

**Teacher’s Guide**

**What is Dental Enamel and How Does It Protect Your Teeth?**

***December 2022***

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Activate students’ prior knowledge and engage them before they read the article.

[***Reading Comprehension Questions***](#_heading=h.3znysh7) ***3***

These questions are designed to help students read the article (and graphics) carefully. They can help the teacher assess how well students understand the content and help direct the need for follow-up discussions and/or activities. You’ll find the questions ordered in increasing difficulty.

[***Graphic Organizer***](#_heading=h.9f8azrtnp6p5) ***6***

Thishelps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.

[***Answers***](#_heading=h.djipzn7z1r1b) ***7***

Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.

[***Additional Resources***](#_heading=h.8qbtv1wio6jt) ***11***

Here you will find additional labs, simulations, lessons, and project ideas that you can use with your students alongside this article

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# Anticipation Guide

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

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. Sugar contributes to dental enamel damage. |
|  |  | 2. Dental enamel protects dentin and pulp, both of which are soft. |
|  |  | 3. Dental enamel contains calcium and phosphorus, in addition to carbon, hydrogen, and oxygen. |
|  |  | 4. The outer layer of dental enamel is about a millimeter thick. |
|  |  | 5. The molecules in inner dental enamel are arranged to provide strength and avoid cracks in the enamel. |
|  |  | 6. Magnesium is needed for strong enamel. |
|  |  | 7. Dental plaque that is scraped off your teeth by the hygienist is mostly minerals. |
|  |  | 8. Acid produced by bacteria weakens tooth enamel. |
|  |  | 9. Brushing your teeth with fluoride toothpaste can make your teeth stronger. |
|  |  | 10. Your teeth can last for more than a hundred years. |

# Student ReadingComprehension Questions

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

1. For compounds classified as apatites, answer the following questions:
	1. What is the major cation?\_\_\_\_\_\_
	2. What is the major anion?\_\_\_\_\_\_\_
		1. If the above two ions were the only components of the compound, what would be its chemical formula?\_\_\_\_\_\_\_\_\_\_\_\_\_
	3. What is the total positive charge in one formula unit of an apatite compound?\_\_\_\_
	4. What are the sign and magnitude of the charge an ion must have in order to complete the generic formula for an apatite by filling in the “X”? Explain your answer.
2. Determine the percent composition for each **ion** in hydroxyapatite. Show your calculations.
3. What is the percentage of oxygen in a sample of hydroxyapatite?
4. One characteristic of simple ionic compounds is that they are brittle, due to their very regular crystalline structures. This means that a sample of an ionic compound is more likely to fracture into pieces when a force is applied than to simply deform and change shape.
	1. Using the model of sodium chloride, NaCl, explain why a force on one part of the crystal would easily cause a fracture to spread along a line all the way to the other side of the crystal.
	2. Explain how the crystal structure of hydroxyapatite in tooth enamel prevents these fractures from causing the enamel to crack away from the teeth.
5. Though tooth enamel is primarily made from hydroxyapatite, small amounts of some magnesium salts are also found between the various formations of the irregular crystals. These salts appear to add to the mechanical strength and quality of the enamel. List the name and chemical formulas for the anions of the magnesium salts that are found within the hydroxyapatite.
6. What is in the plaque that the dentist scrapes from your teeth when you get a dental cleaning?
7. Sugar is not considered a corrosive substance, but we are always warned that sugar will ruin our teeth. Describe the role of sugar in tooth decay.
8. Explain why the fluoride ion, commonly added to either water or toothpaste, helps to make your teeth more resistant to decay. Write the chemical formula for the substance most responsible for this effect.

**The following are appropriate for AP Chemistry or for an advanced chemistry class.**

1. The phosphate ion is a relatively strong base. Write a net ionic equation that shows how an acid would react with phosphate ions if there were an equimolar proportion of each.
2. Draw a Lewis structure for the phosphate ion, including formal charges.
	1. Identify the total number of resonance structures needed to describe this molecular ion.\_\_\_
	2. Describe the molecular polarity of this molecular ion.
	3. Estimate the O-P-O bond angle for this molecular ion.\_\_\_
3. Write the hydrolysis reaction equation that occurs when one phosphate ion reacts with one water molecule.
	1. Draw a Lewis structure for the conjugate acid of the phosphate ion in this reaction.

|  |  |
| --- | --- |
| **Compound** | **Value of Ksp** |
| Ca5(PO4)3OH | 4.34 x 10-26 |
| CaHPO4 | 8.42 x 10-12 |
| Ca3(PO4)2 | 1.01 x 10-3 |

* 1. The Ksp values above are for various calcium and phosphate compounds. Use the Ksp values to explain why acid coming into contact with hydroxyapatite can be destructive.

