outer layer of a strand of hair is hydrophilic. |
|  |  | 1. The middle layer of hair contains proteins and the hair’s pigment. |
|  |  | 1. Frizzy hair occurs when the outer layer of the hair is damaged. |
|  |  | 1. Creating stable emulsions containing positive and negative molecules is easy. |
|  |  | 1. Glycolic acid, derived from sugar cane, interacts with keratin to reduce frizz and it is also used to remove dead skin cells. |
|  |  | 1. Surfactants containing sulfates can strip natural oils from hair. |

### Graphic Organizer

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

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

|  |  |  |
| --- | --- | --- |
| 3 | **New things you learned about hair chemistry** |  |
| 2 | **Ideas from the article that will help you choose hair products** |  |
| 1 | **Question you have about hair products** |  |
| Contact! | **How does an understanding of chemistry help you make decisions about personal care products?** |  |

**Summary:** On the back of this paper, write a short email (a few sentences) to a friend who wants relief from frizzy hair using information from the article.

### Student Reading Comprehension Questions

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

Name

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

* 1. Explain how salon keratin treatments work.
  2. What is a reducing agent?
  3. Why did Alden’s father discourage her from getting a commercial keratin treatment?
  4. (a) What are surfactants, and (b) why are they added to shampoos?
  5. What is the role of polymers in shampoos?
  6. Complete the table below regarding the layers in a strand of hair.

|  |  |
| --- | --- |
| **Name of each layer, from outside to inside** | **Description and function of layer** |
|  |  |
|  |  |
|  |  |

**Student Reading Comprehension Questions, cont.**

* 1. What were three goals Clark held for his shampoo?
  2. (a) What is the principal frizz-fighting substance in Clark’s shampoo, and (b) how does it work to correct two problems in frizzy hair?
  3. What is the function of the hydrolyzed quinoa protein in the shampoo?
  4. Why did Clark eliminate sulfates from his shampoo?

**Critical-Thinking Questions**

***Write your answers on another piece of paper if needed.***

* 1. In shampoo, sodium lauryl sulfate is often added as a surfactant. For cleansing purposes, why is it important that the sodium ion dissociates from the rest of the molecule?
  2. Research the difference between soap and shampoo. Would soap be just as good as shampoo to clean your hair? Use chemistry to explain your answer.

### Answers to Reading Comprehension Questions

1. **What is a reducing agent?**

A reducing agent is a substance that donates electrons in reactions.

1. **Explain how salon keratin treatments work.**

Salon keratin treatments use a mixture with reducing agents like formaldehyde, to break the disulfide bonds that maintain hair’s shape. When the hair re-bonds, amino acids from animal-derived keratin are laminated into the hair during the application of high heat, around 232°C, thus smoothing it.

1. **Why did Alden’s father discourage her from getting a commercial hair-straightening treatment?**

Alden’s father did not want her to get a commercial keratin treatment because the formaldehyde in the treatments is carcinogenic and he did not want her exposed to a cancer-causing substance [and, possibly, the time for each treatment and the cost].

1. **(a) What are surfactants, and (b) why are they added to shampoos?**
2. “Surfactants are molecules that, when added to a liquid, reduce its surface tension.”
3. They are added to shampoos to promote hair cleansing.
4. **What is the role of polymers in shampoos?**

“Polymers are the conditioning agents for hair.”

1. **Name the three layers in a strand of hair, giving a description of each layer.**

Complete the table below regarding the layers in a strand of hair

|  |  |
| --- | --- |
| **Name of each layer, from outside to inside** | **Description and function of layer** |
| Cuticle | The outer layer of hair, like a roof with shingles; a hydrophobic, protective layer of hair—responsible for shine and smoothness |
| Cortex | The middle layer under the cuticle, composed of dead cells packed with hydrophilic proteins that give hair strength and structure; cortex also contains the hair’s pigment |
| Medulla | The inner, spongy center of the hair strand |

1. **What were three goals Clark held for his shampoo?**

Three goals Clark held for his shampoo were that

1. the shampoo needs to clean hair,
2. the shampoo needs to protect hair from damage, and
3. the shampoo needs to be a safe product.
4. **(a) What is the principal frizz-fighting substance in Clark’s shampoo? (b) How does it work to correct two problems in frizzy hair?**
5. Glycolic acid is the principal frizz-fighting substance in Clark’s shampoo.
6. Glycolic acid works to help fight frizz by binding to the keratin in hair to make it more hydrophobic, thus reducing the moisture-induced swelling in the strands of hair. It also causes lifted hair cuticles to lie flat, which makes the hair shinier.

1. **What is the function of the hydrolyzed quinoa protein in the shampoo?**

The hydrolyzed protein in the shampoo provides shorter chains of amino acids, the same as those in hair keratin, which can be used to repair damaged segments of hair protein.

1. **Why did Clark eliminate sulfates from his shampoo?**

Clark eliminated sulfates from his shampoo because they strip natural oils from hair that are needed to guard against moisture and frizz.

**Critical-Thinking Questions**

1. **In shampoo, sodium lauryl sulfate is often added as a surfactant. For cleansing purposes, why is it important that the sodium ion dissociate from the rest of the molecule?**

When the sodium ion dissociates from the sulfate group of the molecule, the sulfate group’s resulting negative charge is attracted to the hydrogen atoms in surrounding water molecules, forming hydrogen bonds between the oxygen atoms in the sulfate and hydrogen atoms in the water. Since the oil and dirt on the hair are dissolved in the nonpolar hydrocarbon tails attached to the sulfate group, when the sulfate group bonds to water, the entire molecule and adhering dirt can be rinsed away. If the sodium ion did not dissociate, the sodium lauryl sulfate would not have a hydrophilic region to hydrogen bond with water molecules and the dirt could not be rinsed away as easily.

1. **Research the difference between soap and shampoo. Would soap be just as good as shampoo to clean your hair? Use chemistry to explain your answer.**

(The responses will vary depending on where the students find their answers. While some sources report there is no difference, the students probably have personal experience that dictates otherwise.)

Based on the editor’s research, soap would not be as good as shampoo to clean hair.

Soap is made from an oil and a base such as sodium or potassium hydroxide while shampoo is made from detergents. Soaps are mildly basic while shampoos are mildly acidic. These factors affect how the hair looks after it is washed. Soap reacts with hard water ions to create soap scum, which can be hard to rinse out of your hair, leaving it dull and sticky. Also, the basic pH of most soaps affects the keratin cuticle such that it does not lay flat and does not reflect light, making the hair appear dull.

Shampoo is made from detergents that do not react with the hard water ions, so there’s no soap scum to worry about. Also, shampoos are slightly acidic, which causes the keratin cuticle to lie flat which allows the hair to reflect more light and have more shine.



**Teacher's Guide for**

### “The Periodic Table’s Final Four”

**April/May 2019**

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## Tools and Resources

### Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Chemical nomenclature** | While teaching a unit on chemical nomenclature, the information in the article about the role of IUPAC and its governance in naming compounds can give insight into how new elements get their names. |
| **Periodic table** | The story of the completion of the last row on the periodic table shows the usefulness and value of the table as a critical organizational tool for chemists. |
| **Elements** | The information about a list of the earliest elements used in Lavoisier’s chemistry book, as well as the creation of the latest elements, can be used to enhance a lesson on elements and what constitutes an element. |
| **Nuclear chemistry** | The stories in the article of making new elements from pairs of a heavy element and a lighter element in a cyclotron can be used during a unit on nuclear chemistry. |
| **Nuclear reactions** | The discussion of the production of curium from alpha particles and plutonium is illustrated with an equation that can be used as an example of how nuclear reactions are written. |
| **Atomic number** | The information about atomic number determining the identity of an element supports what students learn in the curriculum about the composition of atoms. |
| **Radioactivity** | The sidebar discussing radioisotopes and their uses in medicine can be used as an example of the beneficial application of new discoveries. |
| **Scientific discovery** | The process involved in claiming new elements provides an example of the rigors of, and the competition and rivalries often involved in, scientific discovery. |

### Possible Student Misconceptions

1. **“There are exactly 92 naturally-occurring elements.”** Ninety-two is the number that has been found in textbooks for many years as the number of naturally-occurring elements. Sometimes, the number of naturally-occurring elements was reported as 91 because element 43, technetium, didn’t have any stable isotopes and was made by bombarding molybdenum with neutrons. When traces of technetium were detected in uranium as a fission product of U-235 or U-238, the number of naturally-occurring elements was increased to 92. Elements 93–98 were all first produced artificially at the University of California, Berkeley, and scientists believed they did not occur naturally. After detection of neptunium and plutonium in pitchblende, the number was increased to 94. Due to further experimentation with pitchblende, the ore Marie Curie used to extract radium and polonium, the elements 93–98 were observed in trace amounts as products of other nuclear processes of naturally-occurring elements in pitchblende. This brings the number of naturally-occurring elements up to 98. Elements 99–118 have only been found as products of particle accelerator experiments. Some still hold onto 94 as the number of naturally-occurring elements, stating that elements larger than these have half-lives too short to be considered as occurring naturally. (<https://www.thoughtco.com/how-many-elements-found-naturally-606636>)
2. **“The person who discovers an element can name it whatever they want.”** This may have been true prior to 1969, but then IUPAC set forth the guidelines and rules that govern how an element can be named. So now, IUPAC states that once the discoverer of an element has been confirmed, the discoverers must adhere to the following rules:
3. The name must differ as little as possible in different languages.
4. The element can be named after any of the following:

* a mythological concept or character, including astrological bodies, like planets
* a mineral
* a geographical location or place
* a property of the element
* a scientist

1. The element must use the suffix *ium—*unless it is in group 17, where it will end in *ine,* or in group 18, where it will end in *on*.
2. When a name has been used unofficially for an element, but a different name is eventually chosen for that element, the unofficial name can never be used again for any future elements to avoid confusion in the literature.

