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**October/November 2015 Teacher's Guide for**

***Tooth Decay: A Delicate Balance***

**Table of Contents**

[About the Guide 2](#_Toc430858735)

[Student Questions 3](#_Toc430858736)

[Answers to Student Questions 4](#_Toc430858737)

[Anticipation Guide 6](#_Toc430858738)

[Reading Strategies 7](#_Toc430858739)

[Background Information 10](#_Toc430858740)

[Connections to Chemistry Concepts 35](#_Toc430858741)

[Possible Student Misconceptions 35](#_Toc430858742)

[Anticipating Student Questions 36](#_Toc430858743)

[In-Class Activities 38](#_Toc430858744)

[Out-of-Class Activities and Projects 41](#_Toc430858745)

[References 42](#_Toc430858746)

[Web Sites for Additional Information 44](#_Toc430858747)

# About the Guide

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Articles from past issues of *ChemMatters* 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.

The *ChemMatters* DVD also includes Article, Title and Keyword Indexes that covers all issues from February 1983 to April 2013.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558.

Purchase information can be found online at [www.acs.org/chemmatters](http://chemistry.org/chemmatters/cd3.html).

# Student Questions

* 1. Name the three main constituents of the hard parts of the tooth.
  2. What is hydroxyapatite?
  3. Why does the author say the hydroxyapatite in your teeth “is dynamic”?
  4. What are the products of the demineralization of hydroxyapatite?
  5. How does pH differ between that of the mouth and that of the body?
  6. How do the lungs help to control blood pH (e.g., after exercising)?
  7. How does saliva maintain the pH of the mouth after bacteria produce acid from the carbohydrates we’ve consumed?
  8. What happens next to maintain equilibrium?
  9. What are the results of a consistently low pH in the mouth?
  10. What are the two main materials used to fill a decayed tooth, once the decay has been removed?
  11. Name three problems with the use of amalgams for filling teeth.

# Answers to Student Questions

* + 1. **Name the three main constituents of the hard parts of the tooth.**

*The three main constituents of the hard parts of the tooth are mineral, proteins and water.*

* + 1. **What is hydroxyapatite?**

*Hydroxyapatite is the mineral that makes tooth enamel hard. Its formula is Ca5(PO4)3(OH).*

* + 1. **Why does the author say the hydroxyapatite in your teeth “is dynamic”?** *The author mentions that the hydroxyapatite in your teeth “is dynamic” because there is an equilibrium occurring between demineralization and mineralization of the hydroxyapatite, as food is eaten which reduces pH that increases the rate of demineralization, and the subsequent release of saliva with a slightly higher pH that increases the rate of mineralization.*
    2. **What are the products of the demineralization of hydroxyapatite?**

*The products of the demineralization reaction of hydroxyapatite are calcium ions (Ca2+), phosphate ions (PO43–) and hydroxide ions (OH–).*

* + 1. **How does pH differ between that of the mouth and that of the body?**

*The pH in the body differs from that in the mouth in that the blood pH is closely controlled at a slightly alkaline value of 7.4, while the pH of the mouth can vary between 6.2 and 7.4.*

* + 1. **How does the body control blood pH (e.g., after exercising)?**

*When exercising, lactic acid is produced in the muscles, adding H+ ions to the bloodstream. To relieve this equilibrium shift, according to Le Chatelier’s Principle, bicarbonate ions react with the H+ ions and produce carbonic acid. Then the carbonic acid build-up causes an increase in the amount of carbon dioxide and water (which is exhaled through the lungs). This returns the body to a new state of equilibrium and a normal pH.*

* + 1. **How does saliva maintain the pH of the mouth after bacteria produce acid from the carbohydrates we’ve consumed?**

*Saliva maintains the pH balance in the mouth by secreting bicarbonate ions, produced in the salivary ducts, which combine with and neutralize the H+ ions produced in the fermentation process.*

* + 1. **What happens next to maintain equilibrium?**

*As the excess H+ ions from the previous question are consumed, the amount of carbonic acid builds up. To maintain the right amount of carbonic acid in the mouth, some of the excess carbonic acid breaks back down into carbon dioxide and water. The excess carbon dioxide then diffuses out from the saliva.*

* + 1. **What are the results of a consistently low pH in the mouth?**

*Consistently low pH in the mouth results in small holes or pits to form in the enamel of the tooth, which eventually exposes the dentin below the enamel. Dentin, being less resistant to acid than enamel (only 70% hydroxyapatite vs. 96% for enamel), is more quickly and easily demineralized, resulting in more rapid tooth decay.*

* + 1. **What are the two main materials used to fill a decayed tooth, once the decay has been removed?**

*The two main materials used to fill a decayed tooth are composite resins and mercury amalgams.*

* + 1. **Name three problems with the use of amalgams for filling teeth.**

*Three problems with using amalgams to fill teeth are:*

* + - * 1. *More of the healthy part of a tooth must be removed in order to pack the amalgam into the cavity in such a way that it ensures no movement of the filling,*
        2. *Amalgams block X-rays, making it more difficult for the dentist to obtain a useful 3-dimensional panoramic picture of your entire mouth, and*
        3. *Amalgams need to be properly disposed of, since they contain hazardous mercury.*
        4. *(Not mentioned in article: Amalgam fillings appear silver or black, making them obvious and not very attractive.)*

# 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. The enamel in the outer layer of your tooth is the hardest substance in your body. |
|  |  | 1. The mineral that makes up tooth enamel is made of sodium and carbonate ions. |
|  |  | 1. Your saliva contains buffers that resist a change in pH. |
|  |  | 1. When teeth are exposed to low pH for extended periods of time, an unstable equilibrium causes tooth decay. |
|  |  | 1. The pH in your mouth causes the pH in your body to change. |
|  |  | 1. In a chemical equilibrium, the concentration of molecules on both sides of the chemical equation are the same. |
|  |  | 1. Food increases the pH in your mouth. |
|  |  | 1. Carbon dioxide is involved in maintaining equilibrium in your mouth. |
|  |  | 1. Composite resins made of polymers are usually used to fill holes in tooth enamel. |
|  |  | 1. One drawback to using amalgams to fill teeth is that the hole drilled for the filling removes healthy tissue. |

# Reading Strategies

These graphic organizers are provided to help students locate and analyze information from the articles. Students’ 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 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:***

1. Links to **Common Core Standards for Reading**:
   1. 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).
   2. 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.
2. Links to **Common Core Standards for Writing**:
   1. 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).
   2. ELA-Literacy.WHST.11-12.1E: Provide a concluding statement or section that follows from or supports the argument presented.
3. **Vocabulary** and **concepts** that are reinforced in this issue:
   1. Solution chemistry
   2. Chemical equilibrium
   3. Acids and bases
   4. pH
   5. Buffers
   6. Molecular structures
4. The infographic about autumn leaves on page 19 will engage students with more information about some of the natural dyes found in “Eating With Your Eyes.”
5. 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 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 how chemistry helps us understand each topic listed.

|  |  |  |
| --- | --- | --- |
|  | **Chemicals** | **Chemical Structure and/or Chemical Equation** |
| **Tooth enamel** |  |  |
| **Dentin** |  |  |
| **Acids & Bases in your body** |  |  |
| **Acids & Bases in your mouth** |  |  |
| **How tooth decay is treated** |  |  |

**Summary**: On the back of this paper, write a sentence to explain how chemical equilibrium helps prevent tooth decay.

# Background Information

**(teacher information)**

To begin this discussion, it might be nice to think about the teeth as part of a larger structure. This excerpt is from a 2000 *ChemMatters* article:

The mouth is like the entrance to a deep cave. Inside are minerals, a steady trickle of water, and living creatures! Teeth line the upper and lower jaws like stony stalactites and stalagmites composed of protein (collagen) and a hard smooth mineral called hydroxyapatite, Ca5(PO4)3OH. Along the inner walls of the mouth are glands that secrete saliva, a watery solution that flows into the mouth at 1 to 3 mL per minute at mealtimes but slows to barely a trickle during sleep.

Inhabiting the mouth are millions of living bacteria residing on the tongue, in the soft tissue of the gums, and inside the cracks and crevices of our teeth. Many of the metabolic wastes of these bacteria are both corrosive and sticky with a pH low enough to cause harm to teeth and gums. Dissolved in saliva is bicarbonate (HCO3–). Bicarbonate acts as a buffer to keep the watery solution at a fairly constant pH by balancing the relative amounts of hydrogen ions (H+) and hydroxide ions (OH–) in solution. A healthy pH for the mouth environment is a nearly neutral 6.8.

Saliva is saturated with enzymes, the specialized proteins that act as organic catalysts for a variety of chemical reactions in the body. Alpha amylase is a digestive enzyme in saliva that catalyzes the breakdown of starch. Starch—a natural polymer consisting of thousands of tiny sugar molecules linked together like boxcars on a train—is rapidly uncoupled by amylase to release these sugars in the mouth.

Sugar is food. We—and the bacteria that we harbor—obtain life-sustaining energy from the breakdown of this hydrocarbon fuel. Unfortunately for us, bacteria convert some of this sugar into harmful acids. Saliva acts to dilute and neutralize some of this acid, but bacteria living in teeth fissures or crevices may be protected from this cleansing.

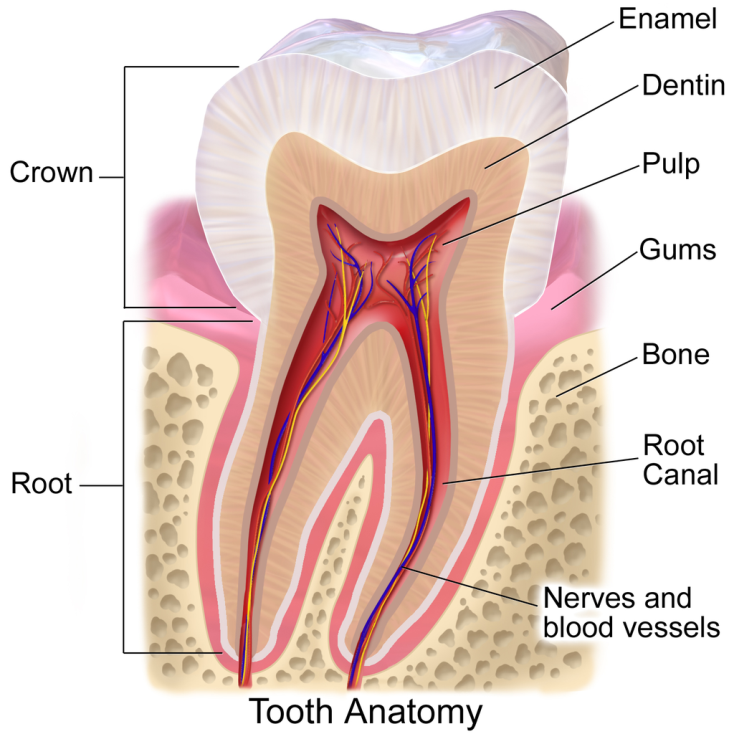
(McClure, M. The Straight Story on Braces. *ChemMatters,* 2000, *18* (1), pp 7–8)

Now that we’ve got the “big picture”, we can proceed with some of the details of tooth decay.

**More on the structure of the tooth**

The tooth consists of three areas: the crown, the neck and the root. (The neck is the area where the crown meets the root, missing from the diagram below.) The internal structure of the tooth is composed of four parts: enamel, dentin, cementum and pulp.

The enamel is located on the surface of the crown. The dentin, which lies just under the enamel, extends through the crown, neck and root, as does the pulp. Cementum surrounds the root. What follows is a description of each of these parts.



*(*[*https://en.wikiversity.org/wiki/Wikiversity\_Journal\_of\_Medicine/Blausen\_gallery\_2014#/media/File:Blausen\_0863\_ToothAnatomy\_02.png*](https://en.wikiversity.org/wiki/Wikiversity_Journal_of_Medicine/Blausen_gallery_2014#/media/File:Blausen_0863_ToothAnatomy_02.png)*)*

**Enamel**

Enamel is the very hard outer surface of the tooth. It is the surface we see when we look at teeth. It appears white, but it is really translucent. The dentin (see below) that shows through the enamel gives the tooth its color.

The role of enamel is to provide the rigid surface needed for mastication—grinding and crushing food by chewing—and to protect the rest of the underlying layers of the tooth from decay. It owes its rigidity to its structure of hydroxyapatite, a crystalline calcium phosphate compound. Although it is a hard substance, it is susceptible to decay through erosion due to exposure to acid. It also serves to insulate the nerves in the tooth from exposure to extremes of hot and cold thus preventing discomfort or pain.

Enamel is also subject to cracking or chipping when exposed to stress, leading to one’s feeling pain, especially when eating hot or cold or sugary foods.

(<https://www.humana.com/learning-center/health-and-wellbeing/healthy-living/tooth-enamel>)

And, lest we oversimplify the enamel in tooth structure, this short paragraph from a *ChemMatters* Teacher’s Guide seeks to set us straight.

The structure and composition of a human tooth is perhaps somewhat more complex than the relatively basic structure and composition presented …. The outer enamel is indeed the hardest material found in the human body, as it is for any mammal that has teeth. It is highly mineralized, but not entirely made of calcium phosphate. It consists of about 95-98% inorganic material by mass. About 90-92% of this inorganic matter is a slightly modified form of calcium phosphate called hydroxyapatite. The formula for hydroxyapatite is Ca5(PO4)3OH. There are also trace amounts of other minerals. The remainder of the enamel consists of about 1% protein and 4% water by mass. The proteins that are contained in tooth enamel are not found anywhere else in the human body. These proteins are called enamelins and amelogenins.

(*ChemMatters* Teacher’s Guide, December 2003, p 29)

**Dentin**

Dentin, part calcified tissue (hydroxyapatite crystallites), part organic material (mainly collagen), and part fluid (mainly water), surrounds the pulp cavity, just under the enamel. It serves several purposes: to absorb the impact of mastication on the tooth enamel, to protect the pulp from infection from the outside (from bacteria in the bacteria-infested mouth), and to provide toughness to the tooth structure, preventing or, at least, minimizing tooth fractures. (Note that enamel, even though it is very hard, is also rather brittle, so it can fracture rather easily.)

Dentin contains dentinal tubules, which are permeable, that radiate outward from the center to the enamel. Mineral buildup surrounds these tubules. Their permeability allows for transfer of the sensations of heat and cold to nerves in the pulp which can, in turn, become sensations of pain. The dentinal tubules also help to prevent tooth fractures by absorbing some of the stress that might normally propagate through and fracture the enamel, forming microfractures within the tubules that prevent a major crack from propagating through the brittle enamel.

It has been noted that older adults seem to be more susceptible to tooth fracturing than younger people. This has been researched and is presently believed to be caused by subtle changes in the behavior of dentin in older teeth, resulting in its becoming more brittle with age. This paper describes current (2008) research: <https://str.llnl.gov/str/JanFeb08/pdfs/01.08.3.pdf>.

