

**February/March 2017 Teacher's Guide for**

**Brush up on Toothpaste!**

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# About the Guide

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

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

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

<https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/products.html>.

# Student Questions

**Brush Up on Toothpaste!**

* + 1. Give two reasons why is it necessary to clean your teeth?
		2. What happens during the process of demineralization of teeth?
		3. How do bacterial acids cause hydroxyapatite to dissolve?
		4. Why is demineralizing not a problem under normal conditions?
		5. What two things happen as bacterial acids decrease the pH?
		6. What happens when the amount of phosphate decreases in the saliva?
		7. What is the composition of biofilms?
		8. What is tartar and why does it present a problem?
		9. Why should you be concerned with the overuse of abrasives?
		10. Give one advantage and one disadvantage of the use of antibiotics in toothpaste.
		11. What is a possible health risk of the presence of triclosan in toothpaste?
		12. How does the addition of fluoride ions to toothpaste help undo bacterial damage and prevent future decay?

# Answers to Student Questions

**(taken from the article)**

1. **Give two reasons why is it necessary to clean your teeth?**

*It is necessary to clean your teeth*

1. *to preserve them and*
2. *to enhance your overall health.*
3. **What happens during the process of demineralization of teeth?**

*During the process of demineralization of teeth, bacteria produce acids that dissolve the outer tooth layer, the enamel.*

1. **How do bacterial acids cause hydroxyapatite to dissolve?**

*Bacterial acids cause hydroxyapatite to dissolve when they decrease the pH and the hydroxide and phosphate ions bind with the hydrogen ions, dissolving the hydroxyapatite.*

1. **Why is demineralizing not a problem under normal conditions?**

*Demineralizing is not a problem under normal conditions because there is a stable equilibrium between calcium and phosphate ions in the saliva and the crystalline hydroxyapatite (tooth enamel).*

1. **What two things happen as bacterial acids decrease the pH?**

*As bacterial acids decrease the pH,*

1. *the tooth surface becomes acidic, and*
2. *the phosphate in the saliva combines with hydrogen ions to form three hydrogen phosphate species: H3PO4, H2PO4–, and HPO42–.*
3. **What happens when the amount of phosphate decreases in the saliva?**

*When the amount of phosphate decreases in the saliva, the rate of the demineralization (forward reaction) increases and the hydroxyapatite dissolves.*

1. **What is the composition of biofilms?**

*Biofilms are composed of bacteria and their slimy, glue-like excretions that stick to all kinds of materials (including teeth).*

1. **What is tartar and why does it present a problem?**

*Tartar is hardened biofilm that forms a crust that must be scraped off during periodic dental cleaning.*

1. **Why should you be concerned with the overuse of abrasives?**

*You should be concerned with the overuse of abrasives because they can remove enamel.*

1. **Give one advantage and one disadvantage of the use of antibiotics in toothpaste.**

*An advantage of antibiotics in toothpaste is that they kill bacteria; a disadvantage, bacteria can become resistant to the antibiotics.*

1. **What is a possible health risk of the presence of triclosan in toothpaste?**

*The possible health risk of the presence of triclosan in toothpaste is the disruption of the endocrine system. Students may add, “… affecting the thyroid gland and male and female hormones”.*

1. **How does the addition of fluoride ions to toothpaste help undo bacterial damage and prevent future decay?**

*Fluoride ions added to toothpaste help undo bacterial damage and prevent future decay because they replace the hydroxide ions in enamel (hydroxyapatite) to form fluorapatite, which is more resistant to bacterial acids.*

# Anticipation Guide

Anticipation guides help 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.

**Directions:**  *Before reading*, 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. Bacteria acids protect the enamel in our teeth.
 |
|  |  | 1. Tooth enamel contains calcium and phosphorous.
 |
|  |  | 1. Abrasion (scrubbing) can remove bacteria from teeth.
 |
|  |  | 1. Abrasives in toothpaste can remove enamel.
 |
|  |  | 1. Toothpastes were first used in the 1900s.
 |
|  |  | 1. Experts agree that antibiotics should be added to toothpaste.
 |
|  |  | 1. Fluorides help protect tooth enamel from bacterial acids.
 |
|  |  | 1. Too much fluoride can permanently discolor your teeth.
 |
|  |  | 1. People have been cleaning their teeth for more than 4000 years.
 |
|  |  | 1. Long ago people used eggshells, pumice, and pulverized bones as abrasives.
 |

# Reading Strategies

These graphic organizers are provided to help students locate and analyze information from the articles. 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 articles. The use of bullets helps them do this. If you use these reading and writing strategies 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 |

***Teaching Strategies:***

* Links to **Common Core State 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** and **concepts** that are reinforced in this issue:
	+ Chemical and physical properties
	+ Chemical reactions
	+ Viscosity
	+ Personal and community health
	+ Oxidation states
	+ Elements
	+ Conservation of matter
	+ Consumer choices
	+ Recycling
* Most of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them make informed choices as consumers. The articles also connect chemistry and engineering.
* Consider asking students to read “Open for Discussion” on page 4 to extend the information in “The Drive for Cleaner Emissions” on pages 5-7.
* The infographic on page 19 provides more support for the article “Brush Up on Toothpaste!” on pages 14-15.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles.
* You might also ask them how information in the articles might affect their choices as consumers. Also ask them if they have different ideas to solve some of the problems discussed in the articles.
* The Background Information in the *ChemMatters* Teachers Guide has suggestions for further research and activities.