The last rule has an interesting story behind it that students might appreciate. The United States chose the name *rutherfordium* in honor of Ernest Rutherford for element 104 and *hahnium* for element 105 in honor of Otto Hahn. Russian scientists chose the name *kurchatovium* in honor of Igor Kurchatov, “the father of the Russian atomic bomb,” for element 104, and *neilsbohrium* for element 105. Both names and symbols were in use on periodic tables and present in the literature. IUPAC felt the name kurchatovium was chosen to anger the Americans, so it awarded naming rights for 104 to the US and chose the name *dubnium* for element 105 in honor of the location of the Russian particle research lab. The name hahnium can never be proposed again for the name of an element. Otto Hahn received a Nobel Prize for his work in discovering nuclear fission while trying to create larger elements than uranium. Although Hahn conducted the actual experiments, it was Lise Meitner, his colleague of many years, who figured out what had happened and wrote the explanation. When Hahn, a German, published the work, he did not include Meitner’s name because she was Jewish and it is thought he did not want to be accused of collaborating with a Jew during Nazi rule. However, after the war, he still did not give her credit. It is perhaps karma that he is not immortalized on the periodic table while Lise Meitner was finally recognized for her part in the discovery and is memorialized on the periodic table with element 109, meitnerium.

1. **“Most elements have been discovered in the United States.”** Actually, more elements have been discovered in the United Kingdom than any other country. Twenty-four elements have been discovered in the UK, followed closely by the US with 21 elements and Sweden with 20. German scientists are credited with the discovery of 19 elements, while 17 have been discovered in France. However, with respect to the 26 transuranium elements, U.S. scientists have discovered 20. Of those 20 elements, the discoveries of eight of them are shared with Russians who, with those eight, have discovered or co-discovered a total of nine. German scientists have discovered five of the new elements, 108–112. (<https://www.businessinsider.com/this-brilliant-graphic-shows-you-which-country-discovered-every-element-in-the-periodic-table-2014-4>)
2. **“The order of the elements on the periodic table is determined by their atomic mass.”** Even though it is presented in every lesson on the periodic table that the current periodic table is arranged according to the number of protons in the nucleus of an element, many students still cling to the idea that the periodic table is arranged according to atomic weight. Perhaps it is because, for the majority of the elements, that appears to be the case. While Dmitri Mendeleev did, in fact, arrange the precursor to today’s periodic table using atomic weight and chemical properties, the proton had not yet been discovered. When the table is arranged strictly by weight today, a few discrepancies in the order of the elements occur. These discrepancies, such as the order of cobalt and nickel (nickel would come before cobalt if weight is used) and argon and potassium, were not an issue when Mendeleev was building his table because the atomic weights he used for cobalt and nickel were identical at the time and argon had not yet been discovered.

When Henry Moseley conducted experiments in 1913 that involved bombarding the elements with high energy electrons and measuring the resulting X-ray frequencies, he found that each element produced a unique frequency. When the elements were ordered according to this frequency, to which he had assigned a unique sequential whole number, the order of the elements was confirmed and those anomalies that had surfaced from solely considering atomic weight were resolved. This number was correctly identified as the number of positive charges, protons, in the nucleus and matches the number of electrons in the atom. Having a simple whole number for each element allowed for easier detection of the “holes” in the periodic table, which led to the discovery of other yet-unknown elements. Moseley’s sequential arrangement exposed the missing elements 43, 61, 72, and 75. Moseley was only 26 at the time of his discovery and left his research to volunteer with the Royal Engineers during World War I. He was killed in action in 1915 at the age of 27. Had he not been killed, it is likely he would have received a Nobel Prize for his work. Nobel Prize-winning physicist Robert Millikan wrote of Moseley’s passing, "In a research which is destined to rank as one of the dozen most brilliant in conception, skillful in execution, and illuminating in results in the history of science, a young man twenty-six years old threw open the windows through which we can glimpse the sub-atomic world with a definiteness and certainty never dreamed of before. Had the European War had no other result than the snuffing out of this young life, that alone would make it one of the most hideous and most irreparable crimes in history.” Following Moseley’s death, Ernest Rutherford lobbied the British government to no longer allow its prominent and promising scientists to enlist for combat duty. (<https://en.wikipedia.org/wiki/Henry_Moseley>)

1. **“With the completion of the 7th row of the periodic table, the table is now complete, there are no more elements to be added.”** While the completion of the 7th row of the periodic table makes the table look complete, there are probably more elements that will be made in the same manner as the last four and will fit on row eight. Exactly how many more elements can be made is up for debate. Some scientists feel that the atoms have a certain stability depending on the number of protons and neutrons in the nucleus. Some isotopes of element 114 may exhibit more stability than the other elements surrounding it. The discovery of new elements may not proceed sequentially due to the stability of certain proton-neutron arrangements in the nucleus. Richard Feynman predicted that the largest element possible will be element 137, while others have proposed elements up to 173. With the 8th period of elements, scientists project *g* orbitals for the additional electrons.
2. **“There’s only one way to organize the periodic table.”** There are many ways to organize the elements other than the order seen in the periodic table that you find in your textbook. The current arrangement of the elements has evolved over time and continues to be challenged with new ideas about the elements. Some scientists propose placing hydrogen above carbon on the periodic table since, like “hybridized” carbon, it has a half-filled shell of electrons. Other tables use different shapes like spirals or helixes, while still others are arranged in 3-D. A plethora of different periodic tables can be found at this site:

<https://www.meta-synthesis.com/webbook/35_pt/pt_database.php>.

1. **“It’s easy to make new elements—just fire a lighter atom at a heavier atom.”** It is not easy to make new elements. Finding a suitable ion source material and a relatively stable heavier element, whose fusion with the ion source results in the desired element, is challenging. It can also be expensive. The calcium-48 isotope that was used in the creation of three of the final four elements costs over $250,000 per gm. Then there are the instrument parameters. Incoming atoms need to be fired with enough speed to overcome nuclear repulsion but not so fast that they would cause fission of the target element. The ion source beam fires at a rate of 6 trillion atoms per second at a thin metal foil target that may only contain a few atoms of the heavier element with the hopes that one nucleus of the ion source will overcome the repulsion of the positively charged nuclei to become fused as one nucleus without causing the fission of the larger atom. Element 113 took scientists at the RIKEN research lab in Japan nine years to produce three atoms. The first atom was produced in 2004 and a second was produced in 2005. However, it took seven more years before they succeeded in producing a third atom and could claim naming rights to the element.