**Cementum**

Cementum is the surface layer of the tooth root. It is calcified material that covers the root of the tooth. Slightly softer than dentin, it consists of 45–50% inorganic material (hydroxyapatite) and 50–55% organic matter and water, by weight. Collagen and proteoglycans comprise the majority of the organic matter.

Cementum is the part of the periodontium that attaches the tooth to the alveolar bone. Because some of the cementoblasts, the cells that actually excrete the cementum, are entrapped within the cementum, becoming cementocytes, cementum is able to repair itself to a limited extent.

**Pulp**

Dental pulp serves two main roles. First, it produces odontoblasts, cells that can form dentin. The dentin surrounds and protects the pulp. The second role is to supply nutrients to, and remove waste from, the pulp via blood vessels contained in the pulp cavity. Other functions include signaling the brain (with pain) when trauma, temperature extremes, pressure or tooth decay has reached the dentin or pulp, areas containing nerves, and forming secondary dentin to help protect the pulp.

Dental pulp fills with an increased amount of collagen fibers with age, resulting in the decrease in the ability of the pulp to regenerate. This causes the recession of the pulp cavity, possibly due to an increase of secondary dentin within the pulp cavity, which results in the reduction in sensitivity in older teeth. Thus older adults may not need local anesthesia when undergoing dental restorations.

The web source for the diagram at the beginning of this section also contains a 3-D diagram of the tooth and a brief (0:50), narrated video clip on the anatomy of a tooth. (<http://blausen.com/?Topic=2106>) (Source of diagram above and video clip: Blausen.com staff. "[Blausen gallery 2014](https://en.wikiversity.org/wiki/Blausen_gallery_2014)". *Wikiversity Journal of Medicine*. DOI:[10.15347/wjm/2014.010](http://dx.doi.org/10.15347/wjm/2014.010). ISSN [20018762](http://www.worldcat.org/issn/20018762). - Own work)

**More on the chemical structure of tooth enamel**

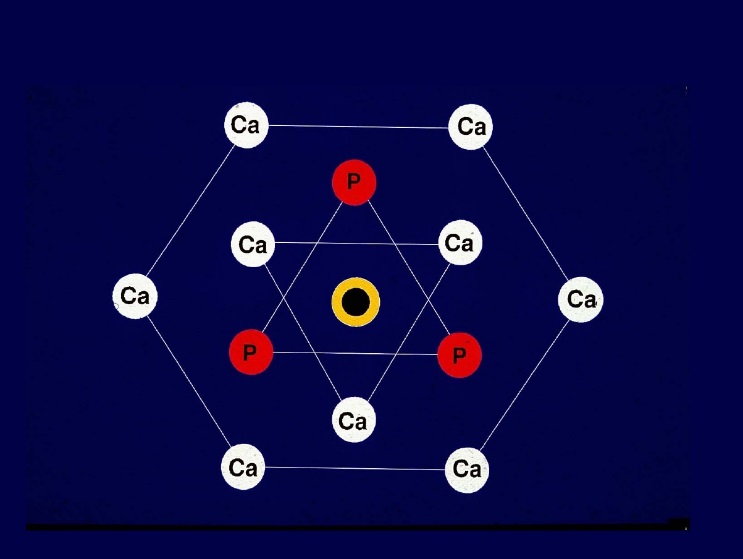
Tooth enamel, as mentioned in the article, is the hardest substance in the human body. The enamel is composed of 96% minerals, primarily hydroxyapatite; the remaining 4% of the enamel is primarily water and organic material. Apatite, the primary constituent of tooth enamel, has a hardness of 5 on the 1–10 Mohs scale of mineral hardness.

The central oxygen atom in the unit cell diagram at right is part of one of the   
–OH groups in the hydroxyapatite formula, Ca10(PO4)6(OH)2 [the dimer of Ca5(PO4)3OH]. In fluorapatite, the fluorine atom replaces that oxygen atom (part of   
–OH) in the center of the hexagonal unit cell.

**©C. Robinson Oral Biology**

The structure of calcium hydroxyapatite.

([*https://www.academia.edu/1732481/Dental\_Enamel\_Chemistry*](https://www.academia.edu/1732481/Dental_Enamel_Chemistry))

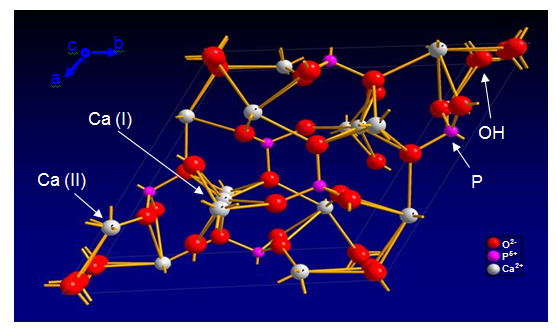


The following passage describes the structure of hydroxyapatite.

The term "apatite" applies to a group of compounds (not only at calcium phosphates) with a general formula in the form M10(XO4)6Z2, where M2+ is a metal and species XO4 3- and Z- are anions. The particular name of each apatite depends on the elements or radicals M, X and Z. In these terms, hydroxyapatite (HAp) has the molecular structure of apatite, where M is calcium (Ca2+), X is phosphorus (P5+) and Z is the hydroxyl radical (OH-). This is known as stoichiometric hydroxyapatite and its atomic ratio Ca/P is 1.67. Its chemical formula is Ca10(PO4)6(OH)2, with 39% by weight of Ca, 18.5% P and 3.38% of OH.

Hydroxyapatite crystallizes in a hexagonal system … Figure 1 shows the unit cell of hydroxyapatite.

HAp structure is formed by a tetrahedral arrangement of phosphate (PO43-), which constitute the "skeleton" of the unit cell. Two of the oxygens are aligned with the c axis and the other two are in a horizontal plane. Within the unit cell, phosphates are divided into two layers, with heights of 1/4 and 3/4, respectively, resulting in the formation of two types of channels along the c axis, denoted by A and B.



**Figure 1.** Crystalline structure of hydroxyapatite.

The walls of channels A type are occupied by oxygen atoms of phosphate group and calcium ions, called calcium ions type II [Ca (II)], consisting of two equilateral triangles rotated 60 degrees relative to each other, at the heights of 1/4 and 3/4, respectively. Type B channels are occupied by other ions of calcium, called calcium ions type I [Ca (I)]. In each cell there are two such channels, each of which contains two calcium ions at heights 0 and 1/2. In the stoichiometric HAp, the centers of the channels type A are occupied by OH radicals, with alternating orientations. …

Despite being taken to the stoichiometric hydroxyapatite as a model, it is noteworthy that hydroxyapatites produced biologically are much more complicated, they are not stoichiometric, have an atomic ratio Ca/P <1.67 and does not contain only ions and radicals of the HAp but also traces of CO3, Mg, Na, F and Cl. These amounts vary according at the specific type of tissue, which is related to the properties and bioactivity of it.

One aspect that is important to note is that, the closer the value of Ca/P to 1.67, the greater the stability of the material inside the human body as they tend to be inert, and on the other hand, if this value decreases (deficient HAp), the better the bioactivity.

Another aspect we must consider is the degree of crystallinity. It has been observed that the crystallinity in the tissues for the tooth enamel is very high, while in the cases corresponding to dentin and bone, it is very poor. This means that the reactivity depends on the degree of crystallinity, since the reactivity in dentin and bone is higher than in tooth enamel.

(Eric M. Rivera-Muñoz (2011). Hydroxyapatite-Based Materials: Synthesis and Characterization, Biomedical Engineering - Frontiers and Challenges, Prof. Reza Fazel (Ed.), ISBN: 978-953-307-309-5, InTech, DOI: 10.5772/19123; <http://www.intechopen.com/books/biomedical-engineering-frontiers-and-challenges/hydroxyapatite-based-materials-synthesis-and-characterization>)

**More on tooth decay vs. tooth erosion**

There seems to be general agreement that two distinct processes occur involving adverse effects on teeth, tooth erosion and tooth decay.

**Tooth erosion**

Tooth erosion occurs primarily due to acids you ingest from outside sources, such as sodas and citrus fruit drinks. These provide acid directly to the tooth, which increases the rate of demineralization of the tooth enamel, which eventually leads to erosion of tooth surfaces and may or may not produce individual caries (cavities).



Microscopic view of erosion on tooth enamel surface.

*(*[*http://www.webmd.com/oral-health/healthy-teeth-14/slideshow-enamel-erosion*](http://www.webmd.com/oral-health/healthy-teeth-14/slideshow-enamel-erosion)*)*

(<https://en.wikipedia.org/wiki/Acid_erosion>)

Frequency and duration of exposure of teeth to these drinks is viewed as more important factors than total intake. These should be drunk, not sipped. Many dentists even recommend using straws to drink these, as then the liquid does not come in direct contact with teeth. Enamel corrosion can even occur in babies if they are allowed to drink fruit juices from a bottle over long periods as a way of quieting them down at bedtime.

The following table summarizes the types of acids found in various types of drinks.

|  |  |  |  |
| --- | --- | --- | --- |
| **Type of Drink** | **Type of Acid in Drink** | **Natural or Added** | **Purpose/Use** |
| Soda/Pop | Carbonic  Phosphoric  Citric (perhaps) | Added  Added  Added | Fizz, “bite”  Tartness, preservative  Fruity taste |
| Fruit Juices | Malic  Citric  Ascorbic (vitamin C)  Tartaric | Natural  Natural/Added  Added  Added | In most fruits, tartness  Citrus flavor  Preservative  Acidity, tartness |
| Juice Drinks | Citric  Ascorbic  Fumaric | Natural/Added  Added  Added | Citrus flavor  Preservative  Tartness |
| Sports/Energy Drinks | Carbonic  Citric | Added  Added | Fizz, “bite”  Citrus flavor |
| Wines | Tartaric  Malic  Lactic  Citric | Natural  Natural  Added  Added | Stability, acidity, tart taste  Tartness, apple flavor  “Milky” flavors  Boosts overall acidity |
| Beers | Carbonic | Natural | Fizz, “bite” |

The phosphoric acid is corrosive, but actually the acid concentration in soda pop is lower than that in orange juice or lemonade. Try submerging identical strips of magnesium (or iron staples) in each of these beverages overnight. Which beverage dissolves more metal? Which dissolves the metal fastest?

Fruit juices and drinks are also tart, but they don't use phosphoric acid as a flavor additive. Phosphoric acid would cause many ions present in fruit juices to settle out as insoluble phosphates. These beverages get their tang from citric acid, a substance found in oranges, limes, lemons and grapefruits. Malic acid, found in apples and cherries, is added to many fruit juices. Fumaric acid is used in noncarbonated soft drinks, and tartaric acid gives grape-flavored candies a subtle sour flavor. All of these substances impart only tartness, without overpowering other flavors present.

(<http://antoine.frostburg.edu/chem/senese/101/consumer/faq/why-phosphoric-acid-in-soda-pop.shtml>)

Tartaric acid isn't added to grape-flavored beverages because of the low solubility of some of its salts:

"... tartaric acid gives a very true flavor, but Mother Nature does not intend for tartrates to stay in solution long. When KH-tartrate precipitates out of a juice, looking very much like glass or metal shavings, and the consumer passes their bottle of juice to the FDA, one really does not care about "true" flavor. We in the juice industry usually use malic or a malic citric blend."

(<http://antoine.frostburg.edu/chem/senese/101/consumer/faq/why-phosphoric-acid-in-soda-pop.shtml>)

Chemists know that it’s acid strength, not just the amount of acid, that really matters. That’s why colas are more likely to cause dental erosion than other sodas; colas contain phosphoric acid, with a higher acid dissociation constant (see table, below) than any of the other acids listed in the drinks from the above table. That means that phosphoric acid provides more H+ ions in solution than other acids. These ions then interact with enamel hydroxyapatite, resulting in the formation of Ca2+ and PO43– ions dissolved from the tooth surface. Unless the saliva in the mouth quickly raises the pH and replenishes the lost calcium and phosphate ions, the tooth enamel surface will remain thinner where those ions were removed by the acid, subject to further degradation with the next cola drink.

|  |  |  |  |
| --- | --- | --- | --- |
| **Acid** | **1st Ka** | **2nd Ka** | **3rd Ka** |
| Phosphoric acid | 7.5 x 10–3 | 6.2 x 10–8 | 4.8 x 10–13 |
| Fumaric acid | 9.3 x 10–4 | 2.9 x 10–5 | --- |
| Tartaric acid | 9.2 x 10–4 | 4.3 x 10–5 | --- |
| Citric acid | 8.4 x 10–4 | 1.8 x 10–5 | 4.0 x 10–6 |
| Malic acid | 3.5 x 10–4 | 8.0 x 10–6 | --- |
| Lactic acid | 1.4 x 10–4 | --- | --- |
| Ascorbic acid | 7.9 x 10–5 | 1.6 x 10–12 | --- |
| Carbonic acid | 4.3 x 10–7 | 4.7 x 10–11 | --- |

(Table of Kas gathered from numerous sources)

Notice that the Ka for carbonic acid is the smallest of any of the first dissociation constants for the acids in the above table. This substantiates the notion that it’s not the carbonic acid in sodas that really causes the problems with dental erosion but, rather, phosphoric acid. This can be shown by testing the pH of a freshly-opened soda and one that has been allowed to go “flat”. Carbon dioxide has escaped from the flat soda, upsetting the CO2 – H2CO3 equilibrium, thereby removing most/all carbonic acid from the drink (Le Châtelier’s principle). Yet both sodas will have approximately the same pH, showing that carbonic acid contributed very little or nothing to the acidity of the drink.

While brushing teeth is a good way to minimize tooth erosion, care must be taken as to *when* brushing is done.

Tooth brushing is a way to keep a good oral hygiene. Hard tissue loss after erosion and tooth brushing is significantly greater than erosion alone … However, after intra-oral periods of 30 and 60 min, wear was not significantly higher in tooth brushing than in unbrushed controls. It is concluded that keeping tooth unbrushed for at least 30 min after an erosive attack is necessary for protecting dentin …

(<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2676420/>)

You may have heard this myth circulating, possibly on the Internet. “Soda is so acidic it can dissolve a tooth overnight.” This is not quite true (at all).

This myth got its start from a nutritionist who made the claim in the 1950s. Sodas contain acids, such as phosphoric, citric, and carbonic acid. But their concentrations are lower in soda than in natural drinks, such as orange or cranberry juice. When left in soda, a tooth will not completely dissolve overnight, or even over a few days. Also, when we drink soda, we don’t tend to hold it in our mouths for long periods of time, and the saliva in our mouths helps protect the enamel.

