



October 2011 Teacher's Guide

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About the Guide

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Student Questions

Sugar in the Blood Boosts Energy

1. According to the article, how much glucose does the body need every fifteen minutes?
2. Name the elements that make up glucose.
3. The article is about “blood sugar.” How much of our blood is actually glucose?
4. How does the human body store glucose?
5. Identify the phosphorus-containing molecules in the body that store and produce energy.

Harnessing Solar Power

1. What are the two sources of electricity on the atoll of Utrik that are not based on fossil fuels?
2. Cite three examples of fossil fuels.
3. What is needed to change solar energy (sunlight) into electricity?
4. Describe the function of the element silicon (Si) in a photovoltaic solar panel.
5. What is the purpose of “doping” silicon in a photovoltaic (PV) panel?
6. Name the two elements mentioned in the article that can be used as “p-type” dopants with silicon.
7. What is meant by “*n-type*” dopant for silicon?
8. How is a “*p-n junction*” created with dopants in silicon?
9. What is the purpose or function of a “*p-n junction*” in a solar or PV cell?
10. How does sunlight produce electricity in a solar or PV cell?
11. What are two different ways by which the owner of a solar PV panel can get electricity at night when the sun is not shining on the solar panel?
12. How can a PV solar panel make money for the panel’s homeowner?

Demystifying Gross Stuff

1. What is responsible for most of the odors that emanate from your body?
2. What is sebum?
3. What are the two main causes of acne?
4. What is the difference between a whitehead and a blackhead?
5. How does soap clean your skin?
6. What are micelles?
7. Why does your breath smell worse upon waking?
8. Why do cavities form?
9. How does fluoride in mouthwash and toothpaste help to prevent cavities?
10. Why do high-fiber foods contribute to flatulence?

The Skinny on Sweeteners: How Do They Work?

1. On average, how much sucrose, or sugar, does an American consume in a year?
2. Why are carbohydrates an excellent fuel for the human body?
3. What are two negative health effects of sucrose?

4. What was the first artificial sweetener? Who discovered it and when?
5. What happens to saccharin in the body that makes it a calorie-free sweetener?
6. What food products are especially suited for use with saccharin? Why?
7. Even though aspartame does produce calories, why is it still beneficial for use as an artificial sweetener?
8. What is a typical concern with artificial sweeteners? What has testing shown?

Fighting Bacteria

1. What are antibiotics?
2. Why is more than one antibiotic needed to treat some cases of bacterial infection?
3. When did the use of antibiotics start?
4. What is the most commonly prescribed antibiotic and what infections can it fight?
5. How do penicillin medications fight bacterial infections?
6. How does penicillin's molecular structure make it highly reactive?
7. What role does peptidoglycan play in the formation of bacterial cell walls?
8. What role does transpeptidase play in formation of bacterial cell walls? How is it affected by penicillin?
9. What do bacteria resistant to amoxicillin do to stop its action?
10. How does Augmentin work to fight bacteria resistant to amoxicillin?
11. What is one of the main reasons the number of antibiotic-resistant bacteria has been increasing?

Answers to Student Questions (from the article)

Sugar in the Blood Boosts Energy

- 1. According to the article, how much glucose does the body need every fifteen minutes?**
The body requires about a teaspoon of glucose every fifteen minutes.
- 2. Name the elements that make up glucose.**
Glucose is a simple carbohydrate made up of carbon, hydrogen and oxygen.
- 3. The article is about “blood sugar.” How much of our blood is actually glucose?**
The article says that about 0.1% of our blood is glucose.
- 4. How does the human body store glucose?**
If more glucose is taken into the body than is needed immediately, the body converts glucose to glycogen.
- 5. Identify the phosphorus-containing molecules in the body that store and produce energy.**
These related molecules are adenosine triphosphate, adenosine diphosphate and adenosine monophosphate. Each time a phosphate radical is lost from the molecule, energy is released.

Harnessing Solar Power

- 1. What are the two sources of electricity on the atoll of Utrik that are not based on fossil fuels?**
The two non-fossil fuel sources of electricity on the atoll are wind and sun.
- 2. Cite three examples of fossil fuels.**
Examples of fossil fuels include petroleum, natural gas and coal.
- 3. What is needed to change solar energy (sunlight) into electricity?**
To change solar energy into electricity, you need a device that absorbs sunlight and converts it to electricity—this is known as a photovoltaic cell.
- 4. Describe the function of the element silicon (Si) in a photovoltaic solar panel.**
Silicon is part of a semi-conductor structure that transfers electrons when light energy is absorbed by the crystalline structure.
- 5. What is the purpose of “doping” silicon in a photovoltaic (PV) panel?**
The purpose of “doping” silicon is to make it easier for silicon to conduct electricity through movement of its outer electrons. Pure silicon with four single covalent bonds between atoms will not readily conduct electricity because the electrons involved in these bonds are hard to move. Two types of dopant are added to the silicon. An n-type (such as phosphorus) has one more electron in its outer level compared with silicon, and a p-type (such as boron) has one less electron in its outer level compared with silicon and is referred to as a “hole”. The two different dopant layers are close to each other and create a one-way flow of electricity from the n- to the p-type layer when the solar cell is exposed to light. The “extra” outer electron of the n-type dopant is free to move to one of the p-type dopant “holes”. This movement of electrons is an electric current.”
- 6. Name the two elements mentioned in the article that can be used as “p-type” dopants with silicon.**
The two elements that can be used as p-type dopants are boron and gallium.

7. **What is meant by “n-type” dopant for silicon?**
An n-type dopant is one that has one more electron in its outer level than silicon and can lose an electron to silicon if silicon loses an electron.
8. **How is a “p-n junction” created with dopants in silicon?**
A silicon layer with a p-dopant is placed next to an n-doped silicon layer.
9. **What is the purpose or function of a “p-n junction” in a solar or PV cell?**
The p-n junction creates a one way flow of electrons whereby electrons, pushed off the silicon when light photons strike the surface, move to an empty electron “hole” in a nearby “p” dopant atom and an “n” type dopant atom replaces the electron lost by the silicon atom.
10. **How does sunlight produce electricity in a solar or PV cell?**
“When a solar cell is exposed to sunlight, the small particles that make up light, called photons, enter the solar cell and knock some of its electrons loose.” Electrons leave the silicon atoms, move to a “hole” in an atom of the p-dopant while an electron from the n-dopant moves to a silicon atom, creating a flow or an electric current.
11. **What are two different ways by which the owner of a solar PV panel can get electricity at night when the sun is not shining on the solar panel?**
The solar panel is set up to store excess electricity in batteries which can then be used at night. Or the panel owner can simply tap electricity from the main public grid.
12. **How can a PV solar panel make money for the panel’s owner?**
When electricity created by the solar panel is not used by the homeowner, it goes into the main electric grid and the homeowner is given credit on his/her electric bill. And by using electricity from the solar panel rather than from the electric company’s grid, the homeowner is not paying the electric company for the electricity.

Demystifying Gross Stuff

1. **What is responsible for most of the odors that emanate from your body?**
The smells emanating from your body are due to the work of bacteria, which produce noxious gases as the result of their metabolism.
2. **What is sebum?**
Sebum, produced from sebaceous glands in the skin, is a skin lubricant and protector, which if produced in excess (as happens frequently in teenagers), can clog pores, resulting in acne.
3. **What are the three main causes of acne?**
The three main causes of acne are excess sebum, dead skin cells and bacteria that feed off them.
4. **What is the difference between a whitehead and a blackhead?**
A whitehead is a pimple with a blocked opening of a pore containing pus. A blackhead is a pimple with a clogged pore but an open surface, where melanin on the surface reacts with oxygen from the air to produce the color.
5. **How does soap clean your skin?**
Soap is amphiphilic, so one end of the molecule clings to water (hydrophilic), while the other end clings to the oil molecules. Once the soap anions have attached to the oil, many of these units group together to form micelles. The micelle contains the oil particle at the center and many charged (water-soluble) particles on the outside. These large particles can then mix with other water molecules and be rinsed away, leaving behind a clean surface.
6. **What are micelles?**
Micelles are tiny spheres that consist “...on the outside of the negatively charged ends [of the stearate anions] attached to water molecules, and on the inside of the nonpolar tails

[again, of the stearate anions] attached to oil molecules.” The sebum, stuck on the inside of the micelles can now be rinsed away with the water.

7. **Why does your breath smell worse upon waking?**

Saliva is produced in your mouth in copious quantities during the day, but not while you sleep. Saliva contains antibacterial compounds, which keep bacteria counts down. But during sleep—when saliva is not produced—bacteria thrive, forming their gaseous metabolic products, making your breath unpleasant when you awake.

8. **Why do cavities form?**

The enamel of the tooth is constantly being attacked by the acid produced by bacteria (and aided by soda consumption). This is demineralization. The enamel is also constantly being rebuilt (remineralization). Cavities form when demineralization proceeds at a faster rate than remineralization.

9. **How does fluoride in mouthwash and toothpaste help to prevent cavities?**

Fluoride in mouthwash or toothpaste is water-soluble and collects on the surface of teeth, acting as a barrier to bacterial acids’ demineralization of the enamel. It also reacts with hydroxyapatite to produce fluoroapatite, which is more stable and less subject to bacterial breakdown than the natural hydroxyapatite.

10. **Why do high-fiber foods contribute to flatulence?**

High-fiber foods consist mainly of cellulose, which is indigestible in the human stomach. Since it doesn’t digest in the stomach, it is passed through your digestive system to the colon. Bacteria there contain an enzyme that allows them to break down the cellulose. The more food present, the more bacteria will thrive, and the more bacteria, the more gaseous metabolic products that must be passed out of your body.

The Skinny on Sweeteners: How Do They Work?

1. **On average, how much sucrose, or sugar, does an American consume in a year?**

On average, an American consumes 156 pounds of a sugar in a year.

2. **Why are carbohydrates an excellent fuel for the human body?**

Carbohydrates are packed full of energy. When they are broken apart in your mouth, stomach, and intestines, these molecules liberate energy that can be used right away or stored for later.

3. **What are two negative health effects of sucrose?**

- When we eat food or drink beverages that contain sucrose, bacteria that live in our mouths use sucrose as an energy source and produce acid that contributes to tooth decay.*
- When we eat or drink too much sucrose, the amount of insulin in our blood spikes, which can eventually lead to insulin resistance and diabetes.*

4. **What was the first artificial sweetener? Who discovered it and when?**

Saccharin was the first artificial sweetener. It was discovered by Constantin Fahlberg in 1878.

5. **What happens to saccharin in the body that makes it a calorie-free sweetener?**

The digestive system does not break saccharin apart to derive energy the same way it does with sugar. Instead, it dissolves into the bloodstream and is flushed out of the body in urine.

6. **What food products are especially suited for use with saccharin? Why?**

Saccharin has a lingering bitter and metallic taste that some people can detect, making it a good choice for sweetening tea and coffee, which have their own bitter taste.

7. **Even though aspartame does produce calories, why is it still beneficial for use as an artificial sweetener?**

Aspartame is 180 times sweeter than sugar, so it can be used in smaller quantities and, as a result, does not generate as many calories as sucrose.

8. **What is a typical concern with artificial sweeteners? What has testing shown?**
Over the years, concerns have been raised that several artificial sweeteners may cause health problems, particularly cancer. No tests have provided clear evidence of an association with cancer in humans.

Fighting Bacteria

1. **What are antibiotics?**
"Antibiotics are drugs that kill bacteria or prevent them from growing in the body."
2. **Why is more than one antibiotic needed to treat some cases of bacterial infection?**
Antibiotics are proving less effective in curing an increasing number of diseases because strains of bacteria are arising that are resistant to antibiotics. More than one antibiotic may need to be tried to treat an antibiotic-resistant strain of bacteria.
3. **When did the use of antibiotics start?**
The use of antibiotics started in the early 1940s.
4. **What is the most commonly prescribed antibiotic and what infections can it fight?**
The most commonly prescribed antibiotic is penicillin. It is used to cure a large number of bacterial diseases, including pneumonia, strep throat, and some sexually-transmitted diseases.
5. **How do penicillin medications fight bacterial infections?**
Penicillin medications stop "...bacteria from multiplying by preventing them from forming the cell walls that surround them. When a bacterium divides, penicillin prevents it from forming a new cell wall, and the two new daughter cells "pop" and die."
6. **How does penicillin's molecular structure make it highly reactive?**
The penicillin molecule contains a square ring in which carbon atoms form 90-degree angles. These smaller-than-usual angles create a strain in the ring, which makes penicillin highly reactive because it seeks to relieve that strain.
7. **What role does peptidoglycan play in the formation of bacterial cell walls?**
Peptidoglycan is a molecule that is the building block of the cell wall of Streptococcus bacteria.
8. **What role does transpeptidase play in formation of bacterial cell walls? How is it affected by penicillin?**
Transpeptidase is an enzyme that helps peptidoglycan units, the building blocks of the cell walls, bind with one another. Penicillin binds to the active site of transpeptidase, which prevents peptidoglycan molecules from entering the active site, where they typically bind with each other to form the cell wall.
9. **What do bacteria resistant to amoxicillin do to stop its action?**
These resistant bacteria contain an enzyme called beta-lactamase that traps the amoxicillin molecules and prevents them from binding to the active site of transpeptidase. The transpeptidase molecules are then available to help build the bacterial cell wall.
10. **How does Augmentin work to fight bacteria resistant to amoxicillin?**
Augmentin contains a mixture of amoxicillin and another substance called clavulanic acid, which looks like a penicillin molecule. Clavulanic acid binds to beta-lactamase but not to transpeptidase. This way, the beta-lactamase molecules are blocked and can't bind to amoxicillin, leaving it available to do its job of blocking transpeptidase.
11. **What is one of the main reasons the number of antibiotic-resistant bacteria has been increasing?**

One of the main reasons for this increase is that people either misuse or overuse antibiotics. People might stop taking an antibiotic midway through the prescription or use antibiotics for conditions not caused by bacteria.

ChemMatters Puzzle: Trail Blazing with the Elements

Here's an interesting variant of a word search puzzle. In the grid below there are 12 names of elements. Below the grid are 12 clues that help identify each. The clues deal with physical properties, roots of their names, uses, position in a periodic table, etc., rather than any chemical property. We will also tell you how many letters are in its name.

The 12 names form a TRAIL of letters from name #1 to name #2 to name #3, etc. Look for the next letter placement to be horizontally or vertically in line... no diagonals ! For example, if element #1 was SODIUM (it isn't !) reading downwards, the first letter of name #2 would be placed in the square either directly below the M, or to its left or to its right. Similarly, any one name may show 90° direction changes within itself, such as SO M
DIU

The trail will not cross itself, nor will it use either of the two squares left open in the grid. Any letter in a square is used just once.

You do not have to start with name 1; hop in and out wherever you like!

M	O	R	B	C	I	N	E	S
I	N	G	S	T	E	N	A	R
N	U	M	E	R	C	U	R	Y
E	T	D		M	U	O	L	T
R		L	O	G	I	N	O	I
A	D	O	N	C	A	R	P	N
R	D	Y	H	N	O	B	M	C
O	M	U	I	T	E	N	U	E
G	E	N	T	E	C	H	I	S

The CLUES	number of letters
1. A liquid (at room temp) metallic element that's very dense (13.6 g/mL)	7
2. Its Latin name is stannum	3
3. The alkali metal that's in period 6	6
4. Named for the country of birth of its discoverer, Marie Curie	8
5. Its symbol has two vowels, no consonants !	4
6. Used as a filament in incandescent light bulbs; formerly called WOLFRAM	8
7. The metalloid in group 15 that is smallest in atomic radius; a notorious poison	7
8. The name for this red-brown halogen comes from the Greek word for STENCH	7
9. <u>All</u> isotopes of this noble gas are radioactive.	5
10. Two allotropes of this element are GRAPHITE and BUCKY-BALLS	6
11. "The chart maker's nightmare"; where should one place it in a periodic table?	8
12. The only completely man-made element of elements 1 through 92	10

Happy trail blazing!

Answers to the *ChemMatters* Puzzle

M	O	R	B 8	C	I	N	E	S
I	N	G	S	T	E	N	A 7	R
N	U	M 1	E	R	C	U	R	Y
E	T 6	D		M	U	O	L	T 2
R 9		L	O	G 5	I	N	O	I
A	D	O	N	C 10	A	R	P 4	N
R	D	Y	H 11	N	O	B	M	C 3
O	M	U	I	T	E	N	U	E
G	E	N	T 12	E	C	H	I	S

The squares with a number in it is the starting letter of an element's name

Here are the names that match the numbers:

- | | | |
|-------------|-------------|----------------|
| 1. mercury | 5. gold | 9. radon |
| 2. tin | 6. tungsten | 10. carbon |
| 3. cesium | 7. arsenic | 11. hydrogen |
| 4. polonium | 8. bromine | 12. technetium |

NSES Correlation

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	Sugar in the Blood	Solar Power	Gross Stuff	Artificial Sweeteners	Fighting Bacteria
Science as Inquiry Standard A: about scientific inquiry.		✓			✓
Physical Science Standard B: of the structure and properties of matter.	✓	✓	✓	✓	✓
Physical Science Standard B: of chemical reactions.	✓		✓		
Physical Science Standard B: of the interaction of energy & matter		✓			
Physical Science Standard C: of the cell.					✓
Physical Science Standard C: of matter, energy, and organization in living systems.	✓			✓	
Science and Technology Standard E: about science and technology.		✓		✓	
Science in Personal and Social Perspectives Standard F: of personal and community health.	✓		✓	✓	✓
Science in Personal and Social Perspectives Standard F: about natural resources.		✓			
Science in Personal and Social Perspectives Standard F: about environmental quality		✓			
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.		✓			✓
History and Nature of Science Standard G: of science as a human endeavor.		✓			
History and Nature of Science Standard G: of historical perspectives.		✓		✓	✓

Anticipation Guides

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 for all Anticipation Guides: *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.

Sugar in the Blood Boosts Energy

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. Energy from the sun is stored in glucose, the most important energy storage for plants and animals.
		2. Glucose makes up about 1% of the blood of a human being.
		3. Carbohydrates and proteins can be broken down to make glucose.
		4. Glucose that is not used immediately by the body is stored in the small intestine.
		5. Glycogen is a large straight-chain molecule made of many glucose molecules linked together.
		6. Adenosine triphosphate (ATP) molecules contain only oxygen, phosphorous, and hydrogen atoms.
		7. ATP molecules react with water to make ADP molecules which react with water to make AMP molecules, then glucose provides energy to re-assemble the ATP molecules to continue the cycle that provides your body with energy.
		8. Studies show that straight glucose improves memory than complex carbohydrates.

Harnessing Solar Power

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. In the United States, more than 90% of the energy we use comes from fossil fuels.
		2. Today’s typical solar panels produce 100% of the energy needed by the average household.
		3. Today’s solar panels have semiconductors that can conduct an electric current at room temperature.
		4. Silicon can be doped with atoms containing one more or one less electron in their outer energy levels than silicon.
		5. Diodes allow electric current to flow in two directions.
		6. When homeowners install solar panels, they should expect to get their financial investment back in energy savings in less than 5 years.
		7. There is no limit on the size of a house that can be entered into the Solar Decathlon competition.
		8. None of the houses in the 2009 Solar Decathlon competition produced as much energy as the houses required.
		9. When a material changes from liquid to solid, heat is absorbed.

Demystifying Gross Stuff

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 same substance that causes acne keeps our skin soft and our hair shiny.
		2. A blackhead is black because it contains dirt.
		3. Amphiphilic molecules have a “water-loving” polar end and an “oil-loving” nonpolar end.
		4. Polar and nonpolar molecules often bind to each other.
		5. Soap can trap oily molecules in tiny spheres called micelles that get washed away.
		6. Acne is caused by a viral infection.
		7. During the day, your body produces more than a liter of saliva.
		8. Fluorine is often found free in nature.

The Skinny on Sweeteners: How Do They Work?

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 average American consumes more than 150 pounds of sugar each year.
		2. Eating too much sucrose can lead to tooth decay as well as diabetes.
		3. The first artificial sweetener was discovered in the 20 th century.
		4. Saccharin and sucrose have similar chemical structures.
		5. Aspartame consists of two amino acids.
		6. Sucralose has a chemical structure similar to sucrose, but it is not digested by the body.
		7. Aspartame and saccharin have no calories, but sucralose has a few calories.
		8. Scientific tests have shown that saccharin and aspartame can cause cancer in humans.

Fighting Bacteria

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. Pneumonia is always caused by bacteria.
		2. Penicillin medications cure viral and bacterial diseases.
		3. Penicillin prevents the cell walls of bacteria from forming.
		4. The C-C bond in penicillin is 109 degrees.
		5. Enzymes speed up chemical reactions but are not changed themselves.
		6. Bacteria may contain more than one type of enzyme.
		7. The Center for Disease Control and Prevention (CDC) estimates that a type of penicillin-resistant bacteria called MRSA kills more Americans every year than AIDS.
		8. Two major reasons for the increase in antibiotic resistant bacteria are that people may not take the antibiotic after they begin to feel better, and some people take antibiotics for diseases not caused by bacteria.

Reading Strategies

These matrices and organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading 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

Sugar in the Blood Boosts Energy

Directions: As you read, complete the chart below comparing different molecules described in the article.

	Found in	Needed for	How many and what kind of atoms are in one molecule?
Glucose			
Sucrose			
Glycogen			
ATP			

Harnessing Solar Power

Directions: As you read, describe the advantages and problems associated with using solar energy for electricity.

Advantages	Problems

→ **How many hours of solar energy do you think your home could collect per day (on average)? Why do you think so?**

Students Build Solar Homes

Directions: As you read, describe the different ways to save energy described in the article and which team was responsible for the idea.

Energy Savings Idea	Team Responsible & Contest won (if 2009)

Demystifying Gross Stuff

Directions: As you read, describe the causes and chemicals involved in the formation of acne, bad breath, and flatulence.

	Cause(s)	Treatment or Prevention	Chemicals involved
Acne			
Bad Breath			
Flatulence			

The Skinny on Sweeteners: How Do They Work?

Directions: As you read, compare the sweetening compounds described in the article using the chart below.

Sweetener	Common name or Brand name(s)	Atoms found in the molecules	Foods where sweetener is used	How the body uses the sweetener	Health effects, if any
Sucrose					
Saccharin					
Aspartame					
Sucralose					

→ After reading the article, which sweetener do you prefer? Explain why.

Fighting Bacteria

Directions: As you read, compare the molecules described in the article by using the chart below.

Molecule	Type of molecule			Elements found in molecule (if stated in the article)	Molecule's role in bacterial diseases
	Antibiotic	Enzyme	Cell wall component		
Penicillin					
Amoxicillin					
Peptidoglycan					
Transpeptidase					
Beta-lactamase					
Augmentin					
Clavulanic acid					

Sugar in the Blood Boosts Energy

Background Information (teacher information)

More on carbohydrates (using glucose as an example)

This article provides a good opportunity for you to connect prior learning from biology class with chemistry concepts, and also to provide students with information relevant to their lives. In a country where nearly 34% of adults and 17% of children and adolescents (ages 2-19) are obese, any conversation about nutrition and health is important. Although this article is about blood sugar (glucose), it may be helpful—and necessary—to review with students some concepts they learned in biology class.

The three main types of food nutrients are carbohydrates, fats and proteins. Many of your students will remember this from their biology class. For this article, of course, we want to focus on carbohydrates since glucose and other sugars are carbohydrates. First, we need a word about biochemical vocabulary. In a biochemical context the term “carbohydrate” is often used interchangeably with the term “saccharide.” There are four classes of saccharides—monosaccharides, disaccharides, oligosaccharides and polysaccharides. Monosaccharides are simple (lower molecular weight) sugars like glucose. Disaccharides are two monosaccharide molecules joined chemically by a covalent bond. Sucrose, or table sugar, and lactose are examples of disaccharides. Sucrose is composed of the monosaccharides glucose and fructose as described in the article. Lactose is made up of sucrose and galactose.

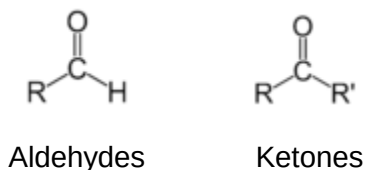
It should be noted that if monosaccharide units like glucose are bonded together to make longer chains, the resulting heavier molecules are properly called polymers. So polysaccharides are really natural polymers. If the number of monosaccharide units is less than about ten, the polymer is called an oligosaccharide, and longer polymer saccharide chains are called polysaccharides.

These heavier polysaccharides have varying biological uses, including starch in plants and glycogen in animals. Both are used to store energy. For example, the article refers to glycogen as the compound that is produced from glucose in order to store excess amounts of the glucose molecule. Even longer and heavier polysaccharides like cellulose are the primary components of cell walls in plants. About a third of all plant matter is cellulose. So simple sugars like glucose can be thought of as monosaccharides, and complex sugars like sucrose can be thought of as disaccharides. Starch and fiber, mentioned above, are polysaccharides.

Since glucose is a monosaccharide, we should say a little about the chemical structure of monosaccharides. They are classified mainly according to a) the number of carbon atoms and b) the location of the carbonyl group (C=O) in the molecule. A third criterion in classifying monosaccharides is related to the symmetry or asymmetry of the molecule, but may be too complex for general chemistry students. You can have students go to a page on the [Nobel Prize site](#) to learn about chirality in a simple game format.