### Anticipating Student Questions

1. **“What elements, besides carbon, copper, gold, and mercury, were used by early civilizations?”** In addition to those above, the other elements that were used in the earliest civilizations were silver, tin, lead, meteoric iron, and sulfur. Copper, silver, gold, and carbon are considered native elements because they can be found in pure form (uncombined).
2. **“If the number of protons determines the element, what significance do the neutrons have?”** The neutrons are responsible for the stability of the nucleus. The protons are positively charged and, like all positively-charged particles, repel each other. The neutrons are not charged and, in occupying the same space as the protons, shield the positive protons from each other, while the strong force of the nucleus holds all the particles in the nucleus together. Nuclei with neutron: proton ratios of 1:1 to 1.5:1 are stable. Nuclei with neutron: proton ratios greater than 1.5:1 become unstable and exhibit beta decay, essentially turning a neutron into a proton, while those with ratios lower than 1:1 are also unstable and exhibit radioactive decay by electron capture, which turns a proton into a neutron.
3. **“Why are the atomic weights of all the transuranium elements in brackets?”** The atomic weight shown on the periodic table is a weighted average of the masses of all the known isotopes of that element. With the man-made elements, the isotope produced depends on the way the element was synthesized, so natural isotopic abundance has no meaning for these elements. Therefore, the total nucleon count—protons + neutrons—of the most stable isotope (the one with the longest half-life) is placed in brackets on the periodic table to distinguish it from the average atomic weights used for all the other elements.
4. **“What happens to the neutrons that are released when scientists smash atoms together? Are they dangerous?”** The neutrons that “smash” atoms are contained within the particle accelerators. Neutrons are not stable outside the nucleus and decay into a proton and an electron within 14 minutes. Neutrons can travel farther and penetrate more types of material than any other type of radiation. They can penetrate thick lead or steel walls, but they can be stopped if blocked by hydrogen-rich materials like concrete or water. Because neutrons are not charged, they are not repelled by either protons or electrons and can penetrate the nucleus of an atom, often causing it to become unstable and radioactive. They can alter a cell’s DNA and interfere with normal cellular function. They are rarely encountered in the environment, due to their short life. The only time large numbers of neutrons can escape into the environment is during a critical nuclear reactor accident or detonation of a nuclear bomb.
5. **“Where is IUPAC’s headquarters? What do they do there?”** IUPAC’s headquarters is located in Zurich, Switzerland. The organization is recognized as the international authority on chemical nomenclature, symbols, and terminology, and for the standardization of atomic weights and units. They provide information that aids in drafting regulations related to chemical manufacturing, international commerce, and matters related to food, health, and the environment. The administrative branch of IUPAC is referred to as the Secretariat and is located in Research Triangle Park, North Carolina.
6. **“The article says there were more names for element 102. What were they?”** Element 102 provided IUPAC with lots of controversy. First, the discovery was claimed by Swedish scientists who chose the name ***nobelium*** after Alfred Nobel and the Nobel Institute. When their claims could not be duplicated and confirmed by work done by Glenn Seaborg’s research team in the U.S., they withdrew their claim. The U.S. team claimed they had made the element and continued to refer to it as *nobelium*. But Russian scientists found flaws in Seaborg’s work and presented their own claim for the discovery, in 1969. They chose the name ***joliotium*** in honor of Irene Joliot-Curie. After IUPAC scientists reviewed all three experiments, they concluded that the Russians had first created element 102. In 1994, IUPAC ratified names for elements 101–109. The name *nobelium* was ratified for element 102, despite the wishes of its discoverers. In 1995, after much protest to the recently ratified names, IUPAC changed the name of element 102 to ***flerovium***, in an attempt to appease Georgy Flyorov and the Flerov Laboratory of Nuclear Reactions. This name also was rejected, so, in 1997, IUPAC changed the name back to *nobelium*, stating that after 30 years the name had become entrenched in the literature and Alfred Nobel was worthy of the honor. It is interesting that the name *flerovium* was eventually used for element 114, despite IUPAC’s own rule disallowing previously-nominated names ever to be used again.
7. **“If only a few atoms of an element are made, how can they determine its properties?** Because of modern equipment like electron microscopes, scientists can work with incredibly small samples, even those that are only one atom. One atom can be reacted in a small capsule and the results analyzed to determine the chemical properties of the new element. A small sample size is challenging, but it does not prevent testing. The incredibly short, fraction-of-a-second half-lives of the newer elements, however, prevents any chemical testing, even with one atom.
8. **“What purpose do the man-made elements serve?”** Most of the synthetic elements are used only in nuclear research. They provide scientists insight and clues on how the neutrons and protons are organized in the nucleus. The elements beyond element 99 serve purely research purposes, but elements 93–99 and 43 (technetium) have a variety of uses.

|  |  |  |
| --- | --- | --- |
| Atomic No. | Name | Use |
| 43 | Technetium | Diagnostic purposes in medical applications, corrosion inhibitors in steel used for enclosed systems |
| 93 | Neptunium | Research, used as the precursor material for the production of plutonium, used in neutron detection equipment |
| 94 | Plutonium | Used in atomic bombs and to power nuclear reactors for generation of electricity |
| 95 | Americium | Used in smoke detectors |
| 96 | Curium | Used to produce heavier elements and provides an alpha source in x-ray spectrometers |
| 97 | Berkelium | Research uses only |
| 98 | Californium | Strong neutron emitter in fuel rod scanners in nuclear reactors, moisture gauges to find water and petroleum in oil wells, and in some treatments of cervical and brain cancer |
| 99 | Einsteinium | Used to calibrate the chemical analysis spectrometer on the Surveyor 5 lunar probe and to make heavier elements |

### Activities

**Labs and demos**

**“Frosty the Snowman Meets His Demise: An Analogy to Carbon Dating” lab:** Students use graduated cylinders to measure the volume of water that is produced from ice or snow melting in a funnel at their lab stations and record the time that corresponds to each measurement. They can use their data to work backwards to determine when Frosty was brought inside. (<http://sciencenetlinks.com/lessons/frosty-the-snowman-meets-his-demise/>)

**“Particle accelerator concept using a ping pong ball” demo:** This videotaped (1:34) demonstration uses a glass bowl containing electric fields, and a coated ping pong ball to demonstrate how a particle accelerator works. (<https://www.youtube.com/watch?v=EKxzXAQJvB8&eurl=http%3A%2F%2Fvideo.google.com%2Fvideosearch%3Fhl%3Den%26source%3Dhp%26q%3Dparticle%2Baccelerator%2Bexperiment%26um%3D1%26ie%3DUTF-8%26ei%3D21uRSu-9HImZlAfu0pG1DA%26sa&feature=player_embedded>)

This video (10:53) shows you how to make a salad bowl particle accelerator similar to the one above: <https://www.youtube.com/watch?v=1x5hupUifBk>. (Note that the project doesn’t produce spectacular results—rather disappointing, actually, but it can work.)

**Simulations**

**“A Cyclotron”:** Students observe particle behavior at the instrument’s original settings and then can double the electric field or the magnetic field to observe the effects these two fields have on particle behavior in a cyclotron.

(<http://physics.bu.edu/~duffy/HTML5/cyclotron.html>)

**Media**

**“Have we found all the elements?” video (5:19):** The narrator seeks to answer this question after presenting the four latest elements to be added to the periodic table (the same four as in the Dingle “The Final Four” article) and discussing how they were made. He mentions the problems found in attempts to create elements larger than these and also mentions which as-yet-to-be-discovered elements might be found to be stable. (<https://www.youtube.com/watch?v=rwC9BBHkaAI>)

**“Lise Meitner” video (4:50):** In this history of the earliest attempts to make new elements by bombarding heavy elements with neutrons, the experiments of Otto Hahn and interpretations of those experiments by Lise Meitner provide insight into the plight of early women scientists. (Free access to video at <https://teachchemistry.org/classroom-resources/lise-meitner-video>) Teacher materials and guided questions for the students to answer after/while viewing the video are available on the site. (Access to the video is open, but access to the teacher materials on the site is restricted to AACT members; however, those materials will be available for free until June 1, 2019.)

**Lessons and lesson plans**

**“Twizzler half-life” activity:** To develop an understanding of the concept of half-life, students continually divide a Twizzler in half and align a piece of each division on the x axis of the graph with the decay cycle, 1, 2, 3, etc. After marking the height of each piece (the y-axis), they draw the resulting curve on the paper. (<https://teachchemistry.org/classroom-resources/twizzler-half-life>)

**“Ptable.com Investigations” lesson:** This site provides three lesson plans and a link to an interactive periodic table that students can use first to explore information about the elements in a scavenger hunt activity, then, observe a periodic trend in a second activity, and finally, learn the basics of the periodic table in a third activity. (<https://teachchemistry.org/classroom-resources/ptable-com-investigations>)

**Projects and extension activities**

**“Element Baby Book” project:** In “Element Baby Book” students adopt an element and create a baby book about their “new baby” while they research and learn about the element. The activity suggests using elements 2–20 but you could adapt it to use the period 7 elements or restrict it to the superheavy elements 99–118.

(Access is restricted to AACT members, but the site will be available for free until June 1, 2019, at <https://teachchemistry.org/classroom-resources/element-baby-book>.)

**“ABC’s of Nuclear Science” experiments:** Besides additional information about nuclear structure, radioactivity, and nuclear reactions, this site provides links to nine nuclear experiments, including a cloud chamber experiment that allows students to visually observe nuclear decay. If you have access to radioactive sources, either at your school or through a local university, these activities provide the students with hands on experiences with radioactivity concepts. (<https://www2.lbl.gov/abc/Contents.html#experiment>)

### References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles and Teacher’s Guides published from the first issue in October 1983 through April 2013.**

**The DVD is available from the ACS for $42 ($135 for a site/ school license) here:** [***http://www.acs.org/chemmatters***](http://www.acs.org/chemmatters)***.***



“The New Alchemy” chronicles the discovery of radiation and the creation of new elements in the experiments of Ernest Rutherford, Irene Joliot-Curie, Enrico Fermi, Edwin McMillan, and Glenn Seaborg, which eventually led to a reorganization of the periodic table (McClure, M. The New Alchemy. *ChemMatters*. 2006, *24* (3), pp 15–17)

This article describes how the elements were made in the stars by the process of nuclear fusion (nucleosynthesis) for elements helium through nickel in the younger stars, and the formation of the heavier elements by neutron capture and beta decay in supernovas.