But this does not mean that soda is harmless to teeth. High-sugar drinks can contribute to tooth decay, and acidic drinks can erode tooth enamel over time. The reason is that although enamel is hard, the substance that makes up most of it, hydroxyapatite [Ca5(PO4)3OH], is in equilibrium with its dissolved form, like any ionic solid in the presence of water. At equilibrium, most of hydroxyapatite is in solid form:

Ca5(PO4)3OH (*s*) ⇌ 5 Ca2+ (*aq*) + 3 PO43– (*aq*) + OH– (*aq*)

But when an acid is added, its free hydrogen ions (H+) neutralize some of the hydroxide ions (OH–), as follows:

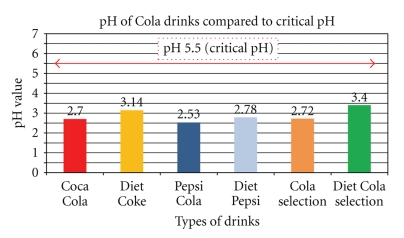
H+ + OH– ➞ H2O

This shifts the hydroxyapatite equilibrium reaction to the right to replace the hydroxide ions removed by the acid, causing more hydroxyapatite to dissolve, thus eroding the tooth enamel.

(Tinnesand, M. Open for Discussion: A Healthy Dose of Skepticism; Soda is so acidic it can dissolve a tooth overnight. *ChemMatters*, 2015,*33* (1), p 4)

Here is another reference to this same myth: <http://io9.com/5903310/the-scientific-myth-that-soda-will-dissolve-your-teeth>.

Before we leave the topic of soda, we should look at its pH. The table below was taken from this 2010 report: “Pop-Cola Acids and Tooth Erosion: An *In Vivo*, *In Vitro*, Electron-Microscopic and Clinical Report.” The report, published in the *International Journal of Dentistry*, provides information on the pH of various colas. Note that all values are in the 2.5–3.5 range, well below the pH of 5.5, which is the pH at which (or below which) tooth enamel is eroded by an acid. Thus all of these colas (and other sodas as well) will cause enamel erosion; indeed, that is the conclusion of the report, as well.



*(*[*http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2997506/?tool=pubmed*](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2997506/?tool=pubmed)*)*

And, as the title suggests, the study tested cola’s effects on teeth *in vivo*, within the mouth of living test subjects, and *in vitro*, in laboratory settings. And microscopic pictures of the teeth studied *in vitro*, taken by the researchers show definite evidence of erosion by the colas. An interesting note: their study groups were divided into those with teeth (average age, 22) and those without teeth (average 52), ostensibly those with dentures. The tests done on those without teeth (and those with teeth) consisted of determining levels of calcium and phosphate in the mouth after swishing with the various colas (and with water as a control).

(<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2997506/?tool=pubmed>)

OK, so now we know it’s best to avoid sodas to avoid cavities. But sodas and other acidic drinks, known as *extrinsic* sources of acids (taken in from outside the body), aren’t the only way for tooth enamel to be exposed to acidic environments. Intrinsic sources (as the name implies) also may account for further exposure.

Acid reflux and GERD (Gastroesophageal reflux disease) can cause stomach acid (HCl) to be regurgitated up the esophagus back into the mouth. This exposes the enamel of teeth to the highly corrosive mix, which increases the severity of enamel erosion.

*(*[*http://www.dentalcare.com/en-US/dental-education/continuing-education/ce301/ce301.aspx?ModuleName=coursecontent&PartID=8&SectionID=2*](http://www.dentalcare.com/en-US/dental-education/continuing-education/ce301/ce301.aspx?ModuleName=coursecontent&PartID=8&SectionID=2)*)*

**Erosion caused by chronic vomiting in bulimia.**

Image source: Copyright © 2003 Lippincott Williams & Wilkins



Another area of concern related to tooth erosion is eating disorders like anorexia and bulimia. Repeated vomiting by sufferers of these disorders exposes tooth enamel to the highly acidic environment of the hydrochloric acid in stomach acid. If this were to occur on a regular basis, it can result in severe damage to tooth enamel—long-lasting damage that can’t be undone, even long after the disorder has been effectively treated.

Note in the photo above the almost complete lack of enamel on parts of the teeth. The yellow color is the dentin showing through what’s left of the enamel. Also note that the primary area of erosion is on the posterior surfaces, where the regurgitated stomach content is most likely to come in contact with the teeth.

**Friction and erosion**

And acids aren’t the only problems our teeth face in their quest to maintain the hydroxyapatite equilibrium and avoid cavities. We also create some of our own problems that erode our teeth. Normal (and abnormal) chewing can wear down teeth, as can bruxism—grinding your teeth, especially at night. Here are some other ways we erode our teeth.

* **Attrition.** This is natural tooth-to-tooth friction that happens when you clench or grind your teeth such as with bruxism, which often occurs involuntary during sleep.
* **Abrasion.** This is physical wear and tear of the tooth surface that happens with brushing teeth too hard, improper flossing, biting on hard objects (such as fingernails, bottle caps, or pens), or chewing tobacco.
* **Abfraction.** This occurs from stress fractures in the tooth such as cracks from flexing or bending of the tooth.
* **Corrosion.** This occurs chemically when acidic content hits the tooth surface such as with certain medications like aspirin or vitamin C tablets, highly acidic foods, GERD, and frequent vomiting from bulimia or alcoholism.

(<http://www.webmd.com/oral-health/guide/tooth-enamel-erosion-restoration#2>)

While these causes of tooth erosion result in the wearing down of tooth surfaces, they don’t usually result in dental caries, as they generally only erode already exposed areas of enamel, like the bite surfaces of teeth; they don’t usually penetrate the enamel down to the dentin, where cavities can really go wild. (In extreme cases, these processes can result in opening areas to bacterial infection, particularly along the gum line.)

**Tooth decay**

OK, so if you stay away from acidic drinks, *and* don’t grind your teeth, you can avoid tooth decay, eh? Not so fast. While all of that may minimize tooth erosion, we haven’t even begun to talk about what actually makes teeth decay—*Streptococcus mutans*. *S. mutans* is a bacteria that lives in your mouth and absolutely loves sugars, especially sucrose. This bacteria attaches as individual cells, produces a slime-like material to help it adhere to the tooth, and then reproduces on the enamel surface to form a biofilm consisting of hundreds of cells.

The biofilm is extremely resistant to being removed. The *S. mutans* bacteria within this biofilm are able to cleave sucrose, a disaccharide, (from food we eat) into the monosaccharides glucose and fructose. *S. mutans* ferments the fructose for use as an energy source for its own growth. The glucose is polymerized into the slime- or glue-like material that attaches to teeth and becomes the biofilm base for dental plaque—the growth of colonies of bacteria.

Subsequent depolymerization of the dextran polymer within the biofilm by the bacteria can result in fermentation of the glucose monosaccharide to produce lactic acid. Some of this acid is trapped within the plaque matrix, confined close to the tooth enamel, where saliva can’t reach to wash the acid away, exposing the enamel to relentless erosion. And note that the Ka for lactic acid is 1.4 x 10–4, more acidic than either citric or carbonic acids. (Bad news for tooth enamel) (<http://microbewiki.kenyon.edu/index.php/Streptococcus_mutans>)

And then, just when you thought there was only one species responsible for tooth decay, here comes another one (or, actually, more).

While streptococci family bacteria (e.g. *Streptococcus mutans*) are the main cause of tooth decay, other varieties of microbes can cause dental caries, but to a lesser extent. For example, although considered beneficial, some *Lactobacillus* species have been associated with dental caries. The *Lactobacillus* count in saliva has been used as a "caries test" for many years. This is one of the arguments used in support of the use of fluoride in toothpaste. Lactobacilli characteristically cause existing carious lesions to progress, especially those in coronal caries. The issue is, however, complex as recent studies show probiotics can allow beneficial lactobacilli to populate sites on teeth, preventing streptococci pathogens from taking hold and inducing dental decay.

(<https://en.wikipedia.org/wiki/Lactobacillus>)

Lactobacilli, like *S. mutans*, produce lactic acid in their fermentation of simple sugars, adding that acid to the stores of acid produced by other bacteria and tucked away in dental plaque, waiting there to cause tooth decay.

Left unchecked (or unbrushed), erosion of tooth enamel will eventually lead to an opening (cavity or carie) in the enamel which will continue to grow until it reaches the dentin. At this time, one may feel twinges of pain when hot or cold drinks hit the cavity. Also at this point, the rate of decay progresses rapidly, as dentin is softer and more susceptible to the effects of acid (and bacteria). By this time, one will probably begin to feel more prolonged (but possibly still mild) pain. Ultimately, the decay will reach the pulp of the tooth, at which point the pain may be unbearable. An abscess may form within the pulp and dentin, making the whole area of the mouth near the tooth painful. To avoid this scenario, one must practice good oral hygiene.

**More on tooth decay & hydroxyapatite equilibrium**

It is interesting to note that tooth formation and decay is almost identical in animals to that in humans. The functions of all the parts of the tooth are identical in both, with slight variations in the enamel. Dogs typically suffer from tooth decay much less frequently than humans because saliva in dogs has a much higher pH than in humans. The less acidic environment in dogs’ mouths results in less demineralization of the enamel.

Teeth are in a constant state of demineralization and remineralization. Acidic conditions increase the rate of demineralization, leading to cavities or dental caries. At a pH of 5.5 or lower, demineralization occurs at a more rapid rate than remineralization. Many foods are in this range of pH, so without remineralization, eating these foods would automatically result in tooth decay.

The constant battle between demineralization and remineralization can be considered chemically to be an equilibrium system which is under constant stress.

The enamel of teeth is made of hydroxyapatite (also called hydroxylapatite), empirical formula Ca5(PO4)3OH. The formula is usually written as a dimer, Ca10(PO4)6(OH)2, to denote that the unit cell contains two empirical formula units. Hydroxyapatite forms a 3-dimensional crystal structure which is very hard and durable.

Demineralization of hydroxyapatite occurs in acidic conditions; e.g., when bacteria produce acids from their metabolism of ingested sugars. The primary acid produced is lactic acid, along with smaller amounts of formic, acetic and succinic acids, all of which act to dissolve the enamel of teeth.

Ca10(PO4)6(OH)2(*s*) + 8 H+(*aq*) → 10 Ca2+(*aq*) + 6 HPO42–(*aq*) + 2 H2O(*l*)

In a less acidic (more basic) environment, remineralization occurs:

10 Ca2+(*aq*) + 6 HPO42–(*aq*) + 8 OH–(*aq*) → Ca10(PO4)6(OH)2(*s*) + 6 H2O(*l*)

Demineralization and remineralization occur at different rates throughout our lives. In children, remineralization occurs more rapidly than demineralization. In adults, the two reactions occur at roughly equal rates (equilibrium), while in older adults, demineralization can occur faster than remineralization, resulting in the slow loss of tooth enamel and the subsequent possible loss of the tooth. Of course, at any point in our lives when we have significant plaque build-up, we may suffer increased rate of demineralization.

As shown above, lower pH (higher acidity) enhances demineralization. When plaque builds up, the bacteria in the plaque supply H+ ions in close proximity to the enamel. The H+ ions react with the OH- ions from the hydroxyapatite, resulting in destruction of the crystal structure, weakening the tooth enamel. And as the OH- ions are consumed, they reduce the rate of the remineralization reaction (Le Châtelier’s principle), furthering the effect.

Normal pH in the mouth is about 6.8. Demineralization becomes the dominant process when the pH drops below 5.5. This can occur within minutes of drinking a sugar (or high fructose corn syrup) based soft drink and can last for about 10 minutes. Saliva will gradually wash away the acidic material and return the mouth environment back to normal within about an hour. Of course, that means that teeth are exposed to an acidic environment for most of that time, promoting demineralization. Brushing teeth right after eating can remove the acid and return the mouth to its normal pH immediately.

(*ChemMatters* Teacher’s Guide. October 2011, pp 59–60)

**More on effects of brushing and flossing**

Brushing teeth (if done right) effectively removes the sugars, acids, plaque and bacterial build-up that would otherwise ensure dental erosion and caries formation. Thus it is an effective weapon against cavity formation. But, as noted above, timing of brushing is important. Acidic drinks can leave the enamel softened for some time after drinking them. So, it’s important to wait, perhaps ½ to 1 hour after drinking, before brushing.

It’s also important not to brush too hard, or particles of the enamel might be ground away by the bristles of the brush. Likewise, it’s better to use a soft bristle toothbrush, for the same reason.

And you need to be sure to use a toothpaste that is not too abrasive, so that it does not remove enamel when you brush. Another ingredient to be concerned about is the sweetener used to make the tooth paste palatable (but not too palatable, or it might be swallowed).

“Toothpaste ingredients do typically include a sweetener. However, because of the process described above, sucrose is not a reasonable choice. Toothpastes commonly use two of the artificial sweeteners … saccharin and aspartame. Some products specifically advertise that they do not use artificial sweeteners. One substitute is the use of essential oils, such as spearmint.”

(*ChemMatters* Teacher’s Guide. October 2011, p 73)

One much overlooked—and underrated—procedure that can contribute significantly to decay prevention is flossing. Dentists almost invariably ask patients whether they floss regularly, because they know the importance of this tool in the oral health arsenal. Flossing essentially picks up where tooth brushing leaves off.

Brushing cleans plaque off the anterior and posterior surfaces, as well as the “nooks and crannies” available to its bristles; however, the brush can’t clean surfaces between the teeth, or the tooth surfaces down at the gum line. So brushing only cleans about 60–65% of enamel surfaces in your mouth. The other 35–40% of the enamel, where the tooth brush can’t reach, is susceptible to plaque build-up, which continues to erode the enamel (remember, bacteria in the plaque produce acid), and that plaque eventually becomes calcareous tartar. This hard material can only be removed by the dentist scraping your teeth, a process called scaling. So, flossing can prevent acid erosion between your teeth and along the gum line, and it can prevent your needing this somewhat painful professional scaling procedure.

As you know, plaque on teeth results in the tooth enamel being held in constant contact with acid produced by bacteria in the plaque, hastening enamel erosion. Along the gum line, those same bacteria can also cause infection resulting in gingivitis, an inflammation of the gums and, eventually, if not treated, to periodontal disease which could lead to teeth loss.

Is gum disease really worrisome? Studies have shown a link between gum disease and serious medical conditions, such as heart disease and stroke, and low birth-weight in babies. So, anything we can do to prevent gum disease seems to be worthwhile, and flossing is high on that list.

According to Rockside Family Dental Care, there are 10 reasons one should floss daily.

In less than one minute per day you can accomplish the following health benefits:

**10 Reasons to Floss!!**

1. Prevent Decay
2. Prevent gum disease
3. Fresher breath
4. Whiter smile (less stain)
5. Younger smile (less gum recession)
6. Less dental expense
7. Less dental pain
8. Less time away from work or family life
9. Healthier Heart (bacteria from gum disease has been linked to certain types of heart disease).
10. Maintains health/condition of dental restorations

(<http://rocksidefamilydentalcare.com/10-reasons-to-floss.html>)

OK, so you’ve seen the light; flossing is important and you will do it from now on. What’s the right way, floss before or after brushing? It really doesn’t matter, but dentists point out that if you floss first and then use a fluoride toothpaste to brush, the fluoride has a better chance of finding its way to the enamel between your teeth and at the gum line to better protect your teeth from decay.