***Directions*:** As you read the article, complete the graphic organizer below to describe why we need to brush our teeth.

|  |  |  |
| --- | --- | --- |
|  | **Why important** | **Chemicals involved** |
| **Effect of Bacteria on Teeth** |  |  |
| **Abrasives in toothpaste** |  |  |
| **Ingredients other than fluoride** |  |  |
| **Fluoride** |  |  |

**Summary:** On the back of this page, summarize the information about the chemistry of toothpaste in a sentence (20 words or less).

# Connections to Chemistry Concepts

**(for correlation to course curriculum)**

1. **Equilibrium**—Information from this article (and this Teacher’s Guide) presents an excellent opportunity to augment the study of equilibrium concepts by combining both the chemical and biological (bacterial production of lactic acid) reactions to explain the factors that can affect equilibrium systems.
2. **Le Châtelier’s Principle**: The demineralization and remineralization of hydroxyapatite provides a good example of Le Châtelier’s Principle, as the stresses from the pH and ion concentration in the saliva affect this equilibrium.
3. **Polyprotic acids**—Class discussion of the equilibrium steps involved in the dissociation of phosphoric acid (H3PO4), a triprotic acid, can begin with the demineralization of our tooth enamel.
4. **pH**—Use the information in this article when discussing the pH scale. If your school has recently eliminated sugary drinks from vending machines, the article provides one reason for the health concerns that may have prompted this move. [Remember that consuming sugary drinks may drop the pH to 5.5, thus increasing the potential for demineralization of tooth enamel.]
5. **Ionic compounds**—The chemical formula for tooth enamel, hydroxyapatite, Ca10(PO4)6(OH)2, provides the opportunity to use an “out of the textbook” way to discuss a complex ionic formula. Since the compound is in equilibrium with its ions, it will provide a good example of anionic and cationic charge balance in the expression.
6. **Balancing chemical equations**—Ask students to use an “atom inventory” to determine if the equilibrium equation between hydroxyapatite and its ions is balanced. To do an “atom inventory” begin by counting the number of each type of atom on the reactant side (i.e., 10 Ca atoms; 6 P atoms, etc.) of the equation, then repeat on the product side. If the numbers for each type of atom match, the equation is balanced.
7. **Double replacement chemical reactions**—When your students study simple double replacement reactions, this is a good place to discuss the health benefits of adding fluoride to water systems and toothpaste. When fluoride ions replace hydroxide ions in hydroxyapatite, the double replacement reaction forms fluorapatite, a mineral that is more acid resistant in tooth enamel than hydroxyapatite.
8. **Solubility**—When students study the solubility of ionic compounds in water, the increased solubility of hydroxyapatite in acid can be used as an example of how an important compound (our tooth enamel) can be destroyed by the removal of phosphate ions.

# Possible Student Misconceptions

**(to aid teacher in addressing misconceptions)**

1. **“I have no pain, so my teeth must be fine.”** *Cavities often don’t cause any pain, so you may not be aware that the enamel has been completely demineralized in the area. In addition to dental caries, this can lead to more serious problems such as gum disease or oral cancer.*
2. **“Since I’m really careful about not eating sweets and sugary drinks for snacks, I don’t have to worry about tooth decay.”** *Bacteria in the mouth need processed sugar to survive and produce enamel-destroying acid. Any food that is a starch or carbohydrate contains processed sugar. So, mouth bacteria can produce acid by feeding on other snacks, such as crackers, bread, potato chips, pasta and peanut butter.*
3. **“Sugar destroys teeth, so sugary products should be banned from our vending machines.”** *While banning sugary food and drinks from vending machines may be a good idea, sugar does not destroy teeth. Cavities are caused by the acid produced when bacteria in the mouth consume sugar.*
4. **“It is best to brush your teeth right away, after every meal.”** *Actually it is better to wait 30–60 minutes before brushing. Your tooth enamel may soften when exposed to acidic juices or foods. Waiting a bit allows the equilibrium to stabilize between hydroxyapatite and its ions.*
5. **“Children’s teeth are weaker, so they are more prone to cavities than adults.”** *Children’s teeth are not weaker. They frequently get more cavities than adults because they don’t brush as well.*
6. **“The whiter your teeth, the healthier they are.”** *This is a misconception. The natural color of teeth varies from person to person. And even if someone’s teeth are very white, there may be cavities or infections between them.*
7. **“What happens in my mouth really doesn’t affect the rest of my body.”** *An infection in the mouth can spread to other parts of the body, so it is important to treat it promptly.*
8. **“I am young, busy and in good shape, so I really don’t need to worry about the importance of brushing and flossing to maintain my health.”** *Actually, failure to take care of your teeth can lead to gum disease that can affect your body’s resistance to more serious diseases such as pneumonia and diabetes, and eventually lead to cardiovascular problems.*
9. **“I think that if some PO43– ions are removed from the right side of the equilibrium expression in the article, there will be no effect on the left side where the hydroxyapatite is located.”** *There is often a misconception when students consider that an equilibrium expression as written means that the products and the reactants behave as if they are in two separate containers. Demonstrations and laboratory exercises can help bridge this gap in understanding between the shorthand symbolic written expression and the actual chemical reaction that occurs dynamically with all chemical species present and mixed together (in one beaker).*