(Ruth, C. Where Do Chemical Elements Come From? *ChemMatters*. 2009, *27* (3), pp 6–8)

The Teacher’s Guide for the October 2009 *ChemMatters* article above provides additional information about nucleosynthesis in stars, including nuclear equations for those fusion reactions. The guide also contains links to lessons on spectroscopy and supernova chemistry.

In this article about creating superheavy elements in a cyclotron, author Brownlee presents a schematic with an explanation of how a cyclotron works, as well as a discussion on the process for naming new elements.

(Brownlee, C. What Uuought to Know About Elements 112–118. *ChemMatters*. 2009, *27* (3), pp 9–10)

The Teacher’s Guide for the October 2009 *ChemMatters* article above contains nuclear equations for the formations of elements 110–118, as well as links to a discussion on how far the periodic table may extend, and multiple links to additional videos, simulations, and lessons.

“The Periodic Table Turns 150: Is the Best Yet to Come?” presents the history of the periodic table, including the discovery of the superheavy elements and Glenn Seaborg’s idea of an “island of stability” related to the organization of the particles in the nucleus. (Warmflash, D. The Periodic Table Turns 150: Is the Best Yet to Come? *ChemMatters*. 2019, *37* (1), pp 11–14)

The Teacher’s Guide for the February 2019 *ChemMatters* article above provides links to lesson plans, videos, and demos that help teach the logic behind the patterns in the table.

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

The September 8, 2003 issue of *Chemical and Engineering News* celebrated the magazine’s 80th anniversary by presenting a variety of essays on the periodic table and the elements. Color graphics complement the essays. (Chem. Eng. News, 2003, *81* (36)

In “Rearranging the table” in the January 7, 2019 issue of *Chemical Engineering News*, author Sam Lemonick presents current discussions on changing the arrangement of the elements in different table formats, based strictly on atomic orbitals and electron-filling order. Particularly problematic for current tables is the question of which elements should belong in group three, under scandium and yttrium.

(Lemonick, S. Rearranging the table. *Chem. Eng. News*, 2019, *97* (1), pp 26–29; “The periodic table is an icon. But chemists still can’t agree on how to arrange it” [same article, different title], <https://cen.acs.org/physical-chemistry/periodic-table/periodic-table-icon-chemists-still/97/i1>. 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 February 2019 special issue of *Science*, “The Periodic Table Turns 150” features six articles about the periodic table that highlight the superheavy elements, nucleosynthesis of the elements in the stars, the order of the table, *p*-block chemistry, the electronic structure of the transition metals, and the modern marvels of the rare earth metals.

(Science, 2019, *363* (6426), pp 464–493)

A special note from the above citation: Author Sam Kean includes his interview with Yuri Oganessian, the scientist for whom element 118 is named, in this article about the most recent superheavy elements. The article contains a schematic of the particle accelerator in Dubna, Russia, details about the difficulties encountered by the Japanese team in creating element 113, and projections of finding heavier elements in the future and where they will be represented on the periodic table. (Kean. S. The Quest for the Superheavies. *Science*, 2019, *363* (6426), pp 466–470)

### Web Resources for More Information

**IUPAC**

The Web site for the IUPAC contains information about the history of the organization, their current responsibilities, upcoming IUPAC sponsored events, as well as pictures and bios of the current leadership.

(<https://iupac.org/>)

**Element names**

“Explainer: How a new element gets its name” contains information about the history of some of the element names on the periodic table, as well as the IUPAC rules for naming a new element.

(<https://www.chemistryworld.com/news/explainer-how-a-new-element-gets-its-name/1017676.article>)

Besides explaining the conventions for naming the early elements, this article also discusses the controversy that surrounded the names for elements 104 and 105.

(<https://www.carolina.com/teacher-resources/Interactive/naming-the-elements/tr28303.tr>)

**Discovering the superheavy elements**

“The limits of nuclear mass and charge” is a scholarly article about the discovery of elements 113, 115, 117, and 118 and the challenges of analyzing the super heavy elements. The author discusses the isotopes that may confirm an “island of stability”, as well as how far the periodic table could possibly be extended.

(<https://www.nature.com/articles/s41567-018-0163-3>)

This article about the creation of the superheavy elements discloses the competitiveness that exists in discovering them and also explains where the upper limit to the number of elements yet to be discovered may be found.

(<http://www.bbc.com/earth/story/20160115-how-many-more-chemical-elements-are-there-for-us-to-find>)

**Elements 115 & 117 and the island of stability**

This article talks about the island of stability and how scientists believe they are getting close to it with the creation of element 117.

[(https://www.scientificamerican.com/article/superheavy-element-117-island-of-stability/](file:///C:\Users\Owner\Downloads\(https:\www.scientificamerican.com\article\superheavy-element-117-island-of-stability\))

“Element 115 and the Island of Stability” discusses the challenges in the creation of element 115 and that it may be approaching a stable number of protons and neutrons.

(<http://www.physicscentral.com/explore/action/element-115.cfm>)

**Radiation**

This article describes alpha, beta, gamma, X-ray, and neutron radiations and contains several links to information about the different sources and effects of radiation.

(<https://www.mirion.com/learning-center/radiation-safety-basics/types-of-ionizing-radiation>)

**Particle accelerators**

This article explains the differences among cyclotrons (used for the creation of new elements), linear accelerators (like the 2 mile long SLAC at Stanford), and synchrotrons (like the Large Hadron Collider located in Switzerland).

(<https://www.machinedesign.com/whats-difference-between/what-are-differences-between-linear-accelerators-cyclotrons-and-synchrotron>)

**Naturally-occurring elements**

This Wikipedia site supports the idea of 94 naturally-occurring elements. It gives arguments for dismissing elements above atomic number 94 as only being the product of man-made synthesis. (<https://en.wikipedia.org/wiki/Chemical_element#Occurrence_and_origin_on_Earth>)

The article “How many elements can be found naturally?” supports considering 98 as the number of naturally-occurring elements. There are several links at the end of the article to more information on the elements.

(<https://www.thoughtco.com/how-many-elements-found-naturally-606636>)

**Other helpful videos**

This 2006 PBS video (6:52) examines the stability of certain elements and the projected stability of element 114. The animated protons and neutrons simulate the strong force of the nucleus and show the idea of patterns of organization of protons and neutrons in the nucleus.

(<https://www.pbslearningmedia.org/resource/lsps07.sci.phys.matter.stability/island-of-stability/>)

In the (5:40) video, “The Element Makers: Making Superheavy Elements”, a Lawrence Berkley scientist explains how mapping the decay products of newly-created elements can be used to prove their discovery.

(<https://www.chemistryworld.com/features/the-element-makers-making-superheavy-elements/3009554.article>)

**Interactive periodic tables**

The Royal Society of Chemistry’s interactive periodic table is complete through element 118. Each element is linked to information, and there’s a video about each one. The video for element 118 contains a good message for all budding science entrepreneurs.

(<http://www.rsc.org/periodic-table>)

This periodic table has information about the physical and chemical properties of each element that can be accessed for all elements simultaneously by changing the property displayed. Each element is linked to the Wikipedia information for the element.

(<https://ptable.com/>)

This site contains links to a plethora of periodic tables of various shapes and content, both chemical and some non-traditional, nonchemical tables.

(<https://www.meta-synthesis.com/webbook/35_pt/pt_database.php?Button=Top_10>)

## Reading Supports

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 designed to help students prepare to read the article and then locate and analyze information from the article.

* **Anticipation Guide (p. 58):** 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.

