



December 2011 Teacher's Guide

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About the Guide

Teacher's Guide editors William Bleam, Donald McKinney, Ronald Tempest, and Erica K. Jacobsen created the Teacher's Guide article material. E-mail: bbleam@verizon.net

Susan Cooper prepared the national science education content, anticipation guides, and reading guides.

David Olney created the puzzle. E-mail: djolney@verizon.net

Patrice Pages, *ChemMatters* editor, coordinated production and prepared the Microsoft Word and PDF versions of the Teacher's Guide. E-mail: chemmatters@acs.org

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The *ChemMatters* CD includes an Index that covers all issues from February 1983 to April 2008.

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

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Student Questions (from the articles)

Mmmm ... Flavorful Food!

1. What two senses combine to produce what we perceive as flavor? Which of the two senses provides the most dominant aspect of flavor?
2. What additional information besides taste and smell can contribute to what we perceive as the flavor of a food or beverage?
3. Where do chemists obtain natural and artificial flavors shown in a food's ingredients list?
4. Do we need all the flavor compounds in a food to recreate its flavor? Explain.
5. From where do artificial flavors get their characteristic odor?
6. How can one achieve different odors when producing esters?
7. Describe the career path of a flavor chemist.
8. Besides in food, where else do you find esters?

Hold the Meat! Meat-Free Food Takes a Seat at the Table

1. Name three sources of protein other than meat.
2. What is the basic chemical component (molecule) of protein?
3. What is the basic structure of the protein collagen?
4. List three reasons why our bodies need amino acids in the diet.
5. What is so special about essential amino acids?
6. In terms of essential amino acids, how does plant protein differ from animal protein?
7. List the major steps in forming tofu from soybean.
8. How does the process for producing tempeh differ essentially from that used to produce tofu?
9. How does the mold growing on soybean change the bean's protein into tempeh?
10. What is the source of protein used to make seitan?
11. How is gluten used to form seitan?
12. What is needed to make Tofurky?

Changing the Course of Diabetes

1. Why is research being done to create an artificial pancreas?
2. What are polymers?
3. Why are polymers used in medical devices?
4. What are monomers?
5. Name the two categories of polymers and give an example of each.
6. What is the main function of the polymer structure in the artificial pancreas?
7. How do chemists accomplish this function in the polymer?
8. Name two other materials that have been used in artificial pancreas research, and describe the problem(s) associated with each.
9. What is the status of the research, as of the date of the article, and where do researchers go from here?
10. Name three other areas of medical research where polymers play an important role.

Your Body Under Construction

1. In which organs of the body are hormones produced?
2. Name the hormone responsible for male sex characteristics.
3. What are androgens?
4. What is anabolism and how does it involve hormones?
5. Describe the concept of molecular “form and function” discussed in the article.
6. What molecular structure do all steroid hormones have in common?
7. Name the hormones responsible for female sex characteristics.

Titanic: Was It Doomed by Chemistry?

1. Give two reasons to explain why the ship makers who constructed *Titanic* believed it was unsinkable.
2. After *Titanic* struck the iceberg, why did it sink?
3. What was responsible for the overnight deaths of the people in the still floating in the water?
4. Why do objects float?
5. What changed to cause *Titanic* to sink? Explain in terms of your answer to question 4.
6. What are the two forces acting on any floating object, and in what direction does each act?
7. What two new discoveries occurred, after studying pieces of *Titanic*'s “remains” from the ocean floor, which changed researchers' understanding of the possible causes for her sinking?
8. What is steel?
9. Explain the role of sulfur in the construction of *Titanic*.
10. What role might slag possibly have played in the sinking?
11. Give four reasons cited by the author for believing that ships today are much safer than they were in the time of *Titanic*.
12. Does the author believe that ships today are unsinkable?

Answers to Student Questions

Mmmm ... Flavorful Food!

- 1. What two senses combine to produce what we perceive as flavor? Which of the two senses provides the most dominant aspect of flavor?**
Flavor is a combination of the senses of taste and smell. Smell is as important, if not more important than taste.
- 2. What additional information besides taste and smell can contribute to what we perceive as the flavor of a food or beverage?**
Other factors that contribute to the flavor of food and beverages include their texture, temperature, and color.
- 3. Where do chemists obtain natural and artificial flavors shown in a food's ingredients list?**
Chemists create these flavors from the chemicals present in plants and animals. They use these in their natural state, or they process them to make new flavors.
- 4. Do we need all the flavor compounds in a food to recreate its flavor? Explain.**
No. A flavor can usually be recreated by combining only a handful of its most abundant or most strongly flavored compounds.
- 5. From where do artificial flavors get their characteristic odor?**
Artificial flavors get their characteristic odor from esters, chemical compounds formed by the chemical reaction of an alcohol with a carboxylic acid.
- 6. How can one achieve different odors when producing esters?**
The odors of different esters are achieved by combining different alcohols and acids. For example, ethanol and butanoic acid produce an ester with a pineapple odor, while octanol and acetic acid produce an ester with the odor of an orange.
- 7. Describe the career path of a flavor chemist.**
Flavor chemists typically have a degree in organic chemistry. Once they obtain a job in the flavor industry, they would train for several years. After they pass a test, they would become a junior flavor chemist for two years. After this time, they take another test to become a senior flavorist.
- 8. Besides in food, where else do you find esters?**
Esters are responsible for the smell of everyday products such as soap, hand cream, carpet powder, and perfume.

Hold the Meat! Meat-Free Food Takes a Seat at the Table

- 1. Name three sources of protein other than meat.**
Three non-meat sources of protein include eggs, milk and legumes.
- 2. What is the basic chemical component (molecule) of protein?**
The basic component of protein is an amino acid.
- 3. What is the basic structure of the protein collagen?**
Protein collagen is made from long chains of amino acids (polypeptides) that are twisted around each other to form long fibers.
- 4. List three reasons why our bodies need amino acids in the diet.**
Our bodies need amino acids in the diet for
 - a) Growth,*

- b) *immune response, and*
- c) *the manufacture of enzymes and hormones.*
- 5. **What is so special about essential amino acids?**
Essential amino acids are those acids that our body cannot synthesize.
- 6. **In terms of essential amino acids, how does plant protein differ from animal protein?**
Plant protein tends to contain a lower amount of essential amino acids in comparison with animal proteins.
- 7. **List the major steps in forming tofu from soybean.**
The soybeans are soaked in water and then ground up into a liquid called soy milk. The milk is further heated to boiling to which is added salt. This combination of heat and salt coagulates the mixture into solids (curds) that can be pressed to remove excess fluid, producing the tofu.
- 8. **How does the process for producing tempeh differ essentially from that used to produce tofu?**
In tofu, the soybeans are ground into soy milk after soaking in water. This soy milk is further heated and treated with salts to coagulate the mixture. Tempeh is made from fermented soybeans that are then injected with a mold that transforms the material by chemical reaction into a mix of polypeptides and free amino acids.
- 9. **How does the mold growing on soybean change the bean's protein into tempeh?**
The mold produces enzymes that break down the soy globulins (protein) into smaller chains of amino acids (polypeptides) and free amino acids that constitute tempeh.
- 10. **What is the source of protein used to make seitan?**
The source of seitan's protein is from gluten found in wheat.
- 11. **How is gluten used to form seitan?**
After gluten is mixed with water and spices, the combination is kneaded (folding and squeezing the mix by hand) in order to get the two components of gluten—glutenin and gliadin—to bind together to form an elastic and stretchy dough material that is then simmered in a seasoned broth.
- 12. **What is needed to make Tofurky?**
Tofurky is made from a combination of tofu and wheat gluten