The naming according to the number of carbons should look familiar to students who remember standard prefixes in chemistry: three-carbon monosaccharides are called trioses, those with four carbons are tetroses, those with five carbon atoms are pentoses and those with six carbon atoms are called hexoses. Glucose, therefore, is a hexose.

If you have not studied organic chemistry by the time you read this article, you can use the following as a preview. Your students likely are able to recognize by now special groupings of atoms within a formula. For example, if the grouping SO_4^{2-} appears in a formula, students should identify it as the sulfate ion. All of the polyatomic ions are simply special groupings of atoms/ions within a formula. In organic chemistry (the chemistry of living systems or the chemistry of carbon-containing substances) there are also unique groupings of atoms that are called functional groups. One family of functional groups is called carbonyl groups, which contain a carbon atom doubled-bonded to an oxygen atom $\text{C}=\text{O}$. You'll have to remind students that in organic notation the letter "R" usually stands for a hydrogen atom, a carbon chain or some other grouping of atoms. The diagrams below are both examples of carbonyl groups that play a role in the naming of monosaccharides—the aldehyde functional group and the ketone functional group.



The aldehyde contains the carbonyl group at the end of the chain (R is a chain), and the ketone is a carbonyl group that is part of a longer chain (R on one side and R' on the other side).

In monosaccharides, if the carbonyl group is located at the end of the six-carbon chain, it is referred to as an aldose. If the carbonyl is located in between other carbons in the chain, it is a ketose. The length of the chain and the location of the carbonyl group are often combined in the naming. So, for example, glucose is an aldohexose (contains an aldehyde functional group as part of a 6-carbon chain). Fructose, on the other hand, is a ketohexose. The structural formula below also shows another functional group in the molecule—the hydroxyl group, -OH .

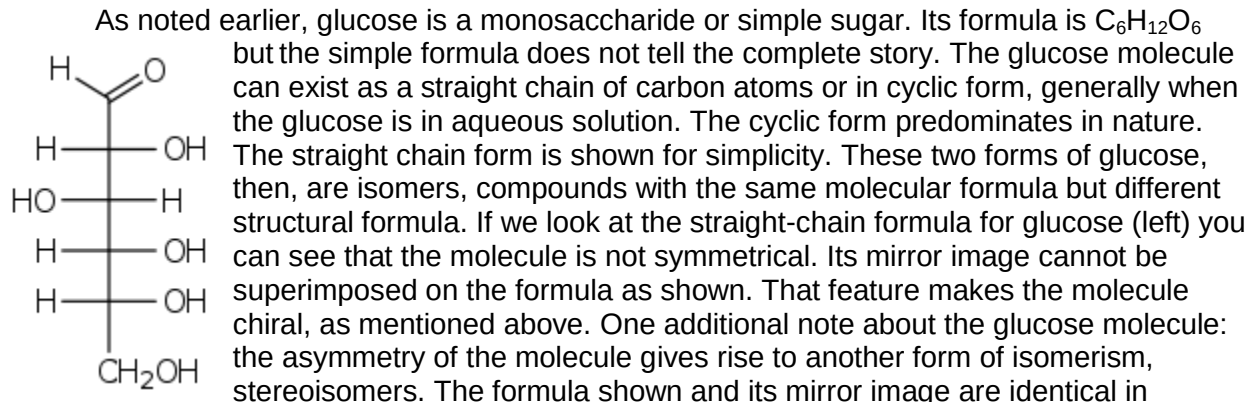
Carbohydrates are the result of photosynthesis, as noted in the article. The equation, also given in the article:



This process requires the plant pigment chlorophyll, and for this reason plants are the best source of carbohydrates. Photosynthesis is an endothermic process, and the energy absorbed in the process is stored as chemical energy in carbohydrate molecules. The generalized formula for carbohydrates is $\text{C}_m(\text{H}_2\text{O})_n$ where the m and n may be different. In any case the ratio of hydrogen to oxygen is 2:1.

In addition to producing energy for the body, carbohydrates like glucose also help protect against disease. Whole grains and fiber reduce heart disease risks, and fiber is important for digestive health. Research suggests that eating vegetables, fruits and whole grains can help with weight control by providing fiber and bulk which makes people feel full with fewer calories.

More on glucose as a chemical substance



composition and in how atoms are bonded to each other, but the bonds have different orientations in space, making them stereoisomers. These differing forms react differently to polarized light. The common form of glucose rotates polarized light clockwise or to the right. This form of glucose is noted as D-glucose since it is dextrorotatory. The other stereoisomer, L-glucose, is not found in nature in appreciable amounts.

Some of the more important physical properties of glucose are:

Formula – $C_6H_{12}O_6$ or $H-(C=O)-(CHOH)_5-H$

Molar Mass – 180.16 g/mol

Density – 1.54 g/mL

Melting point – 146°C (D-glucose)

Solubility in water – 91 g/100mL water

So, the table indicates it is very soluble in water, and this allows it to be transported easily through the body. Its water solubility is the result of the five hydroxyl groups in the molecule. Each of the hydroxyl groups can form hydrogen bonds with water molecules, causing the glucose to dissolve.

Depending on the context of use, glucose is also referred to as D-glucose, dextrose (referring to the fact that it rotates light to the right), blood sugar, corn sugar or grape sugar. The more common names suggest that glucose can be found in nature in many plants. In a few cases glucose is found in its monosaccharide form, but more often it is found as part of disaccharides or polysaccharides. Grapes, as the name “grape sugar” suggests, are a good source of glucose. Other fruit sources include apples and apricots. Vegetable sources include peppers, tomatoes and onions. Grains are rich in carbohydrates that include glucose as a building block—breads, pasta and cereals along with more complex carbohydrates like starch and fiber contained in food products like rice. It occurs in dairy products as a component of lactose. Since glucose is also a component of refined sugar, sucrose, it can also be found in all foods containing refined sugar.

It is likely that students will have heard about corn syrup and the more highly publicized high fructose corn syrup, which seems to be present in many food products. High fructose corn syrup contains mostly glucose. The Teachers Guide for the April, 2011, *ChemMatters* article titled “Sweet But Good for You?” indicates that:

... there are different types of high fructose corn syrup depending on the amount of fructose present. The percentage of fructose in the syrup gives the different corn syrup varieties their name. For example, high

fructose corn syrup with 42% fructose and 55% glucose is labeled as high fructose corn syrup 42, or HFCS 42. Other HFCS varieties in common use are HFCS 55 and HFCS 90. HFCS 90 can be used in specialty applications but is more often blended with glucose syrup to produce the other two varieties of HFCS. These two types of syrup (HFCS 42 and HFCS 55) find extensive use in different types of food products.

Because of its higher fructose content, HFCS-55 is sweeter than sucrose and is thus used extensively as sweetener in soft, juice, and carbonated drinks. HFCS-42 has a mild sweetness and does not mask the natural flavors of food. Thus it is used extensively in canned fruits, sauces, soups, condiments, baked goods, and many other processed foods. It is also used heavily by the dairy industry in yogurt, eggnog, flavored milks, ice cream, and other frozen desserts.

The use of HFCS rather than sucrose as a sweetener in beverages and other foods has certain benefits for manufacturers. HFCS has better stability, particularly in acidic soft drinks, and also has preservative qualities. It is less expensive than sucrose. Manufacturers can also depend on a stable supply of HFCS. Areas where sugar cane is grown can be subject to the chance occurrences of hurricanes, which can affect the eventual crop and its price. As a liquid, HFCS is easier to transport and has a better solubility than sucrose.

The April, 2011 Teacher's Guide is available [on line](#).

Glucose was first isolated in 1747, from raisins, by German chemist Andreas Marggraf in a time period that saw the decline of alchemy and the early beginnings of what we now know as real chemistry. Marggraf analyzed compounds and carefully measured and recorded the resulting masses. He became adept at extracting compounds from plant material and then recrystallizing the substances. He was also among the first to use the microscope and flame tests as a way of identifying compounds. Marggraf believed that substances with a sugary taste contained a specific compound that produced the taste sensation. At the time it was thought that "sugar" came only from sugar cane. Marggraf experimented with white beets, red beet and beet root and was able to extract a compound from each beet variety using alcohol as the solvent. He allowed the extracted compound to crystallize from the alcohol solution and examined the crystals under a microscope. They were identical to the cane sugar crystals. The substance was, of course, sucrose. Marggraf followed the beet experiments with similar experiments with raisins and was able to isolate glucose. Marggraf's findings became the basis for the sugar beet industry.

Marggraf did not name the glucose compound, calling it only "eine Art Zucker," meaning "a type of sugar." Nearly a century later Jean Baptiste Andre Dumas, a French chemist, provided the name. In the late 1800s German chemist Emil Fischer determined the chemical structure of glucose along with its stereochemical nature. Fischer was awarded the Nobel Prize in 1902 for his work on sugars.

As the article emphasizes, glucose is the body's source of energy. Since it is made up of carbon atoms which can be easily oxidized, and since oxidation is an exothermic process, glucose is a good source of energy. When glucose is metabolized in the body about 686 kilocalories (2870 kilojoules) per mole of useful energy is produced. The average adult's blood contains 5-6 grams of glucose at any one time, and this will supply energy for about 15 minutes.

More on glucose as an energy source

As the article states, glucose is the main energy source for the human body. The body requires a minimum of approximately 400 grams of carbohydrates per day to maintain normal activity in the brain, muscles and red blood cells. That represents a 1500 Calorie daily diet. Each gram of carbohydrate supplies about 3.75 kilocalories (15.7 kilojoules) of energy during aerobic respiration. The numbers here are more than a little uncertain because not all of the available energy stored in a carbohydrate, glucose for example, can be converted to useful energy for the body. As in all energy conversions, some energy is “lost”, that is, it ends up in a form other than the desired form. So in the body some of the initial energy in glucose (or any of the digestible carbohydrates) is lost in urine or feces.

Given that most carbohydrates are disaccharides or polysaccharides, ingested carbohydrates like sucrose or starch are broken down into glucose, which is delivered to cells throughout the body by the blood stream. Glycogen is a glucose polymer similar to starch. Immediately after eating a meal, then, blood glucose levels rise. Cells use the glucose as a raw material in aerobic and anaerobic respiration, and water and carbon dioxide are the products. Cells also can store small amounts of glucose as glycogen in cell cytoplasm for immediate use. The pancreas, meanwhile, is producing insulin which triggers a mechanism that causes any excess glucose to be added to the long glycogen molecules in liver cells for storage. When blood sugar levels and insulin levels begin to fall, liver cells convert glycogen into glucose. The glycogen molecule is a very long and has branched side chains, giving the enzymes that convert the glycogen back to glucose many possible sites in the molecule where they can work. This means that the conversion of glycogen to glucose and then to energy can occur rapidly when necessary. When the maximum amount of glycogen is already stored in the body and more carbohydrates are consumed, the body converts the excess into fat. These mechanisms connect carbohydrate metabolism with weight gain or loss.

As most students will know, digestion of carbohydrates begins in the mouth where the enzyme amylase from the salivary glands begins to break the carbohydrates down into maltose. Other enzymes from the pancreas and liver mix with food in the small intestines to further break it down to glucose. Some of the glucose is transported to the brain. Additional glucose is sent to muscle cells, and the liver. Glucose is converted in the liver to glycogen for storage. Glycolysis, a series of ten connected reactions, is the main metabolic process converting glucose in the body followed by aerobic respiration via the citric acid (Krebs') cycle to produce energy (mostly as ATP), carbon dioxide and water. The article describes these reactions. Some glucose may also be metabolized by anaerobic respiration or fermentation. In the latter case the process is controlled by microorganisms like yeast.

Students may have studied these mechanisms in biology. In any case, the details of the processes are not of primary importance here. However, students may remember that one of the key intermediate products of aerobic respiration is pyruvate, but that in anaerobic respiration the key intermediate product is lactate, the compound that builds up in muscles during strenuous exercise when the body takes in an insufficient volume of oxygen to support aerobic respiration. Student will likely know about lactic acid buildup during exercise. According to the *ChemMatters* article from February, 1999, titled “Sports Drinks: Don’t Sweat the Small Stuff”:

“Your body stores carbohydrates in the muscles and liver in the form of a non-reducing, white, amorphous polysaccharide called *glycogen*. Glycogen is converted to a simple sugar called glucose and is released into the bloodstream to be used as fuel to maintain normal body processes. During moderate- to high-intensity exercise, glycogen

reserves can be depleted within 60–90 min. Blood sugar levels drop as the glycogen reserves are used up, and lactic acid builds up in muscle tissue. Lactic acid lowers the pH of muscle cells— causing muscle fatigue, cramps, and pain. This certainly limits the body's ability to perform at peak levels. When carbohydrates are being depleted during exercise, muscles also generate a large amount of heat that must be dissipated for them to work properly. Water, in the form of sweat, which has a large heat of vaporization, is used to take heat away from these muscles. About 600 kcal (one dietician's Calorie, as listed on food labels, equals one kilocalorie) of heat is eliminated per liter of sweat." (page 11)

One of the factors that determine the amount of glucose in the blood is the rate at which complex carbohydrates (which cannot be used by the body) are broken down into glucose which the body *can* use directly. Foods are assigned what is called a glycemic index (GI), a rating that compares the rate of conversion to glucose, which is assigned a rating of 100. The index ranges from 0-100. Although these numbers are not fixed, generally a high glycemic index is between 70 and 100, a medium GI is 56-69 and a low GI is 55 or less. In general, the more complex carbohydrates take longer to break down and the simpler carbs take less time. The lower the glycemic index, the slower the food is broken down in the bloodstream. For example, white bread has a glycemic index of 70, which means it enters the bloodstream 70% as fast as glucose. In general, the more refined or processed the food, the higher its glycemic index. The importance of glycemic index ratings lies in the fact that blood sugar levels are more stable with a diet that has a generally lower GI. Some examples of foods with different levels of glycemic indices:

Index	Foods
Low	Most fruits and vegetables, whole grains, nuts, fructose
Medium	Whole wheat products, sucrose, sweet potato, baked potato
High	White bread, corn flakes, glucose, maltose

You can find a database of glycemic index ratings at <http://www.glycemicindex.com/>, the Glycemic Index Foundation's Web site. You might also want to note that an insulin index exists. It rates foods based on the way in which insulin responds to the foods.

How are glucose levels in the blood regulated? That is the role of insulin. A hormone, insulin is produced in the pancreas and released into the blood stream to keep the blood glucose levels within a narrow range. Too much sugar in the blood, called hyperglycemia, may lead to diabetes. But hypoglycemia, too little blood sugar is also a serious health problem. In the case of diabetes, the pancreas produces an amount of insulin insufficient to keep blood glucose levels at a healthy level. Diabetics, therefore, must inject themselves with insulin, and they sometimes inject too much at one time. Or they exercise without eating adequately. Blood glucose levels quickly fall and hypoglycemia results. A dose of 15 grams of easily absorbed glucose should be administered quickly— half a can of fruit juice or soda, four hard candies or even four teaspoons of table sugar.

More on glucose and diabetes

Diabetes, a deficiency in the body's ability to produce insulin and, therefore, to regulate blood sugar, is a major public health issue in the United States. According to the American Diabetes Association there are 25.8 million children and adults in the United States—8.3% of the population—who have diabetes. Of these 18.8 million are diagnosed and 7.0 million are undiagnosed. In addition, there are 79 million people with pre-diabetic conditions. About 1 in every 400 children and adolescents has type 1 diabetes.

There are two types of diabetes—type 1 and type 2. According to the American Diabetes Association:

Type 1 diabetes is usually diagnosed in children and young adults, and was previously known as juvenile diabetes. In type 1 diabetes, the body does not produce insulin.

Insulin is a hormone that is needed to convert sugar, starches and other food into energy needed for daily life. Only 5% of people with diabetes have this form of the disease. With the help of insulin therapy and other treatments, even young children with type 1 diabetes can learn to manage their condition and live long, healthy, happy lives.

Type 2 diabetes is the most common form of diabetes. Millions of Americans have been diagnosed with type 2 diabetes, and many more are unaware they are at high risk. Some groups have a higher risk for developing type 2 diabetes than others. Type 2 diabetes is more common in African Americans, Latinos, Native Americans, and Asian Americans, Native Hawaiians and other Pacific Islanders, as well as the aged population.

In type 2 diabetes, either the body does not produce enough insulin or the cells ignore the insulin. Insulin is necessary for the body to be able to use glucose for energy. When you eat food, the body breaks down all of the sugars and starches into glucose, which is the basic fuel for the cells in the body. Insulin takes the sugar from the blood into the cells. When glucose builds up in the blood instead of going into cells, it can lead to diabetes complications.”

Diabetes can lead to high blood pressure, kidney failure, blindness, heart disease and stroke, neurological disorders and loss of limbs. For additional information on the disease see the web site of the [American Diabetes Association](http://www.american-diabetes-association.org/).

For a detailed explanation by a high school chemistry teacher of how a glucose meter works, see http://www.chem13news.uwaterloo.ca/issues/343/343_dec_2006_pages_5-6.pdf.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic chemistry**—Any study of carbohydrates requires some knowledge of organic chemistry. This article and its diagrams and illustrations is heavy on organic.
2. **Biochemistry**—The article is primarily about the way in which chemical changes occur in a living system.
3. **Thermochemistry**—Although there is not much discussion of thermochemistry in the article, the energy from chemical processes falls into this realm.
4. **Carbohydrates**—The article emphasizes carbohydrate chemistry and so provides an easy connection to these organic molecules.
5. **Polymers**—If you have already studied polymers or would like to introduce them to students, this article provides that opportunity.
6. **Isomers**—Isomers are not mentioned in the article but are important in understanding the nature of glucose.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“When the bonds in ATP break, energy is released.”** No. It is the reformation of bonds after the ATP bonds break that results in the release of energy. Bond breaking requires energy; bond forming releases energy.
2. **“All sugars are table sugar.”** Table sugar, sucrose, is just one of a class of carbohydrates, commonly called sugars. There are many kinds of sugars—glucose, fructose, maltose, galactose, etc.
3. **“If my blood contains glucose why doesn’t blood taste sweet?”** Because the glucose content of blood is only 0.1%, not enough to make it taste sweet, especially since there are other blood components, like iron, that have a more pronounced effect on the taste of blood.

Anticipating Student Questions (answers to questions students might ask in class)

1. **“The article says that we don’t actually eat ‘straight’ glucose. But if the body needs glucose, how does it get it?”** The article indicates that sugars like fructose or sucrose are contained in the foods we eat. Sucrose and fructose are disaccharides which include glucose molecules chemically bonded to other sugar units. In the body these sugars are broken down chemically to produce glucose for the body’s use.

In-class Activities (lesson ideas, including labs & demonstrations)

1. Given here are procedures for standard tests for carbohydrates, fats and proteins that can be done in class: <http://www.seplessons.org/node/362>.
2. This rich resource is a complete teacher’s guide on food and fitness from Baylor University. The guide contains lab activities on sugars and yeast, sugars as energy sources, measuring food calories and nutrition needs: http://www.bioedonline.org/resources/files/TSO_FF_s.pdf.
3. An activity to determine the sugar content of several brands of sodas appears in “Try This!” in [*ChemMatters*, October, 2004, p. 5.](#)
4. This lab allows students to convert glucose to fructose using enzymes: <http://www.math.unl.edu/~jump/Center1/Labs/ConversionofGlucosetoFructose.pdf>.
5. In this lab activity students can test for starch and glucose in a ripe and unripe banana: <http://www.math.unl.edu/~jump/Center1/Labs/FoodCompositionChemistry.pdf>.
6. This site is a set of two wet-lab chemistry experiments to show digestion of proteins and of carbohydrates. It also has one that tracks student eating habits and one that compares food pyramids, and one activity at the end that allows students to design their own experiment: <http://www.smv.org/jil/mlh/high/MLL9-12dig-CA-dig.pdf>.

7. This site from the Royal Society of Chemistry offers a standard procedure for the fermentation of glucose: <http://www.practicalchemistry.org/experiments/fermentation-of-glucose-using-yeast,109,EX.html>.
8. If you want students to learn more about the chemical structure of carbohydrates, this site allows students to interact with models of the molecules: <http://biomodel.uah.es/en/model3/index.htm>.
9. National Geographic Xpeditions provides this activity on photosynthesis and glucose: <http://www.nationalgeographic.com/xpeditions/lessons/08/g68/brainpopphoto.html>.

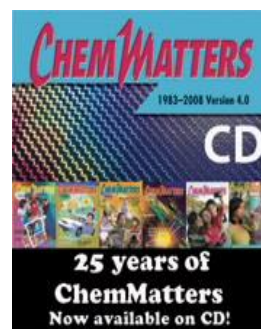
Out-of-class Activities and Projects (student research, class projects)

1. Students can gather ideas about glucose and other carbohydrates and then participate in the interactive feature of this Franklin Institute web site: <http://www.fi.edu/learn/brain/carbs.html#toomuch>.
2. Students can make a project of recording the kind of food they eat for a week and recording the carbohydrate content of the food. They can get this information from food labels.
3. Students can conduct surveys about diabetes among their family and friends and present their findings for class discussion.
4. Students working in teams can research diabetes and put on community presentations as a service project.

References (non-Web-based information sources)

The reference below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. (Part way down the website screen, click on the *ChemMatters* CD icon like the one here at the right.)

Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)



Rohrig, B. Carb Crazy. *ChemMatters*, October, **2004**, 22 (1), p 6. The author describes the controversy surrounding low-carb diets and gives background chemistry—includes carbohydrate chemistry with emphasis on blood sugar.

Web sites for Additional Information (Web-based information sources)

More sites on carbohydrates

This U.S. government nutrition site has multiple resources on carbohydrates, including a nutrition database and a guide to sugar food supplements:

http://www.nutrition.gov/nal_display/index.php?info_center=11&tax_level=2&tax_subject=388&topic_id=1665&placement_default=0.

This site provides a basic introduction to carbohydrates:

<http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/carbyhd.htm>.

This web site is a data base that compares the amount of glucose in foods:

<http://nutritiondata.self.com/foods-00001000000000000000-1.html>.

How Stuff Works gives information on carbohydrates at

<http://science.howstuffworks.com/innovation/edible-innovations/food2.htm>.

The chemistry of carbohydrates is shown on this web site:

<http://chemed.chem.purdue.edu/genchem/topicreview/bp/1biochem/carbo5.html>.

More sites on glucose

A reliable database of glycemic index numbers can be found at

<http://www.glycemicindex.com/>, which was developed by the Human Nutrition Unit, School of Molecular and Microbial Biosciences, University of Sydney, Australia.

Elmhurst College has a Virtual ChemBook that provides background content on

glucose at <http://www.elmhurst.edu/~chm/vchembook/543glucose.html>.

The chemistry of glucose and related compounds is given here:

http://www.ch.ic.ac.uk/vchemlib/mim/bristol/glucose/glucose_text.htm.

More sites on diabetes

The American Diabetes Association has a lot of information on diabetes. View the site at

<http://www.diabetes.org/>.

PubMed provides reliable information on diabetes at

<http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0002194/>.

The Mayo Clinic has a web site devoted to diabetes and its treatment:

<http://www.mayoclinic.com/health/diabetes/DS01121>.

Harnessing Solar Power

Background Information (teacher information)

More on solar cell types

The article on Solar Power describes the basics of a solar cell including the use of silicon crystals and the role of “doping” to make it possible for electron flow in a solar cell when light energy is absorbed by the silicon, releasing electrons into the one-way circuit, the so-called semi-conductor arrangement. But in the present world of solar cell or photovoltaic (PV) panel development, there are a number of different types of solar cell architecture in order to achieve both efficiency as well as reduced cost in electricity production. For solar cells to become more ubiquitous in the world of electricity production, they must be able to produce electricity that is cost competitive with the present-day electricity generators powered by fossil fuels, as well as nuclear and hydroelectric, one of the cheapest but not necessarily the most prevalent generation methods.

As mentioned, traditional solar cells are made from silicon and generally are the most efficient. Second-generation solar cells are called thin film solar cells because they are made from amorphous silicon (rather than cut from solid silicon as “wafers”) or non-silicon materials such as cadmium and tellurium. These thin layers of semiconductor materials are only a few micrometers thick, which gives them flexibility. Therefore they can be used as roofing material, glazing for skylights or siding, while performing photoelectric duties. Third-generation solar cells are being made, not from silicon but from special solar inks that are applied with conventional printing press techniques. Other techniques include the use of solar dyes and conductive plastics.