And let’s not forget about mouthwashes. These decay-preventers help by killing the germs that cause plaque and acid erosion. Most mouthwashes also contain fluoride, which helps to remineralize tooth enamel and make it stronger (fluorapatite is more stable than hydroxyapatite). So mouthwashes pack a “double whammy” for tooth decay prevention.

**More on fluoride treatment of teeth**

This excerpt from an earlier (1986) *ChemMatters* article discusses the use and benefits of using fluoride mouthwash, including the hydroxyapatite equilibrium and fluoroapatite addition to tooth enamel.

One of the best ways you can … strengthen your teeth—is by using mouthwash, which kills the bacteria in your mouth. One key ingredient in many mouthwashes is fluoride, which is known to strengthen tooth enamel (Fig. 6). Fluoride (F–) is the ionic form of fluorine. It forms when a fluorine atom gains an electron. Fluoride does not exist by itself, but it can be found in compounds, such as sodium fluoride (NaF), which is present in many toothpastes and mouthwashes. When this compound is dissolved in water, the fluoride ions are free to move.

Fluoride ions prevent tooth decay by strengthening the enamel. The primary compound found in tooth enamel is a strong, insoluble mineral called hydroxyapatite [Ca5(PO4)3(OH)]. Hydroxyapatite contains positive ions (Ca2+) and negative ions (PO43– and OH–), which are attracted to each other to form the crystalline structure of hydroxyapatite.

The bacteria present on our teeth produce acids that cause hydroxyapatite to break apart—a process called demineralization:

**Ca5(PO4)3(OH) 🡪** **5 Ca2+ + 3 PO43– + OH–**

A certain amount of demineralization is normal. But it is also normal for the reverse process, remineralization, to occur:

**5 Ca2+ + 3 PO43– + OH– 🡪**  **Ca5(PO4)3(OH)**

If too much bacterial acid is produced, demineralization can outstrip mineralization, leading to a cavity. How does this happen? When acids are present in a solution, they dissolve to produce hydrogen ions (H+). In the mouth, as bacteria produce acids, the amount of hydrogen ions builds up. These ions combine with the hydroxide ions produced during demineralization to form water:

**H+ + OH– 🡪**  **H2O**

But hydroxide ions are essential to remineralization, so their neutralization by hydrogen ions causes remineralization to slow down. The hydroxyapatite on the surface of the teeth keeps dissolving, ultimately leading to tooth decay. Fluoride ions present in mouthwashes help the enamel to remineralize. They accumulate on the surface of the enamel, thus creating a barrier that prevents bacterial acids from reaching the enamel. Also, the fluoride ions attract calcium ions, ultimately changing hydroxyapatite into fluoroapatite [Ca5(PO4)3F], which is stronger than the original hydroxyapatite.

(Rohrig, B. Demystifying Gross Stuff. *ChemMatters*, 2011, 29 (3), pp 13–14)

“The fluoride ion takes the place of the OH– during the remineralization process…

The modified enamel, called fluorohydroxyapatite, is more resistant to acid. The F– does not substitute for all of the OH–; even a small uptake of fluoride makes the enamel less susceptible to decay.”

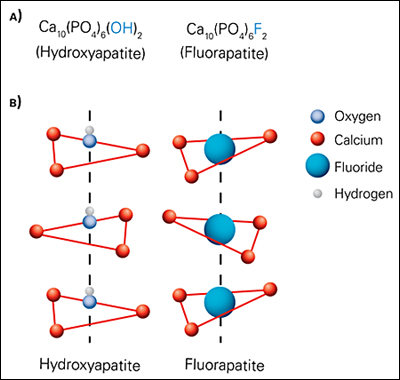
(Yohe, B. Tooth Paste. *ChemMatters,* 1986, *4* (1), pp 12–13)

Fluoride, present either through fluoridated water or through fluoride-enhanced toothpaste or mouthwash, becomes important in the demineralization/remineralization equilibrium because when fluoride ions enter the equilibrium, they produce fluorohydroxyapatite (fluoroapatite), which is harder, more stable and more resistant to acid decay than naturally-occurring hydroxyapatite.

10 Ca2+(*aq*) + 6 HPO42**–**(*aq*) + 6 OH**–**(*aq*) + 2 F**–**(*aq*) → Ca10(PO4)6F2(*s*) + 6 H2O(*l*)

Here’s why fluoride ions are so successful at replacing hydroxide ions in hydroxyapatite.

*(*[*http://www.dentalcare.com/en-US/dental-education/continuing-education/ce410/ce410.aspx?ModuleName=coursecontent&PartID=2&SectionID=1*](http://www.dentalcare.com/en-US/dental-education/continuing-education/ce410/ce410.aspx?ModuleName=coursecontent&PartID=2&SectionID=1)*)*



1. **Fluoride ions (F–) replace hydroxyl groups (OH–) in hydroxyapatite to form fluorapatite in the tooth enamel.**
2. **A portion of the apatite crystal lattice is depicted showing the replacement of hydroxide for fluoride.**

Adapted from: Posner, 1985[20](http://www.dentalcare.com/en-US/dental-education/continuing-education/ce410/ce410.aspx?ModuleName=additionalreference&PartID=-1&SectionID=-1#20)

Fluoride ions are very similar chemically to the hydroxide ion. Their sizes are similar, as are their chemical reactivities. (Recall oxygen and fluorine positions on the periodic table, and their atomic structures.) This makes it easy for the fluoride ion to replace the hydroxide ion in hydroxyapatite [see diagram at right]. And the fluoroapatite produced is actually more stable than the original hydroxyapatite.

In addition to its role in the remineralization process, fluoride also reduces/ prevents cavities by targeting the metabolic processes of bacteria to actually reduce the amount of acid secretions by bacteria in the mouth. This has the effect of reducing the amount of food consumed and thus the amount of acid produced by the bacteria. With a less acidic environment, there is less demineralization. This process seems to be secondary to fluoride’s role in the remineralization process and the formation of fluoroapatite in tooth enamel, however.

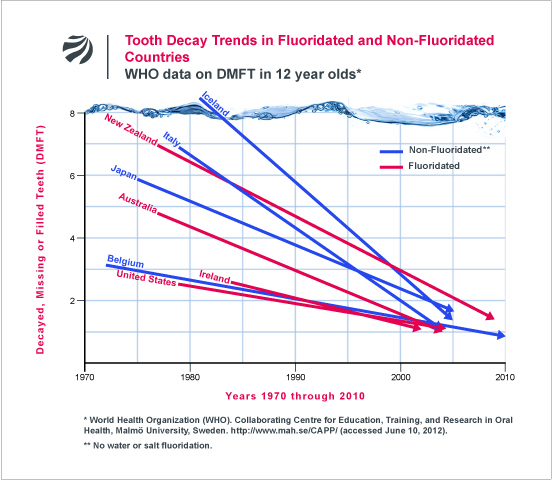
Research has shown that treatment of tooth enamel, bone and calcium phosphate with fluoride all result in lower solubility than just the associated calcium compounds. It is believed that this lower solubility in fluoroapatite is the main (and possibly, the only) factor in the slower rate of demineralization of fluoride-treated enamel. Studies with people exposed to fluoridated water supplies have shown reduced incidence of cavities.

Studies have also been done that also show that fluoride has a greater effect on areas of the tooth enamel already subject to cavity formation—areas of teeth where demineralization has already begun—than in areas where the surface remains intact. This makes sense, since areas of demineralization are areas where the crystal structure has already been compromised and therefore is more prone to rebuilding as fluoride ions come in contact with the greater surface area of “jagged” edges of tooth enamel. These areas of greater fluoride uptake (measured at twice the fluoride concentration of intact enamel) were tested and shown to be much less soluble than intact enamel in the same teeth.

(<http://journals.cambridge.org/action/displayFulltext?type=1&fid=784036&jid=PNS&volumeId=22&issueId=01&aid=784028>)

When enamel is exposed to fluoride, it is also possible to form calcium fluoride, CaF2. Calcium fluoride is less soluble than sodium or stannic fluorides, so it precipitates on the enamel. This can act as a source of fluoride ions, especially in acidic conditions, when demineralization would normally occur. Then the fluoride ion would be right there to join with the hydroxyapatite structure to form fluoroapatite. It can also increase the concentration of fluoride in the saliva, thereby reducing the bacterial metabolism of sugars, the acidity of the environment and hence, demineralization. (<http://www.intelligentdental.com/2011/08/28/fluoride-toothpaste/>)

(The above quote, pp 16–18, was reproduced from *ChemMatters* Teacher’s Guide, October 2011, p 60)

[](http://www.fluoridealert.org/articles/50-reasons/who_data01/)A common means of adding fluoride to our “diet” in the U.S. is by the fluoridation of municipal water supplies. But not everyone believes that water fluoridation is a good idea, including many European countries. The Fluoride Action Network provides some compelling data (in this graph) that they claim refutes the idea that water fluoridation helps fight tooth decay. The data was gathered from the World Health Organization (WHO). (<http://fluoridealert.org>) *(*[*http://fluoridealert.org/studies/caries01/*](http://fluoridealert.org/studies/caries01/)*)*

[Note: DMFT means decayed, missing or filled teeth.]

The graph shows that the general trend across all countries is that the number of DMFTs is decreasing, even in those countries that do NOT fluoridate their water. The Fluoride Action Network claims that this substantial decrease is due to fluoridation of toothpastes and mouthwashes, and they argue therefore that fluoridation of water systems is not warranted.

The <http://fluoridealert.org> Web site provides more data on specific countries, and actively advocates for the removal of fluoridation from our water supplies.

**More on the effect of too much fluoride**

OK, fluoride helps prevent tooth decay, but is fluoride safe?

The oral LD50 value of sodium fluoride, the active ingredient in toothpaste, is 31 mg/kg. This substance is considered highly toxic and is classified as a poison, yet we put it into our mouths every day. But we swallow such small amounts that it causes no harm. It has been estimated that small children (ages 2–4) ingest about 0.3 g of toothpaste every time they brush their teeth and that adults tend to ingest about 0.04 g per brushing.

(Rohrig, B. How Toxic is Toxic? *ChemMatters,* 2014, *32* (4), p 7)

And fluoride is not without its problems, as this brief article from a 1932 J. Chem. Educ. article shows*:*

**Fluorine proved cause of mottled teeth**

Dogs with mottled teeth, an endemic condition of the enamel produced by the presence of fluorine in drinking water, have been achieved experimentally by Dr. Margaret Cammack Smith of the home economics department at the University of Arizona.

Six months ago, Dr. Smith completed her experiments with the drinking water at St. David, Arizona, and determined that fluorine in the drinking water at that place was responsible for the existence of mottled teeth.

At first the mottled condition was only produced experimentally in white rats but now for the first time this condition has been givento the larger animals. The mottled condition has been produced after a six months' feeding experiment.-*Science Service*

(Fluorine proved cause of mottled teeth.J. Chem. Educ., **1932**, 9 (5), p 858)

**More on ways diet can help to prevent tooth decay**

Diet can play a major role in preventing caries formation. These recommendations come from the article “Sugar and Dental Caries” by Riva Touger-Decker and Cor van Loveren, published in the *American Journal of Clinical Nutrition* in 2003:

*1*) eat a balanced diet rich in whole grains, fruit, and vegetables and practice good oral hygiene—particularly the use of fluoridated toothpastes—to maximize oral and systemic health and reduce caries risk.

*2*) eat a combination of foods to reduce the risk of caries and erosion; include dairy products with fermentable carbohydrates and other sugars and consume these foods with, instead of, between meals; add raw fruit or vegetables to meals to increase salivary flow; drink sweetened and acidic beverages with meals, including foods that can buffer the acidogenic effects.

*3*) rinse mouth with water, chew sugarless gum (particularly those containing sugar alcohols, which stimulates remineralization), and eat dairy product such as cheese after the consumption of fermentable carbohydrates.

*4*) chew sugarless gum between meals and snacks to increase salivary flow.

*5*) drink, rather than sip, sweetened and acidic beverages.

*6*) moderate eating frequency to reduce repeated exposure to sugars, other fermentable carbohydrates, and acids.

*7*) avoid putting an infant or child to bed with a bottle of milk, juice, or other sugar-containing beverage.

(Touger-Decker, R. and van Loveren, C. Sugar and Dental Caries. *Am J Clin Nutr,* 2003, 78 (suppl), 881S–92S; <http://ajcn.nutrition.org/content/78/4/881S.full.pdf+html>)

It has been suggested (and studies show) that chewing gum helps to prevent tooth decay. That, apparently, depends on the type of gum and how long it is chewed. It seems logical that chewing gum stimulates the flow of saliva in the mouth, and that can help to neutralize acids produced by plaque bacteria.

On the other hand, sugared gum tends to coat your teeth with sugar, which can lead to tooth decay, the build-up of plaque and the proliferation of bacteria. This is especially true if the gum is removed soon after the flavor is gone. But if gum is chewed for 10-20 minutes, some experts hold that it will then act to decrease tooth decay. One study showed that after chewing gum for 10 minutes each waking hour for two weeks, participants in the study increased their salivary flow, the pH of their saliva, and its buffering capacity, all of which would tend to neutralize some of the acid produced by mouth—the cause of tooth decay.

Sugar-free gum may actually pose more potential problems if not chewed in moderation. Sugar free gums contain hexitols, sorbitol and mannitol as sugar substitutes. The ingestion of these substances can cause diarrhea, as they are not absorbed, but instead pass into the small intestine and colon. It only takes about 10 grams of sorbitol to produce this effect in many individuals. One flight attendant, who had been experiencing abdominal pain and diarrhea for over seven years was given a wide range of diagnostic tests to no avail, but upon questioning, it was found that she had been consuming about 60 sticks of sugar-free chewing gum a day, representing about 75 grams of sorbitol. Upon ceasing to chew gum, her symptoms disappeared.

But then again, there are studies which indicate that one artificial sweetener, Xylitol (e.g. Xylifresh gum) can act to reduce tooth decay if chewed in moderation—two pieces of gum three to five times daily for at least five minutes per chewing session.

*(ChemMatters* Teacher’s Guide, Dec 2000, Chewing Gum)

Research is being done on other foods to see if they might have decay-preventative properties. Score one (more) for the benefits of drinking coffee!

Coffee may also protect teeth. Farah, Gazzani, and Beatriz Gloria, a chemistry professor at the Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, have shown that chemicals in roasted—but not green—coffee inhibit the growth of bacteria that cause tooth decay.