Changing the Course of Diabetes

1. **Why is research being done to create an artificial pancreas?**
People with diabetes must test their blood sugar by pricking their finger, sometimes many times a day, and many can only control the supply of insulin in their body by injection. These are painful procedures that could be eliminated if the artificial pancreas could control their need for and their supply of insulin.
2. **What are polymers?**
Polymers are "... materials that consist of chain-like molecules and that have an extraordinary range of properties."
3. **Why are polymers used in medical devices?**
"Polymers are very important for medical devices because their properties can be 'tuned' to deliver precisely the function that is needed for various demanding clinical applications."
4. **What are monomers?**
Monomers are the smaller repeating molecules that are bonded together to form polymers.
5. **Name the two categories of polymers and give an example of each.**
The two main categories of polymers:
 - a. *Natural—examples, natural rubber, DNA and proteins*
 - b. *Synthetic—example, polyethylene*

6. **What are the main functions of the polymer structure in the artificial pancreas?**
The main functions of the polymer membrane are to allow nutrients and oxygen from outside to enter the artificial pancreas and allow insulin produced by the pancreatic cells to exit the pancreas, while keeping the proteins from the immune system out so that they do not destroy this “foreign” invader (the artificial pancreas) and its contents(the pig pancreatic cells).
7. **How do chemists accomplish this function in the polymer?**
Chemists are able to accomplish this by regulating the size of the tiny holes in the polymer membrane via the degree of cross-linking of polymer chains in the network.
8. **Name two other materials that have been used in artificial pancreas research, and describe the problem(s) associated with each.**
Two other materials used in artificial pancreas research are:
 - a. *Alginates, natural polymers, have been used. Their drawback: “Alginates provide a similar network to synthetic polymers, but can’t be cross linked to create the precise density that we need for our net, so they don’t allow the right molecules to go in or out of the tube,’ Erdodi says.”*
 - b. *Perforated silicon, a non-polymeric material, has been used because it has a net-like structure similar to the Kennedy polymer prototype. The problem: “... proteins from the immune system were able to penetrate the silicon. Also, the material was not flexible and durable enough, unlike the polymers used by the UA scientists.”*
9. **What is the status of the research, as of the date of the article, and where do researchers go from here?**
The prototype is being tested on lab rats presently. The next step is to work on larger animals, in order to get to clinical trials on human patients, eventually to get FDA approval to make it available commercially.
10. **Name three other areas of medical research where polymers play an important role.**
Three other areas of medical research employing polymers are:
 - a. *Artificial hearts*
 - b. *Synthetic lungs*
 - c. *Kidney dialysis membranes*

Your Body Under Construction

1. **In which organs of the body are hormones produced?**
Hormones are produced in glands that are part of the endocrine system.
2. **Name the hormone responsible for male sex characteristics.**
The chemical substance responsible for male sex characteristics is called testosterone.
3. **What are androgens?**
Androgens are the steroid hormones that stimulate and regulate male sex characteristics. In the article testosterone is the androgen that is mentioned. Others include dihydrotestosterone , androstenedione, dehydroepiandrosterone, each of which controls a process related to the development of male sex traits.
4. **What is anabolism and how does it involve hormones?**
Anabolism is the sum of the processes which build up our bodies—for example, increasing bone length and strength or increasing muscle mass. Hormones are the chemical which initiate many anabolic processes. Since the hormones that stimulate the growth of male and female sex organs are steroid hormones, they are commonly called anabolic steroids.
5. **Describe the concept of molecular “form and function” discussed in the article.**
This principle states that the shape of molecules determines how they work. For example, the only cells that are affected by a given hormone are cells that have a “receptor” site, the

shape of which corresponds to the shape of the hormone molecule. If the hormone molecule is able to “fit” into the cell receptor, then the hormone will produce a change in that cell, but will not affect cells that do not have the correct receptor shape.

6. **What molecular structure do all steroid hormones have in common?**

Steroid hormones are derived from the cholesterol molecule which has a basic four-ring structure. There are three six-sided (cyclohexane) rings along with one five-sided (cyclopentane) ring. See the diagram below right. Rings A–C are the cyclohexane rings and ring D is the cyclopentane ring. Functional groups may be added to the basic structure to produce various hormones. (See “More on hormones and the endocrine system” for additional details.)

7. **Name the hormones responsible for female sex characteristics.**

There are a number of these hormones responsible for female sex characteristics, collectively called estrogens—even though the singular “estrogen” is frequently used. The compounds are estradiol, estriol and estrone, as well as progesterone, which is important during pregnancy.

Titanic: Was It Doomed by Chemistry?

1. **Give two reasons to explain why the ship makers who constructed Titanic believed it was unsinkable.**

Ship makers of the day believed Titanic to be unsinkable because the bottom of the hull was a double layer of steel, and the hull was made of 16 watertight compartments, more than four of which would need to be breached in order for the ship to sink.

2. **After Titanic struck the iceberg, why did it sink?**

Titanic sank because five of the watertight compartments were breached, water rushed in to fill these compartments, and the ship became too heavy to stay afloat.

3. **What was responsible for the overnight deaths of the people in the still floating in the water?**

People left floating in the water died from hypothermia due to the frigid water temperature.

4. **Why do objects float?**

Objects float because its density is less than the fluid (in this case, water) around it.

5. **What are the two forces acting on any floating object, and in what direction does each act?**

The two forces acting on a floating object are gravity, acting downward, and buoyancy, acting upward.

6. **What changed to cause Titanic to sink? Explain in terms of your answer to questions 4 and 5.**

Titanic floated because its density was less than the water around it, until the hull was breached. Once the cracks occurred, sea water flooded those compartments, adding weight to the ship. This increased the density of the ship until it exceeded the density of the sea water, whereupon the gravitational pull downward became greater than the buoyant force lifting it up, and it sank.

7. **What two new discoveries occurred, after studying pieces of Titanic’s “remains” from the ocean floor, which changed researchers’ understanding of the possible causes for her sinking?**

The two new discoveries were:

- The abnormally high sulfur content in the steel used to make Titanic’s hull, which resulted in less malleable, more brittle steel (more prone to cracking), and*
- The abnormally high slag content in the steel used to make the rivets that held together the steel plates comprising the hull. This would have resulted in increased brittleness,*

making them more prone to having their heads pop off, loosening the steel plates and allowing water to enter through the gaps in the plates.

8. What is steel?

Steel is an alloy made principally of iron and a little carbon (0.2–2.1%) or other additives to reduce its malleability and to give it more strength. Too much additive can reduce malleability to the point of being brittle.

9. Explain the role of sulfur in the construction of Titanic.

Sulfur added to iron in the manufacture of steel reduces its malleability and increases its strength and brittleness. Large amounts of sulfur make steel brittle. The sulfur content of the steel of Titanic's hull made that steel 10 times more brittle than normal.

10. What role might slag possibly have played in the sinking?

Adding slag to iron also decreases malleability and increases brittleness. Rivets made with this higher-than-normal slag content are more brittle and therefore prone to shearing of the head of the rivet under stress. This could have allowed gaps to form between the plates of steel forming the hull, allowing water in.