More on improving PV cell efficiencies—using rare earth elements

Improving the efficiency of photovoltaic cells means that if certain materials incorporated into the solar cell’s construction increase the amount of usable light energy absorbed and converted into electron flow, then the cost of the materials used translates into more electricity (watts) available which offsets that cost. The ideal of course would be to use the least expensive materials for the maximum amount of electricity produced per quantum of energy absorbed and transformed. Pure silicon and its processing into solar wafers cut from the very hard silicon is the most expensive but also the most efficient, so research continues in the hopes of finding combinations of chemicals that are cost effective and efficient in photovoltaic operations. Among a number of potential chemicals that can be incorporated into PV cells are some of the rare earth metals. The incorporation of rare earth metals increases the efficiency of the photovoltaic process as well as the cost of the cells. They are considered less expensive as raw materials than the elements tellurium, indium and gallium that are popular in another type of PV called thin layer (more on that later). What happens is that the rare-earth complexes in a solar cell absorb light at shorter wavelengths (photovoltaic precursors) but emit at longer wavelengths which matches the longer wavelengths that are absorbed by the basic silicon solar cell. The high energy region of the solar spectrum, normally unused, is thus shifted to longer wavelengths, providing extra longer wavelength transitions, and hence a higher cell output power.

Rare earth metals are actually not that rare in terms of abundance. Interestingly enough, at the moment China seems to be controlling some 97% of the market in terms of availability. This has prompted the US to open up some mines in California that were closed down some years ago because of environmental regulations and costs. But demand has made it profitable to reopen these mines. In addition, Japan has discovered a very large deposit in the ocean seabed and it is assumed that the cost of mining at these depths will not be prohibitive.

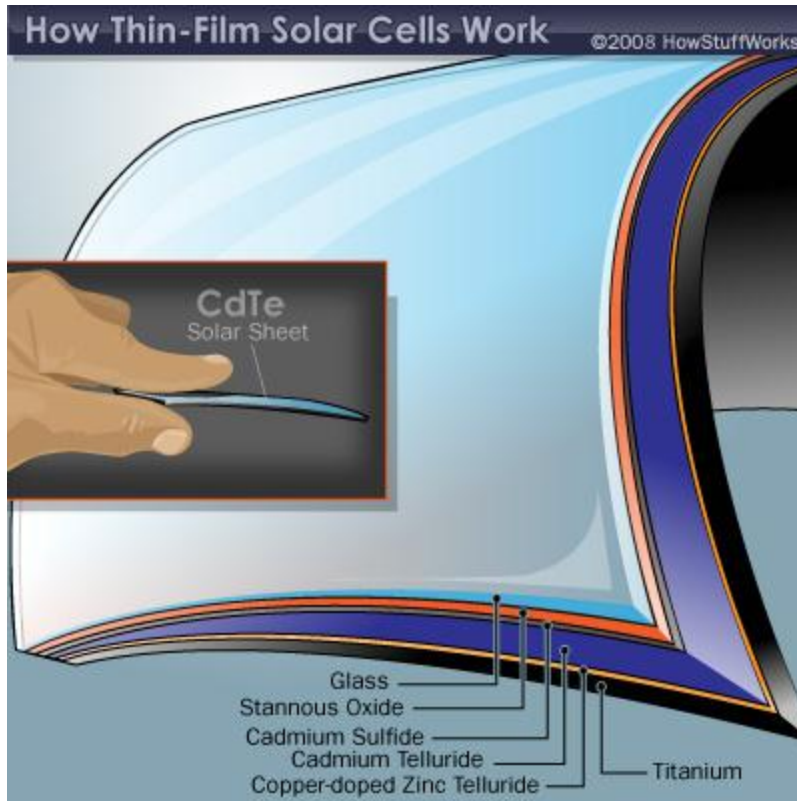
Rare earth metals are used in magnets because they can produce a more powerful field per weight unit, hence less needed, which makes for a lighter magnet. The element neodymium works well for miniaturization in cell phones, computers, loudspeakers and miniature motors. Rare earth elements such as dysprosium and neodymium are seeing use in batteries for hybrid cars and in compact disks. Indium is being used in the next generation of solar panels. Wind turbines use lanthanides in their electromechanical systems, primarily in the induction coils that produce electricity when the generator is turned by the force of wind.

More on thin film PVs

Three common types of thin film panels include Amorphous Silicon, Cadmium Telluride (CdTe) and Copper Indium (Gallium) diSelenide (CIS or CIGS).

Amorphous silicon is a non-crystalline form of silicon, containing only about 1/300th the amount of active material in a crystalline-silicon cell. This is the type of thin film panel that is used in pocket calculators. A variation on this basic structure is to coat a layer of mono-crystalline solar cells with the amorphous silicon keeping the thin layer effect while taking advantage of the high efficiencies of crystalline silicon technology in combination with the simpler and cheaper large area deposition technology of amorphous silicon.

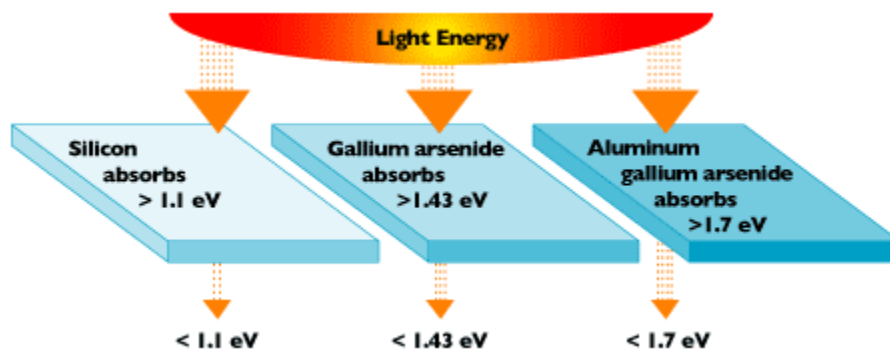
The use of cadmium and tellurium as a thin film photovoltaic cell produces a less expensive type of PV cell that is efficient enough to consider as an alternative to a pure silicon type PV. It is the second most utilized type of solar cell material in the world. Solar panels based on CdTe are the first and only thin film photovoltaic technology to surpass crystalline silicon PV in cheapness for a significant portion of the PV market, the multi-kilowatt systems.



Source: <http://www.solar-facts-and-advice.com/cadmium-telluride.html>

The cadmium-telluride combination that produces high conversion efficiencies is based on a good match between the spectral absorption characteristics of the two elements and that of the optimal spectral band gap of a single junction device.

“The photon energy of light varies according to the wavelengths of the light. The entire spectrum of sunlight, from infrared to ultraviolet, covers a range of about 0.5 eV to about 2.9 eV. Most PV cells cannot use about 55% of the energy of sunlight because this energy is either below the band gap of the material used or carries excess energy. For example, red light has an energy of about 1.7 eV, and blue light has an energy of about 2.7 eV.



Different PV materials have different energy band gaps. Photons with energy equal to the band gap energy are absorbed to create free electrons. Photons with less energy than the

band gap energy pass through the material.”

(http://www.eere.energy.gov/basics/renewable_energy/crystalline_silicon.html)

Efficiencies approaching 20% are expected in mass produced cells of this type. As of July 2011, the company First Solar achieved a record breaking 17.3% efficiency in a laboratory setting, up from a previous 11.7% efficiency. First Solar is able to produce Cd-Te solar panels at \$0.75/watt compared with the standard silicon wafer type at \$1.40 to \$1.80/watt. Any price below \$1.00 is considered extremely competitive. Two problems with this type of cell manufacturing include the limited availability of tellurium and the toxicity of cadmium, a topic with mixed opinions when considering what physical conditions might produce a problem with cadmium (considered less a problem when combined with tellurium).

Other combinations in thin film are copper indium diselenide (CIS) or copper indium gallium diselenide (CIGS). The CIGS alloys are currently the most popular in the manufacturing realm. CIGS technology has also achieved an efficiency at the 20% level but the material is more difficult to work with than CdTe-based technology. A useful cross-section diagram of a thin film polycrystalline solar cell layer can be found at http://en.wikipedia.org/wiki/Thin_film_solar_cell.

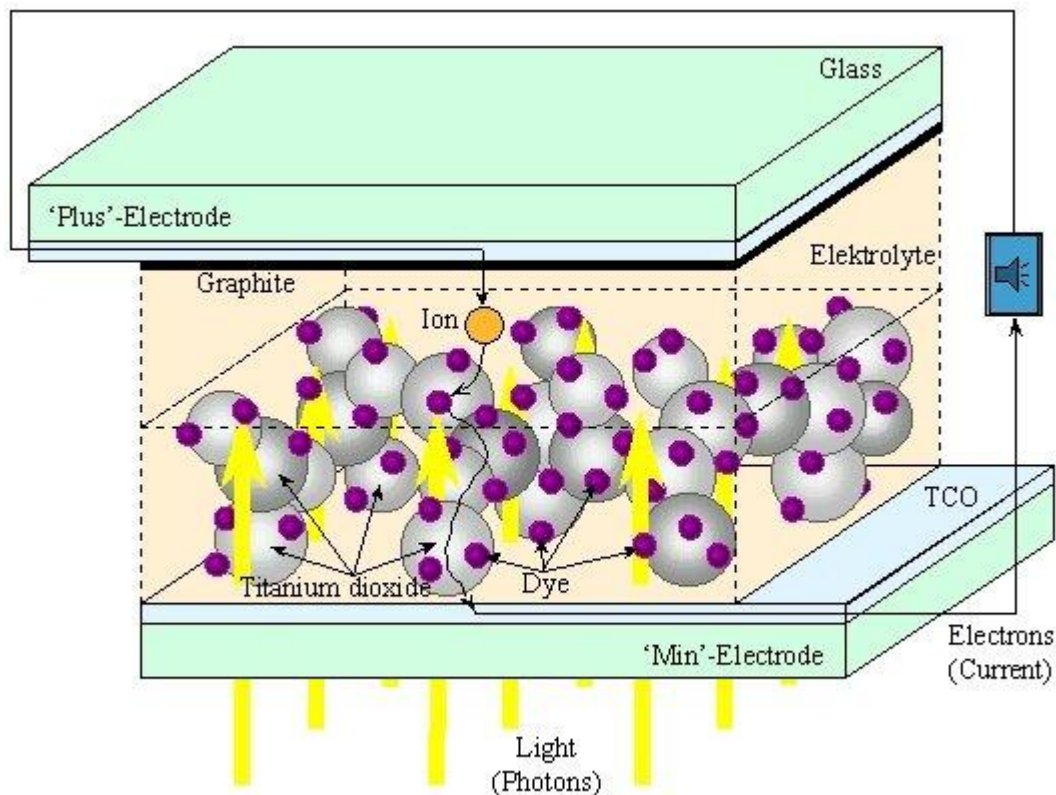
More on polymers and nanotechnology in PVs

A different type of solar cell called a Graetzel cell has a different mode of operation than a regular silicon-based solar cell. (Note that this type of cell can be built by students—see the section on student projects.)

“Dye-sensitized solar cells (DSSC) effectively separate the two functions provided by silicon in a traditional cell design. Normally the silicon acts as both the source of photoelectrons, as well as providing the potential barrier to separate the charges and create a current. In the DSSC, the semiconductor is used solely for charge separation, the photoelectrons are provided from a separate photosensitive dye. Additionally the charge separation is not provided solely by the semiconductor, but works in concert with a third element of the cell, an electrolyte in contact with both.

“In operation, sunlight enters the cell through the transparent $\text{SnO}_2\text{:F}$ top contact, striking the dye on the surface of the TiO_2 . Photons striking the dye with enough energy to be absorbed will create an excited state of the dye, from which an electron can be “injected” directly into the conduction band of the TiO_2 , and from there it moves by a chemical diffusion gradient to the clear anode on top. Meanwhile, the dye molecule has lost an electron and the molecule will decompose if another electron is not provided. The dye strips one (electron) from iodide in electrolyte below the TiO_2 , oxidizing it into triiodide. This reaction occurs quite quickly compared to the time that it takes for the injected electron to recombine with the oxidized dye molecule, preventing this recombination reaction that would effectively short circuit the solar cell. The triiodide then recovers its missing electron by mechanically diffusing to the bottom of the cell, where the counter electrode re-introduces the electrons after flowing through the external circuit.” (http://www.juliantrubin.com/encyclopedia/renewable_energy/dsc.html)

An excellent article, with illustrations (has some grammatical/non-edited reading problems because of translation) that clearly show how a dye sensitive solar cell (DSSC) operates, can be found at http://www.elp.uji.es/juan_home/research/solar_cells.htm. The site includes the diagram below of the DSSC cell.



A DSSC is composed of a porous layer of [titanium dioxide nanoparticles](#), covered with a molecular dye that absorbs sunlight, like the chlorophyll in green leaves. The titanium dioxide is immersed under an electrolyte solution, above which is a platinum-based catalyst. As in a conventional alkaline battery, an anode (the titanium dioxide) and a cathode (the platinum) are placed on either side of a liquid conductor (the electrolyte).

Sunlight passes through the transparent electrode into the dye layer where it can excite electrons that then flow into the titanium dioxide. The electrons flow toward the transparent electrode where they are collected for powering a load. After flowing through the external circuit, they are re-introduced into the cell on a metal electrode on the back, flowing into the electrolyte. The electrolyte then transports the electrons back to the dye molecules.

Dye-sensitized solar cells separate the two functions provided by silicon in a traditional cell design. Normally the silicon acts as both the source of photoelectrons, as well as providing the electric field to separate the charges and create a current. In the dye-sensitized solar cell, the bulk of the semiconductor is used solely for charge transport, the photoelectrons are provided from a separate photosensitive dye. Charge separation occurs at the surfaces between the dye, semiconductor and electrolyte.

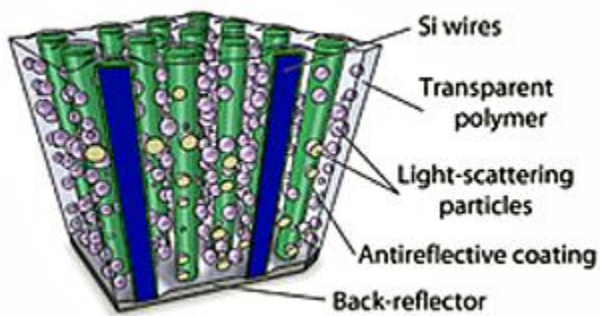
The dye molecules are quite small (nanometer sized), so in order to capture a reasonable amount of the incoming light the layer of dye molecules needs to be made fairly thick, much thicker than the molecules themselves. To address this problem, a nanomaterial is used as a scaffold to hold large numbers of the dye molecules in a 3-D matrix,

increasing the number of molecules for any given surface area of cell. In existing designs, this scaffolding is provided by the semiconductor material, which serves double-duty. (http://en.wikipedia.org/wiki/Dye-sensitized_solar_cell)

Difficulties with this type of cell relate to the electrolyte, which, as a liquid, can freeze at low temperatures. At higher temperatures, the liquid will expand, making sealing of the panels a problem. But the advantage of this type of cell is that it can operate under low light conditions, much lower than the standard silicon-based solar cell which would cut out at such low light levels. The cutoff for the DSSC is so low that it can collect light energy from regular house lights to run small devices!

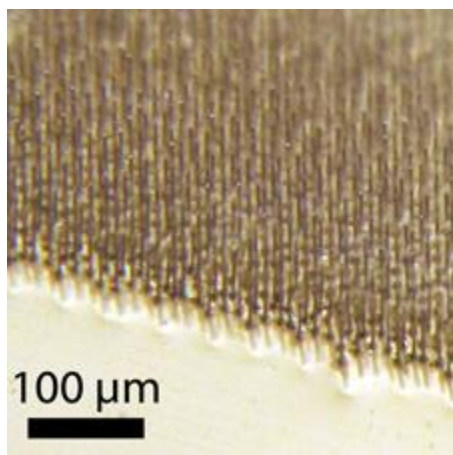
More on tweaks to solar cell composition/construction

Silicon wires—A way to increase the efficiency of silicon-based solar cells is to create what are known as silicon “wires”, taking advantage of internal reflection and increased surface area. A diagram of such a silicon wire arrangement is as follows:



"The light comes in and is both directly absorbed by the wires, and some of the light bounces around in between the wires. The bouncing around or multiple scattering in between the wires results in dramatically enhanced absorption...In fact, the absorption enhancement that we see is in the range of 20 to 50 times the single-pass absorbance." (<http://www.solar-facts-and-advice.com/integrated-photovoltaics.html>)

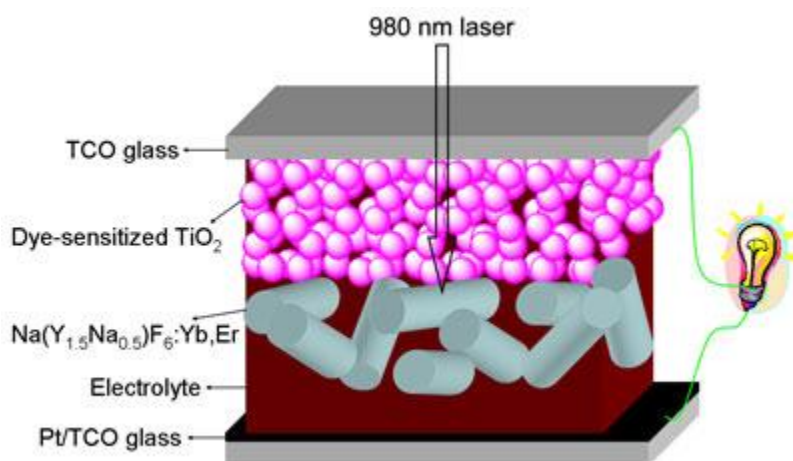
A photomicrograph of the silicon wires is shown below:



Silicon blades—Novel silicon microwires can harvest nearly as much light as traditional photovoltaic wafers, with just one percent of the total silicon. (Image: Courtesy of Harry A. Atwater and found in: <http://www.scientificamerican.com/article.cfm?id=photovoltaic-breakthroughs-brighten-outlook-for-cheap-solar-power>)

More on photovoltaics at the nano-scale

A very unique use of photovoltaic cells occurs in dark areas (e.g., locations where no light is present to operate a normal photovoltaic cell, as inside a cell) at the micro or nano-scale. With this particular design, photovoltaic cells are used to power biological nanorobots. The PV cell is actually of the dye sensitive type (DSCC) which responds to laser light at the 980 nm range (near infrared) which can pass through biological tissue. The idea is that the rare earth nanophosphors (see diagram below) absorb the 980 nm light, re-emit light in the visible luminescent range which can then excite the normal DSCC solar cell to produce enough electrical power (0.28 to 0.02 mW) to run various kinds of biodevices.



Schematic illustration of the photovoltaic cell containing the $\text{Na}(\text{Y}_{1.5}\text{Na}_{0.5})\text{F}_6:\text{Yb,Er}$ film. (<http://www.nanowerk.com/spotlight/spotid=13975.php>)

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Photoelectric effect**—This principle is behind both the biological process of photosynthesis and the operation of photovoltaic cells in which the frequency of electromagnetic radiation determines if enough energy is present to raise the energies of electrons of metal atoms high enough for them to escape to other atoms, as in a photovoltaic cell.
2. **Valence Electrons**—Valence electrons are important in the covalent bonding between a silicon crystal and dopants of phosphorus and boron. Photovoltaic cells respond to a particular frequency of electromagnetic radiation absorbed, breaking covalent bonds between boron and silicon that were formed with electrons from the dopant phosphorus. Free electrons formed create an electric current.
3. **Covalent Bonds**—The covalent bonds formed between a p-dopant and silicon are the sites for freeing electrons upon absorption of a certain frequency of electromagnetic radiation, the basis for an electric current in the solar cell.

4. **Hydrocarbons**—Carbon compounds are important in a variety of special polymers that are conductive and can be used in thin film solar cells, providing both flexibility and conductivity.
5. **Periodic Table**—Family classification of elements based on similar chemical characteristics allows chemists to select elements that might work as electron donors and acceptors in p-n junctions of photovoltaic or solar cells.
6. **Network Solid(s)**—Silicon in solar cells forms network solids through covalent bonds, creating a solid state rather than a gaseous state as in carbon-based compounds because the silicon atoms are larger than carbon atoms and do not readily form double bonds as in carbon dioxide, where weak van der Waals forces result between molecules. Rather silicon forms single bonds forming a three dimensional covalent network solid which has a high melting point (~1700 °C).
7. **Rare earth elements**—Rare earth metals are useful in applications which benefit from light- weight materials, as there is less metal needed to perform the same level of electrical activity as other metals. Rare earth metals produce stronger magnetic force fields than other metals and can be used in such things as small loudspeakers and microphones, as in cell phones, and similar solid state electronics, as well as solar cells of the thin film variety.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“The photoelectric effect operating in a solar cell will only occur with visible light.”**
The photoelectric effect on metals often is most effective in the ultraviolet region, among other wavelengths. What determines if a photoelectric effect takes place is the wavelength or frequency (actually, the energy) of the particular electromagnetic radiation (EMR), not whether it is visible or invisible EMR.
2. **“It is the heat of sunlight that creates electricity in a solar panel.”**
If by heat one means infrared, then it depends on what particular metal or metalloid element is involved in absorption of that particular wavelength of EMR. In reality, any heat buildup inside a solar panel is due to the greenhouse effect where the heat as IR is usually not being absorbed for the photoelectric effect and electricity production. And in fact, too high a temperature will interfere with the electricity production at the atomic level.

Anticipating Student Questions (answers to questions students might ask in class)

1. **“Why can’t you get the ejection of an electron from a metal by simply increasing the intensity of the light source?”**
To eject an electron requires a specific amount of energy which is provided by a particular frequency or energy of a photon of light (or any other electromagnetic radiation or EMR) rather than just increasing the intensity (number of photons) of the light. On the other hand, when using the correct frequency of EMR, one can increase the number of electrons ejected from the atom by also increasing the intensity of the EMR.
2. **“If silicon is in the same chemical family as carbon, why is silicon dioxide a solid and carbon dioxide a gas at room temperature?”**
A silicon atom is larger than a carbon atom, which prevents it from forming double covalent bonds as is the case for carbon. With carbon forming double covalent bonds with oxygen, two atoms of oxygen satisfy the bonding capacity of carbon, with the resulting molecule forming weak intermolecular bonds between carbon dioxide molecules. These weak bonds allow CO₂ to exist as a gas at room

temperature. The silicon forms single covalent bonds with more than one oxygen atom, creating a network solid rather than a gas at room temperature.

3. **“How many atoms are used in doping silicon—what is the concentration?”** Ten atoms of boron per million of Si is enough to make silicon a semiconductor. (That’s ten ppm.)
4. **“After a photon releases an electron in a solar cell, how does the cell ‘reset’ itself to provide another electron for release?”** Because the original arrangement of dopant atoms and silicon atoms provides for a negative state on the p-side of the junction and a positive state on the n-side of the junction, ejecting electrons from covalent bonds formed between a p-dopant, such as boron, and silicon causes the electrons to flow toward the positive n-side of the junction. This is only possible because the absorbed light energy provides enough of a force to push the electron against the original electrical field created by the interaction between the p- and n-dopants and the silicon atoms. This movement of electrons is an electric current. And the p-n junction resets itself to the former resting state with new covalent bonds formed between p-dopant atoms and silicon atoms. The process repeats itself with the absorption of more light energy of the correct frequency.

In-class Activities (lesson ideas, including labs & demonstrations)

1. Demonstration of the Photoelectric Effect can be done using UV light to remove electrons on a negatively charged zinc strip attached to a charged electroscope. This demo works very well and lends itself to a variety of questions that can be asked of students after seeing the results of discharge through UV light exposure. See any of the following references for setup of equipment: (<http://www.physchem.co.za/OB12-ele/photoelectric.htm#effect>; http://buphy.bu.edu/~duffy/modern/7A10_10.html ; [http://chemdemos.uoregon.edu/pages/detail.php?s\[\]=Quantum%20Theory&id=c41d7dd26db60674c90d2a60874de404#](http://chemdemos.uoregon.edu/pages/detail.php?s[]=Quantum%20Theory&id=c41d7dd26db60674c90d2a60874de404#)).
2. A video that demonstrates the principle of the photoelectric effect (animated diagram with various wavelengths of light used) is found at <http://www.youtube.com/watch?v=jAt4Liq3bgc&feature=related> ; a real time video of the same kind of demo for the photoelectric effect using the electroscope and zinc set up mentioned in demo #1 above is found at <http://www.youtube.com/watch?v=dHFIS0u75-8&feature=related>.
3. Kits for making a dye sensitive solar cell (DSSC) can be purchased through the ICE Website at <http://ice.chem.wisc.edu/Catalog/SciKits.html#Anchor-Nanocrystalline-41703>.
4. It is worth having samples of solid silicon and silicon compounds such as quartz, for students to observe. Other silicon compounds with different physical properties include talc ($3\text{MgO} \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$) and asbestos (chains of alternating silicon and oxygen atoms covalently bonded; metallic atoms such as calcium or magnesium are bonded to the silicon). They could also compare conductivity of silicon versus carbon in the form of graphite. They should locate the element silicon on the periodic table and compare with different forms of carbon (charcoal, coal, diamond, graphite). Students could try their hand at building molecular models for silicon and carbon. Using a handbook of physical and chemical characteristics, students could compare the different characteristic properties resulting from the different types of bonding that occur in each of the two family IV elements—a three dimensional network solid (silicon) compared with covalent bonding in pure carbon as graphite. Then compare silicate compounds such as quartz with a compound like carbon dioxide. What produces such differences with carbon dioxide as a gas and quartz as a hard solid at room temperature? What is diamond and what is required, physically, to produce it versus carbon in the form of graphite or charcoal?