**Student Reading Comprehension Questions, cont.**

**Questions for Further Learning**

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

Hydroxyapatite is an example of a double salt.

1. Find the chemical formulas for other double salts, such as dolomite and alum.
2. Determine uses for these double salts.
3. Explain how the properties of the double salt are more favorable for a given use than either of the single cation-anion combinations would be on its own.

# Graphic Organizer

**Directions**: As you read, complete the graphic organizer below to describe the chemistry and structure of dental enamel.

|  |  |  |
| --- | --- | --- |
| **Chemicals** | **Formula** | **Importance to dental enamel** |
| **Hydroxyapatite** |   |   |
| **Magnesium fluoride** |   |   |
| **Magnesium carbonate** |   |   |

|  |  |  |
| --- | --- | --- |
| **Structure** | **Description (in your words)** | **Importance to dental enamel** |
| **Aprismatic enamel** |   |   |
| **Rods** |   |   |
| **Hydroxyapatite microcrystals** |  |   |

**Summary:** On the back of this sheet, write a one-sentence summary (18 words or less) of the article.

# Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. For compounds classified as apatites, answer the following questions:
	1. What is the major cation? Ca2+
	2. What is the major anion? PO43-
		1. If the above two ions were the only components of the compound, what would be its chemical formula? Ca3(PO4)2
	3. What is the total positive charge in one formula unit of an apatite compound? +10
	4. What are the sign and magnitude of the charge an ion must have in order to complete the generic formula for an apatite by filling in the “X”? Explain your answer.

-1. Five calcium ions make up +10 charge. Three phosphate ions make up -9 charge. An ionic compound must have a neutral charge.

1. Determine the percent composition for each **ion** in hydroxyapatite. Show your calculations.

Ca- 40.078 g/mol; P- 30.974 g/mol; O- 15.999 g/mol; H- 1.008 g/mol

Ca2+: 200.390/502.307x100 = 39.9%

PO43-: 284.910/502.307x100 = 56.7%

OH-: 17.007/502.307x100 = 3.4%

1. What is the percentage of oxygen in a sample of hydroxyapatite?

207.987 g O / 502.307 g compound x 100 = 41.4% oxygen

1. One characteristic of simple ionic compounds is that they are brittle, due to their very regular crystalline structures. This means that a sample of an ionic compound is more likely to fracture into pieces when a force is applied than to simply deform and change shape.
	1. Using the model of sodium chloride, NaCl, explain why a force on one part of the crystal would easily cause a fracture to spread along a line all the way to the other side of the crystal.

If a force is applied, it will push like charges to be much closer together than they are in the original crystal. Since the crystal structure is very rigid, most of the ions in line with the force would be shifted. Since this would cause all ions to be closer to other ions with like charges, the overall repulsion would quickly allow the fracture to travel down the line of alternating charges, and split along the plane.

* 1. Explain how the crystal structure of hydroxyapatite in tooth enamel prevents these fractures from causing the enamel to crack away from the teeth.

In hydroxyapatite, the ions are not arranged in one large perfectly crystalline structure. There are areas of crystallinity that are somewhat randomly oriented. In this less regular arrangement, both the energy and the direction of a fracture will be limited to the portion of the structure that is in a very regular arrangement. Once the line of fracture meets a different arrangement, the energy can spread in multiple directions and the dislocation of ions would no longer cause them to shift to a repulsive position. This less regular arrangement allows forces to be applied in many directions without a net effect in any one direction that would cause a piece of the structure to fracture away from the tooth.

1. Though tooth enamel is primarily made from hydroxyapatite, small amounts of some magnesium salts are also found between the various formations of the irregular crystals. These salts appear to add to the mechanical strength and quality of the enamel. List the name and chemical formulas for the anions of the magnesium salts that are found within the hydroxyapatite.

Fluoride, F-

Carbonate, CO32-

1. What is in the plaque that the dentist scrapes from your teeth when you get a dental cleaning?

The plaque is mostly bacteria, with about 30-40% of it being carbohydrates and proteins from our saliva.

1. Sugar is not considered a corrosive substance, but we are always warned that sugar will ruin our teeth. Describe the role of sugar in tooth decay.

Sugar, itself, does not cause the harm. Sugar is, however, readily used as nutrient for bacteria. When the bacteria metabolize the sugar, acids are produced, which can break down the enamel of the tooth.

1. Explain why the fluoride ion, commonly added to either water or toothpaste, helps to make your teeth more resistant to decay. Write the chemical formula for the substance most responsible for this effect.

When fluoride is present, some of the hydroxyapatite can convert into fluorapatite, which is more resistant to acids than the hydroxyapatite.

**The following are appropriate for AP Chemistry or for an advanced chemistry class.**

1. The phosphate ion is a relatively strong base. Write a net ionic equation that shows how an acid would react with phosphate ions if there were an equimolar proportion of each.