# Anticipating Student Questions

**(answers to questions students might ask in class)**

1. **“How will I know when to visit the dentist? Should I wait until I have a lot of pain or my gums start bleeding?”** *Serious dental problems like cavities and gum disease may not cause pain or bleeding initially, so it is best to visit the dentist regularly to have your teeth checked and cleaned professionally before you have severe problems.*
2. **“Do teeth-whitening toothpaste and dental whitening strips weaken your teeth?”** *Prior to 1990, the materials used to bleach teeth were acidic and could break down the enamel. Now whiteners are pH neutral. When used according to instructions they will not erode the enamel or cause cavities. They whiten by simply oxidizing your teeth so that light refracts more favorably off the enamel.*
3. **“Should I worry if my gums bleed a little bit when I brush and floss my teeth?”** *You probably don’t need to worry. Actually it is normal for gums to occasionally become irritated and bleed when removing food and plaque from your teeth. But if your teeth continue to bleed, this could be an indication of gum disease and you should see a dentist.*
4. **“I usually don’t take the time to floss, is this OK?”** *This is not a good idea. Although flossing may seem like an extra time-consuming step, it is important. Regular brushing only cleans the surface; it does not remove the bacteria lodged between your teeth. Bacteria located in places that are hard to reach with a brush can cause gum disease and decay.*
5. **“Should I choose a toothbrush with hard bristles so that I can really scrub my teeth clean?** *No, very hard bristles may damage your enamel and gums. Soft bristles are the best choice for a gentle but thorough teeth cleaning.*
6. **“Will the pain of a toothache go away eventually?”** *No, toothaches are usually caused by infections and the pain will increase until a dentist can determine the cause and treat the infection.*
7. **“I already have three cavities, so I’m really worried about my teeth. I read that hydroxyapatite decays at pH 5.5 and normal saliva can be pH 6.5. If I drink a glass of lemonade, will my enamel decay?”** *A glass of lemonade will not be a problem. First, pH is calculated on a logarithmic scale so one pH unit would mean a ten-fold decrease in acidity; drinking lemonade would not have this effect. In addition, the hydroxyapapite equilibrium quickly adjusts to a small decrease in acidity because the saliva is saturated with calcium and phosphate ions.*
8. **“When a system is at equilibrium, why can’t you see any change?”** *At equilibrium the rate forward (forming products) is equal to the rate reverse (reforming the reactants). At the particle level, products are constantly forming and reversing to become reactants again. The equal forward and reverse rates keep the concentrations of the reactants and products constant (not equal), so change is not visible at equilibrium.*
9. **“Why does orange juice taste bitter after I brush my teeth?”** *Orange juice tastes bitter after you brush your teeth because your toothpaste probably contains the detergent, sodium lauryl sulfate (SLS), and you inherited a gene that signals the receptors on your tongue to perceive SLS as bitter.**Not everyone has this experience. There are genetic differences in people’s perception of bitterness following use of a toothpaste containing the additive, sodium lauryl sulfate.*