**Or** consider the following ideas to engage your students in reading:

**The Periodic Table’s Final Four**

* Before reading, ask students how many elements are in today’s Periodic Table. Ask student when the last four elements were added, how they were created, and where they are found on the Periodic Table.
* As they read, students can find information to confirm or refute their original ideas.
* **Graphic Organizer (p. 59):** 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. 60-61):** 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 Resources for More Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

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

### Anticipation Guide

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. The last row of the Periodic Table was completed in 2018. |
|  |  | 1. All of the final four elements were named for the places where they were created. |
|  |  | 1. The first list of modern elements was published in the early 1800s. |
|  |  | 1. Most naturally occurring elements were discovered before 1900. |
|  |  | 1. Elements are defined by the number of protons and neutrons. |
|  |  | 1. Creating new elements requires overcoming strong repulsive forces between positively charged particles. |
|  |  | 1. No practical uses have been found for synthetic elements. |
|  |  | 1. Elements are officially named before the discovery is confirmed in a different laboratory than where they are discovered. |
|  |  | 1. All of the newest elements have half lives of less than one second. |
|  |  | 1. The last row of the Periodic Table was completed in 2018. |

### Graphic Organizer

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

**Directions**: As you read the article, complete the graphic organizer below to compare naturally occurring elements to synthetic elements.

|  |  |  |
| --- | --- | --- |
|  | **Natural Elements** | **Synthetic Elements** |
| **Examples** (at least 5 for each) |  |  |
| **When discovered** (range) |  |  |
| **Atomic Number** (range) |  |  |
| **Location on the Periodic Table** |  |  |

Use the graphic organizer below to describe an alpha particle:

|  |  |  |  |
| --- | --- | --- | --- |
|  | ***Structure*** | ***Charge*** | ***Role in creating new elements*** |
| **Alpha Particle** |  |  |  |

**Summary:** On the bottom or back of this paper, write a short (2-3 sentence) explanation of the role of IUPAC in confirming and naming new elements.

### Student Reading Comprehension Questions

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

Name

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

* 1. When were the four last open spots in the periodic table filled?
  2. Complete the table below for the four elements most recently added to the periodic table.

|  |  |  |
| --- | --- | --- |
| **New elements** | | |
| **Atomic number** | **Name** | **Origin of name** |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

* 1. (a) Who was the scientist who first published a textbook containing a table identifying 33 simple substances later recognized as the first list of modern elements, and (b) when was it published?
  2. When and by whom was the first organization of elements that resembles the current periodic table established?
  3. How many elements occur naturally on Earth?
  4. What defines any given element?
  5. What is required for creating a new element?

**Student Reading Comprehension Questions, cont.**

* 1. Give the name and atomic number, and the location and date of discovery of the first synthetic element produced.
  2. What are the three main standards IUPAC proposed in regards to naming elements?
  3. What are the most fascinating properties of the new superheavy elements?
  4. Which element is associated with the production of three of the four newest elements?

**Critical-Thinking Questions**

***Write your answers on another piece of paper.***

* 1. Propose a possible procedure for making element 120.
  2. Based on its expected position on the periodic table (directly under radium, element 88), what properties (e.g., outer energy-level electron arrangement) oxidation number, the formula of its compound with chlorine, reactivity with water, nuclear stability, and density) would you predict for element 120 (unbinilium, Ubn)? Explain your predictions.

### Answers to Reading Comprehension Questions

1. **When were the four last open spots in the periodic table filled?**

The four last spots in the periodic table were filled in 2016.

1. **Complete the table below for the four elements most recently added to the periodic table.**

|  |  |  |
| --- | --- | --- |
| **New elements** | | |
| **Atomic number** | **Name** | **Origin of name** |
| 113 | nihonium | Japanese word “nihon”, meaning “land of the rising sun” |
| 115 | moscovium | Discovered in Moscow, Russia |
| 117 | tennessine | Tennessee, site of scientists’ discovery |
| 118 | oganesson | In honor of Yuri Oganessian, nuclear physicist, for his role in discovering heavy elements |

1. **(a) Who was the scientist who first published a textbook containing a table identifying 33 simple substances later recognized as the first list of modern elements, and (b) when was it published?**
2. Antoine Lavoisier published a textbook identifying 33 substances in a “Table of Simple Substances”, later recognized as the first list of modern elements.
3. It was published in 1789.
4. **When and by whom was the first organization of elements that resembles the current periodic table established?**

In 1869, Dmitri Mendeleev organized the elements in a table that resembles the current periodic table of the elements.

1. **How many elements occur naturally on Earth?**

There are 94 known naturally occurring elements on Earth.

1. **What defines any given element?**

Any given element is defined by its number of protons, its atomic number.

1. **What is required for creating any new element?**

Any new element created must have a new and unique number of protons.

1. **Give the name and atomic number, and the location and date of discovery of the first synthetic element produced.**

The first synthetic element produced was curium, atomic number 96, made by scientists at the University of California, Berkeley, in 1944.

1. **What are the three main standards IUPAC proposed in regards to naming elements**?

IUPAC proposed that naming elements should follow these guidelines:

1. The element will be named five years after the initial announcement of its discovery, to allow confirmation by other laboratories, preferably in other countries.
2. The element’s discoverers will choose the name for the element within prescribed IUPAC guidelines.
3. In cases where multiple discoverers claim the right to name the element, IUPAC will ultimately decide who will have the honor of naming the element.
4. **What are the most fascinating properties of the new superheavy elements?**

The most fascinating properties of the new superheavy elements are that they are

1. extremely radioactive and
2. unstable.
3. **Which element is associated with the production of three of the four newest elements?**

Calcium was used to create moscovium, tennessine, and oganesson.

**Critical-Thinking Questions**

1. **Propose a possible procedure for making element 120.**

Although the procedure should be the same for all answers (use of a cyclotron to bombard elements together), the elements students choose to make element 120 will vary. Based on information in the article on three of the four most recently created elements (the use of calcium for three of the four), one likely possibility for students to propose would be to bombard atoms of fermium (element 100) with calcium atoms (element 20) inside a cyclotron to produce an element with an atomic number of 120. (Or they could hypothetically offer any other combination of two elements whose atomic numbers add up to an atomic number of 120.)

1. **Based on its expected position on the periodic table (directly under radium, element 88), what properties (e.g., outer energy level electron arrangement, oxidation number, the formula of its compound with chlorine, reactivity with water, nuclear stability, and density) would you predict for element 120 (unbinilium, Ubn)? Explain your predictions.**

|  |  |
| --- | --- |
| **Description of property** | **Element 120’s property** |
| Outer energy level  electron arrangement | 8s2 – two electrons in its outer energy level, just as other group 2, alkaline earth, elements; they all have *n* s2 arrangements |
| Oxidation number | +2 as it easily loses those 2 outermost electrons |
| Formula of compound with chlorine | UbnCl2, just as other group 2 elements (e.g., MgCl2) |
| Reactivity with water | Reacts vigorously with water, as other group 2 elements react with water, with the trend in reaction rate increasing |
| Nuclear stability | Radioactive, just as radium is radioactive |
| Density | 6.5–7 g/cm3, as the trend increases dramatically with the last (heaviest) few elements in group 2 |



**Teacher's Guide for**

### “What Are Pool Chemicals?”

**April/May 2019**

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## Tools and Resources

### Connections to Chemistry Concepts

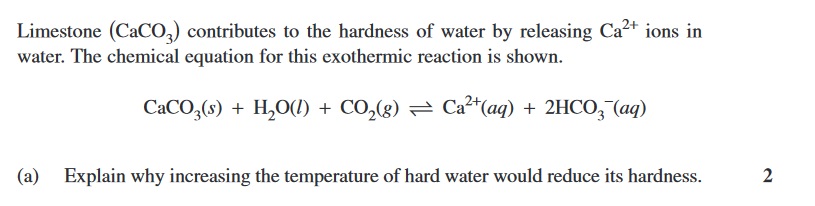
|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **pH** | When students measure solution pH in the chemistry laboratory, information in this article can be used to demonstrate the importance of monitoring pH to maintain healthy pool water. |
| **Buffer systems** | The study of acid-base buffer systems can become relevant to students’ lives when information in this article is used to help them understand the important role that buffers play in protecting human health while swimming. |
| **Equilibrium** | The acid-base equilibrium given in the article uses  Le Châtelier’s principle to explain equilibrium shifts. The study of swimming pool chemistry can add interest and relevance to the concept of equilibrium by discussing the dangers of major equilibrium shifts, often due to negligent monitoring of the pool water pH. |
| **UV radiation** | The study of the electromagnetic spectrum provides an opportunity to discuss material from the article about how UV rays (having relatively high energy) can be used to kill chlorine-resistant microorganisms found in swimming pool water. |
| **Ions** | During the classroom study of ions, information in this article can be used to show the importance of water-soluble ions in destroying pathogens and maintaining swimming pool water at a safe pH. |
| **Acids and bases** | Information in the article can add relevance and importance to the classroom study of acids and bases, where there are ample opportunities to discuss the role of swimming pool chemistry in maintaining proper pH. |