The scientists found a variety of different antibacterial chemicals which killed or inhibited the growth of *Streptococcus mutans,* the major cause of dental decay in humans. Also, Gazzani and colleagues applied roasted coffee to hydroxyapatite, a component of tooth enamel—the hard white substance covering a tooth—and showed that small molecules present in coffee prevented *S. mutans* bacteria from binding to it.

(Haines, G.K. Coffee: Brain Booster to Go. *ChemMatters*, 2008. *26* (4), p 9)

**More on fillings**

A 1929 article in the *Journal of Chemical Education* by a professor from a dental school discusses the needs of dentists in terms of dental fillings and cements needed to hold them in place, and the then-state-of-the-art developments in dental materials, made by chemists. The requirements listed below have not changed in the interim, although the materials available (thanks to chemists) have come a long way.

**Requirements of Filling Materials**

The dentist continues to seek new and improved materials for filling teeth. Few of the materials now available can be regarded as perfect from his standpoint.

A list of the requirements of a perfect filling material is about as follows-:

1. The material should be indestructible in the fluids of the mouth. It must be remembered that saliva is ordinarily somewhat acid and all cements and even some amalgams are slowly dissolved out in the mouth.
2. The material should have adaptability to the walls of the tooth cavity, *i.e.,* the dentist should be able to mallet or tamp it to place.
3. It must be free from shrinkage or expansion after placing in the tooth.
4. It must be hard enough to resist the attrition and wear of mastication.
5. It must be strong and tough to prevent fracture or displacement by the stresses of mastication.
6. The material should have a good color and appearance. If possible it should be available in shades to match the color of tooth structure.
7. It is highly desirable that the filling material should be a non-conductor of thermal changes-heat and cold.
8. It must be remembered that filling material is placed in a living tooth and it must have no toxic effect on the pulp or "nerve."
9. The material should be easy to manipulate, not only readily prepared or mixed, but, if plastic, it should harden promptly when inserted in the tooth.

No material available today for filling teeth possesses all of these desirable qualities. Some materials, like the gold inlay and silver amalgam, possess enough of these properties to make them satisfactory: some, like the cements, are used because nothing better is available.

(Brightfield, L. The Dentist’s Problem—Satisfactory Material for Restoring Teeth. J. Chem. Educ., **1929**, 6 (2), p 308)

The author also discusses at length the state of the art with regard to dental cements used to hold the fillings in place. He concludes his article by saying that

It is likely that some of these dental requirements will be difficult to meet.

But the dentist is confident that the chemist will continue to study dental cements and eventually give him a formula that will answer most if not all his requirements. The dentist's greatest problem has always been that of finding satisfactory materials for restoring teeth and with the aid of the chemist his problem is on the way to satisfactory conclusion.

(Ibid; p 313)

Here is a similar list from 1999, 70 years later:

Ideally, a dental restorative material should be perfectly compatible with the oral environment and should fulfill the criteria set out below:

easily mixed and placed as an unset paste

short working and setting times

rapid buildup in mechanical properties on setting

match of thermal and expansion properties with the tooth

high resistance to erosion and degradation by oral fluids/saliva, brushing, and flossing

biologically inert or bioactive

achieves a hermetic seal with the surrounding tooth tissue

color and translucency to match the tooth

high strength (tensile and compressive)

inexpensive

(Nicholson, J.; Anstice,H. Chemistry Everyday for Everyone: The Chemistry of Modern Dental Filling Materials. *J. Chem. Educ*., 1999, *76* (11), pp 1497–1501; abstract available online at <http://pubs.acs.org/doi/abs/10.1021/ed076p1497>; article available to subscribers only at this same URL)

Comparing the two lists, we have:

|  |  |
| --- | --- |
| **Desirable Physical Properties of Dental Fillings** | |
| **Brightfield, 1929** | **Anstice, 1999** |
| Indestructible in the mouth | High resistance to erosion by saliva, etc. |
| Adaptable to walls of tooth, tampable, malleable | Achieves hermetic seal with surrounding tooth tissue |
| Free from shrinkage | Match expansion properties of tooth |
| Hard – resistant to wear and chewing | High strength |
| Strong and tough to prevent fracture | High tensile and compressive strength |
| Good color and appearance | Color and translucency to match tooth |
| Non-conductor of thermal heat or cold | Match of thermal properties of tooth |
| Non-toxic to root or nerve | Biologically inert or bioactive |
| Easy to manipulate; harden quickly in place | Easily mixed–short working and setting time–rapid buildup in mechanical properties on setting |
|  | inexpensive |

The list from 1999 would be relatively unchanged, even to present times. As you can see, the two lists have not changed in 70-plus years, although the means to achieving these properties has changed significantly, with the invention of the mercury amalgam and, now, composite polymeric materials.

**More on dental amalgams & mercury**

There is no question that there is controversy surrounding the use of mercury amalgam fillings. And yet, almost all professional dental organizations worldwide say that, at the present time, they find them to be safe to use. Here is some background information about amalgam fillings.

Dental amalgam is a dental filling material used to fill cavities caused by tooth decay. It has been used for more than 150 years in hundreds of millions of patients around the world.

Dental amalgam is a mixture of metals, consisting of liquid (elemental) mercury and a powdered alloy composed of silver, tin, and copper. Approximately 50% of dental amalgam is elemental mercury by weight. The chemical properties of elemental mercury allow it to react with and bind together the silver/copper/tin alloy particles to form an amalgam.

Dental amalgam fillings are also known as “silver fillings” because of their silver-like appearance. Despite the name, "silver fillings" do contain elemental mercury.

When placing dental amalgam, the dentist first drills the tooth to remove the decay and then shapes the tooth cavity for placement of the amalgam filling. Next, under appropriate safety conditions, the dentist mixes the powdered alloy with the liquid mercury to form an amalgam putty. (These components are provided to the dentist in a capsule as shown in the graphic.) This softened amalgam putty is placed and shaped in the prepared cavity, where it rapidly hardens into a solid filling.

(U.S. Food and Drug Administration (FDA): <http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/DentalProducts/DentalAmalgam/ucm171094.htm>)

 Here is another description of the amalgam capsule, from a previous (1996) *ChemMatters* article.

A dental amalgam capsule contains two chambers that keep the ingredients separate. When the ingredients are mixed, they form a paste that begins to harden into solid metal in just a few minutes. For this reason, the final mixing must be done in the dentist's office, just before the drilled cavity is filled. The capsule is placed in a machine that shakes it back and forth vigorously. The vibration ruptures the barrier between the two compartments and thoroughly mixes with [sic] mercury with the powdered metals.

(Graham, T. Nightmare on White Street. *ChemMatters,* 1996, *14* (4), pp 9–11)

People worried about mercury in their mouth/body often ask if they should have amalgam fillings removed and replaced with composite fillings. According to the FDA, “If your fillings are in good condition and there is no decay beneath the filling, FDA does not recommend that you have your amalgam fillings removed or replaced. Removing sound amalgam fillings results in unnecessary loss of healthy tooth structure, and exposes you to additional mercury vapor released during the removal process.” (U.S. Food and Drug Administration: <http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/DentalProducts/DentalAmalgam/ucm171094.htm>)

The following quote from a 2009 white paper updates the FDA position on the use of mercury amalgams: “It is concluded that there is insufficient evidence to support an association between exposure to mercury from dental amalgams and adverse health effects in humans, including sensitive subpopulations.” (<http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/DentalProducts/DentalAmalgam/ucm171117.htm#6>)

Here is a list, from the Department of Health and Human Services, Public Health Service, of advantages and disadvantages of mercury amalgam in dental fillings:

|  |  |
| --- | --- |
| **Table 1.  Comparison of the Advantages and Disadvantages of  Dental Amalgam as a Restorative Material** | |
| **Advantages** | **Disadvantages** |
| * Durable * Least technique sensitive of all restorative materials * Applicable to a broad range of clinical situations * Newer formulations have greater long-term resistance to surface corrosion * Good long-term clinical performance * Ease of manipulation by dentist * Minimal placement time compared to other materials * Initially, corrosion products seal the tooth-restoration interface and prevent bacterial leakage * One appointment placement (direct material) * Long lasting if placed under ideal conditions * Often can be repaired * Economical | * Some destruction of sound tooth tissue * Poor esthetic qualities * Long-term corrosion at tooth-restoration interface may result in "ditching" leading to replacement * Galvanic response potential exists * Local allergic potential * Concern about possible mercury toxicity * Marginal breakdown |

([*http://web.health.gov/environment/amalgam1/amalgamu.htm*](http://web.health.gov/environment/amalgam1/amalgamu.htm))

Lest the reader think that “any old” amalgam will do, dentists early on discovered the need for exact amounts of the components and precise measurement of the mixture, in order to ensure a tight fit and good seal when the amalgam is placed in the newly drilled cavity, and thereafter. The hardened metal alloy used in fillings has a coefficient of expansion very different from that of tooth dentin and enamel. Thus it will change volume within the tooth when exposed to temperature changes. When the filling’s temperature increases, with hot food or drink, it expands, more than the tooth; when the temperature drops with cold food or drink, it shrinks, again, more than the tooth.

The tooth is strong enough to withstand the expansion component, but when the filling shrinks, it could possibly open the sides of the cavity, between the tooth material and the amalgam, exposing it to bacterial infestation and infection. Thus it must be “pre-expanded”, so that future temperature-related shrinkage does not result in re-opening the cavity.

Chemists long ago experimented with varying amounts of the metals in the amalgam mix, until they discovered the best mix for this purpose, per the dental association’s parameters of 3–13 micrometers per centimeter of amalgam. The carefully measured mix of ingredients in the amalgam increases its volume slightly as the alloy is hardening, and thus it somewhat forcefully seals shut the cavity. This slight expansion of the alloy as it hardens within the cavity results in a slight compression of the material within the tooth, allowing for slight shrinkage when cold food or drink lowers its temperature, but not enough to open the cavity.

(Philips, R. Dental Amalgam: A Reaction Involving Measurement of Minute Dimensional Change. J. Chem. Educ., 1945, *22* (3), p 117; first page at <http://pubs.acs.org/doi/abs/10.1021/ed022p117>, entire article available to subscribers only at same URL)

**More on composite fillings**

Composite fillings are made primarily of polymeric materials, which exist in the composite resin material as oligomers, short-chain organic molecules, in a matrix. Some of the most used materials include:

… a [bisphenol A-glycidyl methacrylate](https://en.wikipedia.org/w/index.php?title=Bisphenol_A-glycidyl_methacrylate&action=edit&redlink=1) (BISGMA) or [urethane dimethacrylate](https://en.wikipedia.org/w/index.php?title=Urethane_dimethacrylate&action=edit&redlink=1) (UDMA), and an inorganic filler such as silicon dioxide ([silica](https://en.wikipedia.org/wiki/Silica)). Compositions vary widely, with proprietary mixes of resins forming the matrix, as well as engineered filler [glasses](https://en.wikipedia.org/wiki/Glasses) and [glass ceramics](https://en.wikipedia.org/wiki/Glass_ceramics). The [filler](https://en.wikipedia.org/wiki/Filler_(materials)) gives the composite wear resistance and translucency. A coupling agent such as [silane](https://en.wikipedia.org/wiki/Silane) is used to enhance the bond between these two components. An initiator package (such as: [camphorquinone](https://en.wikipedia.org/w/index.php?title=Camphorquinone&action=edit&redlink=1) (CQ), [phenylpropanedione](https://en.wikipedia.org/w/index.php?title=Phenylpropanedione&action=edit&redlink=1) (PPD) or [lucirin](https://en.wikipedia.org/w/index.php?title=Lucirin&action=edit&redlink=1) (TPO)) begins the [polymerization](https://en.wikipedia.org/wiki/Polymerization) reaction of the resins when external [energy](https://en.wikipedia.org/wiki/Energy) (light/heat, etc.) is applied. A [catalyst](https://en.wikipedia.org/wiki/Catalyst) package can control its speed.

(<https://en.wikipedia.org/wiki/Dental_composite>)

Advantages of composite fillings include:

* Esthetics—composite fillings are typically white, or tooth-colored, rather than the silver or black of amalgam fillings
* Less tooth damage—more healthy tooth material must be removed for amalgam fillings in order to ensure a tight lock-and-key fit for the amalgam; in composites, the filling is glued (bonded) in place, so less tooth is removed
* Bonding to tooth—amalgams are mechanically held in place, but composites are actually bonded to the tooth material chemically, ensuring a stronger bond and, hence a stronger tooth
* Possible prevention of tooth removal—if large portions of a tooth are decayed, it may be too much to allow an amalgam filling, but composites may still be used to preserve and strengthen the tooth
* Versatility—composites can be used to repair cracked or chipped teeth, not possible with amalgams
* Maintainability—minor damage to a composite filling may be repaired using additional composite material laid down over top of the original filling; amalgam filling damage would require removal of the old filling and replacing it with an entirely new filling
* Environment—no mercury in the body, no mercury in the dentists’ offices, no mercury in wastewater

But of course nothing has only advantages; here are some disadvantages of composite fillings:

* Durability—composites may not last as long as amalgams, especially in large cavities, and where they bear the brunt of chewing
* Shrinkage—composites shrink a bit more than amalgams, leaving the areas around the filling, next to tooth material, subject to microleakage which can lead to secondary caries; new formulations of composites reduce the shrinkage factor
* Chipping—exposed edges of composite fillings can chip off
* In dentist’s office—placing composites requires more training, skill and talent than needed for amalgams; placing composites takes more time to do than for amalgams; a completely dry environment is needed to place composites, not so for amalgams
* Cost—because they take longer to do, composites are more costly to place than amalgams, so dentists may charge more for composites; because composites are more costly, insurance companies frequently do not cover entire cost of composite filling

Composites were developed as an improvement over amalgam fillings, which they seem to be in most cases. And they certainly pose less of an environmental and health hazard than mercury amalgam fillings. Nevertheless, their safety has been questioned due to the fact that some composites can emit bisphenol-A (BPA), a known endocrine-disruptor, when they are placed in a filling. The emission seems to last only a short while (<1 hour) after they are placed, so exposure is not chronic, as is the case with mercury.

This emission could be from leftover BPA used in the monomer/oligomer resin that was not polymerized into the matrix, or as the result of the degradation of some of the resin after polymerization. Some studies have shown that the amount of BPA released is insignificant.

**More on possible new developments in preventing/treating tooth decay**

**Here’s a possible new treatment to accelerate remineralization of a dental cavity. According to** Dr. Margaret Culotta-Norton, a dentist in Washington, D.C., and former president of the D.C. Dental Society, this would eliminate the need for dental fillings which, she says, generally require repair or replacement, often several times over a lifetime.