# Activities

**Labs and Demos**

1. **Le Châtelier’s Principle: copper chloride equilibrium lab, 5E model:** This familiar laboratory exercise is written in the 5E model format. Prelab discussion material for the teacher as well as teacher guidance through the laboratory activity is clear, thorough, and fits the model well. (<http://nascent-erc.org/wp-content/uploads/2016/03/ChemicalEquilibrium_CariszaLenaburg.pdf>)
2. **Le Châtelier’s Principle lab, cobalt chloride:** This is one of the best wet labs for equilibrium because the colors are bright and clearly show shifts. The FlinnFax version uses 12 M HCl, so it should be done under a hood or as a demonstration. *ACS Chemistry in the Community, 6th Ed.* 5B.2, successfully substitutes sodium chloride (can use non-iodized table salt) for the concentrated acid to make it a safe lab for all 7–12 students. (<https://www.flinnsci.com/globalassets/flinn-scientific/all-free-pdfs/dc91838.pdf>)
3. **Tooth decay lab:** “Acids, Bases, and Tooth Decay” is a laboratory activity designed for Grade 8 students that could easily adapted for use at the high school level. Vinegar and Chicken bones are used to mimic the effect of acid on enamel. Complete laboratory instructions are given, including data tables and questions to be answered. (<http://bela.usc.edu/pdfdocuments/Lesson%20plans/8th/Acids_Bases_and%20You_Lesson_HLai.pdf>)
4. **Fluoride protection demo:** Pretreat one raw egg with an over-the-counter fluoride rinse (available at drug stores or on Amazon). Then place this egg and an untreated egg (control) in separate containers of vinegar and observe. (<http://healthyteeth.org/power-of-fluoride/>) Note: This Web site also contains other lab ideas designed for elementary students that can be adapted as quick demos for high school chemistry students.
5. **Lab—search for plastic microbeads:** Students can check for microbeads in toothpaste, face scrub and laundry detergent. Mix soap material with water, strain through lab or coffee filter and look for beads trapped by the filter. (<http://www.forbes.com/sites/carmendrahl/2016/01/09/what-you-need-to-know-about-microbeads-the-banned-bath-product-ingredients/#59dc06845f35>)
6. **Demo─“Elephant Toothpaste”:** This is the FlinnFax version of a fun demonstration that will grab student interest in the study of “real” toothpaste. Be certain to do this in a large demonstration tray. **Be extremely careful using 30% hydrogen peroxide.** See complete directions here: (<https://www.flinnsci.com/globalassets/flinn-scientific/all-free-pdfs/dc91098.pdf>)

**Safer, 6% hydrogen peroxide version here:** You can get by with the safer beauty salon concentration of hydrogen peroxide. Note that yeast is used in this version. (<https://sciencebob.com/fantastic-foamy-fountain/>)

**Short videos (1:08) of elephant toothpaste reaction:** In case you can’t do the lab, here are two video options:

<http://www.using-hydrogen-peroxide.com/elephant-toothpaste.html>, and
the “sciencebob” URL directly above also contains a video of the reaction.

**Media**

1. **YouTube video (10:35) “Plaque Attack”:** This video might be a fun way to introduce the subject; it provides a good introduction to the process of tooth decay. The animated cartoon bacteria set up acid factories and make gums swell so that others can hide underneath and move down to bones. That is until, a toothbrush comes along and destroys their colonies.
2. **YouTube video (0:55), “Plaque Biofilm”:** This very short video provides a good way to display plaque biofilm on teeth when colored by disclosing-tablet dye. Tell your students that this can be done at home. The dye can be purchased over the counter. In the film, the animated bacteria are shown working together to consume carbohydrates and produce acids. The final picture shows the hardened film as tartar. (<https://www.youtube.com/watch?v=6vVaBebRuRI>)
3. **Two YouTube videos on tooth structure:**
* (1:56) “Tooth Anatomy” (<https://www.youtube.com/watch?v=rDxatqUbkVk&t=15s>)
* (3.24) “Your Teeth Explained by Colgate” (<https://www.youtube.com/watch?v=dpZ0Nv3uZqw>)

Both videos use good diagrams to illustrate the components of a tooth, as the function of each is explained. The first video provides a short description; the second covers the same material in greater depth and includes discussion of gingivitis and periodontitis.

1. **YouTube video (2:00), “Tooth Decay: How it Happens and How to Avoid it”:** This is a well done Australian production that would serve as an excellent classroom introduction to the entire process from eating sugar to cavity formation, and more serious problems. Action pictures of bacteria are shown during a description of colonization. (<https://www.youtube.com/watch?v=Z3rheJVWNt4#t=107.8978979>)
2. **YouTube video (6:00), “What Are Bacterial Biofilms? A Six Minute Montage”:** Researchers describe their experiments on biofilms and the difficulty in removing them when they infect heart values, bones and urinary infection, because they are very resistant to antibiotics. This video explains the growth of biofilms and ways that they can become life-threatening. (<https://www.youtube.com/watch?v=lpI4WCM_9pM>)
3. **YouTube TED Talks (18:04), “How Bacteria Talk”:** As with other TED Talks, this is an excellent presentation about the chemical conversations between bacteria. Although not specifically addressing pathogenic bacteria in the mouth, the moderator discusses the cutting edge research into protective (chemical) mechanisms used by bacteria. (<https://www.ted.com/talks/bonnie_bassler_on_how_bacteria_communicate?language=en>)
4. **ABC News Video (2:53), “Which toothpastes contain microbeads?”:** This clip from a September 23, 2014 newscast features a dental hygienist who notices small beads on the teeth and gums of a patient. Concerns about the non-biodegradable polyethylene beads that are used to color toothpaste are discussed. (<http://dentalpatientnews.com/which-toothpastes-contain-microbeads/>)
5. **YouTube video (1:47), “These are Microbeads”:** This video contains nice photography and music, while well-prepared text explains the pictures (no audio other than the music). The video takes microbeads from humans brushing teeth, to fish, to humans eating fish, to bans on microbeads. And finishes with “What can you do?” (<https://www.youtube.com/watch?v=55Y8ggVURPs>) also located at this URL: <http://www.sciencealert.com/microbeads-are-causing-the-fish-we-eat-to-become-toxic-study-finds>)
6. **YouTube video (7:00), “Le Châtelier’s Principle”:** Bozeman Science produced this excellent production that begins with an explanation of the gaseous Haber process to form ammonia (3 H2 + N2 ⇌ 2 NH3). Next, the equilibrium between N2O4 and NO2 shows gas tubes as the color of the gas changes in response to the stresses of temperature and pressure exerted on the tubes.