11. Give four reasons cited by the author for believing that ships today are much safer than they were in the time of Titanic.

The four reasons cited by the author to support the idea that ships today are much safer than in the time of Titanic are:

a. Improved steel-making techniques, resulting in tougher, less brittle metal,

1) The hull plates of today's ships are welded together, not riveted; welds are as strong as the original steel.

2) Hulls are thicker than they were then.

3) The watertight compartments are not linked together, so water can't leak from one to another.

b. Iceberg detection is much improved, involving radar

c. Sufficient lifeboats for all passengers and crew

d. Satellite communications, GPS and computerized navigations systems are in use today.

12. Does the author believe that ships today are unsinkable?

The author's position is that ships are believed to be safe, and have many features that make them safe, but "no ship is really unsinkable."

ChemMatters Puzzle: Chem Anagrams

Chemistry is everywhere ! And that includes some common English words. Your task in these two puzzles is to find some terms widely used in Chemistry that are present as an anagram of an English word. But to make things more interesting, the English term will have one more letter than the chemistry term. It will be your job to determine which letter that is, and solve the anagram once it's removed. For example, given the word LEMON, one could drop out the N and rearrange the remaining four letters to give MOLE.

Here's a hint. ALL the hidden words in a list have something in common. In list #1 that common theme is units for measurements, such as KELVIN (for measuring temperatures). Some are SI units and some not, but all are in common use. In list #2, it's up to you to find the category ! Once you get a few of the words, you'll know what the commonality is, and that might be helpful in solving other words.

The bottom item on each list is not really fair game, and so we've set them apart. Good luck with the two.

Have fun deciphering these terms !

LIST #1		LIST #2	
Category : Measurement UNITS		--	???
Ex: <u>o h m</u>	HOME	--	hip
---	mast	-----	acid
---	palm	-----	beast
---	loom	-----	least
-----	gamer	-----	sonic
-----	lacks	-----	awake
-----	tiller	-----	tongers
-----	scorned	-----	mortality
-----	palaces	-----	Born dates
---	MERE	--	YAK

Answers to the *ChemMatters* Puzzle

LIST #1	theme is UNITS	LIST #2	theme is ACID /BASE theory
	ohm		pH
	atm		acid
	amp		base
	mol		salt
	gram		ions
	kcal		weak
	liter		strong
	second		molarity
	pascal		Bronsted (as in the Bronsted-Lowry theory of
proton transfer)			
	rem		K_a

K_a is an equilibrium constant that measures the strength of an acid.

rem is a unit for measuring exposure to nuclear radiation by humans.

mol is the official SI unit for measuring amount of substance. For example a common energy term is kJ/mol .

NSES Correlation

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	Flavorful Food	Hold the Meat!	Diabetes	Body Under Construction	Titanic
Science as Inquiry Standard A: of abilities to do scientific inquiry.					✓
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 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: 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.

Mmmm . . . Flavorful Food!

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 flavor of food depends on its smell, texture, color and temperature.
		2. Smelling food is the same as smelling something you don't eat, like roses.
		3. Chocolate, vanilla, and coffee are each made of hundreds of chemicals compounds mixed together.
		4. The artificial orange flavor in Tang beverage has more chemicals in it than the orange flavor from a natural orange.
		5. Lemon-lime candy and lemon-lime soda probably have the same flavor chemicals.
		6. When chemicals combine chemically, they lose their individual characteristics.
		7. Flavor chemists typically train for two years after graduating from college with a degree in chemistry.
		8. Esters are responsible for the flavor and smell of many everyday products.

Hold the Meat!

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. Proteins are found only in meat.
		2. There are 21 known amino acids, and our bodies can make all of them if we eat meat.
		3. You should eat a variety of amino acids at every meal to meet your protein requirement.
		4. The World Health Organization claims that the average American consumes more than three times the amount of protein needed to be healthy.
		5. Soybean, used to make tofu, has all of the essential amino acids.
		6. Some vegetarian proteins are made from wheat.
		7. Soy protein has been added to school lunches and fast food since the 1950s.
		8. Today you can buy protein that has been developed by chemists in a lab.

Changing the Course of Diabetes

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. Diabetics do not produce enough insulin because their immune system destroys the cells that produce insulin.
		2. Scientists are trying to develop an artificial pancreas by using polymers.
		3. So far, scientists have not found polymers in nature.
		4. A semipermeable membrane allows some substances to pass through it, but not all.
		5. An artificial pancreas would work by monitoring the amount of glucose in the blood and delivering insulin to the body when it is needed.
		6. The World Health Organization predicts the number of diabetics worldwide will remain constant for the next few decades.
		7. The artificial pancreas described in the article is currently being tested, in humans and will be available to diabetics within the next two years.
		8. In the future, it may be possible to replace many organs in your body, including your heart, lungs, and kidneys, with polymers.

Your Body Under Construction

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. Growth and development of human beings is based on chemicals.
		2. Every year, your body replaces about 50% of your atoms with new ones.
		3. To have an effect, most hormones must be present in fairly large amounts, often as large as one gram.
		4. Steroids come from cholesterol.
		5. Often, the shape of molecules determine how they work.
		6. Both testosterone and estrogen are steroids.
		7. Many people believe that hormones affect behavior, but that has not been demonstrated in the lab.
		8. Insulin is a hormone.

Titanic: Was It Doomed by Chemistry?

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 Titanic sank more than 100 years ago.
		2. Experts believe that the iceberg was difficult to see because the ice was melting.
		3. Many experts believe that if the Titanic would not have sunk if it had struck the iceberg head-on.
		4. If the damage to the Titanic had occurred near the water line, the water would have rushed into the ship faster.
		5. The Titanic sank because its mass increased.
		6. The buoyant force on an object floating in water depends on how much water is displaced by the object.
		7. The iron in the steel on the Titanic had a high sulfur content, making it much more brittle than today’s steel.
		8. The rivets used to fasten Titanic’s steel plates together were of the highest quality.
		9. Ships today are built much the same as ships 100 years ago.
		10. Since ships today use radar to detect icebergs, no ship using radar has struck an iceberg and sunk.

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

Mmmm. . . Flavorful Food

Directions: As you read, complete the chart below describing how each factor contributes to the flavor of food.

Factor	Effect on flavor
Smell	
Color	
Texture	
Natural flavors	
Artificial flavors	
Esters	

Think of an example of a flavor you enjoy but your best friend doesn't like. Did the article provide information to help you understand the reason for the difference? If so, please explain.

Hold the Meat!

Directions: As you read, complete the chart below to compare the meat substitutes described in the article.

Meat Substitute	Source of Protein	How produced	Texture(s)
Tofu			
Tempeh			
Seitan			
Tofurky			

Have you ever tried any of the meat substitutes described? If so, how did you like them?

Changing the Curse of Diabetes

Directions: As you read, find and describe at least four examples of natural and synthetic polymers, including the ones used to make the artificial pancreas described in the article.

Polymer example	Where found	Use(s)	Synthetic or natural?

In the chart below, explain the importance of the polymer properties named in the chart to the development of an artificial pancreas.

Polymer properties	Why important to development of artificial pancreas
Long-chain	
Semipermeable membrane	

Do you know anyone who has diabetes? How will the artificial pancreas help them?