### Possible Student Misconceptions

1. **“I understand that a strong chlorine smell from the pool is a reminder that the chlorine is present in the water for killing germs so the water is safe for swimming.”** The “chlorine” smell from a swimming pool is actually the opposite of what you think. It means that the concentration of free chlorine is dangerously low and the concentration of chloramines is high. Free, active chlorine has no odor when in water; however, when it is combined with nitrogen or ammonia from sweat, perspiration, urine, and dirt from swimmers’ bodies, smelly chloramines form. The Arnaud article mentions trichloramine (NCl3). The “chlorine” smell indicates the need to remove chloramines (shock treatment) and replenish free chlorine (pool lingo for HClO) to kill pathogens in the pool water.
2. **“My friend has blond hair that turns slightly green when she swims. She says that the indoor pool has too much chlorine.”** While it is true that swimmers with light colored hair may leave a pool with a slight greenish tinge to their hair, the green color is not caused by chlorine, a greenish-yellow poison in the gaseous phase, but colorless in a water solution. The green is caused by dissolved copper ions present in the water due to either heavy use of copper algaecide or leaching from copper pipes. The copper color can be rinsed out by a quick shampoo immediately after swimming.
3. **“Sometimes, the chlorine in a pool burns my eyes and leaves them red.”** Red eyes are not caused by chlorine; these symptoms usually indicate that you are swimming in a pool that has a large concentration of chloramines indicated by a strong chlorine smell. Eye redness can also occur if the pool pH is significantly higher or lower than the pH of your eyes (about 7.3). In addition, if you swim underwater with your eyes open for an extended period of time, the water will flush the eyes of tears leaving you with dry eyes that sting, burn or feel scratchy.
4. **“My golden retriever loves to swim in my pool with me and I don’t see any problem with this because he won’t affect the pool chemistry.”** Unfortunately, this is a problem. The dog can foul your pool water as it will probably bring many types of invisible bacteria on its hair and might even use the water as a toilet. In addition, a long-haired dog like a retriever may shed hair that clogs the pool’s filtering system. Take your dog to a lake or the ocean where there is plenty of water to dilute the added bacteria without changing the pH or alkalinity of the water.
5. **“I know that showers are required at public pools because so many people use them. So, I guess that forgetting to take a shower before swimming in my friend’s pool is not a problem.”** Actually, it is important to shower before entering any pool, large or small, for the health of the pool water, as well as your own health. If you don’t shower, you carry into the pool water everything that is sitting on your skin including sunscreens and lotions. These may contain nitrogen that reacts with free chlorine to produce chloramines.
6. **“The pool water is disinfected, so it’s alright for young kids to swallow some.”** No, kids should be taught to avoid swallowing pool water. While chlorine does kill many waterborne bacteria and viruses, chlorine levels fluctuate in pools, especially when the pools are busy and crowded. And, hypochlorous acid is unable to destroy some cysts and protozoa.
7. **“I’ve heard parents warn kids, ‘Don’t pee in the pool because it will turn blue.’”** This is an old scare tactic used to keep children from urinating in the pool. Even if a chemical indicator was used to show urination in pool water, it wouldn’t be very effective because it would be difficult to keep it from reacting with other substances in the pool, including pool chemicals.
8. **“It’s dangerous to swim in a saltwater pool because it doesn’t contain any free chlorine.”** This is a misconception; a saltwater pool is not a chlorine-free pool. To sanitize a saltwater pool, saltwater is forced across a metal cell charged by an electric current. This electrolysis produces chlorine in the form of hypochlorite ions and hypochlorous acid to disinfect and oxidize bacteria and viruses the pool.

### Anticipating Student Questions

1. **“Why is hypochlorous acid called ‘free chlorine’ in a swimming pool”?”** Rather than pathogens being destroyed by the element chlorine, pool water is actually oxidized and disinfected by hypochlorous acid, a weak acid also commonly known as “free chlorine”. This acid forms when a water-soluble chlorine compound reacts with pool water to form hypochlorite ions (ClO–) and hypochlorous acid (HClO).
2. **“This article says, ‘It’s not OK to pee in the pool!’, but is it OK to pee in the ocean?”** Yes, it is OK to pee in the ocean, because urine is composed of approximately 95% water plus some sodium and chloride ions. These ions are already present in the ocean. The small amount of urea that you release is minuscule compared to 350 quintillion liters of water in the Atlantic Ocean. Enjoy this ACS video (2:50) to answer your question: <https://www.youtube.com/watch?v=eqR2bLsdhs4>.
3. **“How does very hard water affect swimming pools?”** High Ca2+ levels may result in cloudy pool water. Hard-water ions such as calcium (Ca2+) and magnesium (Mg2+) can form a scale that clogs filtration machinery, shortening the life of this equipment, raising costs of heating the pool water by lowering the efficiency of electric water heaters, and, eventually, leading to clogged pipes.
4. **“Will it work to fill pools with soft water that contains low levels of Ca2+?”** No, because if the concentration of Ca2+ ions is very low, the low calcium-content water will remove the calcium in the pool’s plaster or concrete. This is explained by Le Châtelier’s principle. Limestone (CaCO3), a frequent source of Ca+2, dissolves in groundwater to form this equilibrium:



When the system (the pool water) lacks Ca2+, it will remove from the pool walls the calcium needed to restore the equilibrium, leaving pits on wall surfaces. Soft water is more acidic than hard water because it lacks the hard water minerals that act as buffers that reduce the acidity of the water. If the pool is vinyl or fiberglass, with no source of calcium like the concrete pool, this acidic soft water will attack metal fixtures and/or the metal parts of the filtering system.

**“Is UV-treated water safe to drink?”** Unfortunately, the answer is no. UV radiation kills chlorine-resistant parasites with protective outer shells like those of *Cryptosporidium parvum* but, for human safety*,* water passes through a UVtreatment box *before* it enters the pool. However, humans or other animals can contaminate the water by bringing chlorine-resistant microorganisms into the pool *after* UV treatment.

1. **“People talk about ‘shocking the pool’, what does this mean?”** When the pool smells strongly of chlorine and the water is cloudy, it will probably need a shock treatment (superchlorination) to remove a buildup of excess chloramines and to kill algae and other pathogens. A powdered form of chlorine is added to the water and left in the pool overnight.

### Activities

**Labs and demos**

**“Chemistry for the Gifted and Talented: Swimming Pool Chemistry” AP level lab:** This lab from the Royal Society of Chemistry (RSC) investigates many aspects of the reactions that occur in swimming pools, including basic and advanced water chemistry concepts such as equilibrium (Le Châtelier’s principle), buffers, entropy (solvent effects), mass spectrophotometry, and NMR.(<https://www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/swimming-pools.html>)

**“Swimming Pool Chemistry: Student Activities” lab:** Directions and sample data for three Flinn Scientific wet labs (build a swimming pool model, add urea and measure the effect of UV light on each model pool’s water) are given. All materials are usually found in standard high school chemistry stockrooms; dichloroisocyanuric acid (Dichlor) can be purchased at a pool-supply or hardware store). (<http://www.dougdelamatter.com/website1/science/chemistry/pool/student.pdf>)

**Simulations**

**“[ChemVlab+] Acid Base Chemistry: pH and Swimming Pools Info” HS virtual lab:** This real-world, scenario-based lesson from the National Science Digital Library (NSDL) puts the student in the position of a lifeguard who is responsible for the safety and quality of the water at a small pool. (<http://chemcollective.org/activities/info/148>)

**Media**

**“Don’t Pee in the Pool”, video (3:03):** This ACS “Breakthrough Science” video describes the reaction between uric acid and chlorine to produce trichloramine. Possible human health effects from this product (including its early use in warfare) are presented. (<https://www.youtube.com/watch?v=2EWtsxDRP2o>)

**“Le Châtelier’s principle”, video (14:43):** This Khan Academy video demonstrates the effects of various disturbances placed on an equilibrium system and explains how the system responds to establish a new equilibrium state. This is an excellent learning tool. (<https://www.khanacademy.org/science/chemistry/chemical-equilibrium/factors-that-affect-chemical-equilibrium/v/le-chatelier-s-principle>)

**Lessons and lesson plans**

**“The Balancing Act of Swimming Pool Care” lesson:** The importance of balancing and maintaining factors that contribute to a healthy pool are discussed in this lesson: pH, alkalinity, calcium hardness, and stabilizers. (<https://www.frogproducts.com/balancing-act-swimming-pool-water-care/>)

**“Swimming Pool Chemistry” Royal Society of Chemistry (RSC) lesson for gifted and talented students (AP Chemistry):** The chemistry of swimming pools provides the context for solving problems involving equilibria (Kc, Ksp, Ka, buffers, and Le Châtelier’s principle) and the placement of arrows to show the direction of electron movement. Data and student worksheets are provided, and teacher information includes complete keys to all questions. (<http://www.rsc.org/learn-chemistry/resource/res00000649/swimming-pool-chemistry?cmpid=CMP00000675>)

**Projects and extension activities**

**“Maintaining proper pH requires an understanding of acid-base concepts” experimental design project (1 week):** According to the author, this experiment came out of the need to alleviate student boredom near the end of acid-base studies. The text provides suggestions for guiding students toward the goal of maintaining the proper pH in the one-liter model pools that they build. (<https://libres.uncg.edu/ir/uncg/f/C_Matthews_Swimming_1997.pdf>)