**Lessons and lesson plans**

1. **Relevant student research on fluorine in their drinking water:** The U.S. CDC Web site can be used to check the concentration of fluorine in local water supplies. The Web site contains both a place to click on your state and water supplier, and a map that shows participating states. (<https://nccd.cdc.gov/DOH_MWF/Default/Default.aspx>)
2. **A silent PowerPoint presentation (14 slides), “What causes tooth damage”:** Some of the slides on the *Web*MD site include tooth structure and pictures of tooth decay. These can be used to augment a discussion on tooth decay. (<http://www.webmd.com/oral-health/ss/slideshow-enamel-erosion>)
3. **Understanding pH scale:** See a possible classroom lesson using the Hubert Alyea diagram to explain the concept and calculate pH values. This is discussed in the “pH” section of the background information in this Teacher’s Guide.
4. **Supermarket/Internet toothpaste research:** Students list active and inactive ingredients found on toothpaste labels and investigate their use (rationale for including them in toothpaste). They could answer and share questions such as: What is it? Is it safe? Why was this stuff put in toothpaste?
5. **Write a persuasive essay to answer the question, “Should plastic microbead use be banned entirely?”** Microbeads are tiny pieces of plastic that help scrub your face to reduce unsightly acne and scrape plaque from your teeth to prevent dental caries. They also pollute the world’s waterways. The following Web site presents an environmental problem: (<http://www.npr.org/2014/05/21/313157701/why-those-tiny-microbeads-in-soap-may-pose-problem-for-great-lakes>)

The following Web site contains a format, plus detailed information about writing a persuasive essay. Emphasize to students that their essays must include reliable evidence to support their claims. (<http://www2.waterforduhs.k12.wi.us/staffweb/sereno/mainpages/InfoLit/Microsoft%20Word%20-%20Writing%20the%20Persuasive%20Essay.pdf>)

1. **Model acid situations by drawing pictures:** Label four equally sized boxes for acid pictures: (1) weak, (2) strong, (3) concentrated and (4) dilute. Using HA to represent an acid (H+ for the cation, A– for the anion and HA for the molecular/non-disassociated form).

Key:

1. mostly HA, a few H+ and A- in equal amounts
2. a few HA, mostly H+ and A- in equal amounts
3. many HA and H+ and A- in equal amounts
4. the same as (3) but less of each.

Adapted from *ACS Chemistry in the Community* 6th Ed. 4C.11 “Modeling Matter: Strong versus Concentrated”

1. **Khan Academy lesson, “Le Châtelier’s principle” (14:43):** This is a well done lesson that can be watched in class or assigned as homework. Note this URL also provides access to a total of five lessons that follow this introduction. The more advanced lessons include a focus on the reaction quotient (Q and Qc), Q vs K, and a set of practice problems on Le Châtelier’s Principle). **(**<https://www.khanacademy.org/science/chemistry/chemical-equilibrium/factors-that-affect-chemical-equilibrium/v/le-chatelier-s-principle>)

**Projects and Extension Activities**

1. Student groups willdesign their own toothpaste and prepare a sales advertisement for it. They will need to name their toothpaste, choose active and inactive ingredients for their product and highlight the benefits of their product. In their experimental design, ask them to include the reason for their chosen ingredients and note any safety precautions that must be included in their advertisement. Finally, the advertisement will be designed as a classroom presentation using the media of your choice (Prezi, PowerPoint, Video, live skit, poster board, etc.)
2. This extended lab activity might provide an opportunity to work/confer with a biology class. To investigate the antibacterial effectiveness of various brands of toothpaste, students grow teeth swabs on agar following tooth before and after brushing with each brand of toothpaste. Details of this suggested science fair project are located at <http://www.all-science-fair-projects.com/print_project_1294_104>.
3. This experiment is designed to test the effects of various sodas on “tooth enamel”. This can be assigned as a take home lab or an extended in class experiment. Students test the pH of each soda, and then soak granulated limestone (CaCO3) in each. Crumbled white blackboard chalk or marble scraps from kitchen countertop production can be used. Detailed instructions are given. ([http://web.archive.org/web/20090213222225/http://fellowshipch.org/pcasfelizabeth05.html](http://web.archive.org/web/20090213222225/http%3A//fellowshipch.org/pcasfelizabeth05.html))
4. Another similar extended laboratory activity that can be done safely at home or in class is suggested as a science fair project. This lab uses eggshells (CaCO3) to simulate tooth enamel. The shells are soaked in a list of various drinks. ([http://mwvsciencefair.wikispaces.com/Teeth+Decay+in+Liquids](http://mwvsciencefair.wikispaces.com/Teeth%2BDecay%2Bin%2BLiquids))