H+(aq) + PO43-(aq) HPO42-(aq) or H3O+(aq) + PO43-(aq) HPO42-(aq) + H2O(l)

1. Draw a Lewis structure for the phosphate ion, including formal charges.



* 1. Identify the total number of resonance structures needed to describe this molecular ion.

4 total resonance structures (double bond could be in each of the four positions)

* 1. Describe the molecular polarity of this molecular ion.

This ion would be nonpolar, because it has four equivalent P-O bonds symmetrically arranged into a tetrahedron, leaving zero dipole moment.

* 1. Estimate the O-P-O bond angle for this molecular ion.

The tetrahedral angle is approximately 109.5o.

1. Write the hydrolysis reaction equation that occurs when one phosphate ion reacts with one water molecule.

H2O(l) + PO43-(aq) HPO42-(aq) + OH-(aq)

* 1. Draw a Lewis structure for the conjugate acid of the phosphate ion in this reaction.



|  |  |
| --- | --- |
| **Compound** | **Value of Ksp** |
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* 1. The Ksp values above are for various calcium and phosphate compounds. Use the Ksp values to explain why acid coming into contact with hydroxyapatite can be destructive.

Hydroxyapatite has a very low Ksp value, meaning it is largely insoluble. If an acid protonates the phosphate, like in the above reaction, that converts the phosphate into hydrogen phosphate. Hydrogen phosphate, in the presence of calcium is significantly more soluble than phosphate in the presence of calcium, as the Ksp for CaHPO4 is about 14 orders of magnitude greater than that for hydroxyapatite. Since phosphate is a relatively strong base (Kb is approximately 1x10-2), phosphate would readily protonate in the presence of an acid, and the hydroxide from hydroxyapatite would protonate to form water, thus converting some amount of the hydroxyapatite into the more soluble calcium hydrogen phosphate compound.

**Graphic Organizer Rubric**

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

#

# Additional Resources and Teaching Strategies

**Additional Resources**

* **Labs and demos**
	+ Investigate the equilibrium of hydroxyapatite to show how acid shifts the solubility equilibrium to dissolve more of it.
	+ Explore the acid/base equilibrium and solubility equilibrium of calcium phosphate or just the acid/base equilibrium of just the phosphate ion, using sodium phosphate.
	+ Determine the chemical formula for a double salt, like Alum, through a series of chemical reactions and separations.
	+ Students create their own double salts by dissolving two salts and crystallizing by evaporation. They can then investigate how the physical properties differ between the individual salts and the double salt.
* **Lessons and lesson plans**
	+ ChemMatters article, Oct. 2016: “How Sue Became a Rock Star” talks about the role of hydroxyapatite in fossils
* **Projects and extension activities**
	+ Research how hydroxyapatite is being used in tissue engineering to aid bone regeneration.
	+ Research other organisms where hydroxyapatite, or other calcium phosphates, are significant structure components. (*e.g.* fish bones, corals, eggshells)

**Teaching Strategies**

Consider the following tips and strategies for incorporating this article into your classroom:

* **Alternative to Anticipation Guide:** Before reading, ask students if they have ever had dental cavities, and why cavities might form in your teeth. Ask them what dental enamel might be made from, and how durable it is. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
	+ As they read, students can find information to confirm or refute their original ideas.
	+ After they read, ask students how chemistry and physics help explain how strong their dental enamel is.
* After students have read and discussed the article, ask students how they can protect their teeth and how the information in the article informs their decision.
* This article relates somewhat to the Quick Read article on page 14: Chewing Gum. This article describes the many ingredients in chewing gum, including sweeteners. Students may investigate the pros and cons of the sweeteners used to flavor chewing gum.
* On a first-year chemistry level, this would fit nicely into a unit on chemical formulas, when students are just learning about moles and molar mass.
* On an advanced, or AP level, there are a lot of acid/base and solubility equilibrium applications possible here. It can also be used during a bonding unit, or a unit addressing intermolecular and other interparticle forces in different types of substances (ionic, molecular, metallic, network)

# Chemistry Concepts and Standards

**Connections to Chemistry Concepts**

The following chemistry concepts are highlighted in this article:

* Physical properties
* Acids
* pH

**Correlations to Next Generation Science Standards**

This article relates to the following performance expectations and dimensions of the NGSS:

**HS-PS1-3.** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

**Disciplinary Core Ideas:**

* PS.1.A: Structure and Properties of Matter

**Crosscutting Concepts:**

* Cause and effect
* Structure and function

**Science and Engineering Practices:**

* Constructing explanations (for science) and designing solutions (for engineering)

**Nature of Science:**

* Science addresses questions about the natural and material world.

See how *ChemMatters* correlates to the[**Common Core State Standards** online](https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html).