5. An inexpensive small solar panel could be shown to the class. It might also be instructive to try to activate the solar panel with selected different wavelengths of light including infrared, ultraviolet, and selected spectra of visible light vs. white light (full spectrum). Do solar panels work on cloudy or grey days? Is it a function of light intensity or of particular frequencies of light that are missing in the spectrum of visible light? (Infrared and ultraviolet are present on a cloudy or grey day.)

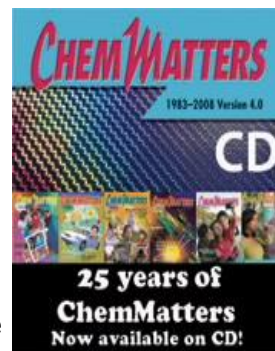
Out-of-class Activities and Projects (student research, class projects)

1. Find out how much it would cost to install a PV system for a family of four. What is meant by a payback period? What determines a payback rate? What cost reductions are available from the government (state and federal)? What are state or federal provisions for homeowner "credits" when excess electricity is fed back into the commercial network from a homeowner's solar-generated electricity? (see <http://www.oksolar.com/q&a/> for starters).
2. Nuclear vs. Solar PV vs. Wind generation: students could do comparisons between these different ways to generate electricity including start-up costs, environmental considerations, government regulations, governmental incentives (tax breaks and outright federal grants), life span of the generating devices, cost per kW generated. This is a major but important exercise that combines internet research, evaluation of information, understanding the science behind the information, evaluating arguments for a given source of energy production, and, finally, making an informed decision/choice with justifications. Perhaps groups of students can be assigned to researching one of the energy sources and eventually debating each other on the best choice for electricity generation.
3. Instructions for making a dye sensitive solar cell can be found at <http://www.solaronix.com/technology/assembly/>
4. A clear series of steps for constructing a dye sensitive solar cell can be found at <http://www.solideas.com/solrcell/english.html> and <http://www.solideas.com/solrcell/coatglas.html>, with an introduction at <http://www.solideas.com/solrcell/kitcomp.html>. But it is best to simply purchase a kit from ICE- see #5.
5. Students can build their own dye sensitive solar cell (a nanocrystalline cell) using an available kit from the Institute for Chemical Education (ICE). For ordering a dye sensitive solar cell (DSSC) kit from Institute for Chemical Education (ICE), go to <http://ice.chem.wisc.edu/Catalog/SciKits.html#Anchor-Nanocrystalline-41703>.

References (non-Web-based information sources)

The reference below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. (At the bottom of the Website screen, click on the *ChemMatters* CD image like the one at the right.)

Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)



Baxter, R. Computer Chips—Loaded Bits *ChemMatters* December, **1997**, 15 (4), pp 7–9. Baxter describes the role of silicon in the construction of computer chips, including n-type and p-type dopants.

Web sites for Additional Information (Web-based information sources)

More sites on photoelectric effect

A very good YouTube video showing the photoelectric effect, with schematics to explain the effect being viewed is found at <http://www.youtube.com/watch?v=muxRZ1irsrk> . When the Website is accessed, related videos on the subject are listed on the side of the video screen. One interesting video is Einstein explain the photoelectric effect (dubbed voice!) with an “animated” picture of Einstein.

More sites on solar kits

One of many sites where one can purchase a variety of solar kits which include small solar panels, storage systems, and toys that can run on solar-generated electricity can be found at <http://www.siliconsolar.com/edusol-college-and-adult-educational-solar-kits.html>

More sites on the basics of solar cells

http://en.wikipedia.org/wiki/Solar_cell is a comprehensive site for all aspects of solar cells including the history behind their development, starting in 1893 with the work of A.E.Becquerel who first recognized the photoelectric effect.

The Interactive Learning Center of the University of Southampton, UK provides a website that discusses the principles behind and applications of photovoltaic technologies. Several animations help students understand the flow of electrons through a cell. (<http://www.soton.ac.uk/~solar/intro/tech1.htm>)

More sites on the manufacture of solar cells

The following URL is a good site for students who should see more about how things are manufactured, in this case, solar cells, starting with the raw materials. Also shown are the inner workings of a solar cell. Refer to <http://www.madehow.com/Volume-1/Solar-Cell.html> .

More sites on polymer thin film solar cells

An article that explains the use of nanoparticles in polymer-based PV cells that can then allow for very thin layers of silicon to produce flexible solar panels with good efficiencies of solar absorption and conversion can be found http://www.solarnovus.com/index.php?option=com_content&view=article&id=557:trends-in-research-the-role-of-nanotechnology-in-pv-developments&catid=38:application-tech-features&Itemid=246

An additional site that provides a good summary of the various types of polymer thin solar cells can be found at <http://www.solar-facts-and-advice.com/thin-film.html>

A Website from a company that manufactures thin film solar cells provides a nice overview of the need for alternate energy, solar in particular. A video shows this company's manufacturing process which includes the more recent approach of photo "engraving" circuits in the solar panel. Again this is another example of the manufacturing process that students ought to see-they are isolated from how things are made. They simply use them! The video can be found at <http://nanosolar.com/nanosolar-technology-overview>

More Web sites on Teacher Information and Lesson Plans (sites geared specifically to teachers)

The University of Oregon Solar Radiation Monitoring Lab provides a lesson plan for doing the chemistry and physics of solar cell operations. It provides information that can be used as a student handout. There are no hands-on activities of any kind. But the explanations at the atomic level are well done, though they will need a bit of teacher interpretation. (<http://solardat.uoregon.edu/download/Lessons/PVLessonPlan1SolarCells.pdf>)

A second comprehensive educational Website on various aspects of renewable energy provided by the government's research center on renewable energy (NREL) can be found at http://www.nrel.gov/learning/sr_photovoltaics.html.

Demystifying Gross Stuff

Background Information (teacher information)

“Can someone please tell me what is the deal with B.O.? Doesn’t make any sense. Do something good—hard work, exercise—smell very bad. This is the way the human being is designed. You move, you stink. Why don’t our bodies help us? Why can’t sweat smell good? Be a different world, wouldn’t it? Instead of putting your laundry in the hamper, you’d put it in a vase. Go down to the drugstore, pick up some odorant and perspirant. You’d have a dirty sweat sock hanging from the rearview mirror of your car.”

—Jerry Seinfeld

(from Kimbrough, D. R. How We Smell and Why We Stink, *ChemMatters*, December, **2001**, 19 (4), p 8)

More on the history of hygiene

In the present, we are, as the author points out, obsessed with keeping clean and smelling “fresh”. Witness the countless brands of soaps, shampoos, deodorants, perfumes, etc. on the market today. The manufacture and sale of just soaps and detergents in the US alone was a more than 17 billion dollar industry in 2002

(http://factfinder.census.gov/servlet/IBQTable?_bm=y&-ds_name=EC0231SX11&-NAICS2002=325611). Our present-day perceived need for cleanliness, however, was not always shared by our ancestors.

For the Greeks and Romans, bathing wasn’t just a cleansing process, but with public baths and latrines, it was also a social ritual. They used fragrant body oils and ointments, rather than soap to clean their bodies.

During medieval times, some people believed that bathing was a way of letting the devil into the body, or that allowing water to touch the body would make one ill. Since bathing was frequently done in rivers and streams, or in water drawn in buckets directly from rivers and streams, and since urine and feces were typically disposed of by dumping it into rivers and streams, these beliefs may not have been so far from the truth.

There has been great debate over the frequency of bathing in our past history. It now seems that we believe that people in medieval times bathed more frequently than we thought, especially after the outbreak of the Black Plague. Nobility no doubt bathed more frequently than did the peasants.

It wasn’t until germ theory had gained traction that cleanliness was recognized as a way to prevent diseases. Hand-washing (and whole-body-washing) was now seen as a way to prevent the spread of germs, and sanitation was seen as a way of removing germ-laden waste from cities. Soap was a major factor in this new drive for cleanliness.

Soapmaking may be the second oldest chemical reaction we know. The honor of being first goes to fermentation of grape juice to make wine. Although we don’t know for sure how soapmaking first happened, it probably was an accident that an ancestor boiled animal fat

contaminated with ashes from the campfire and discovered solid white material (soap) floating on top.

Greeks and Romans both knew about soap. Excavation of the ruins of Pompeii turned up a soap factory. The Romans probably mixed soap with perfumes to make cosmetics and ointments to dress wounds. They probably didn't use it for washing at first, only eventually recognizing its use for cleaning the body.

Soapmaking eventually became the chore for women and children as they used ashes from the hearth and hot, melted beef fat or pork suet and allowed them to react together in a huge pot over the fire to make soap. A thick white layer of soap eventually formed on top. This was "soft" soap, still containing glycerin, a by-product of the chemical reaction. The addition of salt separated the soap from the glycerin, resulting in "hard" soap. Either variety of soap was harsh to both skin and clothing (when laundered), as it inevitably contained excess lye. Soaps of today are made by the same process, except to more exacting standards.

Today, we accept the idea of washing our bodies and clothes with soap and don't realize that, historically, it is a custom of recent origin. Throughout the Dark and Middle Ages, no one, lord or serf, was very inclined to bathe. Queen Isabella of Spain (1451-1504) boasted of taking only two baths in her lifetime, once when she was born and another on her wedding day. By contrast, Queen Elizabeth I of England (1558-1603) was a bathing enthusiast; her chronicles record that "she hath a bath every three months whether she needeth it or no." In addition to the lack of hot water, soap, and social pressure, bathing was also discouraged by strong religious compunctions. Until well into the 19th century bathing nude was considered sinful—an ancient practice of the pagan Greeks and Romans.

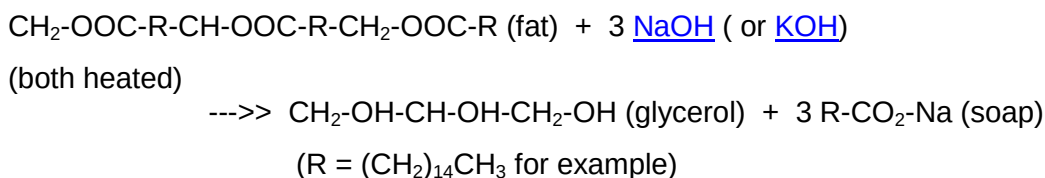
The present practice of bathing with soap and water owes its existence to the Sanitary Movement that began in London as a backlash against the widespread filth that was slowly recognized as the cause for cholera and typhoid epidemics. Sewers were constructed, garbage was carted away, public drinking fountains were isolated from sources of contamination, and people were encouraged to wash themselves and their clothes. In 1846, the British government passed a Public Baths and Wash House Act that established public baths and laundries for the working class of London. The movement spread to Europe, then to the U.S., and, by the turn of the century, bathing was a habitual practice of millions.

Wood, C. Soap *ChemMatters* February, **1985**, 3 (1), pp 4-6.

More on soap

Soaps and detergents are part of a larger group of materials known as surfactants, compounds that lower the surface tension of a liquid or the interfacial tension between two liquids or a liquid and a solid. By reducing interfacial tension, surfactants allow the immiscible nonpolar substances in water to remain suspended in the water, rather than settling on the skin or clothing (in laundry). Surfactants also include wetting agents, emulsifiers, dispersants and foaming agents. The term *surfactant* comes from "surface active agent". Surfactants are usually amphiphilic organic compounds. Soap accounts for about 30% of the current global surfactant market.

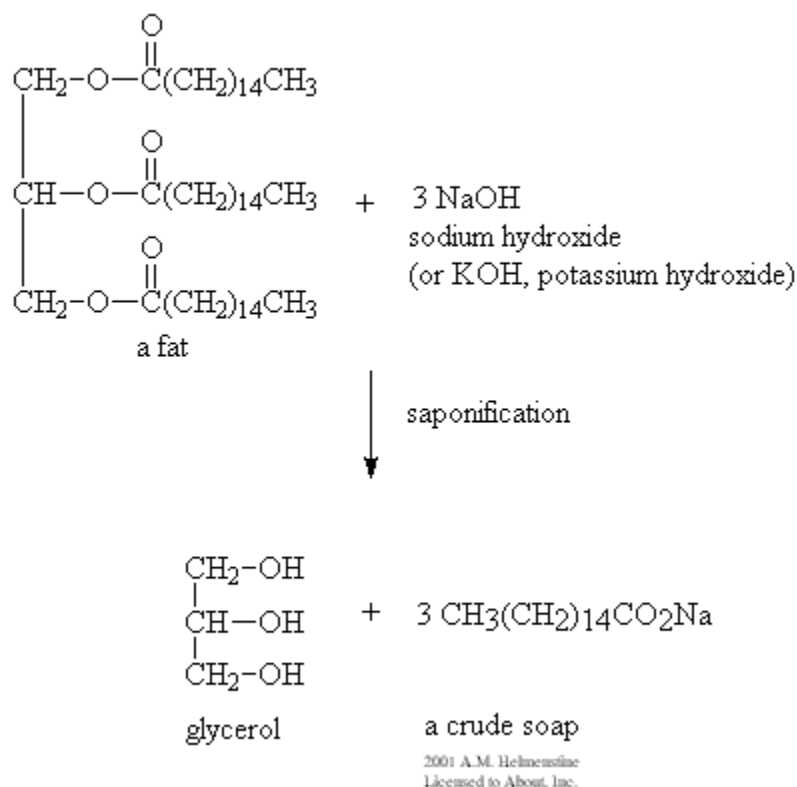
Soap is made by a process called saponification, whereby fats or triglycerides (esters) are hydrolyzed with an alkali metal hydroxide to produce sodium or potassium fatty acid salts (soaps), with an alcohol (glycerol) by-product.



(<http://www.chemistrydaily.com/chemistry/Saponification>)

The soap produced by this reaction would be sodium palmitate, from palmitic acid, the building block of the triglyceride shown above. If the triglyceride of stearic acid [$\text{CH}_3(\text{CH}_2)_{16}\text{COOCH}_3$] had been used, the soap produced would be sodium stearate.

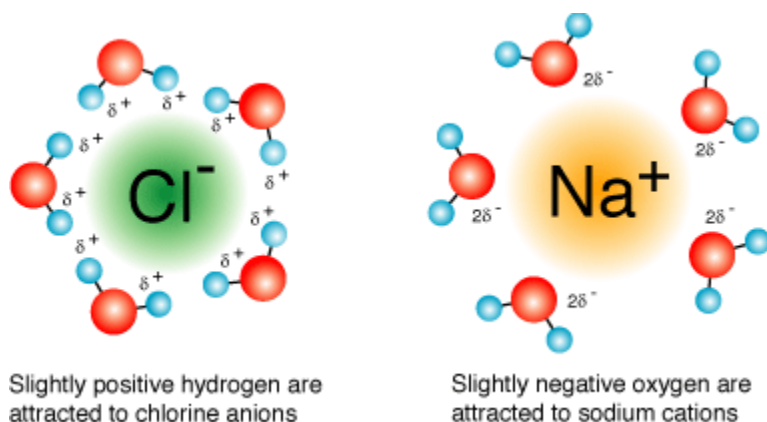
The equation below gives a better spatial representation of the large triglyceride molecule involved in the reaction.



(<http://chemistry.about.com/library/weekly/blsapon.htm>)

As mentioned in the article, these fatty acid salts consist of two parts, a polar anion (a carboxylate group, -CO_2), connected to a long, nonpolar tail. When the alkali metal salt dissolves in water, the sodium or potassium ions float free, surrounded by polar water molecules, turned so that the partially negative oxygen ends of the water molecules are attracted to the cation. This exposes the negatively-charged head of the carboxylate group, which is also surrounded by polar water molecules, except that these water molecules are

turned so that the partially positive hydrogen ends are attracted to the anion. The image below illustrates the water molecules' behavior around anions and cations. (The chloride ion is NOT part of a surfactant, it's the only image of water molecules' behavior around anions I could find.)



(<http://www.bing.com/images/search?q=anion+surrounded+by+water&view=detail&id=E9DAE77F46228A66351A25E156CAA2F9658E8DDE&first=0&FORM=IDFRIR>)

The nonpolar tails of these long anions are attracted to other nonpolar molecules; e.g., the oily grime that comprises bodily secretions and most “dirt”. The nonpolar tails, with their attached nonpolar oily molecules, attract one another by dispersion forces, as do their long hydrocarbon chains, while the anionic carboxylate heads repel one another, resulting in the formation of the micelles discussed in the article. Individual micelles also repel one another, and are surrounded by water molecules, as discussed above. Thus the micelles are isolated in the water from one another, remain in suspension in the water, and are easily rinsed from the mixture.

Although soaps are great cleaning agents, they are not without their problems. Since they are salts of weak organic acids, they can be converted by mineral acids (e.g., HCl) into free fatty acids which, since they are less soluble in water than the anions were, don't dissolve and hence the soap doesn't clean as well in acidic water. The anionic carboxylate groups are also less effective in hard water, where they attract other cations, like Ca^{2+} , Mg^{2+} , and Fe^{3+} , to form compounds that all have low solubility in water. This reduces the cleaning ability of the soap, since it is no longer able to act as a surfactant or emulsifier. The low-solubility compounds produced result in bath tub rings and gray, dingy clothing after laundering. Synthetic detergents overcome these drawbacks, as they are soluble in both acidic and alkaline solutions and don't form insoluble products in hard water; however, this topic is outside the scope of this Teacher's Guide.

More on micelles

Micelles are important in more fields than just soap. They are also used in laundry detergents; in shower cleaning products, to remove soap scum from shower walls and doors; in a salt of liver bile (sodium glycocholate), a natural dissolver of fats in the body; in fire retardants; in surfactants used to de-ink old newspaper; in milk, cheese and yogurt; in drug delivery via oral administration; in transdermal skin care products; and in soil conditioners and insect removers, just to name a few.

More on human skin

The skin is the largest organ in the human body. It serves multiple functions. Besides the obvious one of providing protection, it also serves to regulate body temperature, stores water and fat, and is a sensory organ. It is divided into three main sections, the epidermis, the dermis and the subcutis. Two Websites that provide nice cross-sectional diagrams of human skin can be found at:

http://www.nmsl.chem.ccu.edu.tw/tea/SKIN_910721.htm

The above site is very extensive and consists of a total of thirty-two pages of material devoted to the structure and function of human skin.

http://kidshealth.org/kid/body/skin_noSW.html

The above is a much more limited site designed to inform children about the basic structure and properties of human skin.

The outmost layer, the epidermis, consists of three parts, the stratum corneum, or horny layer, the keratinocytes or squamous cells, and the basal layer. The stratum corneum is made of fully mature keratinocytes that contain fibrous proteins called keratins. It typically is between 15-20 cells thick. These layers of cells are held together by lipids which fill the spaces between the cells, like mortar between layers of brick. This outermost layer is continually being shed and replaced. Just beneath this layer is a layer of keratinocytes, or squamous cells. As these mature, they replace cells shed from the stratum corneum.

Underneath the keratinocytes is a layer of basal cells. This is the deepest layer of the epidermis. These cells constantly divide and form new keratinocytes that in turn replace the keratinocytes that replaced the cells shed from the stratum corneum.

Beneath the epidermis lies another layer called the dermis. This layer contains blood vessels, lymph vessels, hair follicles, sweat glands, collagen bundles, fibroblasts and nerves. It also contains receptors that signal pain and sense touch.

The deepest layer of skin is called the subcutis. It also consists of a network of collagen and fat cells. It conserves the body's heat and protects it from injury by acting as a shock absorber.

(*ChemMatters* Teacher's Guide, "Battling Zits!" April, 2005.)

More on how a zit is formed

As pointed out in the article, the formation of a zit occurs when a sebaceous gland produces sebum that then mixes with dead skin cells in a hair follicle and forms blockages called comedones (plural of comedo).

The oil always found on human skin is a complex mixture. It consists of sebum, lipids from the surface of the skin, sweat, and materials that enter from the environment.

Sebum is produced by the sebaceous glands (now who would have thought that?). Sebaceous glands are found over virtually the entire human body, but are larger and more numerous on certain areas, specifically the mid-back, forehead and chin, where their concentration may reach 400-900 per cm². The hands and feet contain relatively small numbers and there are none on the palms or soles of the feet.

Most sebaceous glands open out into a hair follicle, although there are a few exceptions that open directly to the surface of the skin.

Sebum is not one chemical or even a consistent mixture of chemicals. Its composition can vary, but typically consists of glycerides, free fatty acids, wax esters, squalene (an intermediate in the biosynthesis of cholesterol with the formula $C_{30}H_{50}$), cholesterol esters and cholesterol.

Since it is the blockage of the duct of the hair follicle that leads to the formation of a zit and it is the mixing of sebum with dead skin cells that leads to this blockage, the presence of acne is connected to the overproduction of sebum that often occurs around the age of puberty.

Sebum is always being produced, even in newborns, where its composition closely resembles that produced by an adult. After about age 6 months and until about age 8, a child's sebum contains less wax and squalene and more cholesterol.

At puberty, sebum production increases dramatically, up to fivefold in males, somewhat less in females, which obviously accounts for acne being primarily a problem associated with the teenage years. After that sebum production declines with age.

(ChemMatters Teacher's Guide, "Battling Zits!", April, 2005.)

More on zits

Although acne occurs most prevalently in teenagers, it can occur in anyone at any age. (This may not be comforting to teenagers.) It typically occurs on the face, neck, chest, back and shoulders, where the largest numbers of functional oil glands are located. The three main contributing factors to acne are: overproduction of oil (sebum), irregular shedding of dead skin cells that results in irritation of the hair follicles, and bacterial buildup. Each hair follicle is connected to sebaceous glands that produce sebum. Normally, that sebum travels out through the opening of the hair follicle to the surface of skin, but if there is an excess of the sebum and dead skin cells, they can build up in the hair follicle and form a plug. A plugged follicle can become inflamed or infected, resulting in the zit, perhaps a whitehead or a blackhead. It is interesting to note that other pores in skin; e.g., those that are connected to sweat glands, are not normally involved in acne.

So, not all skin on the body is alike, and it is constantly changing, as old cells die and new ones are generated to take their place. According to acne.com, "... one square inch of your skin is home to:

- 65 hairs
- 100 sebaceous glands
- 78 yards of nerves
- 650 sweat glands
- 19 yards of blood vessels
- 9,500,000 cells
- 1,300 nerve endings
- 20,000 sensory cells

Your skin covers 20 square feet, so do the math: We're talking billions and billions of cells, nerve endings, blood vessels and more."

(<http://www.acne.com/prevention/skin-basics/>)

Acne is a very common skin condition, and not only among teens. "Researchers writing in the journal *Lancet* explain that almost everyone between the ages of 15 and 17 is affected by some degree of acne. They also highlight recent studies suggesting that more than 60 percent of twenty-something's and 40 percent of adults in their thirties have regular, visible pimples." (Huffington Post, http://www.huffingtonpost.com/2011/08/31/acne-treatment-mystery-study_n_943938.html)

Does chocolate cause acne?

Two recent studies conclude that chocolate neither causes nor aggravates this skin problem. In a study by the University of Pennsylvania School of Medicine, a control group ate bars that resembled chocolate bars, but contained no chocolate. Another group ate chocolate bars with 10 times the usual amount of chocolate. No significant changes in the acne conditions of either group were observed.

A study involving 80 midshipmen at the U.S. Naval Academy had similar results. Volunteers with existing acne conditions were divided into groups. One group avoided chocolate for four weeks. Another group ate at least three chocolate bars a day. There were no significant changes in the acne conditions of either group. Then, the groups switched diets. Again, there were no changes in the acne conditions. The message? Don't give up chocolate for fear of skin problems!

That delicious chocolate bar or cup of cocoa may be a far cry from the bitter beverage that delighted the ancient Aztecs. Whether or not we know and appreciate all of its history and chemistry, many of us—especially the "chocoholics" among us— would agree with Montezuma in calling it the food of the gods.

(Baxter, R. Chocolate—How Sweet It Is! *ChemMatters*. December, 1999, 17 (4), p 5)

More on bad breath

Garlic seems to always get a bad (odor) rap. "Garlic breath" is one of the most offensive of the bad breath odors. WebMD explains the origins of this condition.

Researchers at the University of Minnesota, in Minneapolis, explain the basis for 'garlic breath' in a study published in the *American Journal of Physiology*.

"When you eat garlic you produce several sulfur-containing gases," lead researcher Fabrizio Suarez, MD, PhD, tells WebMD. "But what we found is most of the sulfur-containing gases, with exception of one, [are of oral origin]. AMS [allyl methyl sulfide] $[\text{CH}_2\text{CHCH}_2\text{SCH}_3]$ is the only one that is not metabolized by [intestine] or the liver, and this is why this gas can go back and be released in your mouth. It's coming from the [gut], not from the mouth, and that is what gives you the odor that you have after you eat garlic." Suarez is an assistant professor at the University of Minnesota and on the staff at the Minneapolis VA Medical Center.

"This paper gives us the idea that sometimes you can have halitosis -- if you want to call the odor of garlic 'halitosis' -- that can come from the intestine instead of your mouth," he says. "But in most cases, the gases [that cause] halitosis are coming from your mouth, from the bacteria that is [on] the tongue."