Culotta-Norton said that a new treatment for cavities may be on the horizon. A process called electrically accelerated and enhanced remineralization (EAER) is being developed in London. She explained that this process "accelerates the natural movement of calcium and phosphorous minerals into the cavity to repair it. This process would eliminate drills and injections. It emits tiny electrical currents into the tooth to push the minerals into the repair site. It encourages the tooth to repair itself." According to [The Guardian](http://www.theguardian.com/society/2014/jun/16/fillings-dentists-tooth-decay-treatment), this new process could be available by 2017.

(<http://www.livescience.com/44223-cavities-tooth-decay.html>)

On a similar note, news (as of May 2012) from the University of Maryland School of Dentistry tells us about a nanomaterial that acts as an antibacterial agent is being added to existing—and new—composites to control the growth of bacteria in a cavity that has been prepped for a filling. It is very difficult, even impossible, to remove 100% of the decay in a cavity. Leftover bacteria are able to continue growing and reproducing—and producing acids that will continue to eat away at the enamel and dentin in the cavity—even after the filling has been placed, increasing the likelihood that the filling will eventually fail.

The new material is composed of existing composites and quaternary ammonium and silver nanoparticles, at a high pH (which helps to neutralize acid produced by bacteria). Another key feature is the addition of amorphous calcium phosphate, which helps to remineralize the tooth. This combined material is used primarily in the primer used by dentists to prepare the drilled-out cavity, and in the adhesive used to coat the cavity surface to help the composite filling stick to the remaining surface of the tooth. (<http://www.sciencedaily.com/releases/2012/05/120501182830.htm>)

This study shows that adding hydroxyapatite (HAP) nanofibers to existing composite resins effectively reinforces the composites and significantly improves biaxial flexural strength of the composites. (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3422879/>)

And here’s a somewhat novel approach, to genetically engineer a non-stick strain of bacteria that will adhere to tooth enamel so that *S. mutans* can’t!

**No cavities!**

Through genetic engineering, strains of harmless bacteria have been altered to carry desirable traits into plants, making them disease and insect resistant. Other strains have been altered to be tiny factories for otherwise very expensive proteins, insulin and human growth hormone, to name just two. Soon a new strain of Salmonella may be used as an anticavity vaccine, and tooth decay may become only a bad memory The bacteria *Streptococcus mutans* form plaque on teeth, where they convert sugars in food to acids. Once these acids dissolve tooth enamel, teeth decay rapidly. Dr. Roy Curtiss of Washington University in Missouri discovered how *Streptococcus mutans* bacteria stick to teeth. One of the proteins on the surface of the bacteria, called "SpaA," attaches to tooth enamel first, then other surface proteins convert the loose hold to a much tighter one.

The human body forms antibodies against foreign proteins, and should do so against SpaA as well, if enough is present. If surface SpaA were attacked, the bacteria couldn't attach themselves to teeth! Animal experiments on rats and monkeys have been promising, but because *Streptococcal* bacteria are implicated in heart and kidney damage, great caution is needed.

The antibody response cannot be created directly from the bacteria. SpaA is believed safe enough itself, so a harmless strain of Salmonella bacteria was genetically altered to produce SpaA. When injected in a vaccine, the Salmonella attach themselves to lymph nodes of the small intestine and go to work, producing lots of SpaA, enough to trigger the production of lymphocytes (produce antibodies). They migrate through the lymph system to the salivary glands, where the lymphocytes protect against new SpaA and give a permanent protection against *Streptococcus mutans.* Even if an anti-decay vaccine becomes a reality, you will still have to brush and floss regularly. No one wants to kiss someone with rotten gums and bad breath.

(ChemComments: No Cavities! *ChemMatters,* 1990, *8* (2), p 16)

I have to wonder what ever happened to this idea, since 25 years have elapsed. …

# Connections to Chemistry Concepts

**(for correlation to course curriculum)**

1. **Precipitation**—This refers to the chemist’s precipitation, not the meteorologist’s term. Precipitation, the formation of a solid, certainly applies to the process of mineralization, the formation of tooth enamel via the deposition of hydroxyapatite on the surface of the tooth.
2. **Dissolving and dissolution**—The dissolving of a solid into solution occurs in demineralization, the process whereby hydroxyapatite dissolves off the tooth’s surface due to increased acidity in the mouth.
3. **Equilibrium**—The equilibria discussed in this article, acid-base interactions in the mouth and those in the body, are great examples of chemical equilibria at work in nature.
4. **Le Châtelier’s Principle and factors affecting equilibrium**—The article shows how eating food and exercise can be stresses to equilibrium systems within the body.
5. **Acid-Base chemistry**—Although the article focuses primarily on acids, specifically lactic and carbonic acids, this information is a nice segue into the effects of bases on these equilibrium systems, and it offers the teacher a chance to show the interrelatedness of acids and bases in chemical reactions.
6. **pH**—The article reinforces the importance of pH in our study of acids and bases.
7. **pH, Kas, pKas**—The acidity of the mouth with/without food, and its role in enamel/dentin decay could be used in a class discussion of acid strength.
8. **Minerals**—Minerals are usually thought of as materials that are mined from or just under the Earth’s surface, but we frequently forget that they can also be found in living organisms, as in teeth and bones in animals.
9. **Fluorine/fluoride chemistry**—Students don’t get many opportunities to discuss fluorine’s chemical reactivity. The application of fluoride treatments in the prevention of tooth decay gives them one example.
10. **Adsorption**—Fluoride used to prevent tooth decay is adsorbed onto the tooth surface, protecting the enamel from acids produced in the mouth by bacteria, or ingested from outside food/drink sources.
11. **Biochemistry**—Almost all of biochemistry involves rather complex organic chemistry; this article provides a few simple, easy-to-understand (for first year chemistry students) inorganic reactions that affect myriad biochemical reactions in the body.

# Possible Student Misconceptions

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

1. **“Chemical reactions are irreversible—they only go one way, ‘left to right’.”** *Early in the academic year, all equations representing chemical reactions are written for students with the arrow pointing exclusively to the right, giving the student the illusion that reactions only go one way. It isn’t until we reach the topic of equilibrium that most students finally see that chemical reactions can be reversed, or can go in both directions simultaneously.*
2. **“It doesn’t matter when I eat sweet snacks, they’re always bad for my teeth.”** *Current research in tooth decay shows that sweets eaten with a meal are less likely to cause tooth decay than sweets eaten by themselves between meals, primarily because the residual sugars that feed the bacteria that reside in the mouth are washed away with the rest of the food and beverage during a meal. And saliva produced from the foods eaten during the meal helps buffer the effects of the acids produced. Also, you’re more likely to brush your teeth after meals than after between-meal snacks.*
3. **“If I use fluoride toothpaste, I won’t get any cavities.”** *While fluoride treatment does provide another level of protection for your teeth, it does not prevent food materials from getting stuck to teeth. Plaque can still build up on tooth surfaces, resulting in bacterial decay of the enamel that eventually will lead to cavities. Good oral hygiene is still critical—see next misconception.*
4. **“If I use a fluoride mouth rinse and my dentist puts fluoride stuff on my teeth, I don’t have to brush them.”** *While both these procedures will reduce tooth decay, nothing works as well as brushing after meals (and snacks). The fluoride in mouth rinses and dental treatments makes tooth enamel more resistant to acids produced by bacteria as they digest sugars. (see “More on fluoride treatments”, in the Background Information section, above) Fluoride does not, however, make teeth impervious to those acids. So it’s critical that you remove the foodstuff and bacteria by brushing and flossing regularly.*
5. **“Mercury in amalgam fillings is dangerous and dentists should stop using them.”** *There is much controversy today about the use of mercury amalgam fillings, but there is little scientific evidence that the mercury leaches out of the amalgams into the bloodstream, and the American Dental Association and the Federal Food and Drug Administration have not banned their use.*
6. **“If I have mercury amalgam fillings, I should go to my dentist right away and have them removed.”** *If your fillings are in good condition and there is no decay beneath the filling, FDA does not recommend that you have your amalgam fillings removed or replaced. Removing sound amalgam fillings results in unnecessary loss of healthy tooth structure, and exposes you to additional mercury vapor released during the removal process.” (*[*http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/DentalProducts/DentalAmalgam/ucm171094.htm*](http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/DentalProducts/DentalAmalgam/ucm171094.htm)*)*

# Anticipating Student Questions

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

1. **“How do acids attack tooth enamel?”** Essentially, the H+ ion from the organic acids produced by bacteria digesting food reacts with the hydroxyl group (OH–) from hydroxyapatite, as well as with the phosphate groups (PO43-). See “More on tooth decay” in the Background Information section, above.
2. **“What is it about sweets that makes them so bad for our oral health?”** *Sweets contain sugars, and sugars are the main food source for bacterial metabolic processes. Bacteria metabolizing these sugars results produce organic acids, which are responsible for demineralizing tooth enamel.*
3. **“What is the other 4% of the enamel layer of teeth?”** *The remaining 4% of tooth enamel is organic material and water.*
4. **“Is carbonic acid a ‘strong’ acid? Is that why it’s bad for our teeth?”** *Carbonic acid is not a particularly strong acid, as acids go; in fact, it is a rather weak acid, compared to laboratory acids like sulfuric and hydrochloric acids. But even weaker acids can, over time, affect the dissolution of hydroxyapatite from tooth enamel. Acidic foods, such as citrus fruit and spaghetti sauce, also contain weak acids. Actually, strong acids cannot be used in foods, as they would react adversely with organic material in the body. Think battery acid, or concentrated hydrochloric acid from the lab.*
5. **“Is the carbonic acid involved in the chemical equilibrium equations in this article the same carbonic acid as the stuff found in sodas (or ‘pop’)?”** *Yup. See following question.*
6. **“Why is drinking soda (pop) so bad for your teeth?”** *See previous question. But it’s not only (or even primarily) the carbonic acid found “naturally” in carbonated beverages that is responsible for the acidic erosion of tooth enamel, rather it is the extra, stronger acids added to sodas—phosphoric acid and/or citric acid that are added to increase the “sharp” or tingly taste in sodas. In addition, sodas typically contain high fructose corn syrup (HFCS), a simple sugar “loved” by bacteria, enabling them to produce more organic acids that attack enamel. This bacteria food source and the additional acid provided by the dissolved carbon dioxide in soda and the other added inorganic acids, plus all the organic acids produced by the ebullient bacteria, provides a double whammy for your teeth. But don’t think for a moment that diet sodas are off the hook. Although they do not contain HFCSs, they still contain phosphoric and/or citric acids that will erode tooth enamel over time. So, although they’re better than sodas in terms of enamel erosion, they still contribute to the process.*
7. **“Does fluoride really help fight cavities?”** *Many studies have shown the positive effect fluoride has on tooth decay. Chemically, it greatly aids the remineralization of tooth enamel.*
8. **“Is it true that fluoride in drinking water will stain your teeth?”** *Yes and no. It is true that at concentrations higher than 1 ppm fluoride in drinking water can definitely produce stained, or what are referred to as “mottled” teeth. In fact, the discovery that fluoride in drinking water can reduce the incidence of cavities in teeth came about when early in this century it was noted that people who lived around Colorado Springs had a very high incidence of stained or “mottled” teeth, but at the same time had a very low incidence of dental cavities. Both effects were eventually connected to high concentrations of fluoride in the local drinking water. But at concentrations below 1 ppm this staining does not occur to any significant degree.*
9. **“Are mercury amalgams dangerous?”** *This question has been argued over for decades, and the debate continues even today. See “More on treating tooth decay” in the Background Section above. There are definitely drawbacks to using amalgams—problems obtaining a useful 3-dimensional panoramic x-ray picture, the need to cut away extra, healthy tooth to accommodate the shaping of the filling to ensure an immobile fit, and the need for proper disposal due to the mercury content—all as mentioned in the article. In addition, many people believe that some of the mercury itself can leach out of the amalgam and travel through the bloodstream and cause nerve damage within the body. Studies to-date have not supported that belief, and the American Dental Association and other professional groups have not seen the need to ban the use of amalgams, although composite resin fillings are certainly becoming more prevalent and popular.*
10. **“If I have mercury amalgam fillings, should I ask my dentist to remove them and replace them with composite resin fillings?”** *“If your fillings are in good condition and there is no decay beneath the filling, FDA [U.S. Food and Drug Administration] does not recommend that you have your amalgam fillings removed or replaced. Removing sound amalgam fillings results in unnecessary loss of healthy tooth structure, and exposes you to additional mercury vapor released during the removal process.” (U.S. Food and Drug Administration:* [*http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/DentalProducts/DentalAmalgam/ucm171094.htm*](http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/DentalProducts/DentalAmalgam/ucm171094.htm)*)*

## In-Class Activities

**(lesson ideas, including labs & demonstrations)**

1. The following experiments/demonstrations can be used to investigate dissolution of solids, as in demineralization of tooth enamel. All the following use either egg shell or bone to represent teeth (although some use actual teeth):
   1. Dissolve CaCO3 in HCl or vinegar—egg shell, limestone or even marble dissolving in the acid. Although tooth enamel is notexactly analogous to CaCO3, you could use this as an example of what happens to a calcium-based mineral when it is exposed to acid secretions. Put an egg into vinegar and observe it over several days. The acid will dissolve the shell, similar to what happens when acid attacks tooth enamel, although that is a much slower process.
   2. This simple experiment uses chicken bones (allegedly akin to tooth material) and vinegar to show erosion. It misses the chance to use soda as the acid. Students could check pKas of relevant acids (acetic, phosphoric, citric, malic, carbonic) to predict effects on bones and do the experiment to test their hypothesis. (<http://healthyteeth.org/acid-attack/>) (perhaps they can also draft revised experiment with improved procedure)
   3. You could have students design an experiment using actual citric and phosphoric acids in varying concentrations acting on extracted teeth (obtained from a local dentist, perhaps?) to test their effects. (See this site for a science fair experiment, as an example: <http://www.selah.k12.wa.us/SOAR/SciProj99/ElisaSciProj.html#TOP>.)
   4. Here’s a simple demonstration to show fluoride’s protective effect on teeth (or similar substance, at least): <http://healthyteeth.org/power-of-fluoride/>.
   5. This student science fair project tests various liquids, mostly sodas, to see their effect on the decay of egg shells, chosen to represent real teeth: <http://mwvsciencefair.wikispaces.com/Teeth+Decay+in+Liquids>. You could have students evaluate the project in terms of how well it simulates tooth decay, and how well it was designed/executed, to test their understanding of the process of science.
2. You can show examples of precipitation to simulate the remineralization of hydroxyapatite on tooth surfaces using solutions of 0.1 M CaCl2 in Na2CO3 or CaCl2 & NaOH.
3. To show students how an equilibrium works, you could do the standard equilibrium demonstration or lab activity involving iron(III) nitrate (KNO3) and potassium thiocyanate (KSCN). This site presents a nice visual description of the very simple lab showing the effects of stresses on this equilibrium: <http://www.chem.uiuc.edu/chem103/equilibrium/iron.htm>. And this one provides some nice questions as follow-up to the activity: <http://www.chalkbored.com/lessons/chemistry-12/Le-Chatelier-lab.pdf>.