### References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles and Teacher’s Guides published from the first issue in October 1983 through April 2013.**

**The DVD is available from the ACS for $42 ($135 for a site/ school license) here:** [***http://www.acs.org/chemmatters***](http://www.acs.org/chemmatters)***.***



The original *ChemMatters* article on swimming pool chemistry presents a valuable way to demonstrate the effect of pH on the equilibrium reaction for hypochlorous acid and its ions, using the size (and bold print) of chemical symbols (H+, OCl–, and HOCl) to show concentrations. (Tanis, T. and Dombrink, K. Swimming Pool Chemistry. *ChemMatters*. 1983, *1* (2), pp 4–5)

“Swimming Pools” details the chemistry behind protecting the health of swimmers and the pool by maintaining an appropriate pH range and stabilizing free chlorine when exposed to UV radiation. (Baxter, R. Swimming Pools. *ChemMatters*. 1994, *I2* (2), pp 10–12)

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This ACS ChemClub bulletin lists seven “Experiments and Activities” and a long list of “Articles and Information” about swimming pool chemistry. (American Chemical Society. “Chemistry of Swimming Pools”. *ACS ChemClub*, 2016, *May,* p 1; <https://www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/swimming-pools.html>) Free access for all at this link.

### Web Resources for More Information

**Pool maintenance**

“Guide to swimming pool water chemistry” is a good basic guide for pool users. Topics discussed are the use of disinfectants, total hardness, ways to reduce or elevate pH including the dangers of an imbalance, ways to prevent algae growth and various swimming pool water-testing procedures.

(<http://www.elecro.co.uk/guide-to-swimming-pool-water-chemistry>)

“The Chemistry of Swimming Pool Maintenance” from the *Journal of Chemical Education* teaches the basic chemistry behind maintaining healthy pools. Two acid-base equilibria (hypochlorous acid and calcium hydroxide), plus simple testing techniques (indicators to replace pH meters and hardness measured by drop-count titration) are discussed.

(<https://pdfs.semanticscholar.org/f245/ebb7f16860356aa814f598227133d33d58e5.pdf>)

**Basics of pool chemistry**

“Swimming pool chemistry water fact sheet” shows that chlorine in any form reacts with water to yield hypochlorous acid, the agent that kills algae and bacteria and oxidizes other organic matter in pools. Facts are provided on ways to maintain optimum pH, alkalinity (buffer systems), the level of cyanuric acid (CYA) needed to stabilize chlorine, and the effects of water temperature.

(<https://www.co.shasta.ca.us/docs/libraries/resource-management-docs/ehd-docs/Pool_Chemistry_Fact_Sheet.pdf>)

This basic pool chemistry lesson provides additional details on the use of CYA to protect chlorine from being degraded by UV radiation and discussed what happens when calcium ion concentration and/or pH are outside of their ideal range.

(<https://www.swimmingpoollearning.com/basic-pool-chemistry>)

**Stabilizing free chlorine**

This excellent resource uses graphs to show the results of studies to determine the effect of adding CYA to maintain the free chlorine (HClO) level in swimming pools.

(<https://www.qcaa.qld.edu.au/downloads/senior/snr_chemistry_07_ass_chlorine.pdf>)

The ability of CYA to protect free chlorine from degradation by the sun’s ultraviolet rays is discussed in a three minute video. The molecular structure helps explain CYA’s ability to protect free chlorine.

(<http://blog.orendatech.com/five-things-cyanuric-acid>)

**Disinfection**

The “Hypochlorous Acid Information Sheet” describes how hypochlorous acid kills bacteria and viruses.

(<https://www.trycare.co.uk/files/ww/Dentiguard%20-%20Hypochlorous%20Acid%20Information%20Sheet.pdf>)

A technical guide on using UV sanitation in swimming pools discusses how to eliminate microorganisms such as *Cryptosporidium* and *Giardia* that have chlorine-resistant cysts.

(<https://www.poolspanews.com/facilities/maintenance/technical-guide-to-using-uv-sanitation-on-swimming-pools_o>)

**Disinfection byproducts (DBPs)**

Disinfectants used to kill microbes react with organic materials in pools (most brought in by swimmers) to form DBPs. Effects on human health by DBPs are explained.

(<https://cen.acs.org/articles/94/i31/chemical-reactions-taking-place-swimming.html>)

Swimmers’ breath and blood were tested for the formation of trihalomethanes (THMs) (a consequence of water chlorination) after sitting on the edge of an indoor pool for one hour before swimming and then tested again after swimming for one hour; all tests detected THMs.

(<https://www.sciencedirect.com/science/article/pii/S0048969798001740?via%3Dihub>)

**Balancing pH, alkalinity and hardness**

This article emphasizes the importance and provides the rationale for balancing pool-water alkalinity first, followed by pH and finally by calcium hardness.

(<https://poolforthought.com/maintaining-pool-calcium-hardness/>)

“Pool Chemistry: Backyard Perils and Experiments” from *Chem13 News* uses equilibrium expressions and structural formulas to discuss alkalinity and pH and describes how trichloroisocyanuric acid stabilizes free chlorine by lowering the pH. Excellent article!

(<https://uwaterloo.ca/chem13news/sites/ca.chem13news/files/uploads/files/March2007_1_4_5.pdf>)

**Chelation and sequestration**

Metal ions can discolor water and form rust or copper stains on pools; chelating agents bind the ions tightly in chemical bonds, keeping them suspended in the water. The source of metal ions in pools, ways to test for their presence, and how to remove them are explained.

(<https://www.poolcenter.com/swimming-pool-metal-control>)

This excellent article contains a table showing the difference between chelation and sequestration; both are involved in pool chemistry. A structural diagram shows how a metal ion such as copper or iron is chelated by EDTA, and an illustration shows hard water ions sequestered.

(<http://pediaa.com/difference-between-chelating-agent-and-sequestering-agent/>)

## Reading Supports

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 designed to help students prepare to read the article and then locate and analyze information from the article.

* **Anticipation Guide (p. 77):** 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.

**Or** consider the following ideas to engage your students in reading:

**What Are Pool Chemicals?**

* Before reading, ask students what chemicals are used to keep pools clean, and why they are needed.
* As they read, students should record information they find interesting, as well as answers to their questions.
* **Graphic Organizer (p. 78):** 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. 79-80):** 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 Resources for More Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

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

### Anticipation Guide

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Free chlorine is used to disinfect commercial pools. |
|  |  | 1. Trichlor contains the same elements as trichloramine. |
|  |  | 1. Bromine compounds are often used to disinfect hot tubs. |
|  |  | 1. Chlorine compounds kill all common pathogens. |
|  |  | 1. UV radiation to control microbes in pool water is done prior to releasing water into a pool. |
|  |  | 1. The “chlorine” smell associated with indoor pools comes from chlorine reacting with compounds found in urine and sweat. |
|  |  | 1. Pool chemicals work best when the pH is between 8 and 9 (basic). |
|  |  | 1. No one is sure why the diving pool at the 2016 Summer Olympics turned emerald green. |
|  |  | 1. Because the chemical reactions in a pool are in equilibrium, an understanding of LeChatelier’s principle helps pool operators know how to adjust the pH. |
|  |  | 1. Green hair from swimming is caused by compounds containing copper. |

### Graphic Organizer

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

**Directions:** As you read the article, complete the graphic organizer below to analyze how pool chemicals protect swimmers.

|  |  |  |
| --- | --- | --- |
|  | ***Structure or formula*** | ***What does it do?*** |
| **Hypochlorous acid** |  |  |
| **Trichlor** |  |  |
| **Chemicals to balance pH** |  |  |
| **Green color in a pool or your hair** |  |  |

**Summary**: On the bottom or back of this paper, write a tweet (280 characters or less) about the chemistry of pool water, based on what you learned from reading the article.

### Student Reading Comprehension Questions

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

Name

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

* 1. (a) Give three reasons why people complain about chlorine-based compounds in pool water. (b) So, then, why *is* chlorine added to pools?
  2. Why is chlorine (Cl) added to pool water as a part of more complex molecules?
  3. List three reasons why residential pool owners usually use trichlor for disinfecting their home pools.
  4. Why is maintaining the proper concentration of the disinfectant important?
  5. Why is a stabilizer added to pool water?
  6. (a) How do bromine-containing compounds work as disinfectants, and (b) why are they a better choice than chlorine for hot tubs?

**Student Reading Comprehension Questions, cont.**

* 1. (a) Why is the intestinal parasite *Cryptosporidium* resistant to chlorine? (b) How does UV radiation destroy this organism?
  2. How are swimmers protected from UV radiation used to disinfect swimming pool water?
  3. Why are people asked to urinate and shower before entering a swimming pool?
  4. List three sources of copper that can turn swimmers’ hair greenish.
  5. According to Le Châtelier’s principle, (a) if the pool pH is too high (too basic), how will this affect the concentration of hypochlorous acid and the safety of the water, and (b) what is the problem if the pH is too low (too acidic)?