Your Body Under Construction

Directions: As you read, compare testosterone and estrogen using the chart below. Write the differences in the top part of the chart, and the similarities in the bottom part.

Testosterone	Estrogen
Similarities	

Titanic: Was It Doomed by Chemistry?

Directions: As you read, describe the different factors that many experts conclude may have contributed to the sinking of the Titanic.

Factor	How did this factor affect the sinking of the Titanic?	What, if anything, is done today to protect ships from this factor?
Ice was melting.		
Iceberg was struck on the side of the ship.		
Damage occurred at a depth of 6 meters below water line.		
The force of gravity on the ship exceeded the buoyant force on the ship.		
Steel had a high sulfur content.		
Rivets contained a high amount of slag.		

Mmmm ... Flavorful Food!

Background Information (teacher information)

More on the senses of taste and smell

As the Heiss article states, “The flavor of food is due mostly to how it tastes and smells.” Extensive information on how these two senses function has been part of recent *ChemMatters* Teacher’s Guides.

The April 2008 Teacher’s Guide (http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/archive/WPCP_012145) contained the following in-depth description of the sense of smell. Interestingly, the article it was connected with was “Sniffing Landmines”, which focused on the ability of dogs to use their sense of smell to detect landmines.

Taste and smell respond to the specific chemical nature of substances, and for this reason they are collectively known as the chemical senses.

Much of our detailed understanding of how smell works was discovered by Linda B. Buck and Richard Axel, who independently carried out intensive studies into how olfaction, the process of smelling, works. The two scientists shared the Nobel Prize for Physiology or Medicine in 2004 for their discoveries.

Buck and Axel studied a type of cell found in the nose called olfactory receptor cells, and a family of proteins called receptor proteins found in those cells. By studying mouse olfactory receptor cells, they found that each such cell contained only one type of receptor protein. In mice there are over 1,000 different kinds of receptor proteins, although humans may possess only about 350.

Proteins are long chain-like molecules, made by joining together many amino acid molecules. Receptor proteins are found at the surfaces of receptor cells, and the proteins snake in and out of the cell membrane, crossing it seven times. In the process, receptor proteins are twisted and bent into different shapes, creating cavities of different shapes and sizes. Each receptor protein has a different cavity shape. Odorant molecules can dock with these cavities in the receptor proteins. The shape of the cavity of a particular receptor protein is shaped to allow only members of specific families of molecules to dock with it, in the familiar lock-and-key manner of protein-substrate chemistry. This means that each kind of receptor protein responds to only a specific family of compounds. While a human may only have 350 or so different kinds of receptor cells, many odors are made of combinations of substances. Humans can discern as many as 10,000 different odors, that is, 10,000 different combinations of substances. In addition, within a chemical family, different members may not bind to the same receptor protein, allowing additional levels of nuance in the smell that is perceived.

When a molecule docks with a receptor protein, the shape of the protein changes, triggering an electrical signal which is transmitted first to an organ called the olfactory bulb, which sits just over the bone that forms the roof of the nasal cavity in the skull. From the olfactory bulb, signals are then relayed to the brain where they are interpreted as odor.

Inside the nose, receptor cells are attached to a tissue called the olfactory epithelium. In humans, the olfactory epithelium is rather small, and only covers a small part of the surface of the inside of the nasal cavity near the cavity's roof. (pp 40–41)

The way that chemicals are able to reach the olfactory receptor cells described above was discussed in the October 2010 *ChemMatters* Teacher's Guide (http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/archive/CNBP_025802):

The nose is associated with the sense of smell. Receptors in the nose line the top of the nasal cavity. They are covered with a coating of mucus and have hair-like attachments that project into the nasal cavity. As air moves over the receptors, chemicals present in the air can dissolve in the mucus and interact with the hair-like attachments in order to pass along information that will eventually reach the brain. A substance must produce a vapor in order to be part of this process; smells are sensed only when gaseous molecules dissolve in the mucus. Some individuals cannot detect the odor of a particular substance or group of substances, and are called "anosmic" toward a particular odor. This is similar to the condition of color blindness that is associated with the sense of sight. (p 49)

Processes involved in the sense of taste were described in the December 2008 *ChemMatters* Teacher's Guide (http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/archive/WPCP_011348):

In humans the sense of taste consists of taste buds, receptor cells, and taste nerves. Taste buds are located on the tongue on small bumps of skin called papillae. Taste buds themselves are too small to see, but the papillae are clearly visible, especially if you place a drop or two of blue food coloring on the tongue. There are about 10,000 taste buds in humans.

The article ["Tasteful Chemistry"] describes a taste bud being made up of bundles of taste cells, and on the surface of these taste cells are taste receptors. There are typically 50–150 taste cells per taste bud. On any taste bud there are receptors for all five tastes. The receptors respond to molecules of food or drink by triggering chemical changes that eventually send signals to the brain, which the brain interprets as some kind of taste.

Within each taste bud there are receptors cells for each of the five types of taste—sweet, sour, salty, bitter and umami. Each of these receptors cells can detect and respond to potentially hundreds or thousands of individual molecules in food and drink. Current research has found that taste has a genetic base with specific genes producing specific proteins that act within the receptors. These proteins are described in families such as T1R (sweet tastes) or T2R (bitter tastes). Receptor cells are replaced in humans about every ten days.

Interspersed between receptors cells are nerve cells which eventually transmit impulses to the brain. The process begins when a molecule binds to a receptor. This causes the cells to depolarize, which in turn activates the taste nerves. Two substances involved in the neurotransmission are neuropeptide Y (NPY) and cholecystokinin (CCK).

Underlying this complex neurobiology are three simpler chemical concepts—solubility, electrolytes and molecular polarity. When food is first ingested, saliva in the mouth begins the digestive process. Molecules in food dissolve in the water, which brings molecules in contact with taste receptors. If the dissolved molecules are polar, the resulting electrolyte ions play a role in the taste process. Polar molecules bind with the receptors, which triggers a micro-potential difference in nearby nerves, thus sending signals to the brain via one of three cranial nerves—the facial nerve, the vagus nerve, and the glossopharyngeal nerve. Ions like Na^+ and Ca^{++} play an important role in taste. Nonpolar solutes create taste sensations by entering the taste cell itself where a potential difference is created to send signals to the central nervous system

The intensity of a specific taste is directly related to the concentration of dissolved solute. The greater the number of dissolved molecules coming in contact with taste receptors, the more intense the taste. Receptors also have thresholds for taste. If the solute concentration is too low, there will be no taste reported. Below are some examples of threshold concentrations for various tastes:

Taste	Compound	Concentration (Molarity)
Salty	NaCl	0.01
Sour	HCl	0.0009
Sweet	Sucrose	0.01
Bitter	Quinine	0.000008
Umami	Glutamate	0.0007

It should be noted that many chemicals can produce the same taste. Within a given taste there are different thresholds for different chemicals. For example, sucrose, 1-propyl-2 amino-4-nitrobenzene and lactose all taste sweet, but the range of threshold concentrations of these three varies by a factor of 15,000.

As the article [“Tasteful Chemistry”] states, there are four traditional tastes—sweet, sour, bitter and salty—and one more recent addition to the list—umami. Each of these is believed to have a specific role. For example, sweet taste lets a person know that what they are ingesting is probably rich in energy. The salty taste is important in humans in order to maintain an electrolyte balance. And bitter and sour tastes raise the alarm about foods that are rotten or poisonous.