Suarez and colleagues tested the mouth air, lung air, and urine from five healthy volunteers (with no history of halitosis) on two separate occasions. On one day they were given 6 grams of raw garlic to eat, on the other day no garlic was eaten. On the day when no garlic was eaten, the researchers detected low levels of three sulfur-containing gases in the mouth air, indicating that the mouth usually contains low concentrations of these gases. In contrast, when garlic was eaten, the researchers found higher concentrations of those three gases, plus two other sulfur-containing gases. For all gases except allyl methyl sulfide, the concentration of gas was much higher in the mouth air than in the lung air or the urine, suggesting that they originate in the mouth.

"Conversely, AMS concentrations in mouth air remained high for the four hours after garlic ingestion and were similar to levels in the alveolar [lung] and urine samples, indicating that this gas had undergone absorption from the gut and was being released from systemic sites," write the authors. In other words, the gas was going into the blood, circulating around the body, and being excreted in the breath and urine.

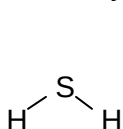
The researchers also showed that, after the five subjects brushed their teeth with [toothpaste](#) containing baking soda and [hydrogen peroxide](#), levels of the orally generated sulfur gases went down to almost nothing -- but not the levels of allyl methyl sulfide, which remained pretty high.

"If you eat garlic, it doesn't matter what you do," Suarez says. "You are always going to smell some garlic."

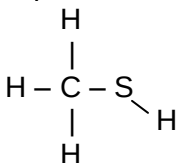
(<http://www.webmd.com/food-recipes/news/19991127/garlic-bad-breath-king>)

See "More sites on bad breath" below for original article.

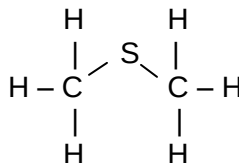
But even if you don't eat garlic, bad breath is almost inevitable. Its source is bacterial waste, which includes sulfur-containing compounds. These volatile sulfur compounds—VSCs—are the principle cause of bad breath. They include hydrogen sulfide, the rotten egg smell, methyl mercaptan, a "barnyard" smell and dimethyl sulfide, the smell of cabbage. Their volatility assures that they will escape as vapors from the mouth.



Hydrogen sulfide H_2S



methyl mercaptan
(methanethiol) CH_3SH



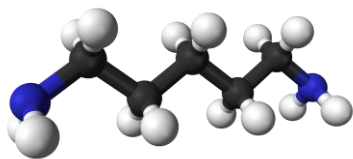
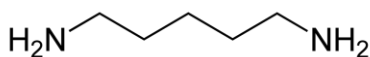
dimethyl sulfide H_3CSCH_3

Another group of toxic, odoriferous products of bacterial metabolism present in bad breath include these amines:

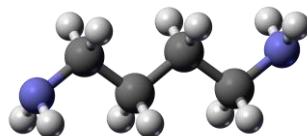
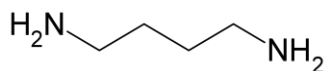
<u>Common Name</u>	<u>Formula</u>	<u>Odor</u>	<u>Chemical or IUPAC Name</u>
Cadaverine	$\text{NH}_2(\text{CH}_2)_5\text{NH}_2$	corpses	1,5-diaminopentane or pentane-1,5-diamine
Putrescine	$\text{NH}_2(\text{CH}_2)_4\text{NH}_2$	decayed meat	1,4-diaminobutane or butane-1,4-diamine
Indole	$(\text{C}_6\text{H}_4)(\text{NH}(\text{CH}_2)_2)$	fecal matter	indole or 2,3-benzopyrrole
Skatole	$(\text{C}_6\text{H}_4)(\text{NHCH}_2\text{CH}_3)$	fecal matter	3-methylindole or 4-methyl-2,3-benzopyrrole

And this organic acid:

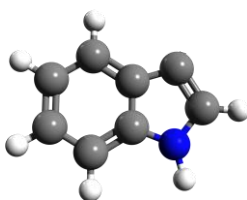
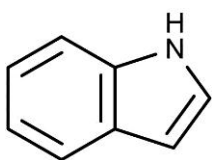
Isovaleric acid	$(\text{CH}_3)_2\text{CHCH}_2\text{COOH}$	sweaty feet	3-methylbutanoic acid or 3-methylbutyric acid
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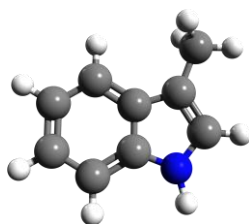
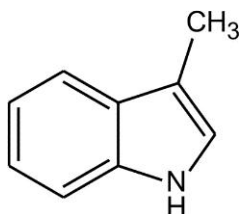
Cadaverine



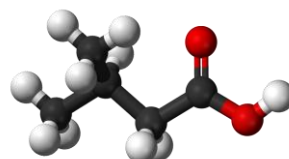
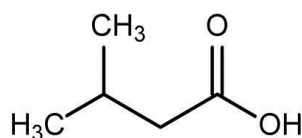
Putrescine



Indole



Skatole



Isovaleric acid

(images: Wikipedia commons)

It is interesting to note that indole, a compound with an intense fecal odor, is a constituent of many flower scents; e.g., orange blossoms, and is found in many perfumes, due to the fact that at low concentrations the substance has a flowery smell.

Healthtree.com (a Rohrig reference) provides an extensive list of less-well-known possible causes of bad breath:

- Alcohol (caused by gases produced in the digestive tract, and dry-mouth)
- Constipation/poor digestion (foul-smelling gases produced in the digestive tract)
- Dehydration (dry-mouth allows bacteria to grow unchecked)
- Intestinal bacteria imbalance (shortage of "good" bacteria allows bad-breath bacteria to proliferate)
- Intestinal parasites (causes constipation or diarrhea, resulting in bad breath)
- Running out of fuel (crash-dieting/ fasting (lack of carbohydrates causes body to burn fat instead, producing ketones, increasing acidity in body)
- Menstrual cycle (hormonal changes increase of proteins in saliva, which feed anaerobic bacteria in mouth)
- Lactose intolerance (stomach and intestinal distress produces gases that may rise to the mouth)

- Sinus problems (postnasal drip produces mucus in back of mouth, allowing bacteria to feed on it making noxious waste products)
- Stress (can intensely affect digestive system, producing gases that rise to mouth)

Bad breath can also be symptomatic of serious diseases within the body, such as cancer, diabetes, kidney and liver problems, lung disease and stomach problems. If one has persistent bad breath that has not cleared up by other means, one might want to consult a physician to begin further diagnosis.

More on tooth decay & equilibrium

It is interesting to note that tooth formation and decay is almost identical in animals as it is 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.

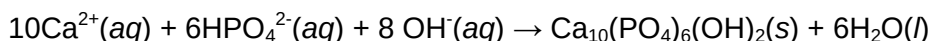
The constant battle between demineralization and remineralization can be considered chemically to be an equilibrium system which is under constant stress.

The enamel of teeth is made of hydroxyapatite (also called hydroxylapatite), empirical formula $\text{Ca}_5(\text{PO}_4)_3\text{OH}$. The formula is usually written as a dimer, $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$, 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.



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



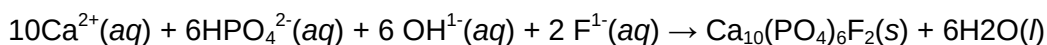
Demineralization and remineralization occur at different rates throughout our lives. In children, remineralization occurs more rapidly than demineralization. In adults, the two reactions occur at roughly equal rates (equilibrium), while in older adults, demineralization can occur faster than remineralization, 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 Chatelier'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.

More on fluoride

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.



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. 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 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, CaF_2 . 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/>)

More on flatulence

Many of the gases noted above as being causes of bad breath are also those produced in small quantities in the digestive process, contributing to flatulence. This should come as no surprise, as these gases are the products of bacterial metabolism in the stomach and intestines—and the mouth—and frequently rise through the digestive tract to escape into the mouth. Belching allows these gases to escape in significant quantities.

Excerpts from a February 2003 ChemMatters article, “Flatus: Chemistry in the Wind”, provide additional useful information on flatulence.

Most people pass gas between 5 and 15 times each day, each time resulting in 35–90 mL. (You’ve always wanted to know that! Admit it.)
[That amounts to about 150 mL to 1.4 L per day.]

It might surprise you that the odorless gases nitrogen, oxygen, hydrogen, carbon dioxide, and methane account for more than 99% of human flatus. Nitrogen (N_2), which diffuses from the blood, is usually present in the greatest quantities; oxygen, the least. The volumes of the other three gases vary for individuals, their diets, and even for time of day.

The amount of hydrogen, carbon dioxide, and methane in flatus depends on the population of hydrogen-consuming bacteria in your digestive tract. Each day, you produce about 1 liter of hydrogen (H_2) in your intestinal colon. But other bacteria may be present to use some of that hydrogen to produce methane (CH_4) and other gases.

Here’s an interesting fact. Only about one-third of people in the Western Hemisphere are methane producers. If you are one of them, you produce a lower volume of gas, and your stools tend to float in water.

Methane production by animals is considered a contributor to global warming. Termites alone produce an estimated 165 million tons of methane each year. A typical cow probably emits 200 liters of methane into the atmosphere each day.

Despite what many females firmly believe, studies show that they release both the same volume of flatus as men, with the same—um, *qualities*. But studies do show that females may score higher on sensitivity to odors. Both men and women can distinguish tens of thousands of odors, but only three sulfur-containing compounds give flatus its characteristic odor.

Hydrogen sulfide (H_2S), sometimes called “rotten egg gas”, is the main culprit. Our noses begin to detect H_2S in concentrations of 0.005 ppm. In flatus, its concentration averages 0.36 ppm. At concentrations of 50 ppm,

most find H₂S very offensive; and at concentrations of 300 ppm, H₂S is deadly—literally! Two other gases—methanethiol (CH₃SH) and dimethyl sulfide (CH₃SCH₃)—are present in much smaller concentrations, but our noses are very sensitive to their presence.

Blame your bacteria and your diet for the odors in flatus. Sulfur-containing foods like onions, eggs, broccoli, beer, and some beans are often not fully digested when they reach the large intestine. If your intestinal bacteria can ferment sulfur-containing compounds, the resulting gas products will register it. But there is some good news. Four moles of hydrogen gas are consumed to make one mole of hydrogen sulfide [according to the equation below]. At least the volume of flatus diminishes in the process.



(Vanderborght, C. Flatus: Chemistry in the Wind. *ChemMatters* February, **2003**, 21 (1), pp 11-13.)

And from the Teacher's Guide to that same article:

Flatulence is caused by the incomplete digestion of food before it reaches the large intestine. For example, as the article points out, individuals who are lactose intolerant lack a sufficient amount of the enzyme lactase. This enzyme acts to break down lactose, a complex sugar found in dairy products, into two simpler sugars. When incompletely digested food reaches the large intestine, it is attacked by bacteria, perhaps between about 100-1000 different kinds. Although these bacteria act to digest the food, they also produce various gases in the process—much in the way yeast produces carbon dioxide when bread is leavened.

Because the type and number of bacteria present in the intestines of different people varies, foods that produce gas in one person may not produce gas in another.

Several different gases are produced, including nitrogen, carbon dioxide, oxygen, hydrogen, methane, methanethiol, dimethylsulfide, and hydrogen sulfide. As the article points out, the last three are odoriferous compounds.

Not all the gas produced is emitted. Some is absorbed into the body. About one-third of individuals are “methane producers.” Although it is not yet known why only certain individuals produce significant amounts of methane during digestion, they can be easily identified because their stools will consistently float in water.

Dietary carbohydrates result in more gas than fats or proteins. Some key offenders are bread, bran, potatoes, fruits, and vegetables. Beans, onions, cabbage, cauliflower, broccoli, and dairy products are also cited as being particularly “gassy”. Beer, some fruit juices, and deli meats containing sulfites can also be problems. Mushrooms, cabbages, onions, and asparagus contain raffinose, a sugar which is indigestible for humans, but readily consumed by intestinal bacteria. Beans contain large amounts raffinose—thus, their reputation as gas producers.

Diet foods containing the sweetener sorbitol can also produce flatulence. But aspartame and saccharin basically do not.

Eating too quickly increases flatulence, as well as being under increased stress. Other activities known to increase flatulence are chewing gum, eating hard candies, and smoking—although these are more closely associated with the swallowing of air (aerophagia) into the stomach (and possible subsequent belching) rather than flatulence.

Carl Sagan once suggested that alien beings could conclude that there was carbon-based life on earth by simply doing a spectral analysis of our atmosphere. They would detect the presence of methane, and since methane breaks down rapidly in the presence of oxygen, its continued presence in the atmosphere would indicate that there must be a continual source of bio-production.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic chemistry**—Cellulose, glucose and carbohydrates are all organic compounds.
2. **Polarity/Nonpolarity**—Water's polarity helps to explain its ability to dissolve polar compounds.
3. **Hydrophobic/hydrophilic/amphiphilic**—Oils are almost always non-polar and therefore hydrophobic, while ionic compounds and water are usually hydrophilic. Soaps and detergents are amphiphilic, since they attract both non-polar and polar molecules.
4. **Micelles**—Large accretions of amphiphilic soap anions form micelles as many anions surround an oil particle to form these bodies, which are amphiphilic.
5. **Saponification**—soap can be prepared by the process of saponification.
6. **Equilibrium**—The demineralization/remineralization reactions discussed in the article are involved in an equilibrium system within your mouth. The fluoride ion acts as a (Le Chatelier) stress.
7. **Acid-base reaction**—The fluoride reactions mentioned in 5, above is an example of acid-base chemistry.
8. **Adsorption**—Fluoride in toothpastes, mouthwashes and fluoridated water is adsorbed onto the tooth surface, where tooth decay has occurred, in the remineralization process.
9. **Gas laws**—Flatulence can be a painful experience for pilots ascending to great heights.
10. **Enzyme catalysis**—Flatulence can be curbed by using Beano, an enzyme catalyst that prevents the production of gases by breaking down the indigestible complex sugars in carbohydrates into simpler sugars that can be digested.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"If washing my face with soap can remove the sebum, preventing acne, then the more often I wash my face, the less acne I'll have."** *Unfortunately, washing your skin with soap has another effect—it dries it out, causing the skin to produce even more sebum. Frequent washing can also irritate the skin, making the condition worse. So washing too frequently can have a deleterious effect on the skin and on acne. It seems almost like a no-win situation.*
2. **"I have to stay away from chocolates and greasy food if I want to keep my acne in check."** *Actually, studies have shown little or no correlation between the consumption of chocolate and greasy food and the development of acne. Ongoing studies are investigating*

the effect of other dietary factors—including high-starch foods like breads and bagels—on acne.

3. **“Mouthwash makes bad breath go away.”** *Actually, mouthwash only eliminates bad breath temporarily. Antiseptic mouthwashes can “kill the germs that cause bad breath”, but again, this is only temporary as new bacteria grow back and continue causing bad breath.*
4. **“Brushing my teeth will eliminate bad breath.”** *This is wrong (or at least, incomplete) for three reasons: 1) The typical toothbrushing event only lasts about 30-45 seconds, which is not enough to clean all the surfaces of one’s teeth sufficiently (a 2-minute brushing will result in a better job); 2) Brushing more thoroughly will improve the effect, but flossing is also required in order to eliminate leftover food that gets trapped between teeth and gums; and 3) The tongue is also a breeding ground for bacteria and it too must be brushed.*
5. **“Methane is the gas I smell when I pass gas.”** *Students may think this because they smell gas when they light the Bunsen burners in the lab. But Bunsen burner gas (“natural” gas) contains added mercaptans, sulfur-containing compounds, so that the gas can be detected by smell; methane alone is essentially odorless. Thus the odors emanating from passed gas are not due to methane, but the other VSCs mentioned in the Background Information above.*
6. **“Everyone passes methane gas.”** *Only about one-third of the human population passes methane. The biggest living culprit for methane gas production is the cow, which passes about 200 L per day! (This is primarily through belching, however.)*
7. **“Beans are the main food that gives me gas.”** *Actually, beans are only one of many foods, all belonging to the carbohydrate group, which can cause flatulence. Fats and proteins are much less likely to cause flatulence than carbohydrates.*

Anticipating Student Questions (answers to questions students might ask in class)

1. **“Can any pore in my skin become clogged and result in acne?”** *Actually, only those pores connected to hair follicles seem susceptible to produce zits. Pores associated with sweat glands don’t usually clog and produce zits or pimples.*
2. **“Will I eventually outgrow acne?”** *While acne is typically associated with, and the severity of the condition is greatest in, teenagers, people of any age can get acne.*
3. **“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.*
4. **“What gases are passed in flatulence?”** *See “More on bad breath” above for a list of gases involved in bad breath, most of which are also produced by bacteria in the digestive process. (Methane is not listed there.)*
5. **“Does ‘Beano’ really work?”** *Yes, but not for all foods, and not for everyone. Beano contains an enzyme that breaks down raffinose, an indigestible sugar found in many foods, especially beans (hence the product name). It is not effective in reducing gas caused by the inability to digest lactose or fiber.*
6. **“Don’t some insects pass methane, too?”** *Yes, termites in particular produce copious quantities of methane, estimated to be between 2 and 22 megatonnes (Tg’s) annually. They are the second largest producer of methane, after wetlands, which produce methane by anaerobic bacterial decay of organic material.*

In-class Activities (lesson ideas, including labs & demonstrations)

10. As a quick way to introduce the effects of soap in cleaning, you could do a demonstration for students like the one shown here:
<http://candleandsoap.about.com/od/soapmakingbasics/ss/howsoapcleans.htm>.
11. Kevin Dunn's Caveman Chemistry contains a chapter on soap-making. You can find the chapter on soap from the first edition of the book at
<http://cavemanchemistry.com/oldcave/projects/soap/index.html>. It contains a description of an experiment to make soap.
12. You can have students make soap and then test their products' effectiveness. See
<http://www.madsci.org/experiments/archive/854443814.Ch.html> for the lab procedure, or go to <http://khub.com/keyword/making-soap.html> and choose a lab to download from among their 100 files.
 A Charles Sturt University webpage contains a set of chemistry lessons on saponification (soapmaking). (<http://www.hsc.csu.edu.au/chemistry/options/industrial/2764/Ch955.htm>)
13. Students can research the science of (or lack thereof) on-line claims about various forms of water; e.g., "Willard Water" (http://www.ehow.com/about_5042407_willard-water.html). This could lead to a class discussion of what constitutes a scientific claim and the evidence to support it. (Willard Water is purported to contain a substance with micelles.)
14. Although tooth enamel is **not** exactly analogous to CaCO_3 , you could use this as an example of what happens to a calcium-based mineral when it is exposed to acid secretions by putting an egg into vinegar and observing 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). (And what happens after that if you leave the egg in the acid is even more impressive, although not related to tooth decay.)
15. You might tie a Boyle's Law activity to the flatulence problem posed as pilots ascend through the atmosphere:
 - a. A Vernier software probe lab:
<http://www.westminster.edu/acad/sim/documents/SBoyleslaw.COMP.pdf>
 - b. A Pasco software probe lab (download the lab here):
<http://www.pasco.com/chemistry/experiments/online/boyles-law.cfm>
 - c. Or an animation from NASA: <http://www.grc.nasa.gov/WWW/k-12/airplane/boyle.html>
 - d. Or a simulation:
http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/flashfiles/gaslaw/boyles_law_graph.html.
16. Gas chromatography is typically used to analyze gases present in flatulence. Most high schools won't have or have access to a gas chromatograph, but paper chromatography could be used to simulate the process of separating a mixture into its components. See http://www.yesmag.bc.ca/projects/paper_chroma.html or <http://dwb.unl.edu/Chemistry/MicroScale/MScale06.html> for a description of such an experiment.
17. This doesn't have much to do with gross stuff, but Ivory bar soap can do funky things in a microwave oven. You might be able to use this in the gas laws section of your curriculum. See http://www.ehow.com/way_5953191_microwave-soap-science-fair-project.html.
18. *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, $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ ($K_{sp} = 6.8 \times 10^{-37}$). 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 $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ to form the more decay resistant fluorapatite, $\text{Ca}_5(\text{PO}_4)_3\text{F}$

($K_{sp} = 1.0 \times 10^{-60}$). These measures have resulted in a dramatic decrease in the number of cavities among children. Calculate the solubility of $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ and $\text{Ca}_5(\text{PO}_4)_3\text{F}$ in water.

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

b. Calculate the solubility of $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ in water

	$\text{Ca}_5(\text{PO}_4)_3\text{OH}$	Ca^{2+}	PO_4^{3-}	OH^-
Initial				
Change				
equilibrium				

c. Calculate the solubility of $\text{Ca}_5(\text{PO}_4)_3\text{F}$ in water

	$\text{Ca}_5(\text{PO}_4)_3\text{F}$	Ca^{2+}	PO_4^{3-}	F^-
initial				
Change				
equilibrium				

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

Out-of-class Activities and Projects (student research, class projects)

1. Students could test the cleaning ability of various commercial soaps.
2. Students might want to test the effect of various beverages on cavity formation in teeth. A sample study can be found at <http://www.free-science-fair-projects.net/science-fair-projects-on-tooth-decay.html>. This study could be used as a starting point of discussion for experimental design.
3. Students might want to do research on the topic of chocolate causing acne. They might want to interview their own doctors to get their views of the relationship between chocolate and acne.
4. When students go to a local drugstore and peruse the various over-the-counter products designed to treat acne, the names under which the various products are sold can be, at best, somewhat confusing, and at worse, perhaps misleading. Words and phrases like "maximum," "maximum strength," "ultra," often appear, but do not seem to have any specific meaning. For example, one product from the same company is labeled "ultra," and contains 10% salicylic acid, while another product is labeled "maximum strength," but still only contains the same 10% formulation.

An interesting and educational project might be to examine the labels on several over-the-counter medications and then compare the actual ingredients to the suggestive words that

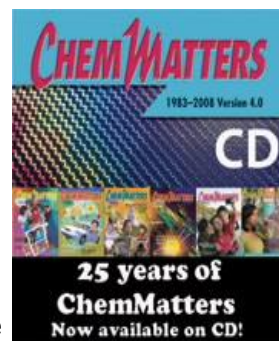
appear on the front of the package. Is there any consistency at all? Do some of the labels on the front of the packages appear to perhaps even be intentionally misleading?

The project could also involve comparing the cost per given amount of active ingredient for various brand name products and non-brand name products.

5. You might want students to investigate claims made by online sales companies regarding their products, or check the scientific validity of statements they make; e.g., "When your mouth is drier, you have less saliva, among other soluble components. Saliva contains a healthy helping of Oxygen, which keeps your mouth healthy and fresh." (Dr. Katz's "Bad Breath Bible", downloadable at <http://www.therabreath.com/>)
6. Students could research and report on gas chromatography, used to analyze gaseous specimens of flatus.
7. You might (or might not) want to ask students to design an experiment to measure the average daily production of flatus, taking into consideration all the variables that are present in the human population. Engaging them in this design challenge would confront them with many problems common to scientific research—particularly research involving human subjects.

References (non-Web-based information sources)

The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. (Part way down the website screen, click on the *ChemMatters* CD icon like the one shown here at the right.)



Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full *ChemMatters* articles and and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Fruen, L. Chem History, Cleopatra's Perfume Factory and Day Spa. *ChemMatters* October, **2004**, 22 (3), pp 13-15. Even as far back as the Egyptians, people were worried about smelling good. Author Fruen describes some of the methods used by Cleopatra, as unearthed by archaeologists. The findings include information about skin treatments as well as cosmetics and tooth care. (This issue is available online at the ChemMatters Archive web page at http://portal.acs.org/portal/acs/corg/content?nfpb=true&pageLabel=PP_SUPERARTICLE&no_de_id=2119&use_sec=false&sec_url_var=region1&uuid=3c57bd2f-91e0-4a2f-b532-1727071f0fe0.)

Kimbrough, D. R. How We Smell and Why We Stink. *ChemMatters* December, **2001**, 19 (4), pp 8-11. The author discusses olfactory receptors in the nose, the smells that originate in armpits, hands and feet, and what we need to do to counteract those smells. She also discusses a bit of the history of deodorants and antiperspirants. The last page is devoted to an array of sources of odors—good and bad (and ugly)—and their chemical structures. (very useful if you cover organic chemistry)

Smith, W. Skin Deep. *ChemMatters* December, **1987**, 5 (4), pp 4-7. Smith discusses the function of the skin, why we need moisturizers and cleansers, cleansing creams, soap and cold cream, as well as the simple causes of acne.

Baxter, R. Battling Zits! *ChemMatters* April, **2005**, 23 (2), pp 4-6. Baxter spends little time discussing the cause of zits, and she gets right to the cures, including recent developments with vitamin A and lasers.

The Teacher's Guide for this issue contains useful background information about acne.

Wood, C. Soap *ChemMatters* February, **1985**, 3 (1), pp 4-6. Wood discusses the history and chemistry of soap. A sidebar describes the amphiphilic (term not used) nature of soap and the role of the micelle in cleaning.

Wood, C. Detergents *ChemMatters* April, **1985**, 3 (2), pp 4-7. Wood discusses detergents and surfactants. A micelle is shown, but not listed as such.

Dorrian, J. Dissolving Household Chores *ChemMatters* December, **1997**, 15 (4), pp 13-15. Author Dorrian describes the discovery/production of Clean Shower, a product that involves a glycol ether that forms inverted micelles to do its cleaning. He describes micelles in detail, and he shows a simple method of observing the micelle inversion in Clean Shower. (Apparently it is still available for purchase: <http://www.amazon.com/Clean-Shower-Eliminates-Soap-Scum/dp/B000NOTC5W>.)