# References

**(non-Web-based information sources)**

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

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

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Some of the many ingredients in toothpaste and their uses are listed by category, along with explanations. Additional details regarding foaming agents, solvents and binders are included. Also discussed is the hypersensitivity to eating hot, cold or sour foods experienced by some people as tooth pain. This problem can be alleviated by use of Sensodyne® toothpaste containing potassium nitrate, sodium citrate or strontium chloride. This article does a nice job of condensing much of the background information contained in this Teacher’s Guide. (Yohe, B. Toothpaste. *ChemMatters*, 1986, *4* (1), pp 12–13)

Students often ask why orange juice tastes bitter after you brush your teeth, yet some students will disagree. This article explains the genetic differences in people’s perception of bitterness following brushing with toothpaste containing the detergent sodium lauryl sulfate (SLS). This article was written in 1995; some now question the potential for side effects linked to the use of SLS. This is noted in the section, “Detergents” in this Teacher’s Guide. (DeCristofaro, P. The Taste Effect of Sodium Lauryl Sulfate or Why does orange juice taste so bad after you brush your teeth? *ChemMatters*, 1995, *13* (2), pp 14–15)

The Teacher’s Guide for the April 1995 *ChemMatters* article above contains information and data from participants who were asked to compare sweet, sour and bitter tastes before and after brushing with an SLS containing toothpaste. Further information is given about the genetic differences in bitterness perception following oral exposure to SLS.

The function of ingredients in mouth wash are described (e.g., oils used to mask the taste of thymol, an antibacterial and fungicide, and to sweeten bad breath). Several structural formulas are included. In addition, ingredients used to reduce plaque and thus reduce cavity formation are discussed. (Baxter, R. Mouthwash What’s In It for You? *ChemMatters*, 1996, *14* (4), pp.6–8)

While not involved in tooth brushing, this article presents an exciting way to discuss the importance of dynamic equilibrium. Maintenance of the solubility equilibrium between oxygen gas and hemoglobin is vital to the survival of Mt. Everest climbers. This article focuses on Le Châtelier’s Principle to explain the results of stresses placed on this equilibrium by the altitude and by the pH changes in the climber’s blood. (Rohrig, B. Mt. Everest Climbing in Thin Air. *ChemMatters*, 2000, *18* (1), pp 4–6)

This article contains a section on “Smelly Breath” attributed to failure to brush teeth before bedtime. This gives bacteria time to “munch” on leftover food particles during the night, preventing the remineralization of hydroxyapatite and leading to tooth decay. Nice illustrations and explanations are included that could be used to augment material in the Brown article. (Rohrig, B. Demystifying Gross Stuff. *ChemMatters*, 2011, *29* (3), pp 12–14)

The Teacher’s Guide for the October 2011 *ChemMatters* article above contains additional information about the role that fluoride ions play in protecting tooth enamel. In addition, a detailed explanation of the biochemistry involved in the metabolism of sugar by *S. mutans* is included.

A nice microscopic picture showing how enamel is composed of the bundles of crystalline rods is included this article. The how, why and safety of teeth-whitening methods is discussed. (Sitzman, B. and Goode, R. Open for Discussion: Teeth Whiteners. *ChemMatters*, 2013, *31* (1), p 4)

This article contains detailed information about the risks and benefits of triclosan in everyday products. Chemical structures indicate the ease of triclosan’s ability to mimic other hormones. (Harper, K. Bacteria Buster! Triclosan Kills Bacteria, but Is It Safe? *ChemMatters*, 2015, *33* (4), pp 13–15)

 The Teacher’s Guide for the December 2015 *ChemMatters* article above contains additional information about triclosan’s structure and characteristic properties. These contribute to the molecule’s ability to cross cell membranes and interfere with the actions of human hormones such as estrogen and thyroxine.

# Web Sites for Additional Information

**(Web-based information sources)**

**History of dental care**

 In July 2015, *Nature* published an article describing the process of analyzing indications of early dentistry on prehistoric teeth. The entire research article, “Earliest evidence of dental caries manipulation in the Late Upper Paleolithic” is available at <http://www.nature.com/articles/srep12150#f2>.