More on flavors

The things we eat provide us with a multitude of different flavors. One classification of flavors places them into nine different classes (see below). The December 2008 *ChemMatters* Teacher’s Guide included the listing of flavor classes, along with information on flavor compounds present in food (http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/archive/WPCP_011348).

The major nutrients—fats, carbohydrates and proteins—have no flavor compounds. However, amino acids (protein), sugars (carbs) and fatty acids (fats) do have hundreds of flavor compounds that elicit one of the five tastes. The major nutrients develop flavor compounds when they are heated to 250-500F. Likewise, heating increases the number of flavor

compounds in amino acids, sugars and fatty acids. Fermentation also increases the number of flavor compounds in many foods.

The Department of Food Science Technology at Ohio State University provides this list of flavors:

Flavor Class	Subdivision	Representative Example
Fruit flavor	citrus-type flavors	grapefruit, orange
	berry-type flavors	apple, raspberry, banana
Vegetable flavors		lettuce, celery
Spice flavors	aromatic	cinnamon, peppermint
	lachrymogenic	onion, garlic
Beverage flavors	unfermented flavors	hot pepper, ginger
	fermented flavors	juices, milk
	compounded flavors	wine, beer, tea
Meat flavors	mammal flavors	soft drinks
	seafood flavors	lean beef
Fat flavors		fish, clams
		olive oil, coconut fat, pork fat, butter fat
Cooked flavors		broth beef bouillon
		vegetable legume, potatoes
		fruit marmalade
Processed flavors	smoky flavors	ham
	broiled, fried flavors	processed meat products
	roasted, toasted, baked	coffee, snack foods, processed cereals
Stench flavors		cheese

(Taken from <http://class.fst.ohio-state.edu/fst820/820-1.pdf>)

The flavor industry is a major industry in the United States. Chemical flavors and additives are produced for almost every food on the market. In addition to isolating and identifying natural flavor compounds, the industry also produces synthetic flavor compounds for a wide variety of uses. (p 33)

One product that students may be familiar with that can be used to contrast the idea of natural versus artificial flavors is the difference between pure and artificial vanilla flavoring. Pure vanilla flavoring is made from vanilla beans. When the beans are ripened and fermented, they generate vanillin, the dominant flavor of vanilla bean extract. The vanillin, along with many other organic compounds in the beans, is extracted using ethyl alcohol. The compounds all add to the complex flavor of the extract. The process is extensive; the *ChemMatters* article "Vanilla! It's Everywhere!" states, "From planting to market can take five years, making natural-grown vanilla the second most expensive flavor, after saffron" (p 4). A much less expensive substitute is to use synthetic vanillin. It used to be produced from lignin, a waste product generated during papermaking, but it is now more likely to be made from petroleum or coal tar (p 6). Artificial vanilla flavoring is mostly synthetic vanillin and is much less expensive than pure vanilla flavoring. In the United States, the Food and Drug Administration has laws regarding the proper labeling of vanilla products. Artificial vanilla flavoring is sometimes illegally passed off as vanilla extract because it can be sold for much more than it cost to produce it. So even flavors can sometimes be "counterfeited"!

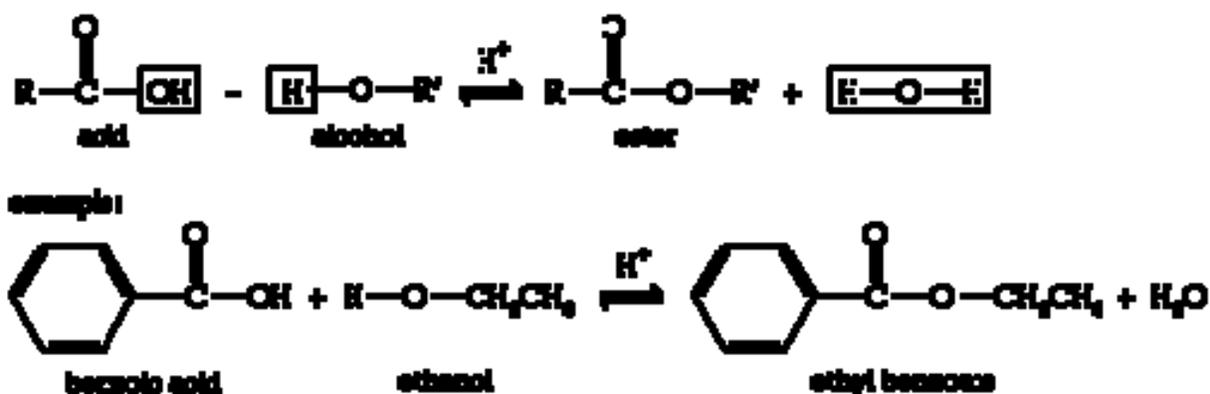
The effect of other chemicals on how we perceive a particular flavor is another interesting topic. The April 1995 *ChemMatters* article "Why does orange juice taste so bad after you brush your teeth?" investigated the question asked by its title. The answer involves the fact

that sodium lauryl sulfate (SLS), which is a common ingredient in toothpaste, can affect how we sense the tastes of sweet, sour, salty, and bitter. The article describes an experiment where people “were asked to report the relative intensities of tastes from sucrose and citric acid. Later, the same people rinsed their mouths with a solution of SLS, tasted the compounds again, and made another report. SLS slightly reduced the sweet taste of sucrose but strengthened the bitter taste of citric acid” (p 15). So, if one drinks orange juice, an acidic citrus beverage, after brushing his or her teeth, the bitter taste can be strengthened. But, the effect may not be the same for all, as people “have genetic differences in their ability to taste bitterness” (p 15). The author, for example, reports that “orange juice tastes fine to me after I brush my teeth” (p 15).

Both teachers and students may be interested in Molly Birnbaum’s book *Season to Taste*, a recently published first-person account of someone who lost her sense of smell due to a car accident (and ends up regaining it). The event derailed her plans to become a chef. She describes how depending only on her sense of taste and other cues such as texture, temperature, etc., affected the flavor of foods. The book also chronicles her exploration into how the sense of smell works. She spoke to scientists, flavor chemists, and perfumers. She even talked to Ben Cohen, of Ben & Jerry’s ice cream. Because he has had little sense of smell for most of his life, he wanted the ice cream to have lots of “textural chunks” to add to his eating experience. Some of her experiences are described online at http://www.nytimes.com/2011/06/15/dining/molly-birnbaum-the-cook-who-couldnt-taste.html?_r=1&pagewanted=all.

More on esters

Esters can be synthesized through a condensation reaction between a carboxylic acid and an alcohol in the presence of a catalyst, such as sulfuric acid. The products are the ester and a water molecule. A generalized form of the reaction, followed by a specific example, is shown below (images from <http://www.britannica.com/EBchecked/topic/193393/ester>):



In the second reaction, ethanol reacts with benzoic acid to produce ethyl benzoate and water. Ethyl benzoate has been described as having a fruity flavor, but also reminiscent of wintergreen (<http://www.thegoodscentscompany.com/data/rw1004771.html>). A detailed look at the mechanism of the esterification reaction can be found online at <http://www.chemguide.co.uk/physical/catalysis/esterify.html>.