And this one provides a bit more chemistry at a slightly higher academic level: <http://faculty.scf.edu/GambinC/CHM%202046/CHM%202046%20Lab/Le%20Chatelier%27s.doc>

This 7:40 YouTube video clip shows various stresses on the iron-thiocyanate equilibrium: <https://www.youtube.com/watch?v=xT43fdoT_4w>

1. Or you can do one of many other demonstrations of equilibrium, such as this one:
   1. This 3:04 YouTube video clip shows an instructor simulating a chemical equilibrium system using a “reaction” (water being transferred between two aquaria) approaching and reaching equilibrium: <https://www.youtube.com/watch?feature=player_embedded&v=_QnRt7PYzeY>
   2. This 14:51 Flinn video has Irwin Talesnick teaching teachers how to do the equilibrium demonstration discussed in a: <https://www.youtube.com/watch?feature=player_embedded&v=ksGWvU8KaGE>.
   3. You could also do this demonstration using clear cups as the reservoirs and straws (of differing diameters) to transfer the water between the cups. Remember to color the water to make it more obvious to your audience and be sure you have a one-color background behind the cups—or the aquaria.
2. You can show pH change using Universal indicator in the reaction of baking soda (NaHCO3) in HCl or vinegar; or test the pH of a colorless soda, like 7 Up or Sprite.
3. Almost all of the acidity of soda pop comes from the phosphoric acid and not from the carbonic acid from the dissolved CO2. You can verify this by measuring the pH of fresh and flat soda pop (minus the CO2 and, hence the carbonic acid); there's very little difference in pH. The phosphoric acid is corrosive, but actually the acid concentration in soda pop is lower than that in orange juice or lemonade. Try submerging identical strips of magnesium (or iron staples) in each of these beverages overnight, including soda pop. Which beverage dissolves more metal? Which dissolves the metal fastest? (<http://antoine.frostburg.edu/chem/senese/101/consumer/faq/why-phosphoric-acid-in-soda-pop.shtml>)
4. Vernier Software’s “Chemistry with Vernier” lab manual, experiment 35 has students determine the phosphoric acid content of various sodas. This site provides an evaluation copy of the activity, but it includes a statement that it is an incomplete document, lacking safety instructions, preparation of materials, etc.; they provide the link for you to buy the lab manual. (<http://www2.vernier.com/sample_labs/CWV-35-COMP-phosphoric_acid.pdf>)
5. Show pH change—e.g., Universal indicator, baking soda & HCl or vinegar
6. If you teach an AP or second-year level class, this lab that describes using infrared spectroscopy (830 nm) to experimentally determine the amount of phosphorus (from phosphoric acid) in cola soft drinks may be of interest: Lozano-Calero, D.; Martin-Palomeque, P. Determination of Phosphorus in Cola Drinks. J. Chem. Educ., 1996, 73 (12), p 1173. The abstract of the article is available online at <http://pubs.acs.org/doi/abs/10.1021/ed073p1173>. The pdf is available to subscribers only at this same URL.
7. Have kids design an experiment to test the acidity of various sour candies. Here’s a sample from Mensa for Kids: <http://www.mensaforkids.org/teach/activity-plans/the-science-of-candy/>. Students can review this procedure to determine its efficacy. After discussion of this test, they can devise their own, hopefully improved procedure. (You can download a pdf of the activity for classroom distribution.) This is a list of candy products and their corresponding pH levels: <http://www.drokeefe.com/pages/candy-ph.htm>.
8. Here’s another science experiment testing sugar and dental erosion: <http://scijourner.org/index.php?option=com_content&view=article&id=236:experiment-sports-drinks-possible-cause-of-tooth-erosion>.
9. Have students make their own toothpaste. Here’s an article from *J. Chem. Educ.* that provides the student and teacher versions of the lab activity: Trantow, A. JCE Classroom Activity #47: Brushing Up on Chemistry. *J. Chem. Educ*., 2002, *79* (10), pp 1168A–1168B; abstract available online at <http://pubs.acs.org/doi/abs/10.1021/ed079p1168A>, pdf of entire article available only to subscribers, at this same URL.
10. This *Journal of Chemical Education* article provides five questions (and answers) that students of AP, second year or IB courses could be asked to solve regarding fluoride in dental applications, to give them applications of chemistry to the real world. Chemistry topics included in these questions are: “stoichiometry, concentration units, resonance in polyatomic ions, bond order, bond length, geometry of polyatomic ions, and treatment of water.” (Resources for Student Assessment. Pinto, G. Fluorine Compounds and Dental Health: Applications of General Chemistry Topics. J. Chem. Educ., **2009**, 86 (2), p 185; abstract available at <http://pubs.acs.org/doi/abs/10.1021/ed086p185>; the pdf of the article is also available to subscribers at this same URL)
11. You can have students research and debate the water fluoridation controversy. “Pros” can start with information from the Fluoride Information Network, <http://fluorideinfo.org/>, while “cons” can begin with information from the Fluoride Alert Network, this source: <http://fluoridealert.org/>. Perhaps a more balanced view can be found at the Centers for Disease Control (CDC) Web site, here: <http://www.cdc.gov/fluoridation/benefits/index.htm>
12. As mentioned in the “More on saliva and equilibrium in the mouth” section, amylase is one of the enzymes in saliva that helps digest starches.
13. There is a standard activity that shows amylase activity on starch. The student chews on a carbohydrate and tests the result with tincture of iodine. (simple: <http://www.coolscience.org/CoolScience/KidScientists/IodineStarch.htm>) and

(a bit more complex: <http://www.juliantrubin.com/encyclopedia/biochemistry/saliva_amylase.html>)

1. Or you can use amylase by itself. Here’s a YouTube video clip (7:13) that shows the process in detail, and then the result after several minutes: <https://www.youtube.com/watch?v=cZyq4koUCNM>.
2. And here is an inquiry-based student activity from *The Science Teacher*, “Enzyme Inquiry”, to take the previous student activity a step further: <http://science.kennesaw.edu/~mdias/SCED%204415/Biology%20Teaching%20Resources/Enzyme%20Inquiry.pdf>.
3. Another activity showing saliva’s effects is to test mouth pH before and after eating. “Wait at least two hours after eating or drinking to ensure that the food consumed does not alter test results. Cleanse the mouth by filling the mouth with saliva and then swallowing or spitting. Fill the mouth again with saliva and place a small amount on a pH strip. The strip will change colors based on the results.” <http://www.livestrong.com/article/192281-what-is-ph-of-saliva/>
4. In this student activity (college-level, but not that difficult), students measure the “amylase number”, a relative value that reflects the individual’s amount of amylase and its ability to break down starch. They then compare class results. (<https://www.apsu.edu/sites/apsu.edu/files/chemistry/SP11_1021_BREAKING_DOWN_STARCH_USING_SALIVARY_ENZYMES.pdf>)
5. You may want to use the idea of the photo-initiated catalysts to begin the polymerization process in materials used for composite fillings as an example of light’s effects on chemical reactions. The light used in this process is usually a blue, or even ultraviolet light. You can ask students why a blue light is used, rather than a red or green light, for example.
6. Depending on the level of your students, you might want to have them do the following calculations to show the difference in solubility between hydroxyapatite and fluoroapatite.

Exercise: SOLUBILITY and SOLUBILITY PRODUCT

Tooth enamel is composed of the mineral hydroxyapatite, Ca5(PO4)3OH   
(Ksp = 6.8 x 10-37). The presence of acids, i.e. acidic fruits and fruit juices or acids that are formed when various sugars are metabolized by bacteria, will react with the hydroxyapatite, thus leading to tooth decay. Fluoride is often added to toothpaste and water treatment plants in some communities add fluoride to drinking water to prevent tooth decay. The fluoride reacts with the Ca5(PO4)3OH to form the more decay resistant fluorapatite, Ca5(PO4)3F (Ksp = 1.0 x 10-60). These measures have resulted in a dramatic decrease in the number of cavities among children. Calculate the solubility of Ca5(PO4)3OH and Ca5(PO4)3F in water.

1. Write a chemical equation for the reaction of hydroxyapatite with acids (H+):

2. Calculate the solubility of Ca5(PO4)3OH in water

[*ICE* tables—samples are given on the site below to show how to solve this problem]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | *Ca5(PO4)3OH* | *Ca2+* | *PO43-* | *OH-* |
| ***I***nitial |  |  |  |  |
| ***C***hange |  |  |  |  |
| ***E***quilibrium |  |  |  |  |

3. Calculate the solubility of Ca5(PO4)3F in water

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | *Ca5(PO4)3F* | *Ca2+* | *PO43-* | *F-* |
| ***I***nitial |  |  |  |  |
| ***C***hange |  |  |  |  |
| ***E***quilibrium |  |  |  |  |

(<http://wc.pima.edu/~skolchens/C152OL/Ch19/Ksp.htm>)

# Out-of-Class Activities and Projects

**(student research, class projects)**

1. Students can research and debate the mercury-in-amalgam fillings issue. Anti-amalgam groups abound online. Here is one set of documents said to support the anti-amalgam position: <http://www.flcv.com/dams.html>. Here is another: <http://www.thenaturalrecoveryplan.com/research.php>. Students must be made aware of the bias inherent in some of these sites. Pro-amalgam positions include the ADA <http://www.ada.org/en/about-the-ada/ada-positions-policies-and-statements/statement-on-dental-amalgam>), the FDA (<http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/DentalProducts/DentalAmalgam/ucm171094.htm>) and FDI World Dental Federation (<http://www.fdiworldental.org/media/11351/Safety-of-dental-amalgam-2007.pdf>). It is enlightening to see how one group can cite specific scientific studies that support its position, while the group espousing the opposite position uses the same study to support their position. (reminiscent of global warming, er … I mean, climate change) Wikipedia’s page on the dental amalgam controversy can be found here: <https://en.wikipedia.org/wiki/Dental_amalgam_controversy>.

Also see “Web Sites for Additional Information” below for more sites on amalgam fillings.

1. Students can research and debate the fluoride treatment issue.
2. Students might be able to obtain teeth from their dentist on which to do long-term research re: dental caries formation and prevention.
3. Students can research and report on other equilibrium systems at work in the body.
4. Students can research and report on acidic and basic foods and their effects on tooth erosion/decay.
5. Students can research and report on types of acid contained in various candies (from food labels) and seek a correlation between type of acid and level of tartness/sourness. Here is a sample, very rudimentary experiment: <http://www.education.com/science-fair/article/candy-ph/>. Although rudimentary, it requires melting of each of the candies, perhaps a painstakingly slow process. This one dissolves the candies instead (although no chocolates were tested): <http://cascience6isp.wikispaces.com/file/view/Emily%20K2013.pdf/415709538/Emily%20K2013.pdf>. It also uses a pH meter, rather than pH paper, as in the first experiment.
6. Students can investigate this study on tooth erosion as it relates to Gatorade imbibement, and comment on the scientific rigor of the experiment, possibly suggesting ways to improve the procedure. (<http://www.webdental.com/profiles/blogs/why-gatorade-erodes-teeth>)
7. Interested students can test their own saliva before and after eating, to show changes in pH as a result of ingested food. The standard way of testing pH of saliva is the following: Wait at least two hours after eating or drinking to ensure that the food consumed does not alter test results. Cleanse the mouth by filling the mouth with saliva and then swallowing or spitting. Fill the mouth again with saliva and place a small amount on a pH strip. The strip will change colors based on the results. (<http://www.livestrong.com/article/192281-what-is-ph-of-saliva/>) Varying the times following eating can show changes in pH. Be sure to include a test after brushing the teeth.
8. If you’re not planning to do a debate on the role of water fluoridation in reducing tooth decay in your classes, students can research the pros and cons of this topic and write a report/make a class presentation. See the reference in the “In-Class Activities” section, above, for links to sites to begin their online research. Note: you may NOT want to give them this site: <http://www.debate.org/debates/Water-fluoridation-is-safe/1/>, as it contains an already-established debate. Alternatively, you may want to restrict the debate to one aspect of the controversy, as the debate above does, focusing on the safety of fluoride in the diet.

# References

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



**30 Years of *ChemMatters***

Available Now!

**The references below can be found on the *ChemMatters* 30-year DVD (which includes all articles published during the years 1983 through April 2013 and all available Teacher’s Guides, beginning February 1990). 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 “Archive” tab in the middle of the screen just under the *ChemMatters* logo. On this new page click on the “Get 30 Years of ChemMatters on DVD!” tab at the right for more information and to purchase the DVD.**

**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. Simply access the link and click on the aforementioned “Archive” tab.**

This article from 1986 provides a brief history of tooth decay prevention and discusses the role tooth paste plays in preventing tooth decay and the ingredients of present-day tooth pastes. The author also discusses demineralization and re-mineralization of tooth enamel. (Yohe, B. Tooth Paste. *ChemMatters,* 1986, *4* (1), pp 12–13)

OK, fluoride is used to prevent cavities, but where does fluorine come from? Here’s a brief history of the trials and tribulations of the search for and discovery/isolation of the element fluorine. (Davenport, D. The Back Burner: Going Against the Flow: The Isolation of Fluorine. *ChemMatters,* 1986, *4* (4), pp 13–15)

This 1988 article discusses sugar and artificial sweeteners. It shows their structures and discusses a “triangle of sweetness” (a 3-sided structure containing corners of a hydrogen bond donor site, a receptor site, and a hydrophobic site) to which all sweeteners must relate chemically and by shape. At the end of the article is a 2-page insert form that contains paper molecular models of glucose and cyclamate that can be cut out and then used to show how they relate to the triangle of sweetness. (Emsley, J. Artificial Sweeteners. *ChemMatters,* 1988, *6* (1), pp 4–8, plus 2-page insert)

Author Owsley relates the story of a horrific murder in which the body was burned and crushed, leaving almost no traceable evidence. But small bone and tooth fragments left behind were enough to test using forensic apparatus. In this case, amalgam fillings finally led to the solving of the case. (Owsley, D. Fragments of Murder. *ChemMatters*, 1996, *14* (2), pp 12–15)

In this article, author Baxter investigates mouthwashes and their effectiveness at reducing bad breath and tooth decay. (Baxter, R. Mouthwash: What’s in it for You? *ChemMatters*, 1996, *14* (4), pp 6–8)

Author Graham describes the mysterious deaths of 4 family members after a fire. He describes the symptoms of the family members and the investigation done by scientists to establish mercury poisoning—from the refining of contaminated metals from unused mercury-amalgam dental capsules. A sidebar explains the chemistry behind the toxicity of mercury. (Graham, T. *Mystery Matters*: Nightmare on White Street. *ChemMatters,* 1996, *14* (4), pp 9–11)

This is an early article on whitening of teeth that briefly discusses the history of tooth whitening, and the present-day use of carbamide peroxide as a source of hydrogen peroxide to bleach teeth. (Ruth, C. Teeth Whitening. *ChemMatters*, 2003, *21* (4), pp 7–9)

The December 2003 *ChemMatters* Teacher’s Guide accompanying the “Teeth Whitening” article above contains more on the history of whitening agents and toothpaste. It even offers a “toothbrush timeline”.