**Critical-Thinking Question**

***Write your answer(s) on another piece of paper.***

1. List the advantages and disadvantages of using the various methods listed in the article to disinfect municipal pool water.
2. Based on your analysis of these factors, describe how you would safeguard the water in your school’s pool and explain the rationale for your plan. (Note: If your school doesn’t have a swimming pool, consider this to be your plan for a possible future pool at your school.)

### Answers to Reading Comprehension Questions

1. **(a) Give three reasons why people complain about chlorine-based compounds in pool water.   
   (b) So, then, why *is* chlorine added to pools?**
2. People complain about chlorine-based compounds in pool water because they can
3. dry out skin.
4. turn eyes red.
5. produce the familiar, pungent pool smell.
6. Chlorine is added to pools to keep the water free of microbes, such as *Escherichia coli*, that can cause digestive troubles.
7. **Why is chlorine (Cl) added to pool water as a part of more complex molecules?**

Chlorine is added to pool water as part of more complex molecules because when these compounds are added to water, they spontaneously form hypochlorous acid (HClO), which is the disinfecting agent misleadingly called “free chlorine”.

1. **List three reasons why residential pool owners usually use trichlor for disinfecting their home pools.**

Residential pool owners usually use an isocyanurate known as trichlor to disinfect their home pools because it

dissolves slowly,

has high chlorine content, and

is easy to use.

1. **Why is maintaining the proper concentration of the disinfectant important?**

Maintaining the proper concentration of the disinfectant is important because it must be high enough so that some disinfectant is always in the water and also low enough to be comfortable for swimmers.

1. **Why is a stabilizer added to pool water?**

A stabilizer is added to pool water to help protect the hypochlorous acid from breaking down in sunlight.

1. **(a) How do bromine-containing compounds work as disinfectants? (b) Why are they a better choice than chlorine for hot tubs?**

Bromine-containing compounds can also be used to kill pathogens.

Bromine is a better choice than chlorine for hot tubs because it is more stable than chlorine at warm temperatures.

1. **(a) Why is the intestinal parasite *Cryptosporidium* resistant to chlorine? (b) How does UV radiation destroy this organism?**
2. *Cryptosporidium* has a protective coat that makes it hard to destroy with chlorine.
3. The UV light penetrates the organisms’ cell walls and damages their DNA.
4. **How are swimmers protected from UV radiation used to disinfect swimming pool water?**

Swimmers are protected from UV radiation used to disinfect pool water because the UV treatment takes place in a chamber away from swimmers, before water is released into the pool.

1. **Why are people asked to urinate and shower before entering a swimming pool?**

People are asked to urinate and shower before entering swimming pools to remove body sweat and urine that contain urea and other products that react with chlorine to form trichloramine (pool smell) that may also be linked to asthma in swimmers.

1. **List three sources of copper that can turn swimmers’ hair greenish.**

Swimmers’ green hair can be caused by copper introduced to the pool water from

1. copper-containing compounds added to water to kill algae.
2. copper already present in the water used to fill the pool.
3. copper from corroded plumbing.
4. **According to Le Châtelier’s principle, (a) if the pool pH is too high (too basic), how will this affect the concentration of hypochlorous acid and the safety of the water, and (b) what is the problem if the pH is too low (too acidic)?**

If the pool pH is too high, the reaction will favor the products (shift to the right) reducing the concentration of HClO and its ability to disinfect the water.

If the pH is too low (too acidic) the equilibrium will shift toward the reactants, and too much HClO (hypochlorous acid) could burn swimmers’ eyes.

**Critical-Thinking Question**

1. **List the advantages and disadvantages of using the various methods listed in the article to disinfect municipal pool water.**
2. **Based on your analysis of these factors, describe how *you* would safeguard the water in your school’s pool. Explain the rationale for your plan. (Note: If your school does not have a swimming pool, consider this to be your plan for a possible future pool at your school.)**

Accept student answers that demonstrate their understanding of the material in the article or, if assigned as homework, the students should demonstrate their understanding of aspects beyond those stated in the article.

1. **Advantages and disadvantages**

**Advantages**

**Chlorine- and bromine-containing compounds**

* Molecules include hypochlorite (ClO–) ions that form hypochlorous acid (HClO) when added to water.
* HClO kills most pathogens in pool water.
* Trichlor dissolves slowly and has a high chlorine content.
* Bromine-containing compounds kill pathogens and are more stable in hot water.

**UV radiation**

* UV radiation can kill *Cryptosporidium* by destroying its protective coat.
* UV radiation kills other harmful microbes.
* UV radiation can degrade trichloramine (NCl3), the potent “chlorine” smell in pools that might be linked to asthma in swimmers.
* The effects of UV radiation are not dependent upon the pH of the pool water.

**Disadvantages**

**Chlorine- and bromine-containing compounds**

* HClO breaks down in sunlight so requires a stabilizer for protection.
* Microbes with protective coats are hard to destroy with chlorine.
* Chlorine reacts with compounds such as urea (CO(NH3)2) in urine and sweat to produce trichloramine (NCl3) causing pool smell.
* Other by-products of chlorine reactions may be linked to asthma in swimmers.

**UV radiation**

* UV radiation can damage the skin.
* Pool water must be exposed to UV light before it enters the pool to avoid human exposure to the UV light.
* UV radiation does not continue to disinfect the water after it leaves the UV chamber.
* UV light does not destroy microbes that enter the water from people’s clothing and bodies.

If this Critical-Thinking Question is assigned as a mini-research project, you might want to direct students to these sites:

“Swimming Pools: Alternatives to Chlorine” discusses and gives pros and cons for disinfection procedures, including bromine. (<https://www.houselogic.com/by-room/yard-patio/swimming-pools-alternatives-chlorine/>)

The Pros and Cons of Using UV Rays for Water Treatment” lists some of the advantages and disadvantages of using UV radiation as part of the water treatment process. (<https://www.skillingsandsons.com/blog/the-pros-and-cons-of-using-ultraviolet-rays-for-water-treatment>)

**b. Possible student analysis**

I live in a rural area where it’s cold and it snows, so an outside pool would not be practical. Our school pool is indoors and much of our water supply comes from wells.

* Our school’s pool will definitely need a disinfecting agent such as trichlor, because it dissolves slowly in water and has a high chlorine content to destroy pathogens.
* Since our pool is indoors, we won’t have to worry about sunlight breaking down the microbe-destroying hypochlorous acid, a product of trichlor.
* We will encourage students to use bathrooms and require that students use the shower before entering the pool, to prevent the formation of chloramines, the products of chlorine reacting with urine and sweat.
* We do not have a hot spa, so chlorine-producing compounds will be more effective against pathogens than those of bromine.
* Since we fill our pool primarily with well water, we need to treat the water with UV radiation before it enters the pool, in order to kill chlorine-resistant pathogens like *Cryptosporidia*.
* UV radiation also degrades trichloramine present in the well water. This is important for me, since I am already an asthmatic.
* The UV disinfectant chamber must be sealed so that water is disinfected before it enters the pool, and swimmers aren’t affected by direct exposure to a high concentration of UV radiation.
* Although the pH of our well water fluctuates, this is not a huge problem because, despite the changes in HOCl concentration and its ability to kill pathogens due to changes in pH, UV disinfection will still be effective because UV radiation’s ability to kill pathogens is independent of the pH of the water.

# Standards and Vocabulary

**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.

#### Vocabulary

* **Vocabulary** and **concepts** that are reinforced in the April 2016 issue:
  + Structural formulas
  + Proteins
  + Hydrogen bonding
  + Environmental impacts of personal and societal decisions
  + Periodic properties
  + Nuclear chemistry
  + Equilibrium
  + Green chemistry
* Consider asking students to read “Open for Discussion: Paper vs. Pixel” on page 4 of the magazine before or after they read “Celebrating Paper!” to help them understand the complexity of making decisions about whether to use paper or electronic versions of paper products such as e-textbooks.
* The theme of Chemists Celebrate Earth Week (CCEW) this year is “The Chemistry of Paper,” so you and your students can check out some of the activities that can be found at the website found on the back cover of the magazine.
* The engaging video “Is it OK to pee in the pool?” (see p. 18 of the magazine), produced by ACS, has excellent chemistry information.
* 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, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.

### About the Guide

Teacher’s Guide team leader William Bleam and editors Pamela Diaz, Steven Long, and Barbara Sitzman created the Teacher’s Guide article material.

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Susan Cooper prepared the anticipation and reading guides.

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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 or $135 for a site license. 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>.