The naming of esters can be illustrated using the example reaction from the article (butanoic acid + ethanol). The name of an ester first has the name of the group from which the

alcohol came from (ethanol → ethyl), then the group from which the acid came from (butanoic acid → butanoate). The *-ate* ending in an organic compound signifies an ester. The pattern can also be seen in the additional three esters shown in table 1 from the article.

A long list of esters, along with their structures and odors, is available online at <http://en.wikipedia.org/wiki/Ester>.

The February 2007 *ChemMatters* Teacher's Guide (http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/CTP_005412) included a section on esters (p 58):

Physical Properties:

1. Physical State: Lower molecular weight esters are colorless liquids. Higher weight esters are waxy solids.
2. Odor: All esters have a strong odor.
3. Solubility: Lower weight esters are soluble in water. The solubility decreases with increase in molecular weight. See examples below. Esters form hydrogen bonds with water. Esters are soluble in organic solvents. Esters themselves are good organic solvents.

Name	Mol. Mass	Solubility (g/100 g water)
ethyl methanoate	64	10.5
ethyl ethanoate	76	8.7
ethyl propanoate	102	1.7

4. Acidic nature: Esters are neutral to litmus tests.

Chemical Properties:

As the article ["Alice A. Ball: Young Chemist Gave Hope to Millions"] describes, esters are one class of organic compounds. Ester molecules tend to be polar molecules and so have dipole interactions and dispersion forces. They do not form hydrogen bonds.

Hydrolysis of esters: Esters break down into their respective organic acid and alcohol from which they are formed in a process called hydrolysis. Hydrolysis of ester with an alkaline solution like sodium hydroxide is known as saponification (soap making).

Uses of organic esters:

- in artificial perfumes or scents as they emit a sweet smell
- in making artificial food flavors that are added in foods like ice cream, soft drinks, sweets, etc. Some of the flavors and the esters responsible for them include:

ethyl acetate	peach, pineapple, raspberry
ethyl butyrate	banana, pineapple, strawberry
ethyl cinnamate	cinnamon
methyl acetate	peppermint
methyl butyrate	pineapple
methyl salicylate	wintergreen
- as industrial solvents for making cellulose, fats, paints and varnishes
- as solvents in pharmaceutical industries
- as softeners in plastic industries and molding industries

Of some interest to students are more complex esters, specifically esters which are formed by the reaction of fatty acids with glycerol, which has three alcohol groups.

Glycerol is also called 1,2,3-propantriol. These are called triesters or triglycerides. These are better known to students as fats or oils. (p 58)

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic Chemistry**—The article's discussion of esters can be linked to the topics of organic structures, functional groups, and nomenclature. The article shows the reaction of a carboxylic acid and an alcohol to form an ester, in both general and specific examples. Students could investigate different combinations of acids and alcohols, with their accompanying structures, names, and odors.
2. **Biochemistry**—The senses of taste and smell are discussed in the article. The ways that chemicals are sensed through taste and smell could be investigated.
3. **Enzymes**—Receptor protein cavities in the nose are certain shapes that allow only certain odorant molecules to dock with them, as in the familiar lock-and-key manner associated with enzymes.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **"The flavor of a food or beverage is only a result of information collected by our taste buds."** *Flavor is a combination of the senses of both taste and smell. Smell is actually the most dominant aspect of flavor. Other things also contribute to our perception of flavor, including temperature, texture, and color of the food or beverages.*
2. **"The flavor of a food or beverage is the same all of the time."** *The flavor of a food or beverage changes depending on how it is prepared or cooked. For example, tomatoes could be prepared as a sauce with various spices, dried until crunchy, served cold in a salad, as a juice, etc. These preparations can affect the temperature, texture, and color of a food, which also affect how we perceive its flavor.*
3. **"To recreate the natural flavor of a food and make an artificial flavor, we need all the flavor compounds from that food."** *We don't need all the flavor compounds in a food to recreate its flavor. For instance, an orange contains 250 aromatic chemicals, which all combine to create an orange flavor. In contrast, artificially-flavored Tang has only six aromatic chemicals in its makeup, yet it tastes like an orange.*
"Esters are only found in food." *Esters are added to many other products we use in our everyday lives, such as soap, hand cream, candles, carpet powder, and more, to give them a pleasant odor.*

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

1. **"Can all flavors be duplicated?"** *The book Food Bites: The Science of the Foods We Eat (Hartel, R. W.; Hartel, A. Food Bites: The Science of the Foods We Eat; Copernicus Books: New York, 2008) states "Flavor chemists synthesize imitation flavors by analyzing all the different component chemicals that go into a flavor, then mixing together the primary chemical components in those flavors. Many artificial flavors, such as strawberry and cherry,*

can be quite close to the natural version because they contain just a few main flavor chemicals. Because of the broad spectrum of chemical components in chocolate, some of which are found at extremely low, but significant, levels, a decent imitation chocolate remains elusive.” (pp 60–61) (available at http://books.google.com/books?id=PMOrW3zkiwC&pg=PA60&lpg=PA60&dq=synthetic+chocolate+flavor&source=bl&ots=-IPlwytUS7&sig=JO5scR6z4pE5h_uzOc4BTg1nW7s&hl=en&ei=zZeKTq7HCcfsQLqn9WIB_A&sa=X&oi=book_result&ct=result&resnum=5&ved=0CEsQ6AEwBA#v=onepage&q=synthe)

2. **“Do all esters smell pleasant?”** When one thinks of esters, they are most often associated with a pleasant, often fruity, smell. However, not all esters even have an odor and some may have an odor we find unpleasant. For example, the ester ethyl acetate is found in nail polish remover, model paint, and model airplane glue, most likely smells we would not enjoy.

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

1. The December 2003 *ChemMatters* Teacher’s Guide (http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/CTP_005457) describes one activity as, “A somewhat nonscientific comparison of different types of vanilla”, where the Teacher’s Guide author and his wife investigated imitation vanilla and pure vanilla extract to answer the questions: “(1) Can we discern any difference, and (2) which product would we prefer if we couldn’t see the labels?” (pp 21–23).
2. The combination of taste, smell, texture, appearance, etc. to give us a perception of a particular flavor can be investigated by students using actual food using the *JCE* Classroom Activity “Apple Fool! An Introduction to Artificial Flavors” (*J. Chem. Educ.* **2003**, *80* (4), pp 408A–B). The description of the activity reads, “Students investigate flavorings by making artificial ‘cooked apples’ from a mixture of crackers, sugar, cream of tartar, and water, as is done for the filling in recipes for Mock Apple Pie. The mixture looks much like applesauce, and the Activity can be extended to include taste testing and pie baking.” (*J. Chem. Educ.* **2003**, *80* (4), pp 408A–B)
3. Laboratory manuals and textbooks often include an experiment where students make different esters by reacting various combinations of carboxylic acids with alcohols in the presence of a catalyst such as sulfuric acid. One laboratory is available in *ChemCom*, 5th ed., pp 275–277; students make esters that smell like wintergreen, banana, and orange. Another laboratory is in *ChemSource 3.0*, Organic Chemistry Module, pp 5–10.
4. Students can try the “orange juice test” described in the April 1995 *ChemMatters* article “Why does orange juice taste so bad after you brush your teeth?” The directions read: “Take a sip of orange juice and note the relative strength of the sweet, sour, and bitter tastes. Rinse your mouth with water, then vigorously brush your teeth with SLS-containing toothpaste [sodium lauryl sulfate]. Rinse with water again, then taste the orange juice again. Are the relative intensities of the tastes very different?” (p 15)
5. Have students compare their ability to identify foods using taste alone, versus taste and smell together. Two “smell and taste test” experiments available online are <http://www.reachoutmichigan.org/funexperiments/agesubject/lessons/newton/tstesmll.html>, which uses jelly beans, and <http://faculty.washington.edu/chudler/pdf/tastetg.pdf>, which uses various food items, and asks students to devise their own experiment regarding the sense of taste. (from *ChemMatters* October 2010 Teacher’s Guide, p 57,

http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/archive/CNBP_025802)