Here’s another, more recent article on artificial sweeteners. (Brownlee, C. The Skinny on Sweeteners. *ChemMatters*, 2011, *29* (3), pp 15–16)

The October 2011 *ChemMatters* Teacher’s Guide has lots more information on artificial sweeteners.

This article discusses bodily functions that result in bad smells or less-than-flattering appearance (acne, bad breath and flatulence). In his coverage of bad breath, author Rohrig discusses tooth decay as an offshoot of bad breath. He describes demineralization and remineralization and the role of fluoride in tooth decay. (Rohrig, B. Demystifying Gross Stuff. *ChemMatters*, 2011, *29* (3), pp 12–14)

The October 2011 *ChemMatters* Teacher’s Guide has lots more information about tooth decay and fluoride water treatment to combat decay.

The topic of tooth whitening is discussed in this article. It includes the safety of whitening methods used today. (Sitzman, B.; Goode, R. Open for Discussion: Teeth Whiteners. *ChemMatters,* 2013, *31* (1), p 5)

# Web Sites for Additional Information

**(Web-based information sources)**

**More sites on the structure of the tooth**

A good black-and-white diagram of a tooth’s structure can be found at <http://www1.us.elsevierhealth.com/SIMON/Bird/modern/EIC/graphics/7627_04_24.jpg>.

This 2007 paper, “An Overview of the Dental Pulp: Its Function and Responses to Injury,” describes the role of dental pulp in maintaining healthy teeth: <http://www.ada.org.au/app_cmslib/media/lib/0704/m70470_v1_633112728503963750.pdf>.

This paper, “The Role of Dentin in Tooth Fracture”, reports on studies using scanning electron microscopes (SEM) that show that the softer-than-enamel dentin absorbs some of the stresses of mastication on the enamel, thus preventing propagation of microfractures through the enamel, which would result in cracking the enamel: <https://str.llnl.gov/str/JanFeb08/pdfs/01.08.3.pdf>.

**More sites on the chemical structure of tooth enamel**

A May 2006 article in the *Journal of Chemical Education*, “Calcium Phosphates and Human Beings” by Sergey V. Dorozhkin discusses at length the naturally-occurring crystalline varieties of apatite (calcium phosphate) in rocks and minerals, and its role in mammals, especially humans, in their bones and teeth. (Dorozhkin, S. Calcium Phosphates and Human Beings. J. Chem. Educ., **2006**, 83 (5), p 713) The abstract of the article is available online at <http://pubs.acs.org/doi/abs/10.1021/ed083p713>; the pdf of the article is available only to subscribers *of J Chem. Educ.* at this same URL.

A series of 32 slides from Prof. Colin Robinson of the Leeds Dental Institute, UK, provides information on tooth enamel. His slides aim

* To recognise the structure of calcium hydroxyapatite, the main mineral component of the dental tissues
* To understand apatite structure in terms of foreign ion substitutions and their effect in relation to enamel behaviour
* To recognise the variations in chemical composition of dental enamel in relation to disease and eventually development

The slides illustrate the chemical content and structural arrangement of hydroxyapatite, and the varying chemical content of tooth enamel in various locations on the tooth. (<http://www.academia.edu/1732481/Dental_Enamel_Chemistry>)

This page from webmineral.com provides the unit-cell structure of apatite. This page requires Java to work, and you probably will need to add this site to your “exceptions list” in Java, otherwise security prevents you from viewing it. The Java structure is rotatable, it can be animated to rotate, and you can change the appearance to include/exclude atoms, bonds, polyhedral structures, labels, etc. (<http://webmineral.com/jpowd/JPX/jpowd.php?target_file=Apatite-%28CaOH%29.jpx#.Ve3uWM-FNOQ>)

**More sites on tooth decay**

Simplyteeth.com provides a wealth of basic information about teeth, from anatomy to decay causes, prevention, and treatment: <http://simplyteeth.com/>.

This site discusses the dental erosion experienced by a man who drank 1.5 liters of cola per day for several years. It offers a detailed medical description of his case. It also includes photos of his teeth. (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2676420/>)

This PubMed site provides a very detailed 2010 report discussing tests done with colas to show their effects on teeth and the environment of the mouth: <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2997506/?tool=pubmed>.

This webmd.com site discusses the various causes of dental erosion: extrinsic, intrinsic and environmental: <http://www.webmd.com/oral-health/guide/tooth-enamel-erosion-restoration>.

This site provides a brief table of Kas and pKas of various common acids (with names and formulas), including carbonic, phosphoric and citric acids: <http://2012books.lardbucket.org/books/principles-of-general-chemistry-v1.0/s31-appendix-c-dissociation-consta.html>.

Here’s a site that covers rather extensively “Acidity, Basicity, and pKa”. This might be most useful as a teacher introduction/review of the topics, although portions (or maybe all for a better student) could be used by students. <http://www.columbia.edu/~crg2133/Files/CambridgeIA/Chemistry/AcidityBasicitykPa.pdf>

Here is a set of 9 sessions from the Khan Academy on acid-base equilibria: <https://www.khanacademy.org/science/chemistry/acids-and-bases-topic/copy-of-acid-base-equilibria>.

The American Chemical Society publication *Chemical and Engineering News* (*C&EN*) frequently publishes “What’s That Stuff?”, one-page articles on specific useful items. This article focuses on fluoride toothpaste and fluoridated water, and the sources for the fluoride in both: <http://pubs.acs.org/cen/whatstuff/stuff/7916sci4.html>, available to all.

You can access a rather detailed description of how enamel forms and how it demineralizes, as well as photomicrographs of tooth enamel, with and without fluoride, at <http://www.dimensionsofdentalhygiene.com/ddhright.aspx?id=5620>.

This site discusses what causes tooth decay, and how to prevent it. Its focus is on the role played by foods we eat. (<http://www.human-health-and-animal-ethics.com/health/dental-care/tooth-decay.php#How%20to%20prevent%20tooth%20decay>)

This site from Virtual Chembook describes the process of food, saliva and *S. mutans* mixing in the mouth, most likely resulting in dental cavities: <http://chemistry.elmhurst.edu/vchembook/548toothdecay.html>.

Dentist Brian Palmer’s site contains 3 pdf documents (among others) that discuss abfraction of teeth. Apparently, some dentists believe this theory and some do not. (<http://www.brianpalmerdds.com/hypothesis_abfractions.htm>)

**More sites on food’s effects on tooth decay**

This site from the Mayo Clinic discusses artificial sweeteners and sugar substitutes: <http://www.mayoclinic.org/healthy-lifestyle/nutrition-and-healthy-eating/in-depth/artificial-sweeteners/art-20046936>.

This 2003 paper from the *American Journal of Clinical Nutrition* reports on research done on the relationship between food intake and dental caries worldwide. (Touger-Decker, R. and van Loveren, C. Sugar and Dental Caries. *Am J Clin Nutr,* 2003, 78 (suppl), 881S–92S; <http://ajcn.nutrition.org/content/78/4/881S.full.pdf+html>)

**More sites on effects of brushing and flossing**

Here’s a site from “Save Your Smile”. Everything You Wanted to Know about Toothpaste: <http://www.saveyoursmile.com/toothpaste/toothpaste-a.html>.

This 1978 article from *J. Chem. Educ.*, Chem I Supplement: Chemistry in Oral Health describes the four main ingredients in oral dentifrices. (Chemistry in Oral Health. J. Chem. Educ., 1978, 55 (11), p 736; abstract only, <http://pubs.acs.org/doi/abs/10.1021/ed055p736>. The article is available at this same URL only to subscribers.)

**More sites on fluorine and fluoride treatment of teeth**

This page from the *Journal of Chemical Education* discusses fluorine’s history of discovery and uses: Banks, A. What’s the Use? Fluorine. *J. Chem. Educ.* 1990, *67* (5), p 373; abstract here: <http://pubs.acs.org/doi/abs/10.1021/ed055p736>; article available to subscribers at this same URL.

Another article from *J. Chem. Educ*. Discusses fluoride: its history, natural source, various compounds used in dental materials, and chemistry in preventing caries. (Rakita, P. Chemistry for Everyone: Dentifrice Fluoride. *J. Chem. Educ.,* 2004, *81* (5), pp 677–679; abstract online at <http://pubs.acs.org/doi/abs/10.1021/ed081p677>; article for subscribers at same URL.

An article in the 1963 Proceedings of the Nutrition Society titled, “Theories on the Mode of Action of Fluoride in Reducing Dental Decay,” presents an in-depth treatment of the role of fluoride in prevention of tooth decay, at <http://journals.cambridge.org/action/displayFulltext?type=1&fid=784036&jid=PNS&volumeId=22&issueId=01&aid=784028>.

The 1963 paper “Theories on the Mode of Action by Fluoride in Reducing Dental Decay” from the Proceedings of the Nutrition Society discusses then-recent research into the ways that fluoride aids in cavity-reduction: <http://journals.cambridge.org/download.php?file=%2FPNS%2FPNS22_01%2FS0029665163000227a.pdf&code=6b757e835089bfe0cc1b3917051f9ad5>.

Here is a 2006 very brief, 2-page flyer from the Centers for Disease Control (CDC) on the benefits of water fluoridation: <http://www.cdc.gov/fluoridation/pdf/natures_way.pdf>.

And a 69-page 2005 document, “Fluoridation Facts”, from the American Dental Association (ADA) provides detailed answers and facts to substantiate their answers to more than 50 commonly-asked questions about water fluoridation. The document also contains more than 350 references (vast majority of references are not linked to World Wide Web). (<http://www.ada.org/~/media/ADA/Member%20Center/FIles/fluoridation_facts.ashx>)

This is a 2013 video clip (9:09) from an Australian (Queensland [Qld]) ABC television news show that discusses the pros and cons of water fluoridation: <http://www.abc.net.au/catalyst/stories/3821248.htm>. Viewing this might be a good way to begin a research study/debate on the controversy, as it presents some of both sides of the issue.

This site from the Fluoride Action Network provides 50 reasons NOT to fluoridate drinking water: <http://fluoridealert.org/articles/50-reasons/>.

And from the same organization comes the document “The Case Against Fluoride”, with 40 ways to rebut claims from pro-fluoridation groups: <http://www.fluoridealert.org/wp-content/uploads/proponent_claims.pdf>

From the National Academy of Sciences (NAP), you can download a pdf copy of the 507-page 2006 National Research Council’s document “Fluoride in Drinking Water: A Scientific Review of EPA’s Standards” at <http://www.nap.edu/openbook.php?record_id=11571>. The document is replete with detailed information on all known aspects of fluoride effects on health, and only a small portion is concerned with fluoride in teeth. You can download chapter by chapter or the entire document. You can register with NAP, or you can download a copy as a guest. NAP has many very useful documents available for purchase or for free download, so it might be useful to register.

**More sites on saliva and equilibrium in the mouth**

This site from the European Food Information Council (EUFIC), “Saliva—more than just water in your mouth”, provides much information on the role of saliva in preventing tooth erosion. It includes material on inorganic erosion (providing calcium and phosphate ions), as its effects on bacteria (preventing bacterial build-up on enamel via its slipperiness, attracting bacteria to it instead of to enamel, thus subsequently being swallowed, and actually killing bacteria via lysozyme). (<http://www.eufic.org/article/en/artid/Saliva-more-than-just-water-in-your-mouth/>)

**More sites on treating tooth decay—mercury amalgam fillings**

The National Capital Poison Center has an extensive, well-documented Web page describing fillings in general and amalgam fillings in particular, especially relative to their safety. (<http://www.poison.org/current/dentalamalgamsandmercury.htm>)

This 116-page pdf document comprises the complete FDA 2008 final ruling on “Dental Devices: Classification of Dental Amalgam, Reclassification of Dental Mercury, Designation of Special Controls for Dental Amalgam, Mercury, and Amalgam Alloy. It includes more than 80 references the FDA used in its study/decision to change dental amalgams from Class I to Class II devices. (<http://www.fda.gov/downloads/MedicalDevices/ProductsandMedicalProcedures/DentalProducts/DentalAmalgam/UCM174024.pdf>)

This site from the European Commission, Health & Consumer Protection, Consulate-General’s Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), presents information on amalgam fillings, and alternative materials used for fillings, through a simple series of Q & As. The document is distributed via GreenFacts.org. (<http://ec.europa.eu/health/opinions/dental-amalgam-l1_en.pdf>)

This 74-page 2008 document from the European Commission, Health & Consumer Protection, Consulate-General’s Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) provides detailed information on their research and findings regarding the safety of mercury amalgams. This is the complete document from which the preceding source was taken and reformatted. (<http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_016.pdf>)

Here is a 4:26 video clip close-up of a cavity and its repair via an amalgam restoration: <https://www.youtube.com/watch?v=ehFUq2t5O-U&feature=player_embedded>

<http://www.azom.com/article.aspx?ArticleID=8081>

The online source “Dental Amalgam: A Scientific Review and Recommended Public Health Service Strategy for Research, Education and Regulation” is an extensive report published in 1993 of research done and compiled by the Subcommittee on Risk Management of the Committee to Coordinate Environmental Health and Related Programs, of the Public Health Service. <http://web.health.gov/environment/amalgam1/ct.htm>.

This 6-page pdf document discusses the history, production and use of mercury amalgam in tooth fillings: <http://prospect.rsc.org/metalsandlife/9.16b.pdf>.

This site on the FDA Web site provides a passionate plea by doctors, dentists, and researchers, backed up by much evidence, asking the FDA to ban mercury in the United States: <http://www.fda.gov/downloads/advisorycommittees/committeesmeetingmaterials/medicaldevices/medicaldevicesadvisorycommittee/dentalproductspanel/ucm236379.pdf>.

The article “Toxic Teeth: Are Amalgam Fillings Safe?” from the Dr. Oz television show, discusses amalgam fillings: <http://www.doctoroz.com/article/toxic-teeth-are-our-amalgam-fillings-safe>.

**More sites on treating tooth decay—composite fillings**

Webmd.com provides a 7-page Web site detailing the work dentists do on fillings. Page 2 in particular lists advantages and disadvantages of each type of tooth filling: cast gold, mercury amalgam, and composite: <http://www.webmd.com/oral-health/guide/dental-health-fillings>.

The bisphenol-A.org Web site provides much information about bisphenol-A (BPA) in general, and this page specifically deals with the topic of BPA leaching from composite fillings and dental sealants: <http://bisphenol-a.org/human/dental.html>. Going to their “Myths about BPA” page (<http://bisphenol-a.org/about/bpa-myths/index.html>) gives the discerning reader a better understanding on their position concerning the health effects of BPA.