 This site titled, “Human Teeth Fossils”, contains many photographs with short descriptions of the fossil teeth, including those showing early “dental” practices. The site references *National Geographic Study* and BBC programs. (<http://www.crystalinks.com/fossilteeth.html>)

 The Colgate-Palmolive Manufacturing Company published an article about early teeth cleaning processes; it discusses the early toothbrushes described in the Brown article. “The history of toothbrushes and toothpaste” is located at: (<http://www.colgateprofessional.com/patient-education/articles/history-of-toothbrushes-and-toothpastes>)

**History of human dental caries**

 In 2004, the World Health Organization (WHO) published a thorough study of public health nutrition, “Diet, nutrition and the prevention of dental diseases”. Their investigation compares the oral health of people in industrialized nations with that of those who live in developing countries. The investigation describes the effects on the health of teeth by the amount of free sugars, carbohydrates and fluorides in the diet. Free sugars are those from honey, fruit juices and syrups, plus those added by manufacturers and consumers. (<http://www.who.int/nutrition/publications/public_health_nut7.pdf>)

This *Scientific American* article discusses the details and shortcomings of the “Paleo Diet” designed to follow the diet of hunter-gatherers, people who lived before the age of agriculture. (<https://www.scientificamerican.com/article/why-paleo-diet-half-baked-how-hunter-gatherer-really-eat/>)

**The oral microbiome**

 This paper published in the *Journal of Young Investigators* in December 2007 provides an excellent description of Yale University research. Investigators looked at the high rate of dental caries in low income populations. They attribute this to diets high in sugar that disrupt the homeostasis of the oral microbiome, shifting the acid-base equilibrium of hydroxyapatite leading to tooth decay. The research findings include modes of transmission and treatment options. One example shows that when Swedish children were given medication to prevent *S. mutans* colonization, the development of dental caries was delayed by an average of three years. (<http://www.jyi.org/issue/the-role-of-streptococcus-mutans-and-oral-ecology-in-the-formation-of-dental-caries/>)

 The July 2016 *Journal of the Canadian Dental Association (CDA)* features four articles on the “Oral Microbiome”, stating that the microbiome is “Critical for Understanding Oral Health and Disease”. These articles discuss research data from the 2008 U.S. National Institutes of Health (NIH) “Human Microbiome Project” (HMP):

* Ancient Dental Calculus: Dental calculus from ancient teeth contains trapped human and microbial DNA. Analysis of this material leads to better understanding of the evolution of the human oral microbiome.
* Subgingival Microbiome Shifts: During the last 50 years, identification of oral bacterial species has increased seven fold. This enables scientists to better describe bacterial adaptations and host responses during transitions from gingivitis to periodontitis.
* Caries Pathology: *S. mutans* is not the only acid producing bacterium. Some beneficial bacteria actually help mitigate the acid producing response to sugars. Better understanding may lead to improved therapies caries prevention.
* Uncultured Oral Bacteria: New technologies have led to increased ability to culture bacteria and better understanding of species that remain uncultured.

(<http://www.cda.org/Portals/0/journal/journal_072016.pdf>)

Elmhurst College has produced a “Virtual ChemBook” that contains excellent diagrams and explanations in the section “Sugar and Tooth Decay”. These structural diagrams might serve as a good way to introduce the chemistry behind the formation of acid that causes dental caries. (<http://chemistry.elmhurst.edu/vchembook/548toothdecay.html>)

**Gum disease**

This paper, “Life below the Gum Line: Pathogenic Mechanisms of *Porphyromonas gingivalis*”was originally published in *Microbiology and Molecular Biology Reviews*. It provides details of the colonization and virulence features of the bacteria that cause gingivalis. *P. gingivalis* has a commensal relationship with its host, where it successfully adheres to teeth structures. While its activity is generally limited to tooth structures, if untreated it may lead to more systemic problems such as cardiovascular disease and premature births. (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC98945/>)

 This article describes the relationship between health and inflammation. The link between inflammation of dental tissues and systemic problems (diseases) is informative. (<http://www.colgateprofessional.com/professional-education/articles/inflammation-relationship-between-oral-health-systemic-disease>)

 The paper “Systemic Diseases Caused by Oral Infection” acknowledges that current epidemiological research can describe the relationships between oral problems and systemic diseases, but the research does not explain the causes of these links. (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC88948/>)

 “Chronic inflammation in periodontal diseases: immunopathogenesis and treatment”, published in *Dentistry,* discusses plaque formation and the role of inflammation and its effects on other body systems. Along with a classification of periodontal diseases, the article shows radiographs of teeth in various stages of aggressive periodontitis.

(<http://www.dentistryiq.com/articles/gr/print/volume-2/issue-3/original-article/chronic-inflammation-in-periodontal-diseases-immunopathogenesis-and-treatment.html>)

**Biofilm detection**

This *Web*MD article, “Self-Examination for Dental Plaque”, discusses the formation of dental plaque and how it can be detected at home after inadequate brushing and flossing. Detailed instructions on the use and risk of self-disclosing tablets are given. (<http://www.webmd.com/oral-health/self-examination-for-dental-plaque#1>)

 “Disclosing Agents in Periodontics: An Update Paper” provides some history of attempts to develop dyes designed to indicate how well biofilm has been removed by tooth brushing. There are also suggestions for dentists on how to instruct their patients on proper dental hygiene and the use of disclosing dyes to identify areas that have not been cleaned. (<https://nebula.wsimg.com/5d867182ab0040f0f175ee9bef4988b7?AccessKeyId=E54D0FD2D82F47860512&disposition=0&alloworigin=1>)

 Researchers used a three-dye disclosing agent to study the relationship between the risk of caries development and the formation of plaque. This study was mentioned in the section on biofilm detection in the background information section of this Teacher’s Guide. The complete paper on the study contains details on the experimental design and the data collected and analyzed. “Efficacy of three-tone disclosing agent as an adjunct in caries risk assessment” is available at this URL: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4549987/>.