6. Students can investigate the linkage of taste and the color of a beverage. Students could color drinks using different colors of food dye and study whether the color of the drink affects flavor identification by a taster. A site summarizes studies that examined the results of similar activities (see <http://faculty.washington.edu/chudler/coltaste.html>). (from *ChemMatters* October 2010 Teacher's Guide, p 57, http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/archive/CNBP_025802)

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

1. Students could locate and bring to class everyday products other than food that contain esters.

References (non-Web-based information sources)

The authors of a *Journal of Chemical Education* article describe a demonstration program focusing on the ideas of “odor + taste = flavor” and the role of esters in foods. The program includes the use of scratch-and-sniff stickers, taste testing sodas without being able to see their colors (with noses plugged and unplugged), and chewing spearmint gum with noses plugged and unplugged. (Clarke, M.; Brown, A.; Epp, D. N.; Gallup, M.; Wilson, J. R.; Wuerthele, J. A. Ester, What's in My Food? *J. Chem. Educ.* **1986**, 63 (12), pp 1050–1051)

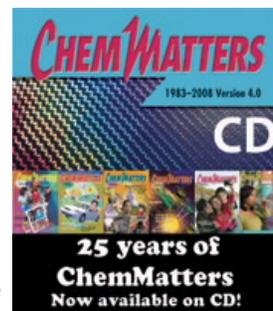
In a *Journal of Chemical Education* activity, students use grocery store materials (snack crackers, sugar, cream of tartar, and water) to attempt to recreate the flavor of cooked apples. (*JCE* Staff. Apple Fool! An Introduction to Artificial Flavors. *J. Chem. Educ.* **2003**, 80 (4), pp 408A–B)

The *Chemistry in the Community (ChemCom)* 5th ed., textbook contains a section on condensation reactions, which includes the formation of esters. A laboratory investigation is included. (American Chemical Society: Washington DC, 2006; pp 275–277)

A SourceBook module includes a laboratory investigation focusing on the synthesis of esters. (Becker, W.; Epperson, B.; Lamb, W. “Organic Chemistry” in *SourceBook*, Version 3.0, edited by Orna, M. V.; Smith, P. J. V. ChemSource, Inc.: New Rochelle, NY, 2010)

A woman's experience of losing her sense of smell and its affect on her ability to experience flavors is described in the book *Season to Taste*. (Birnbaum, M. *Season to Taste*; HarperCollins: New York, 2011)

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>. (At the bottom of the Web site 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.)

An in-depth discussion of the sense of taste is the focus of a past *ChemMatters* article. (Pages, P. Taste of Chemistry. *ChemMatters* **2008**, 26 (4), pp 4–6)

Different aspects of vanilla, such as its growth and harvesting, history, and medical use, are discussed in this article: Haines, G. K. Vanilla! It's Everywhere! *ChemMatters* **2003**, 21 (4), pp 4–6.

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

More sites on the senses of taste and smell

The report "Seeing, Hearing, and Smelling the World" on the Howard Hughes Medical Institute Web site contains a section "The Mystery of Smell". (<http://www.hhmi.org/senses/d110.html>)

The Web site http://www.nobelprize.org/nobel_prizes/medicine/laureates/2004/illpres/ describes the workings of the olfactory system, for which Richard Axel and Linda Buck shared the 2004 Nobel Prize in Physiology or Medicine.

Bassam Z. Shkhashiri's Web site includes an informational Chemical of the Week handout entitled "Chemoreception: The Chemistry of Odors". (<http://www.scifun.org/CHEMWEEK/PDF/Chemoreception.pdf>) (from the October 2010 *ChemMatters* Teacher's Guide, p 59)

Artificial versions of sense organs have already been produced. *Wired Magazine* reported on the use of an artificial tongue to distinguish between different sweeteners at <http://www.wired.com/wiredscience/2009/08/tastesweet/>.

The Web site http://science.nasa.gov/science-news/science-at-nasa/2004/06oct_enose/ reports on the work NASA researchers have done on an artificial nose for use in space. (from the October 2010 *ChemMatters* Teacher's Guide, p 61)

More sites on flavors

A 2008 *Chemical & Engineering News* article describes how three start-up flavor companies are borrowing the methods of pharmaceutical research companies in order to look for new flavors. (<http://pubs.acs.org/cen/business/86/8614bus1.html>)

The “HowStuffWorks” Web site addresses the question “How do artificial flavors work?” (<http://www.howstuffworks.com/question391.htm>)

A 2002 *Scientific American* article discusses the difference between artificial and natural flavors. (<http://www.scientificamerican.com/article.cfm?id=what-is-the-difference-be-2002-07-29>)

The American Chemical Society Web site describes the careers of food and flavor chemists. (http://portal.acs.org/portal/acs/corg/content?nfpb=true&pageLabel=PP_ARTICLEMAIN&node_id=1188&content_id=CTP_003389&use_sec=true&sec_url_var=region1&uuid=ddcfcd5b-59ed-4a8b-b026-61456fae520c)

The *Occupational Outlook Quarterly* Web site describes the career of a flavorist. (<http://www.bls.gov/opub/ooq/2004/winter/yawhat.htm>)

A five-minute DiscoveryNews video profiles a flavor chemist. (<http://news.discovery.com/videos/human-flavor-chemist-cool-jobs.html>)

The Department of Food Science and Technology of Ohio State University offers a multi-part page on flavor chemistry. (<http://fst.osu.edu/min/Flavor%20Chemistry.htm>)

More sites on esters

Two Web sites offer laboratories focusing on ester synthesis, with introductory information on esters, experiment procedures, and student questions. (<http://www.hartnell.cc.ca.us/faculty/shovde/chem12b/esters.htm> and <http://www.chymist.com/Esters - Introduction.pdf>)

An introduction to esters includes multiple examples of chemical structures and a list of esters with their odors. (<http://www.3rd1000.com/chem301/chem301v.htm>)

More than a dozen manipulable Jmol molecular models of esters are available online at <http://www.JCE.DivCHED.org/JCEWWW/Features/MonthlyMolecules/2009/Nov/>.

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

“The Flavor of Organic Chemistry” is a three-part unit that introduces students to organic chemistry through the study of flavor. The three lessons are titled “What is flavor....and how do we know?”, “Making scents of esters”, and “Flavor-‘fool’”. Student handouts and teacher preparation instructions are included. (<http://apps.caes.uga.edu/sbof/main/lessonPlan/FlavorofOrganicChemistry.pdf>)

Students can investigate the sense of smell and the idea of olfactory fatigue using the materials at <http://faculty.washington.edu/chudler/chems.html>. The site contains background information, teacher and student guides, and connections to Benchmarks for Science Literacy.