Borchardt, J. Old News, New Paper *ChemMatters* April, **1993**, 11 (2), pp 12-14. Content in this article focuses on the de-inking and recycling of old newspaper. Surfactants play a key role in the de-inking process; micelles are discussed and diagrammed in a sidebar.

Baxter, R. Say Cheese *ChemMatters* February, **1995**, 13 (1), pp 4-7. Baxter discusses the composition of cheese, including casein from milk, and the role of micelles and chains of micelles in the coagulating of cheeses. A lab is included for students to make their own lemon cheese.

Evans, G. Yogurt *ChemMatters* October, **1989**, 7 (3), pp 9-12. Evans describes the role of casein and micelles and bacteria in the formation of various forms of yogurt.

Baxter, R. Mouthwash: What's in it for You? *ChemMatters* December, **1996**, 14 (4), pp 6-8. Baxter investigates mouthwashes and their effectiveness at reducing bad breath and tooth decay.

Yohe, B. Toothpaste. *ChemMatters* February, **1986**, 4 (1), pp 12-13. In this article, author Yohe describes the various components of toothpaste and the demineralization / remineralization equilibrium in teeth.

Vanderborght, C. Flatulence: Chemistry in the Wind. *ChemMatters* February, **2003**, 21 (1), pp 11-13. Author Vanderborght gives a good accounting of the causes (and effects) and prevention of gas production in the digestive tract—flatulence. She also discusses some of the chemistry involved.

For a student (or teacher) really interested in soap making, you might want to recommend Dunn, K. *Scientific Soapmaking: The Chemistry of the Cold Process*, Clavícula Press, Farmville,

VA, 2010. From the author, “This is less a book of answers and more a book about how to formulate answerable questions.” (Sounds like it’s written by a teacher, eh?)

Web sites for Additional Information (Web-based information sources)

More sites on the history of hygiene

The Pasteur Institute gives a brief history of hygiene at http://www.hygiene-educ.com/en/learn/history/sci_data/frame1.htm.

History Undressed, a blog spot, written by romance novelist Eliza Knight, discusses the history of hygiene she researched during the times of her books:
<http://historyundressed.blogspot.com/2008/07/history-of-hygiene-bathing-teeth.html>.

To see three examples of how personal hygiene and sanitation were led by scientific discoveries, see http://infectiousdiseases.about.com/od/prevention/a/history_hygiene.htm.

More sites on soap

The TeachSoap.com website, “the premier site for soap making tutorials, soap recipes, soap making tips and everything you'd want to know about making soap”, has lots of information about soap (but not very much science or chemistry). (<http://www.teachsoap.com/>)

Virtual ChemBook from Charles Ophardt of Elmhurst College has a good section on the chemistry of soap, including diagrams of soap molecules and a Chime model of a micelle, at <http://www.elmhurst.edu/~chm/vchembook/554soap.html>.

Chandler Soaps at <http://www.chandlerssoaps.com/> has several pages dealing with the history and the chemistry of soap. (buttons at left of screen)

SlideShare contains a short slide show on the chemistry of soaps vs. detergents. View it at <http://www.slideshare.net/070794/soap-detergnt-chemistry>.

More sites on surfactants and micelles

Visit <http://en.wikipedia.org/wiki/Surfactant> for a discussion of surfactants, as well as applications of these amphiphilic compounds.

For a comparison of natural and synthetic surfactants, considering their raw materials and energy costs, see P & G’s website at http://www.scienceinthebox.com/en_UK/programs/natural_synthetic_en.html.

For a complete teaching/learning module on surfactants from the Key Centre for Polymers and Colloids, of the University of Sydney, Australia, visit <http://discovery.kcpc.usyd.edu.au/9.5.5-short/index.html>. The site takes one through a lengthy series of topics dealing with surfactants.

For a good basic explanation of the role of micelles in the cleaning abilities of soap, see Wikipedia's article on micelles at <http://en.wikipedia.org/wiki/Micelle>. This site also provides a discussion of the driving forces behind micelle formation.

A series of four short videos on YouTube by MWV Specialty Chemicals shows the use of surfactants in the asphalt paving industry (but the paving process is secondary to the chemistry of surfactants). The videos use animations to show the formation of micelles. The first video shows polar and nonpolar molecules and establishes that polar and nonpolar molecules don't mix; the second video illustrates surfactants and shows micelles forming in soap in water; the third shows where the surfactant comes from and how these micelles are inverted in oil; and the fourth video shows the role of micelles in reducing the viscosity of oil in the process of compaction of rock and hot petroleum. At the end of each video, one can click on a link to the next video. (<http://www.youtube.com/watch?v=yOfZrhzmzPIY&feature=related>)

View a series of four very short video clips (total of 36 seconds) showing surface tension of water using pepper floating on water, followed by the addition of a tiny amount of dishwashing liquid at <http://www.youtube.com/watch?v=2W-byUP68fs&feature=related>.

For an explanation of the pepper on water demonstration of surface tension on another YouTube video (4 minutes), go to <http://www.youtube.com/watch?v=3BMT0Gw5bSY&feature=related>.

To view a Chime model of a specific soap micelle, visit <http://www.elmhurst.edu/~chm/vchembook/558micelle.html>. This model is rotatable and will help students visualize all the micelle drawings they see.

C&E N highlighted Clean Shower in one of its "What's That Stuff?" features: <http://pubs.acs.org/cen/whatstuff/stuff/7949sci2.html#top>.

More sites on acne

The Mayo Clinic provides an informational site on acne at <http://www.mayoclinic.com/health/acne/DS00169>. The coverage includes what to do when home treatments don't work (go see your doctor).

More sites on bad breath

The American Journal of Physiology provides a discussion of a study to discover the source of odors coming from garlic ingestion. The article, "Differentiation of mouth versus gut as site of origin of odoriferous breath gases after garlic ingestion" can be found at <http://ajpgi.physiology.org/content/276/2/G425.full>.

The animated-teeth.com website provides a comprehensive coverage (several screens) of the sources, risk factors, causes and measurement and treatment of bad breath. (http://www.animated-teeth.com/bad_breath/t1_halitosis.htm#breath.movie)

One of author Rohrig's selected references, healthtree.com (www.healthtree.com) provides many, many articles on various aspects of our bodies and diseases, including bad breath and tooth decay.

TheraBreath's website (<http://www.therabreath.com/>) contains articles on the causes and "cures" for bad breath. Beware that this site sells products; don't click on the buttons on the sidebar unless you want to purchase materials. Instead, click on the "Research" button at the top of the screen to get to articles written by the owner(?) of the site, or scroll down to the "Oral Care News from TheraBreath" at the bottom of the screen. You can download Dr. Katz's 50-page "Bad Breath Bible", but you must identify yourself to do so and, while the book does have some possibly useful factual information for you or students, it is strewn throughout with details of the need to use that company's products to cure your bad breath.

More sites on tooth decay

Animated teeth.com shows demineralization and remineralization in brief animated sequences at http://www.animated-teeth.com/tooth_decay/t2_tooth_decay_caries.htm#demineralization and http://www.animated-teeth.com/tooth_decay/t4_tooth_decay_fluoride.htm. This site also gives a good description of the demineralization-remineralization dynamic equilibrium (although it doesn't call it that).

The American Chemical Society publication Chemical and Engineering News (C&E N) 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>.

An article in the 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 tooth decay, at: <http://journals.cambridge.org/action/displayFulltext?type=1&fid=784036&jid=PNS&volumeId=22&issueId=01&aid=784028>).

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>.

More sites on flatulence

Emedicinehealth.org's site covers flatulence and digestion at http://www.emedicinehealth.com/flatulence_gas/article_em.htm.

The Flatulence Deodorizer might be a good place to begin discussing with students the modus operandi of activated charcoal. You can even zoom in on the image of the pad! (<http://www.flat-d.com/flatdreusable.html>)

Benjamin Franklin wrote a proposal for a scientific study to be done in Europe, titled "To The Royal Academy of Farting", or "Fart Proudly", to study flatulence and investigate substances that would render "...flatulence 'not only inoffensive, but agreeable as Perfumes'". (http://en.wikipedia.org/wiki/Fart_Proudly) This work was recently included in a compendium of writings by Franklin, "Fart Proudly: Writings of Benjamin Franklin You Never Read in School" (available at Amazon, <http://www.amazon.com/Fart-Proudly-Writings-Benjamin-Franklin/dp/1583940790>)

The Skinny on Sweeteners: How Do They Work?

Background Information (teacher information)

More on sweeteners

The existence of sweeteners extends back throughout history. One natural sweetener that is mentioned in connection with early history is honey. A papyrus from the 4th century BCE describes methods of beekeeping; in Egypt, honey was a luxury item that found use as a sweetener, in medicines, and as gifts to their gods. (<http://www.reshafim.org.il/ad/egypt/timelines/topics/beekeeping.htm>) Other natural sweeteners have included syrup made from tree sap and preserved fruits.

Other somewhat unusual (but unsafe) sweet-tasting compounds have also been discussed in history. The February 1988 *ChemMatters* article “Artificial Sweeteners” (see References section) mentions two instances:

More than 2000 years ago the Greeks and Romans found that boiling grape juice in lead pans produced a syrup that was intensely sweet. This is because it contained lead acetate, $\text{Pb}(\text{CH}_3\text{CO}_2)_2 \cdot 3\text{H}_2\text{O}$, which is very sweet and was once called “sugar of lead.” Blissfully unaware that lead is toxic, cooks of the Roman Empire used *sapa*, their name for the sweetener, to flavor their foods. It was also used to sweeten and preserve wine. Some modern historians have suggested that the decline of the Roman Empire was caused in part by too much lead in the diet and a resulting decrease in birthrates.

The next sweet-tasting chemical to be discovered was beryllium. Salts of this metal taste sweet, and the first name given to the element was glucinum, meaning sweet. But, like lead compounds, those of beryllium are poisonous, and they were never widely used as sweeteners. (p 5)

Someone who likes to eat sugary treats may be labeled as having a “sweet tooth”, but research has shown that this tendency has a biological basis. A July 2007 article from *The American Journal of Clinical Nutrition* states: “Humans are genetically predisposed to prefer sweet taste. Because sweet foods are naturally good and are safe sources of energy and nutrients, adaptive evolutionary development has resulted in a preference for them. However, this evolution happened long ago when food was scarce. Today, with a great variety of sweet foods readily available in Western countries, the preference for these foods may also have disadvantages.” (<http://www.ajcn.org/content/86/1/55.full>)

More on sucrose

The Brownlee article mentions two negative health effects associated with consuming sucrose. The first is sucrose’s contribution to tooth decay. A more in-depth description of how this happens is part of the online Virtual ChemBook (<http://www.elmhurst.edu/~chm/vchembook/548toothdecay.html>):

Sugar, saliva, and bacteria lead to a formidable combination that may lead to tooth decay. After eating sugar, particularly sucrose, and even within minutes of brushing your teeth, sticky glycoproteins (combination of carbohydrate and protein molecule) adhere to the teeth to start the

formation of plaque. At the same time millions of bacteria known as *Streptococcus mutans* also adhere to the glycoprotein. Although, many oral bacteria also adhere, only the *S. mutans* is able to cause cavities.

Only the *S. mutans* bacteria has an enzyme called glucosyl transferase on its surface that is able to cause the polymerization of glucose on the sucrose with the release of the fructose.

The same enzyme continues to add many glucose molecules to each other to form dextran which is very similar in structure to amylose in starch. The dextran along with the bacteria adheres tightly to the tooth enamel and leads to the formation of plaque. This is just the first phase of cavity formation.

In the next stage, the bacteria use the fructose in a metabolism process of glycolysis to get energy. The end product of glycolysis under anaerobic conditions is lactic acid. The lactic acid creates extra acidity to decrease the pH to the extent of dissolving the calcium phosphate in the tooth enamel leading to the start of a cavity.

Preventative measures include frequent brushing and flossing to prevent plaque build up. A diet rich in calcium and fluoride in the water lead to stronger tooth enamel. A diet of more complex carbon hydrates that are low in sugar and no sucrose snacks between meals is also a good preventative measure.

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 mentioned in the Brownlee article, 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.

The second negative health effect connected with too much sucrose mentioned in the article is a connection with insulin resistance and type 2 diabetes. A direct connection may not be so clear-cut. Different research studies have varying results. A study of young and middle-aged women investigated the association between drinking sugar-sweetened beverages, weight gain, and the risk of type 2 diabetes. Results were reported in the *Journal of the American Medical Association* in 2004 (<http://jama.ama-assn.org/content/292/8/927.full.pdf+html>). The authors stated “In this 8-year follow-up study of women, we found positive associations between sugar-sweetened beverage consumption and both greater weight gain and risk of type 2 diabetes, independent of known risk factors.” In this case, “sugar-sweetened” likely refers to high fructose corn syrup, which is used in the majority of soft drinks. There has been some debate about whether high fructose corn syrup contributes more to conditions such as obesity than sucrose does, or vice versa. A study reported in 2003 in *Diabetes Care*, on the other hand, reported that “According to our data, sugar intake does not appear to increase significantly the risk of developing type 2 diabetes.” (<http://care.diabetesjournals.org/content/26/4/1008.long>) A 2011 article in *The New York Times* also makes the point that more studies and conclusive evidence are needed (<http://www.nytimes.com/2011/04/17/magazine/mag-17Sugar-t.html?pagewanted=all>). The article is an in-depth discussion of a lecture that appeared on YouTube that makes a case that “sugar is a ‘toxin’ or a ‘poison’.” The author describes a study that is currently underway at the University of California, Davis, which “is directly addressing the question of how much sugar is required to trigger the symptoms of insulin resistance and metabolic syndrome.”

Two plants are commonly used as sources of sucrose: sugar cane and the sugar beet. Of the more than 120 million tons of sugar produced a year in the world, approximately 70% is produced from sugar cane, typically grown in tropical areas, and 30% from sugar beet, grown in the temperate regions of the north. (<http://www.sucrose.com/learn.html>) A discussion of photosynthesis briefly describes how plants such as sugar cane and sugar beets are able to produce sucrose. "All green plants manufacture sugar through photosynthesis, the process by which plants transform sunlight into their food and energy supply. Once photosynthesis creates sugar, plants have the unique ability to change sugar to starch and starch to various sugars [including sucrose] for storage. This diversity provides us with a wide variety of tasty fruits and vegetables, from the starchy potato to the sweet carrot. Sugar cane and sugar beet plants contain sucrose in large quantities, and that's why they are used as commercial sources of sugar. A stalk of the cane plant contains about 14% sugar. Sugar beets contain about 16% sugar." (<http://www.westernsugar.com/pdf/AboutSugar.pdf>) A more in-depth discussion of photosynthesis and the Calvin cycle provides further information (http://plantphys.info/plant_physiology/calvincycle.shtml).

More on carbohydrates

Table sugar, or sucrose, is mentioned in the Brownlee article as belonging to a family of molecules called carbohydrates. The April 2011 *ChemMatters* Teacher's Guide (<http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/CNBP026994>) contained a section on carbohydrates in connection with an article (also by Brownlee) on high fructose corn syrup. Information from pages 75–76 of the Teacher's Guide is below:

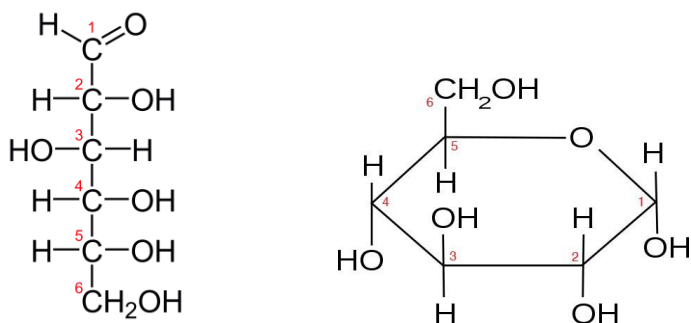
Starch, glucose, fructose, and sucrose are all compounds that are known as carbohydrates. A carbohydrate is made up of the elements carbon, hydrogen, and water. For example, glucose, the body's main fuel source, has the molecular formula $C_6H_{12}O_6$. The history of the use of the name carbohydrate is briefly described in the textbook *Chemistry in the Community* (5th ed.). "When such formulas were first established, chemists noted a 2:1 ratio of hydrogen atoms to oxygen atoms in carbohydrates, the same as in water. They were tempted to write the glucose formula as $C(H_2O)_6$, implying a chemical combination of carbon with six water molecules. Chemists even invented the term 'carbohydrates' (water-containing carbon substances) for glucose and related compounds. Although chemists later determined that carbohydrates contained no water molecules, the name persisted. However, like water, carbohydrate molecules *do* contain O–H bonds in their structures." (p 583)

Rather than being hydrates of carbon, as the name suggests, carbohydrates are polyhydroxy aldehydes or ketones.

Carbohydrates ... can be arranged into three main groups:

- **Monosaccharides.** The prefix *mono-* suggests that one unit of a saccharide, or sugar, is present. Monosaccharides are referred to as simple sugars. Examples ... are glucose and fructose ... galactose, xylose, mannose, and ribose. Monosaccharides may exist in linear structures, but more often are found as cyclic structures. For example, *Chemistry: The Central Science* states about glucose: "Glucose, having both alcohol and aldehyde functional groups and having a reasonably long and flexible backbone, can react with itself to form a six-member-ring structure. Indeed, only a small percentage

of the glucose molecules are in the open-chain form in aqueous solution” (p 962). The figures below show linear (left) and ring (right) structures of glucose. When the ring structure forms, the OH group located on the first carbon (labeled with red numbers in the figures below) can either be on the same side or the opposite side of the ring as the OH group located on the second carbon. If these two OH groups are on the same side, it is called α -glucose; if on opposite sides, it is called β -glucose. The α -ring structure of glucose is the one shown below. Fructose is also found in cyclic structures, forming either five- or six-carbon rings.



- **Disaccharides** are formed through the linkage of two monosaccharides. Two common disaccharides are sucrose, which is formed from the linkage of the two monosaccharides glucose and fructose, and lactose (milk sugar), which links the monosaccharides galactose and glucose. The two monosaccharides are linked by a glycosidic bond. The condensation reaction between glucose and fructose to form the products sucrose and water is shown in the article and also as an animation online at <http://nutrition.jbpub.com/resources/animations.cfm?id=6>.
- **Polysaccharides** are polymers made up of many smaller sugar units. Starch ... is an example of a polysaccharide. Starch consists of glucose molecules linked together. ...starch molecules come in two varieties: amylose, a long, linear chain of the glucose units, and amylopectin, which has a branched structure of glucose units. The linear chains in amylose are connected with α -1,4-glycosidic linkages. In order to make the branching chains present in amylopectin, there are also α -1,6-linkages present. The “1,4” and “1,6” notation describes which carbon atoms in each glucose participate in the bond; in “1,4” the glycosidic bond links carbon #1 of the first glucose molecule to carbon #4 of the second glucose molecule.

Another common polysaccharide is cellulose, which is also found in plants as a place to store energy. Cellulose is also made up of repeating units of glucose. However, in cellulose, the glucose units are instead connected with β -1,4-glycosidic linkages. α -1,4-glycosidic linkages, such as those found in starch, are able to be digested by animals, including humans, while β -1,4-glycosidic linkages found in cellulose are not, making the starch present in plants, rather than the cellulose, the portion used for human consumption. Herbivores that consume cellulose as the main part of their diet use cellulase, an enzyme that breaks down cellulose into other saccharides that can be digested. Cellulase is

produced by grazing animals such as cows, with the aid of the beneficial bacteria that reside in the animal's digestive tract (http://www.naturalhealthschool.com/6_5.html).

More on artificial sweeteners

The Mayo Clinic website provides this definition of artificial sweeteners: “Artificial sweeteners are synthetic sugar substitutes but may be derived from naturally occurring substances, including herbs or sugar itself. Artificial sweeteners are also known as intense sweeteners because they are many times sweeter than regular sugar.” (<http://www.mayoclinic.com/health/artificial-sweeteners/MY00073>) The site also lists five artificial sweeteners, along with their brand names, that are currently approved by the U.S. Food and Drug Administration (FDA):

- Acesulfame potassium (Sunett, Sweet One)
- Aspartame (Equal, NutraSweet)
- Neotame
- Saccharin (SugarTwin, Sweet'N Low)
- Sucralose (Splenda)

Three of these, aspartame, saccharin, and sucralose, are described in the Brownlee article. The site also mentions that “FDA approval is being sought for other artificial sweeteners. And some sweeteners, such as cyclamate, are not approved in the United States but are approved for use in other countries.”

The relative sweetness of several artificial sweeteners compared to sucrose is summarized in the table below.

Relative Sweetness (sucrose sweetness = 1)	
Cyclamate	30 X
Aspartame	180 X
Acesulfame	200 X
Saccharin	300 X
Sucralose	600 X
Neotame	8,000 X

(adapted from <http://www.elmhurst.edu/~chm/vchembook/549sweet.html>; neotame data from http://www.neotame-sweetener.com/Sweetness_potency.html)

As seen from the relative sweetness table, it would take much less of an artificial sweetener to achieve the same taste of sweetness that a particular amount of sucrose would give. This makes artificial sweeteners good alternatives to help avoid the possible negative effects of sucrose: 1) no sucrose on teeth to contribute to tooth decay, 2) a way to reduce calories if trying to lose or maintain weight and 3) artificial sweeteners can be used by diabetics, since they don't affect blood sugar levels.

The use of artificial sweeteners was also a help during wartime shortages of table sugar, as described in the February 1988 *ChemMatters* article “Artificial Sweeteners”: “Saccharin was especially useful during the two world wars. With sucrose in short supply, real sugar was added to the rations destined for soldiers, who needed the caloric energy, and the folks at home “made

do” with artificial sweeteners. Yet saccharin did not become popular until the modern fashion for slimness came into vogue around 1950.” (p 5)

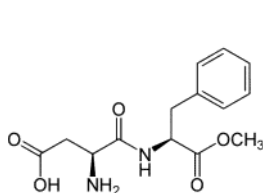
There are certain limitations as to which artificial sweeteners can be used in particular food products. As mentioned in the Brownlee article, saccharin has a bitter and metallic taste that can be used with coffee and tea, since these drinks already have a somewhat bitter taste, while aspartame, with no bitter taste, is a good choice for products such as soft drinks. The October 2007 *ChemMatters* article “Serendipitous Chemistry” describes situations in which aspartame is *not* used due to its properties:

One drawback to aspartame is that it breaks down upon heating, so it cannot be used in cooking. Furthermore, it decomposes under conditions of high pH. One byproduct of aspartame breakdown is methanol (CH_3OH), which is further metabolized to produce formaldehyde (CH_2O), a toxic substance, thereby raising questions about its safety.

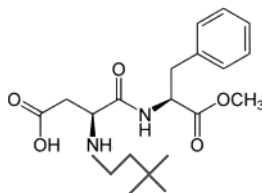
Proponents of aspartame counter that although methanol is hazardous in large doses, it occurs naturally in the body in small quantities, and the human body has well-developed pathways for methanol detoxification. Exhaustive and rigorous controlled testing has shown aspartame to be safe when used in reasonable quantities. (p 6)

However, the article also mentions that sucralose is able to step in: “Unlike aspartame, sucralose is stable when heated and does not break down when subjected to extremes of pH. As a result, it is useful in baking and in the preparation of acidic foods.” (p 6)

Individuals with the condition phenylketonuria are not able to metabolize phenylalanine. Products containing aspartame are labeled with the warning “Phenylketonurics: Contains Phenylalanine”, because when aspartame breaks down in the body, one of the products is phenylalanine. The NutraSweet company, which also manufactures aspartame, developed another artificial sweetener, neotame. The structure is nearly identical to that of aspartame, except that a 3,3-dimethylbutyl group is attached to the aspartic acid that makes up part of the molecule. This group “was added to block the action of peptidases, enzymes that break the peptide bond between the amino acids aspartic acid and phenylalanine. This reduces the availability of phenylalanine, eliminating the need for a warning on labels directed at people who cannot properly metabolize phenylalanine.” (<http://sci-toys.com/ingredients/neotame.html>)



Aspartame



Neotame

(from <http://www.scientificpsychic.com/fitness/artificial-sweeteners.html>)

In an interesting coincidence, the history of the discovery of the three artificial sweeteners mentioned in the article, along with two other sweeteners, all travel a path of serendipity. The three from the Brownlee article are described in the October 2007 *ChemMatters* article “Serendipitous Chemistry”:

The discovery of aspartame (aka NutraSweet or Equal) was a classic accident. In 1965, Dr. James Schlatter, a chemist at the G. D. Searle Laboratories, a pharmaceutical manufacturer, was researching antiulcer drugs. While heating a flask of an experimental drug, he accidentally bumped it, spilling some [of] its contents down the sides of the flask and onto his hand. Later, while licking his finger to pick up a piece of paper, he noticed a very sweet taste.