**Tooth structure**

 The University of Pittsburgh School of Dental Medicine article, “Introduction: The Periodontium Supporting Structure of Teeth” contains additional information on the function and structure of major tooth tissues. (<http://dental.pitt.edu/periodontium>)

**Demineralization and equilibrium**

 This site discusses the equilibrium (cycles) involved in the demineralization and mineralization of tooth enamel at the biofilm/tooth interface. Also discussed are normal and dangerously low oral pH values for children as well as for adults. (<http://www.oralhealthgroup.com/features/dental-remineralization-simplified/>)

**Le Châtelier’s Principle**

 Le Châtelier’s Principle is defined, dynamic equilibrium is described, and shifts in response to changes in concentration, temperature and pressure are discussed with examples. An explanation is given to dispel the misconception that catalysts affect the equilibrium position. (<http://www.chemguide.co.uk/physical/equilibria/lechatelier.html>)

**Toothpaste ingredients**

This URL takes you to a blog about toothpaste and the many varieties on store shelves. The blogger lists five active ingredients and the incredibly long list of inactives. He also lists the probable use of each! (<http://theatticlight.net/posts/Toothpaste/>)

 “Toothpaste─What’s in it?” provides a good summary of toothpaste ingredients divided into sections of abrasives, detergents, fluoride compounds, humectants systems and flavoring. This might provide a good beginning for a classroom discussion. (<http://www.deardoctor.com/articles/toothpaste-whats-in-it/>)

**Active ingredients**

The original research, “Resisting the Onset of Hydroxyapatite Dissolution through the incorporation of Fluoride” by Nora de Leeuw (School of Crystallography, Department of Chemistry, University College London) was done by computer simulation and published in the *ACS Journal of Physical Chemistry* in 2004. Abstract is available here: <http://pubs.acs.org/doi/full/10.1021/jp036784v>; only subscribers can access the full article.

 This wiki site describes the history of contentious situations regarding the use of fluoride in U.S. municipal water supplies. Students may find it interesting to check the laws regarding their water supplies. (<https://en.wikipedia.org/wiki/Water_fluoridation_in_the_United_States>)

**Fluoride and dental** **fluorosis**

This *Web*MD article, “Fluorosis: Symptoms, Causes and Treatments”, summarizes the dental condition that affects teeth below the gum line as they mature. Only one in four people in the U.S. (between the ages of four and forty nine) are affected by dental fluorosis. Most cases are so mild that they are not noticeable. But about 2% have moderate fluorosis, and 1% of the cases are severe as shown in the pictures in the “Fluoride—excess” section of this Teacher’s Guide. These ugly teeth are not a symptom of a severe health problem, but they can present a serious cosmetic (psychological) problem. (<http://www.webmd.com/children/fluorosis-symptoms-causes-treatments>)

**Triclosan**

The U.S. FDA compares the risks with the benefits of triclosan use in “Antibacterial Soap? You Can Skip It -- Use Plain Soap and Water”. As the title suggests, washing thoroughly with soap and water is a very effective way to remove bacteria. Whereas, the risk of antibacterial resistance is a serious, often deadly, problem in our health care system. Data from studies has led to the ban on household use of triclosan (except in Colgate toothpaste). (<http://www.fda.gov/ForConsumers/ConsumerUpdates/ucm378393.htm>)

**Xylitol**

 The March 27, 2015 article in the *American Dental Association (ADA) News, “*New research shows clinical evidence unclear on effects of xylitol products preventing dental caries”, sheds more light on the questions about xylitol as a cavity preventing agent. This article discusses the need for better designed studies that include randomized, placebo-controlled trials that include data on side effects such as bloating and diarrhea. (<http://www.ada.org/en/publications/ada-news/2015-archive/march/new-research-shows-clinical-evidence-unclear-on-effects-of-xylitol-products-preventing-dental-carie>)

**Inactive ingredients**

This site contains a physical geology student’s paper on minerals used as abrasives in toothpastes. This Cochise College student project includes nice color pictures and descriptions of the minerals that might be useful for display in the classroom. (<http://skywalker.cochise.edu/wellerr/students/toothpaste/project.htm>)

**Sweeteners**

 “The Theory of Sweet Taste”, published in the *ACS Journal of Chemical Education*, discusses the connection between the molecular structure of compounds and their sweet taste. The abstract is available here: <http://pubs.acs.org/doi/abs/10.1021/ed049p171>; only subscribers can access the full article.