Remembering his earlier accident, he tasted a little of the substance from the flask—a clear violation of proper lab protocol! Dr. Schlatter's chemistry knowledge made him *reasonably* confident that the substance in the flask was not toxic, as it was a small peptide that he expected would break down rapidly in the stomach to a few dietary amino acids. It did indeed taste sweet, much sweeter than sugar. Thus, aspartame ($C_{14}H_{18}N_2O_5$), the king of artificial sweeteners, was discovered—totally by accident.

Ira Remsen, a professor at Johns Hopkins University, and Constantine Fahlberg, a postdoctoral fellow working in Remsen's lab, were eating when they noticed a very sweet taste. Realizing that they had not washed their hands ... since working in the lab, they deduced it was from some chemical with which they had been working. The resulting substance became the first widely used artificial sweetener—saccharin ($C_7H_4NNaO_3S \cdot 2H_2O$), most widely marketed as Sweet 'N Low.

Its [sucralose's] discovery could have been tragic. A graduate student by the name of Shashikant Phadnis was working in a lab at King's College in London in 1976. With a limited grasp of English, he did not understand when his instructor told him to test a substance. Phadnis thought the instructor said "taste," and he did just that! Fortunately for him, he survived to describe a very sweet-tasting substance—approximately 650 times sweeter than sugar. (pp 5–6)

Two others are described in the February 1988 *ChemMatters* article "Artificial Sweeteners":

Cyclamate, like saccharin, was discovered accidentally. While Michael Sveda of the University of Illinois was working with the compound, he momentarily rested his cigarette on the lab bench, returned it to his mouth, and found that it tasted extremely sweet. The cigarette had picked up a tiny crystal of cyclamate.

In 1967 Karl Clauss, a chemist at the German company Hoechst, licked his fingers in order to pick up a filter paper. Clauss had discovered acesulfame, a chemical that is now popular in Europe, where it is known commercially as Sunett. (p 6)

More on health risks of artificial sweeteners

Artificial sweeteners are considered a food additive. In the United States, these and other food additives are regulated by the U.S. Food and Drug Administration (FDA). These regulations are designed to ensure that additives have been tested and found to be safe to eat and that products including them are properly labeled. The FDA website (<http://www.fda.gov/food/foodingredientspackaging/ucm094211.htm>) contains a section that answers the question "How Are Additives Approved for Use in Foods?":

Today, food and color additives are more strictly studied, regulated and monitored than at any other time in history. FDA has the primary legal responsibility for determining their safe use. To market a new food or color additive (or before using an additive already approved for one use in another manner not yet approved), a manufacturer or other sponsor must first petition FDA for its approval. These petitions must provide evidence that the substance is safe for the ways in which it will be used.

When evaluating the safety of a substance and whether it should be approved, FDA considers: 1) the composition and properties of the substance, 2) the amount that would typically be consumed, 3) immediate and long-term health effects, and 4) various safety factors. The evaluation determines an appropriate level of use that includes a built-in safety margin - a factor that allows for uncertainty about the levels of consumption that are expected to be harmless. In other words, the levels of use that gain approval are much lower than what would be expected to have any adverse effect.

Because of inherent limitations of science, FDA can never be *absolutely* certain of the absence of any risk from the use of any substance. Therefore, FDA must determine - based on the best science available - if there is a *reasonable certainty of no harm* to consumers when an additive is used as proposed.

If an additive is approved, FDA issues regulations that may include the types of foods in which it can be used, the maximum amounts to be used, and how it should be identified on food labels. Federal officials then monitor the extent of Americans' consumption of the new additive and results of any new research on its safety to ensure its use continues to be within safe limits.

If new evidence suggests that a product already in use may be unsafe, or if consumption levels have changed enough to require another look, federal authorities may prohibit its use or conduct further studies to determine if the use can still be considered safe.

As mentioned above in the section "More on artificial sweeteners", five sweeteners have been approved by the FDA: acesulfame potassium, aspartame, neotame, saccharin, and sucralose.

Various controversies have surrounded the testing of saccharin and aspartame. Some consumers may have a vague idea about the testing surrounding these two sweeteners; for example, they may remember hearing that "saccharin can cause cancer", but no further details. A summary of the history of saccharin testing is found at <http://www.cancer.gov/cancertopics/factsheet/Risk/artificial-sweeteners>:

Studies in laboratory rats during the early 1970s linked saccharin with the development of bladder cancer. For this reason, Congress mandated that further studies of saccharin be performed and required that all food containing saccharin bear the following warning label: *"Use of this product may be hazardous to your health. This product contains saccharin, which has been determined to cause cancer in laboratory animals."*

Subsequent studies in rats showed an increased incidence of urinary bladder cancer at high doses of saccharin, especially in male rats. However, mechanistic studies (studies that examine how a substance works in the body) have shown that these results apply only to rats. Human epidemiology studies (studies of patterns, causes, and control of diseases in groups of people) have shown no consistent evidence that saccharin is associated with bladder cancer incidence.

Because the bladder tumors seen in rats are due to a mechanism not relevant to humans and because there is no clear evidence that saccharin causes cancer in humans, saccharin was delisted in 2000 from the U.S. National Toxicology Program's *Report on Carcinogens*, where it had been listed since 1981 as a substance reasonably anticipated to be a human carcinogen (a substance known to cause cancer). The delisting led to legislation, which was signed into law on December 21, 2000, repealing the warning label requirement for products containing saccharin.

The same site summarizes testing information regarding aspartame:

Aspartame, distributed under several trade names (e.g., NutraSweet® and Equal®), was approved in 1981 by the FDA after numerous tests showed that it did not cause cancer or other adverse effects in laboratory animals. Questions regarding the safety of aspartame were renewed by a 1996 report suggesting that an increase in the number of people with brain tumors between 1975 and 1992 might be associated with the introduction and use of this sweetener in the United States. However, an analysis of then-current NCI [National Cancer Institute] statistics showed that the overall incidence of brain and central nervous system cancers began to rise in 1973, 8 years prior to the approval of aspartame, and continued to rise until 1985. Moreover, increases in overall brain cancer incidence occurred primarily in people age 70 and older, a group that was not exposed to the highest doses of aspartame since its introduction. These data do not establish a clear link between the consumption of aspartame and the development of brain tumors.

In 2005, a laboratory study found more lymphomas and leukemias in rats fed very high doses of aspartame (equivalent to drinking 8 to 2,083 cans of diet soda daily). However, there were some inconsistencies in the findings. For example, the number of cancer cases did not rise with increasing amounts of aspartame as would be expected.

Subsequently, NCI examined human data from the NIH-AARP Diet and Health Study of over half a million retirees. Increasing consumption of aspartame-containing beverages was not associated with the development of lymphoma, leukemia, or brain cancer.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Molecular Structure**—Chemical structures of carbohydrates, amino acids, and different artificial sweeteners are shown in the article. Students could compare and contrast the structures and investigate whether there is any common thread between structures of different sweeteners.

2. **Biochemistry**—The article discusses compounds that relate to biochemistry: sucrose, a common carbohydrate, and two amino acids that make up aspartame. Instructors could discuss other carbohydrates, along with other families of molecules such as proteins and fats. Instructors could also discuss the entire collection of amino acids and their role in protein construction.
3. **Nutrition**—The article could be linked with a discussion of calories, how different sweeteners are metabolized in the body, and the effects our eating choices can have on our bodies.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“It’s safe to eat and drink in the laboratory or to taste things that you make there because other scientists have done it.”** *Eating and drinking should never be a part of the chemistry laboratory since foods and beverages can easily become contaminated with potentially hazardous materials. In the past, scientists used to routinely taste laboratory products as part of their testing. Besides the dangers associated with this practice, chemical processes we now have available make this unnecessary.*
2. **“Researchers discover only things they’re specifically looking for.”** *Throughout history, researchers have often discovered things they have not specifically been looking for. The researchers who discovered aspartame were trying to create anti-ulcer drugs by using a molecule normally produced in the stomach.*
3. **“Artificial sweeteners are safe for everyone to consume.”** *Artificial sweeteners approved by the FDA have undergone rigorous testing to ensure that they are safe to include in products we ingest. However, products that contain aspartame can be hazardous for people who are unable to metabolize the amino acid phenylalanine. Such products carry a warning label for people with this condition, called phenylketonuria.*
4. **“I can substitute one artificial sweetener for any other sweetener.”** *Properties of different artificial sweeteners can make them appropriate for use in one product, but not in another. For example, sucralose is stable when heated and can be used in baking, while aspartame cannot. Sweeteners also have different sweetness levels in relation to sucrose, and different amounts would be needed to achieve the same level of sweetness.*

Anticipating Student Questions (answers to questions students might ask in class)

1. **“Do all sweeteners have similar structures?”** *In general, there is no immediate similarity that jumps out when comparing the structures of many different sweeteners (see <http://www.scientificpsychic.com/fitness/artificial-sweeteners.html> for multiple structures). Some sweeteners are very similar to one another; for example, aspartame and neotame, and sucrose and sucralose.*

In-class Activities (lesson ideas, including labs & demonstrations)

1. A common demonstration is to place unopened cans of diet and regular soda in a tank of water and to observe whether they float or sink. The use of sugar vs. an artificial sweetener

such as aspartame in the sodas results in drastically different densities. Two examples are <http://www.stevespanglerscience.com/experiment/00000051> and <http://scifun.chem.wisc.edu/homeexpts/cans.htm>.

2. An experiment in the October 2004 issue of *ChemMatters* (p 5) investigates the sugar content of beverages. Students make standardized sugar solutions, find their densities, and use a plot of the densities versus % sugar content to then approximate the sugar content of several other beverages. (The experiment can be seen as part of the issue at http://portal.acs.org:80/portal/PublicWebSite/education/resources/highschool/chemmatters/CTP_005395.)
3. In a food-safe area, such as the home or a school kitchen, students could prepare two batches of baked goods, such as sugar cookies, using sugar and sucralose, and compare the two. A report on a science fair experiment describes one such investigation at http://mwvsciencefair.wikispaces.com/degsc_kto.
4. Students can test their taste threshold for sweet and salty solutions and map where they are each tasted on the tongue. For one example, see http://www.fofweb.com/Onfiles/SEOF/Science_Experiments/4-4.pdf.

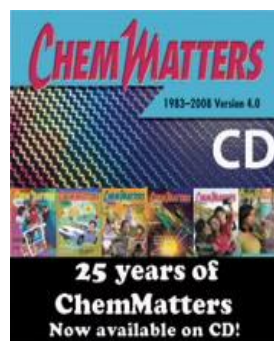
Out-of-class Activities and Projects (student research, class projects)

1. Students could research the history of cyclamate. This artificial sweetener found wide use in the U.S. after coming on the market in the early 1950's, but was banned by the FDA in the late 1960's. It is still banned in the U.S., but is used in other countries.
2. Students could locate packets of different artificial sweeteners and food products containing the sweeteners and bring them to class for comparison. For example, do the sweeteners each have a different taste? In what type of products is each sweetener used?

References (non-Web-based information sources)

The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. (Part way down the Website screen, click on the *ChemMatters* CD icon shown at the right.)

Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)



Rohrig describes the serendipitous discoveries connected with different products, such as Vaseline, Silly Putty, and the artificial sweeteners aspartame, saccharin, and sucralose. (Rohrig, B. Serendipitous Chemistry. *ChemMatters* **2007**, 25, (3) pp 4–6.)

The article “Artificial Sweeteners” discusses various artificial sweeteners and the idea of the “triangle of sweetness”, a theory about why particular compounds taste sweet. (Emsley, J. Artificial Sweeteners. *ChemMatters*, **1988**, 6 (1), pp 4–8.)

Two textbooks quoted in this Teacher's Guide are *Chemistry: The Central Science* (Brown, T. L.; LeMay, H. E., Jr.; Bursten, B. E., 7th ed.; Prentice Hall: Upper Saddle River, NJ, 1997) and *Chemistry in the Community* (5th ed.; American Chemical Society: Washington, DC, 2006).

Web sites for Additional Information (Web-based information sources)

More sites on sweeteners

The site <http://www.reshafim.org.il/ad/egypt/timelines/topics/beekeeping.htm> provides information on the history of the use of honey as a sweetener and includes photos of ancient artwork that illustrates bee-keeping.

"All About Sweeteners" contains links to pages describing various sweeteners, such as sucrose, aspartame, high fructose corn syrup, and more. The first page <http://www.sweetenerbook.com/> has a description about sweet taste receptors located not only on our tongues, but also in the lining of the small intestine.

The site <http://chemistry.about.com/cs/5/f/bl031504a.htm> answers the question "What is the sweetest compound?"

More sites on sucrose

The Sugar Knowledge International website (<http://www.sucrose.com/>; click on "Learn how sugar is made") has multiple tabs that lead to pages describing how sugar is made, cane sugar, beet sugar, refining, the history of sugar, and sugar types.

An extensive description of the processing of sugar cane to produce cane sugar (sucrose) is available at <http://www.epa.gov/ttn/chief/ap42/ch09/final/c9s10-1a.pdf>.

A description of sugar and its connection to candy-making is available at <http://www.exploratorium.edu/cooking/candy/sugar.html>.

More sites on carbohydrates

A "ChemCard stack" focusing on carbohydrates is available online at <http://www.hcc.mnscu.edu/chem/V.25/index.html>. The stack of 58 cards is meant to be viewed sequentially, with each card providing a small chunk of information. The cards include many different carbohydrate structures, such as glucose, galactose, maltose, lactose, and sucrose. (*ChemMatters* April 2011 Teacher's Guide, p 85)

The basics of carbohydrates are presented at (<http://staff.jccc.net/pdecell/biochemistry/carbohyd.html> - top). (*ChemMatters* April 2011 Teacher's Guide, p 86)

More sites on artificial sweeteners

The Mayo Clinic website provides background on artificial sweeteners and other substitutes for sucrose, with information on possible health benefits and concerns. (<http://www.mayoclinic.com/health/artificial-sweeteners/MY00073>)

Information about the U.S. Food and Drug Administration's regulation of ingredients added to food, including additives such as artificial sweeteners, is available at <http://www.fda.gov/food/foodingredientspackaging/ucm094211.htm>.

MedicineNet.com has a multi-page section on artificial sweeteners, including discussions of the pros and cons of various artificial sweeteners.
(http://www.medicinenet.com/artificial_sweeteners/article.htm)

More sites on health risks of artificial sweeteners

A fact sheet from the National Cancer Institute discusses possible associations between specific artificial sweeteners and cancer.
(<http://www.cancer.gov/cancertopics/factsheet/Risk/artificial-sweeteners>)

The full text of the 2004 article "Artificial sweeteners—do they bear a carcinogenic risk?", published in the *Annals of Oncology*, is available at <http://annonc.oxfordjournals.org/content/15/10/1460.long>.

Fighting Bacteria

Background Information (teacher information)

More on antibiotics

The term *antibiotic* can be broken down into two Greek roots, *anti-* and *bio-*, which, taken together, mean “against life”. This meaning ties into the action of antibiotics, in that they are compounds that kill bacteria or other microorganisms, or are able to slow their growth. Antibiotics may be termed “bactericidal”, in that they kill bacteria, or “bacteriostatic”, if they stop the growth of bacteria. Antibiotics are used to fight harmful bacteria by preventing or disrupting cellular processes. For example, the penicillin compound described in the Orford article did this by affecting the ability of bacterial cells to construct cell walls. Other bacterial cellular processes that can be affected include membrane function, DNA replication, DNA transcription, and RNA translation or protein synthesis

(http://www.hhmi.org/biointeractive/Antibiotics_Attack/frameset.html). Antibiotics are *not* effective against viruses, since these same cellular processes do not occur in viruses. Viruses are not made of cells and are able to reproduce only when using the processes of a host cell. There are several different classes of antibiotics, including the β -lactam class, of which penicillins are a part; others are fluoroquinolones, glycopeptides, and macrolides, with a longer listing shown as Table 2 at http://www.mumj.org/Issues/v8_2011/articles/v8_58.pdf. The table also lists the bacterial cellular process targeted by each class, such as cell wall synthesis, DNA synthesis, etc.

Antibiotics can be obtained from natural sources, such as organisms found in soil, as well as the mold accidentally discovered by Alexander Fleming that was eventually developed into the antibiotic penicillin. They can also be chemically designed and synthesized in the laboratory, often by altering the structures of already-known antibiotics. Obtaining antibiotics from natural sources led to the use of some unusual laboratory equipment, described in the tutorial “Antibiotics Attack” (http://www.hhmi.org/biointeractive/Antibiotics_Attack/frameset.html): “Molds such as *Penicillium chrysogenum* and soil organisms such as *Bacillus brevis* were grown to collect the first crude samples of antibiotics and are still grown by commercial companies to produce antibiotics. In the early days of antibiotics, scientists used whatever jars, pans, [and] containers were available to grow great quantities of mold or bacteria. Later, scientists found that beer brewing equipment did the job effectively and in mass quantities. Old beer brewing equipment is no longer used, instead, massive fermentation chambers filled with liquids and nutrients are used.”

Antibiotics can be delivered to the site of infection in different ways. They include oral forms, such as pills or liquids that are swallowed, topical forms, such as creams or gels that can be applied directly to the infection (e.g. antibiotic acne creams), liquid antibiotic drops that can be placed in an infected ear or eye, and intravenous (IV) antibiotics that are delivered directly to the bloodstream. IV antibiotics are useful in emergency situations, since the compounds can more quickly reach the site of infection inside the body. Oral antibiotics must first be absorbed through the digestive system. A list of over 60 antibiotics is at the site <http://www.antibioticslist.com/>; each antibiotic has a link that shows its chemical structure, describes how it works, conditions it is typically used to treat, and common side effects. Two side effects that are commonly mentioned in connection with antibiotics are allergic reactions

and stomach upset/diarrhea. Allergic reactions include rashes, swelling of tissue, and difficulty breathing. Penicillin allergy is the most common. Difficulties with stomach upset and diarrhea are caused because antibiotics can affect not only the harmful bacteria in one's body, but also beneficial bacteria. Beneficial bacteria live in our intestines and help with digestion and regulation of bowel movements. Yogurt, since it contains live bacteria, is sometimes taken to help restore these beneficial bacteria to the digestive system, although it can interfere when used with certain antibiotics. Yeast infections can also occur in those taking antibiotics because an antibiotic can kill organisms that would normally help to control yeast populations in the body (<http://www.scientificamerican.com/article.cfm?id=human-microbiome-change>).

More on bacteria

When people hear the word “bacteria”, they commonly think of a harmful organism (see Possible Student Misconceptions section below). It is true that certain bacteria are associated with particular diseases, such as tuberculosis, strep throat, cholera, and salmonella poisoning, as well as merely unpleasant things such as body odor and acne. However, only one bacterium out of one thousand is harmful (*Biology: Principles and Explorations*, teacher ed., 1996, p 463). Bacteria are literally everywhere—the soil, the air, and even our own digestive systems. The majority of bacteria are either harmless to us or perform some beneficial function. For example, certain bacteria in our small intestine and colon provide protection against harmful bacteria that can enter the digestive system. Some manufacturers even offer products such as probiotic yogurt, which is yogurt to which live cultures of beneficial bacteria are added. Some beneficial uses of bacteria include cleaning up oil spills and producing various foods such as sour cream, sauerkraut, and cheese. In one application, the potentially harmful *E. coli* bacteria has been genetically engineered to produce useful polymers (<http://www.scientificamerican.com/article.cfm?id=turning-bacteria-into-plastic-factories-replacing-fossil-fuels>). Some bacteria exist in the clouds and play a role in the formation of ice and rain (<http://www.npr.org/templates/story/story.php?storyId=87761584>).

Bacteria are single-celled organisms that are classified as prokaryotes. Their size is in the micrometer range; they cannot be seen with the naked eye. A bacterial cell is usually described as being one of three different basic shapes: bacillus (rod-shaped), coccus (spherical), or spirillum (spiral). Each of these shape categories also contains different arrangements, such as pairs, chains, cubes, clusters, etc. (<http://faculty.ccbcmd.edu/courses/bio141/lecguide/unit1/shape/shape.html>). As stated in the Orford article, a bacterial cell has a cell wall formed of peptidoglycan on the outer surface of the cell, with a plasma membrane underneath. Bacteria also are further categorized as gram-positive or gram-negative, based on differences in the structure of their cell walls. The differences and their use in medicine are described in *Biology: Principles and Explorations*:

A bacterium with a cell wall containing a large amount of peptidoglycan is classified as gram-positive. A bacterium with a cell wall containing a thin layer of peptidoglycan covered by an outer membrane is classified as gram-negative. These terms refer to a bacterium's reaction to a staining procedure developed by the Danish microbiologist Hans Gram. ... Gram staining is an important technique in medicine. In many cases, the reaction to a Gram stain provides valuable information for the treatment of a bacterial disease. For example, gram-positive bacteria tend to be killed by penicillin, an antibiotic that prevents the proper formation of peptidoglycan in cell walls. Because of their outer membranes, gram-negative bacteria tend to be resistant to penicillin, but much more susceptible to the antibiotic tetracycline. Thus Gram stain identification of

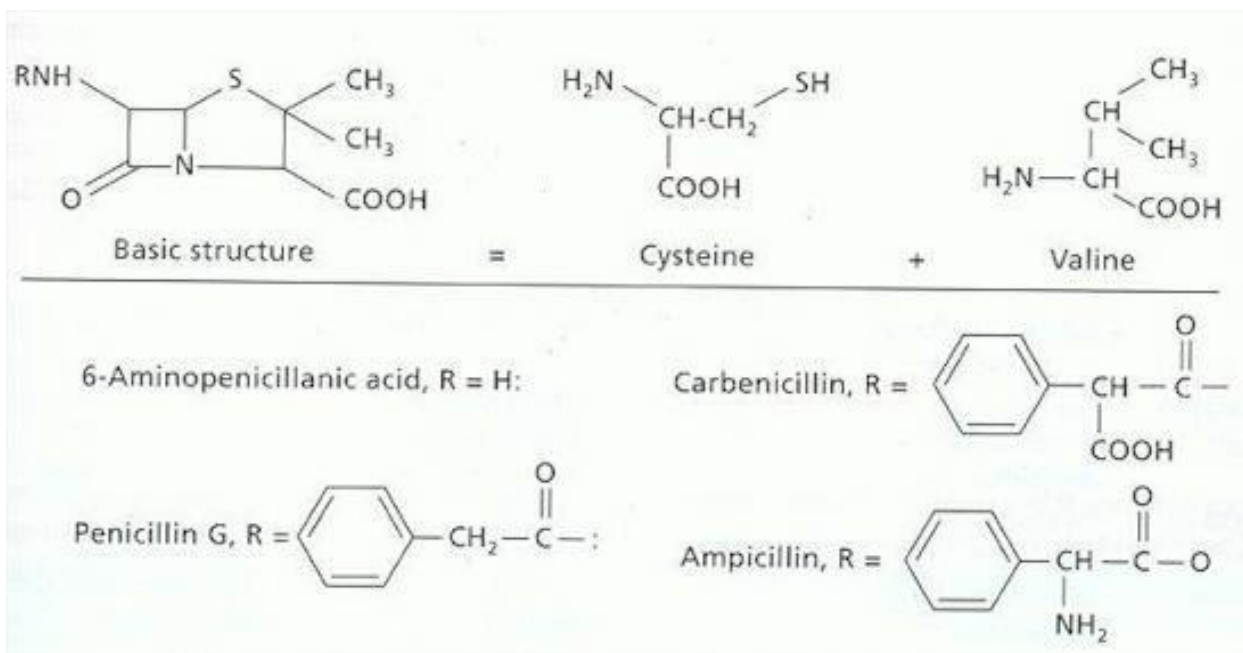
a bacterium can help determine which drug will be most effective against a disease. (p 463)

The action of penicillin described in the article works by preventing bacteria from constructing a cell wall, without which it cannot survive. The *ChemMatters* article “Penicillin” has a good analogy for the cell wall construction process: “The construction of a cell wall can be compared to making a fishing net. One could first lay down parallel strands of rope, then cross-link neighboring rope strands by tying them together with string. Bacterial cell walls are made of long sugar polymers that are then cross-linked to make a netlike cell wall. It is the cross-linking which is blocked by penicillin.” (p 12) The article also describes how this causes the destruction of the cells: “The cells of bacteria have unusually high internal pressure. In growing bacteria, penicillin interferes with the formation of cell walls and the internal pressure ruptures the cell. This lets the cytoplasm spill out, killing the cell.” (p 12) (This explains the “pop” of the penicillin-treated daughter cells mentioned in the article.)

Bacteria have also been used throughout history as bioweapons to specifically harm others. The Website http://www.globalsecurity.org/wmd/intro/bio_bact.htm describes several past uses: “The Greek historian Herodotus from the 5th Century BCE wrote of Scythian archers who lived in the Black Sea region and used poisoned arrows. The poison was composed of the decomposed bodies of venomous adders, human blood, and dung that were mixed together and left to putrefy. Scientists suggested that such a concoction would contain gangrene and tetanus. ... During World War I, Germany began its bioweapons program infecting Romanian sheep with anthrax before they were transported to Russia. During World War II, the Japanese bioweapons program known as Unit 731 poisoned Chinese wells with cholera and typhus bacteria.” A more recent use was soon after the September 11, 2001, terror attacks in the U.S. Letters containing anthrax spores were sent through the mail to various recipients. The Federal Bureau of Investigation Website states: “Five Americans were killed and 17 were sickened in what became the worst biological attacks in U.S. history.” (<http://www.fbi.gov/about-us/history/famous-cases/anthrax-amerithrax>)

More on penicillin

Penicillin refers to a group of compounds, rather than just one specific compound. The compounds all have the β -lactam ring described in Orford’s article. Different penicillin compounds have different functional groups attached to the ring. The site “The Microbial World: Penicillin and other antibiotics” (<http://www.biology.ed.ac.uk/research/groups/jdeacon/microbes/penicill.htm>) shows several penicillins in the structure diagram below, describing the foundation as “the same basic ring-like structure (a beta-lactam) derived from two amino acids (valine and cysteine) via a tripeptide intermediate. The third amino acid of this tripeptide is replaced by an acyl group (R in the diagram), and the nature of this acyl group confers specific properties on different types of penicillin.” The site describes several of the different penicillins: two natural penicillins, penicillin G and penicillin V, which are active only against gram-positive bacteria, and semi-synthetic penicillins such as Ampicillin, Carbenicillin and Oxacillin, which were made by chemically modifying natural penicillins with the substitution of different acyl groups to confer new properties. Some of these properties include resistance to stomach acids so that they can be taken orally, a degree of resistance to penicillinase (a penicillin-destroying enzyme produced by some bacteria), and an extended range of activity against some gram-negative bacteria.



(Figure from <http://www.biology.ed.ac.uk/research/groups/ideacon/microbes/penicill.htm>)

Many students may be familiar with the account of Alexander Fleming's serendipitous discovery of penicillin. The *ChemMatters* article "Penicillin" (Apr. 1987, pp 10–12) gives the following description: "Scientists have known since the 1870s that certain molds have the ability to kill bacteria. In 1928, Alexander Fleming, returning from holiday, examined a culture plate that had grown moldy in his absence. From above, the mold looked like a castle surrounded by a moat that separated the mold from the colonies of staphylococcus bacteria (which cause strep throat and a variety of other infections). The bacteria were dying as the mold advanced. Clearly, this mold was an exceptionally powerful bactericide." (p 10)

However, fewer may be aware of the history that followed its discovery, particularly the lengthy time period that elapsed before penicillin was even tested (by someone other than Fleming) for its potential use in animals and humans, and the difficulties encountered when chemists first attempted to produce large amounts of penicillin for use during World War II. The *ChemMatters* "Penicillin" article describes these events:

Fleming experimented with an extract of the mold, which he named penicillin. He found that it could kill the cells of a wide range of infectious bacteria, yet was harmless to the cells of mammals. This suggested that it might be safe for people, but Fleming did not follow up on his discovery, and 11 years passed before tests demonstrated penicillin's power in animals, and later in humans.

Why didn't Fleming pursue penicillin? Experts disagree. In an article in the British journal *New Scientist*, R. G. Macfarlane, professor emeritus of clinical pathology at Oxford University, said that Fleming was discouraged by test results that showed penicillin to be slow-acting and to lose its power in blood serum.

But MIT chemistry professor John Sheehan disputes Macfarlane's story. "At that time, British science was structured. People were very turf conscious," says Sheehan. Following normal channels, Fleming sent

samples to the man who specialized in mold metabolites, biochemist Harold Raistrick.

But neither Raistrick nor several other scientists who worked on penicillin had much luck with it. “Part of the reason is that Fleming didn’t describe the mold accurately,” says Sheehan. “It wasn’t until Dr. Charles Thom described it as *Penicillium notatum* that others were able to repeat the experiments.”

Whatever the reason, it was not until 1940 that Ernst Chain and Sir Howard Florey, then of Oxford University, performed the first successful animal studies. Trials on humans came the following year.

Ironically, it was Fleming who brought penicillin back into the limelight. One of Fleming’s friends had fallen ill with meningitis and—after sulphonamides had proven useless—appeared to be dying. Fleming decided to try penicillin. Florey supplied the drug and explained how to use it. When the patient recovered, the press called penicillin a wonder drug. (p 10)

Sir Alexander Fleming, Ernst Chain, and Sir Howard Florey were jointly awarded the Nobel Prize in Physiology or Medicine in 1945 “for the discovery of penicillin and its curative effect in various infectious diseases”.

(http://nobelprize.org/nobel_prizes/medicine/laureates/1945/)

Penicillin’s potential for use in the treatment of wounded soldiers during World War II brought its further development to the forefront.

The Office of Scientific Research and Development, newly established in 1941 by President Roosevelt, made the development of large quantities of penicillin a priority. Some 1000 chemists joined the war effort to develop penicillin.

Two approaches looked promising. The drug could be produced by a fermentation process—a massive scaling-up of the way the mold had been grown in the laboratory. Alternatively, chemists could learn how to synthesize it. Although fermentation was a well-established technique, experience at the Merck Company with vitamin B suggested that laboratory synthesis was the way to go.

Early efforts proved highly frustrating. “The amazing success of the natural fermentation program and the endless frustrations encountered in the chemical synthesis of penicillin led serious scientists to doubt whether a penicillin synthesis was even possible,” Sheehan wrote. (p 11)

What made the synthesis so difficult?

The difficulties at nearly every step in this process lay in the molecule’s cantankerous personality. Robert B. Woodward, an outstanding organic chemist, called penicillin “a diabolical concatenation of reactive groups.”

The penicillin molecule is composed of two rings and two side chains—all with chemically reactive “functional groups.” Part of the difficulty of synthesizing penicillin lay in keeping so many functional groups under control at one time. (p 10)

The step that proved impossible to the thousand or so scientists working during World War II was to “close” the β -lactam ring—that is, entice a chain of one nitrogen and three carbon atoms to form a tight circle.

“One needed a reagent that was neither acidic nor basic but was a powerful dehydrating agent and could operate in water,” says Sheehan. Even a small deviation from neutral pH can destroy penicillin’s activity, but most dehydrating agents are acidic or basic. “It seems like a fantastic combination of properties, and it is,” he continues. But Sheehan found such a reagent in an obscure group of compounds called the carbodiimides.

Sheehan closed the β -lactam ring using carbodiimides. To prevent certain active groups on the molecule from reacting during the closing of the ring, he “covered” them with *blocking groups*. (pp 11–12)

The synthesis was reported in the national news; for example, one article appeared in *Time Magazine* on March 18, 1957 (<http://www.time.com/time/magazine/article/0,9171,809227,00.html>). The article stated “There is little chance that Sheehan’s method will be used to manufacture penicillin V commercially, since it can be made cheaply by fermentation. But now that the delicate molecule can be built up and modified in the laboratory, new kinds of penicillin can be produced. ... Dr. Sheehan’s great hope is that the new synthetic penicillins may prove free of natural penicillin’s tendency to cause serious allergic effects in some patients. Best of all, they may cope with those sophisticated germs that have developed complete resistance to natural penicillin and even (in some cases) thrive on it.” It is interesting to contrast Fleming’s original accidental discovery of penicillin versus specific tinkering with the molecule in order to produce new synthetic penicillins and also to note that the difficulties encountered with antibiotics back then, those of potential allergic effects and resistance of bacteria, are still encountered today.

More on antibiotic resistance

Antibiotics are often viewed as “miracle drugs”, but as described in the Orford article, in some cases, the results are not as effective as expected due to the ability of bacteria to develop antibiotic resistance. As bacterial cells multiply, mutants can arise in the population. Sometimes, the properties of a particular mutant can help it to fight against the action of antibiotics. The development of mutants in bacteria can be faster than one might imagine. “The large numbers of bacterial cells, combined with short generation times facilitate the development of mutants. In a typical bacterial population of 10^{11} bacterial cells (e.g. in an infected patient) there can easily be 1000 mutants. If a mutant confers a selective advantage upon the bacterium (e.g. the ability to survive in the presence of an antibiotic) then that resistant bacterium will be selected and continue to grow while its neighbors perish. This can happen in a matter of days in patients being treated with antibiotics.” (http://faculty.smu.edu/jbuynak/Medicinal_Outline_11_4_04.pdf)

Bacteria have developed various ways of resisting the action of antibiotics. “These mechanisms can either chemically modify the antibiotic, render it inactive through physical removal from the cell, or modify [a] target site so that it is not recognized by the antibiotic. The most common mode is enzymatic inactivation of the antibiotic. An existing cellular enzyme is modified to react with the antibiotic in such a way that it no longer affects the microorganism.” (http://www.textbookofbacteriology.net/resantimicrobial_3.html) For example, β -lactamase enzymes are able to react with penicillin and other β -lactams by breaking the β -lactam ring.

Human actions also have the potential to contribute to increased levels of bacterial resistance to antibiotics. One way this can happen is through inappropriate use of antibiotics. This can include patients demanding an antibiotic in cases of illness where it would not be effective, such as with a viral infection. Doctors may give in to these demands, unnecessarily prescribing the medication. The October 2000 *ChemMatters* Teacher's Guide describes the extent of this practice, along with other patient behaviors:

A 1998 report by the Institute of Medicine estimated that about 50% of antibiotics are prescribed unnecessarily, and patient behavior can make the problem even worse. Another survey indicated that about half of patients for whom antibiotics are prescribed never finish their medication. This careless use of antibiotics is the perfect setup for encouraging the growth of antibiotic resistant strains. Patients who stop taking the medication when they feel better often find that the infection returns and is more difficult to control the second time around.

Inappropriate use of antibiotics is particularly widespread in developing countries. Whereas people in developed countries may often overuse antibiotics, in developing countries people often do not take the full course of antibiotic treatment because they cannot afford the cost. In addition, antibiotics are often sold at "flea markets", where no doctor's exam or prescription is required. In the Philippines, for example, some people mistakenly use low doses of an antituberculosis drug as a "long vitamin". (p 9)

The increased use of antibacterial products (e.g. soap, lotion, cleaners) has also been tagged as a possible contributor to the rise in bacterial resistance. These products have a broad effect against bacteria, wiping out not only bacteria that may be harmful to our bodies, but also beneficial, or benign, bacteria. The October 2002 *ChemMatters* article "Antibacterials—Fighting Infection Where It Lives" states "As bacteria are exposed to antibacterial agents, susceptible bacteria die, leaving the more resistant ones to reproduce. Bacterial resistance is well documented with the misuse of antibiotic drugs in treating infections. Now, some doctors are worried that use of antibacterial cleaning products will lead to the same resistance, making bacteria even harder to fight." (p 11)

Another controversial practice that is still undergoing debate is the use of antibiotics in animal feed. The history of this practice is described in the *ChemMatters* article "Antibiotics in the Food Chain" (October 2000, pp 14–15):

The practice [of adding antibiotics to animal feed] stems from an accidental discovery of the positive effects of low-dose antibiotics on the growth of fish. In 1949, a pharmaceutical manufacturer on the Pearl River in New York state was producing quantities of tetracycline-producing mold in large batches of grain mash. Leftovers, loaded with the antibiotic were dumped in the river. A chemist, Thomas Jukes, found out that fish swimming downstream from the plant were markedly larger than their upstream counterparts. Jukes investigated the phenomenon by feeding the mash to laboratory animals and found the results astounding—mice, chicks, piglets, all grew at rates 10 to 20% faster than normal. The effects were traced to the antibiotic itself. Although the mechanism is not entirely clear, the low dose of antibiotics seems to spare some of the animal's energy needed for fighting ever-present infections, making this energy available for growth. (p 15)

This use can contribute to the rise of antibiotic-resistant bacteria, which are then able to infect humans. The U.S. Food and Drug Administration, the Centers for Disease Control and Prevention, and the World Health Organization are working to limit or prevent this use in agriculture. “It [the FDA] proposes to begin by ranking new and existing antibiotics by their importance to human health. Those at the top of the list would be reserved for human use and avoided for veterinary uses.” (p 15) Other voices in the debate include farmers and researchers. Farmers argue that antibiotic use keeps animals healthy and growing quickly and that without its use, food prices would rise. Some scientists argue that there is not enough evidence that the practice is dangerous.

Solutions to the problem of the rise in antibiotic resistance involve multiple approaches. Researchers continue to work toward the development of new antibiotics, although some worry that eventually our ability to develop these will be outstripped by the speed with which bacteria are able to develop resistance. Other efforts involve patient and doctor education regarding appropriate use of antibiotics. The Centers for Disease Control and Prevention are promoting a “Get Smart: Know When Antibiotics Work” campaign. Materials share information about the fact that antibiotics have no effect on viral infections and encourage those who are properly prescribed antibiotics to use them as directed, that is, to complete the entire course of antibiotics even if they feel better and not to save any medication for later use. Stopping or limiting the use of antibiotics in animal feed is an additional approach.

Other possible solutions focus on the development of alternative pharmaceutical approaches. A 2009 article describes one of these approaches: “[Timothy] Lu and James Collins, Howard Hughes Medical Institute investigator and professor of biomedical engineering at Boston University, took a new approach: engineering existing bacteriophages (viruses that infect bacteria) to attack specific targets. ‘It’s much easier to modify phages than to invent a new drug,’ said Lu.” (<http://web.mit.edu/newsoffice/2009/antibiotic-resistance-0302.html>) Other researchers are studying the effectiveness of other compounds, such as garlic extracts, against antibiotic-resistant bacteria (http://www.mrsasupportgroup.org/files/ALLICIN_MRSA_DRCutler_Paper_1_.pdf).

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Scientific Discovery**—A comparison of serendipitous discovery, such as Fleming’s original discovery of penicillin, versus a concentrated search for compounds with specific properties, such as the work being done to find new solutions to antibiotic-resistant bacteria, could be made.
2. **Organic Chemistry**—The structures contained in the article can be used as illustrations of a wide variety of structures and how they are typically drawn. For example, different penicillin molecules show four-, five-, and six-sided ring structures.
3. **Enzymes**—A discussion of the chemistry of enzymes, active sites, and inhibitors could be used. Transpeptidase is an enzyme used by bacteria to form cell walls, while penicillin binds to the active site of the enzyme to act as an inhibitor, preventing construction of the cell wall.
4. **Bonding**—The article discusses the 90-degree angles formed by carbon atoms bonding in β -lactam rings versus other bonding angles for carbon, such as 109 and 120 degrees.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“There is only one penicillin.”** Penicillin is actually a group of antibiotics. Their structures share a common feature, a β -lactam ring, while a functional group on the ring varies from one type of penicillin to another. They all work by interfering with the formation of bacterial cell walls.
2. **“All bacteria are harmful.”** The majority of bacteria, which exist all around us, even within our own bodies, are actually benign or even beneficial. A very small fraction of the bacteria in the world have harmful effects.
3. **“Antibiotics are ‘wonder drugs’, so they can work any time I’m sick.”** Antibiotics are only effective against bacterial infections and not infections caused by viruses. Some common viral infections are colds, flu, some sore throats, and most coughs and bronchitis. Taking antibiotics in these cases will not cure the infection or help you feel better, and can contribute to the rise of antibiotic-resistant bacterial infections.

Anticipating Student Questions (answers to questions students might ask in class)

1. **“Do antibiotics always ‘work’ the first time?”** As described in the article, some bacterial infections may take more than one antibiotic to fully treat the infection if a person is infected with an antibiotic-resistant strain of bacteria that doesn’t respond to the first antibiotic.
2. **“Are antibiotic-resistant strains of bacteria more destructive than ‘normal’ bacteria?”** These strains are not more destructive than other bacteria. Their danger lies in the fact that antibiotics that are effective against non-resistant strains are not effective against the antibiotic-resistant strains, and thus cannot knock out the infection. (ChemMatters Teacher’s Guide, October 2000, p 11)
3. **“Is any one antibiotic effective against all kinds of bacterial infection?”** No. For example, when penicillin was discovered, it was found to not be effective against the bacterium that is responsible for tuberculosis. But by 1943, streptomycin was isolated, which could kill the tubercle bacillus, as well as other bacteria not affected by penicillin. (ChemMatters Teacher’s Guide, October 2000, p 12)

In-class Activities (lesson ideas, including labs & demonstrations)

1. A typical laboratory experiment on enzymes investigates the ability of the enzyme catalase to decompose hydrogen peroxide, along with the effects of changing the temperature and of adding an inhibitor. One version is available in ChemSource’s *Sourcebook*, version 3.0 (Enzymes: Biochemical Catalysts (ENZY) module, pp 4–10).
2. Some spices have been found to have antimicrobial properties and can inhibit the growth of bacteria. The lab “Biodiversity: The Spice of Life” and its accompanying materials allow students to test the antimicrobial action of certain spices against known bacteria. (<http://www.woodrow.org/teachers/bi/1999/projects/group5/index.html>)
3. An entire collection of microbe-related activities, split out into elementary, middle, and high school levels, is available at <http://www.umsl.edu/~microbes/activities.html>. They include oil degradation by bacteria, microbiology of yogurt, isolating a strain of bacterium from soil, and others.

4. Students can test chosen objects such as doorknobs, countertops, pens, etc. for the presence of microbes and investigate the effect of disinfectant using the experiment found at <http://www.sdnhm.org/exhibits/epidemic/teachers/fomites.html>.
5. The difference between a cell wall and cell membrane can be illustrated with an analogy using balloons and pantyhose (<http://people.ku.edu/~jbrown/penicillin.html>, approximately two-thirds down page). First, a balloon is inflated until it bursts. Then, a similar balloon is placed inside pantyhose and also inflated as much as possible. The balloon in the pantyhose will not burst. The balloon is similar to a cell membrane; the pantyhose, with many fibers cross-linked with other fibers, is similar to a cell wall.

Out-of-class Activities and Projects (student research, class projects)

1. Students could research the discovery and development of penicillin and investigate similarities and differences between work done with penicillin and the current search for new antibiotics to combat antibiotic-resistant bacteria.
2. Students could debate various issues connected with the use of antibiotics, such as the use of antibiotics in livestock feed as growth promoters or the inappropriate use of antibiotics by patients for infections where an antibiotic will not be effective. Students could interview stakeholders on both sides of these issues.

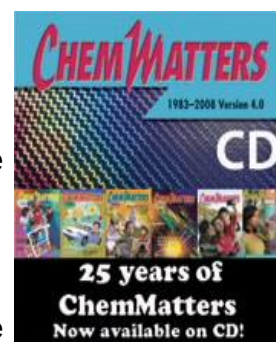
References (non-Web-based information sources)

Biology textbooks are a good source for more in-depth information about bacteria, its structure, how different types of bacteria obtain energy, along with images of actual bacteria that students may find interesting. One can typically find a section that discusses bacteria, often in connection with information about viruses, since both can cause diseases. The following textbook was used as a resource for this Teacher's Guide: Johnson, G. B.; Raven, P. H. *Biology: Principles and Explorations*, teacher's ed., Holt, Rinehart, and Winston, Inc.: Austin, TX, 1996.

A SourceBook module focuses on enzymes, including the experiment described in the In-class Activities section above. Davis, R.; Owens, P.; Summerlin, L. "Enzymes: Biochemical Catalysts." In *SourceBook*, Version 3.0, edited by Orna, M. V.; Smith, P. J. V. ChemSource, Inc.: New Rochelle, NY, 2010.

The references below can be found on the *ChemMatters* 25-year CD (which includes all articles published during the years 1983 through 2008). The CD is available from ACS for \$30 (or a site/school license is available for \$105) at this site: <http://www.acs.org/chemmatters>. (Part way down the Website screen, click on the *ChemMatters* CD icon shown at the right.)

Selected articles and the complete set of Teacher's Guides for all issues from the past five years are also available free online at this same site. (Full *ChemMatters* articles and Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)



The article “Penicillin” describes the history of the discovery and development of penicillin and briefly describes how it is able to kill bacteria. (Holzman, D. Penicillin. *ChemMatters*, **1987**, 5 (2), pp 10–12.)

In “Fighting Infection Where it Lives”, author Baxter discusses bacteria and the use and potential disadvantages of antibacterial products. (Baxter, R. Antibacterials—Fighting Infection Where It Lives. *ChemMatters*, **2002**, 20 (3), pp 10–11.)

The article “Antibiotics in the Food Chain” discusses the use of antibiotics in animal feed and potential problems with this practice. (Herlocker, H. Antibiotics in the Food Chain. *ChemMatters*, **2000**, 18 (3), pp 10–11.)

The “Mystery Matters” series in *ChemMatters* includes an article that describes a real-life instance of epidemiologists searching for the cause of a salmonella outbreak. The case brings together a web of the use of amoxicillin, drug-resistant strains of salmonella, and antibiotics added to animal feed. (Holzman, D. Mystery Matters: The Salmonella Search. *ChemMatters* **1987**, 5 (2), pp 13–15.)

Web sites for Additional Information (Web-based information sources)

More sites on antibiotics

Students can work through the Howard Hughes Medical Institute’s online tutorial “Antibiotics Attack”, which uses Shockwave animations, diagrams, and text to learn more about antibiotics, their function, and their targets.

(http://www.hhmi.org/biointeractive/Antibiotics_Attack/frameset.html)

This site describes Selman Waksman’s work with antibiotics, which included the isolation of streptomycin, the first effective treatment for tuberculosis.

(<http://acswebcontent.acs.org/landmarks/antibiotics/antibiotics.html>)

The Centers for Disease Control and Prevention (CDC) promotes knowledge about when antibiotics can be effective and the risks of inappropriate use of antibiotics with its “Get Smart” program. (<http://www.cdc.gov/getsmart/>)

These two Virtual ChemBook sections are short primers on antibiotics, particularly penicillin. Both include several figures.

(<http://www.elmhurst.edu/~chm/vchembook/652penicillin.html> and
<http://www.elmhurst.edu/~chm/vchembook/654antibiotic.html>)

More sites on bacteria

There is an excellent feature illustrating the size and scale of cells, including an *E. coli* bacterium. The illustration begins with a coffee bean and grain of rice; as one drags the slider to the right, it shows progressively smaller objects, such as a grain of salt, a skin cell, viruses, and ends with a carbon atom. (<http://learn.genetics.utah.edu/content/begin/cells/scale/>)

Wikipedia contains an exceptionally extensive page focusing on bacteria, with a reference list. (<http://en.wikipedia.org/wiki/Bacteria>)

The Microbe Zoo Website discusses different kinds of microbes and where they can be found. Students can “visit” different areas in the zoo, which emphasize that microbes are found everywhere, including dirt, animals, food, the atmosphere, and water.

(<http://commtechlab.msu.edu/sites/dlc-me/zoo/index.html>)

Students can view images showing bacteria dividing and multiplying, including links to a time-lapse movie and a “real time” BioCam. (<http://www.cellsalive.com/ecoli.htm>)

Khan Academy offers an 18-½ minute-long video lesson focusing on bacteria. (<http://www.khanacademy.org/video/bacteria?playlist=Biology>)

More sites on penicillin

The discovery of penicillin is one of the events highlighted on the American Chemical Society site “365: Chemistry for Life”, designed to highlight 2011 as the International Year of Chemistry. The penicillin page can be found at <http://iyc2011.acs.org/2011/09/03/discovery-of-penicillin/>.

The American Chemical Society National Historic Chemical Landmarks site includes a description of the history of penicillin, including its discovery, development, work done on scaling-up its production, and more.

(<http://acswebcontent.acs.org/landmarks/landmarks/penicillin/penicillin.html>)

A fully manipulable version (Jmol, MDLChime) of the penicillin molecule can be found as a *Journal of Chemical Education* featured molecule at <http://www.jce.divched.org/JCEWWW/Features/MonthlyMolecules/2003/Jul/index.html>.

More sites on antibiotic resistance

The Centers for Disease Control and Prevention Website contains a section on antibiotic and antimicrobial resistance, with information about diseases that are resistant and campaigns to help educate the public about the topic. (<http://www.cdc.gov/drugresistance/index.html>)

A white paper by the Infectious Diseases Society of America discusses the decline in research and discovery of antibiotics to combat the increasing number of antibiotic-resistant bacterial strains. (<http://idsociety.org/BBNDWhitePaper04.htm>)

An August 11, 2008, article in *The New Yorker* discusses the difficulties with treating a new generation of antibiotic-resistant infections, or “superbugs”. (http://www.newyorker.com/reporting/2008/08/11/080811fa_fact_groopman?currentPage=1)

The Website <http://web.mit.edu/newsoffice/2009/antibiotic-resistance-0302.html> contains an article describing a new approach to fighting antibiotic-resistant bacteria: using viruses to attack bacteria.

A September 27, 2010, *Los Angeles Times* article describes possible new ways to fight antibiotic-resistant bacteria, such as the use of viruses, probiotic organisms improved in the laboratory, and looking to new sources, such as frogs, for antibacterial agents. (<http://articles.latimes.com/2010/sep/27/health/la-he-in-the-works-antibiotics-20100927>)

The Centers for Disease Control and Prevention Website has a section on methicillin-resistant *Staphylococcus Aureus* (MRSA). (<http://www.cdc.gov/mrsa/>)

More Web sites on Teacher Information and Lesson Plans (sites geared specifically to teachers)

The Utah Education Network lesson plan “Bacteria’s Role in Food” investigates the role of microorganisms such as bacteria, yeasts, and molds in food. The site includes a pre-assessment, transparency masters, yogurt and fermentation activities, and a summative evaluation. (<http://www.uen.org/Lessonplan/preview?LPid=1167>)