Hold the Meat!

Background Information (teacher information)

More on overview of protein

When you think of meat and its basic constituent, *protein*, you are dealing with a molecule associated with living things. Proteins are the most plentiful organic substances in cells; about half of the dry mass of cells is composed of proteins. And due to its cellular abundance, important functions in a living organism depend on protein. Protein may be classified according to its physiologic function. Some of the functions of proteins include the following.

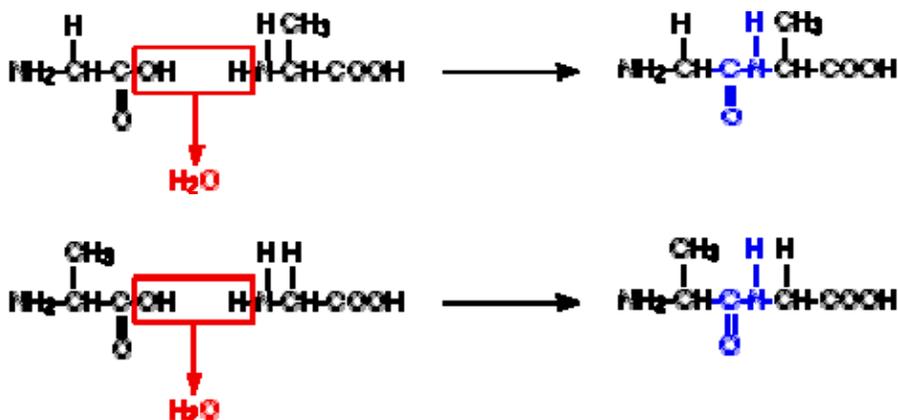
- **Transport and Storage**—*Hemoglobin* is the protein that carries oxygen through the bloodstream from lungs to tissues where it is used for energy production. The protein *myoglobin* stores oxygen in muscle until it is needed for energy production. In addition, specialized proteins embedded in the cell membrane assist in the movement of ions and molecules into and out of a cell from the tissue fluid.
- **Formation of structural tissues**—Structural proteins are important constituents of many tissues such as teeth, skin, bones, tendons and hair. Remember that when eating animal meat, you are eating muscle tissue.
- **Catalysis**—Enzymes are a large group of proteins that catalyze biochemical reactions.
- **Motion**—Contraction and expansion of muscles result from interactions between special protein molecules that make up muscle fiber.
- **Information transmission**—Proteins act in the nervous system as receptors of nerve impulses. Hormones exert their action by interacting with protein receptors on the surfaces of cells, such as insulin controlling the permeability of a cell membrane to glucose. Proteins are the receptors for light in photosynthesis and vision.
- **Genetic information**—Repressor proteins control how much information contained in the hereditary material is used at a given time. These proteins also govern cell growth and multiplication.

More on basic protein structure

Structure of protein molecules is associated with function. In the case of protein, which is a large molecule (a polymer called a polyamide), several categories of structure exist. The building blocks of proteins are **alpha-amino acids**, carboxylic acids that have amino groups ($-\text{NH}_2$) attached to the same carbon atoms as the carboxyl groups ($-\text{COOH}$). The carbon atoms to which both the $-\text{NH}_2$ and $-\text{COOH}$ groups are attached are called the alpha carbons. Amino acids have both acidic groups, $-\text{COOH}$, and basic groups, $-\text{NH}_2$, in the same molecule. The acidic groups and the basic groups neutralize each other. Pure amino acids exist as inner salts, which means they exist in two forms. One of the forms is the standard amino acid form, $\text{H}_2\text{NCH(R)COOH}$ and the other is the ionic form (zwitterion), $\text{H}_3\text{N}^+\text{CH(R)COO}^-$. All proteins, from the proteins of bacteria to the proteins of the human body, are synthesized from the same 20 alpha-amino acids. As mentioned in the article, those amino acids that cannot be synthesized in the body are called **essential amino acids** and must be obtained from foods or food supplements.

In the synthesis of a protein molecule, amino acids are joined through bonding of the amino group ($-\text{NH}_2$) of one amino acid to the carboxyl group ($-\text{COOH}$) of a second amino acid, producing a **peptide bond** (link) and the formation of one water molecule.

An example of a protein synthesis is shown below. Glycine and alanine combine, and with the elimination of a water molecule, form a dipeptide. Notice that there are two possible ways that the two amino acids can combine, and these two different approaches result in two different dipeptides.



(from <http://www.chemguide.co.uk/organicprops/aminoacids/proteinstruct.html>)

For a given protein or peptide molecule, the order of the amino acids is always the same. The order in which the amino acids are arranged is called the **primary structure** of the protein or peptide. Molecules with 1–50 peptide links are called peptides. Molecules with more than 10 peptide links are called polypeptides. Proteins, by definition, have more than 50 peptide linkages. Most proteins have more than 100 peptide links with some as high as 8000 per molecule.

More on protein function related to structure

The order of amino acids in a peptide or protein gives the protein its particular specificity. Further, the order of the amino acids in the synthesis of a particular protein is determined by specific enzymes, themselves protein. The enzyme structure in turn is determined by genetic material (DNA, RNA).

One example of how the function of a specific protein is determined by the order of the amino acids is to compare the two hormones oxytocin and vasopressin. Oxytocin stimulates milk ejection in females and contraction of smooth muscle of the uterus in labor. Vasopressin is an antidiuretic—it helps to maintain a proper water balance in the bodies of both sexes. The structure of the two peptides differs by only two amino acids in the 3rd (isoleucine/phenylalanine) and 8th (leucine/arginine) positions of the chain.

Cys-Tyr-Ile-Gln-Asn-Cys-Pro-Leu-GlyNH₂ (Oxytocin)

Cys-Tyr-Phe-Gln-Asn-Cys-Pro-Arg-GlyNH₂ (Vasopressin)

There is the general statement that one gene determines one enzyme. Any error in the order of the amino acids of the enzyme will produce an error in the structure of a given protein, which in turn can create a functional problem. One such example of this is the condition known

as sickle cell anemia, in which just one amino acid, glutamic acid, is replaced by valine. This is a synthesis error in the protein molecule of hemoglobin due to a genetic mutation. In turn, the hemoglobin molecule changes its shape (donut or tire shape) under low oxygen conditions to a sickle shape that reduces the amount of oxygen that can be carried by the hemoglobin.

The protein chains that are formed do not usually exist as straight chains; rather they are coiled or folded. This folding or coiling produces what is known as a **secondary structure** which contributes to the chemical activity of the protein and is specific; i.e., both in structure and function. The bonding that holds the folded chains together include hydrogen bonds, disulfide bonds, and ionic bonds (between the COO^- and NH_2^+ groups on opposing parts of a folded chain). **Denaturation** of a protein occurs when it unfolds from its native state or configuration.

This unfolding is due to cleavage of the covalent disulfide bonds, or disruption of the weaker hydrogen and ionic bonds (between the carboxyl group, COO^- of one amino acid and the NH_3^+ group of a second amino acid). One force of disruption is simply higher-than-normal temperatures. Enzymes operate within certain temperature ranges. Raising the temperature beyond this range will inactivate the enzymes by denaturation. The most common visual example of denaturation is the conversion of egg white (albumin) into a solid, opaque material (your fried egg!).

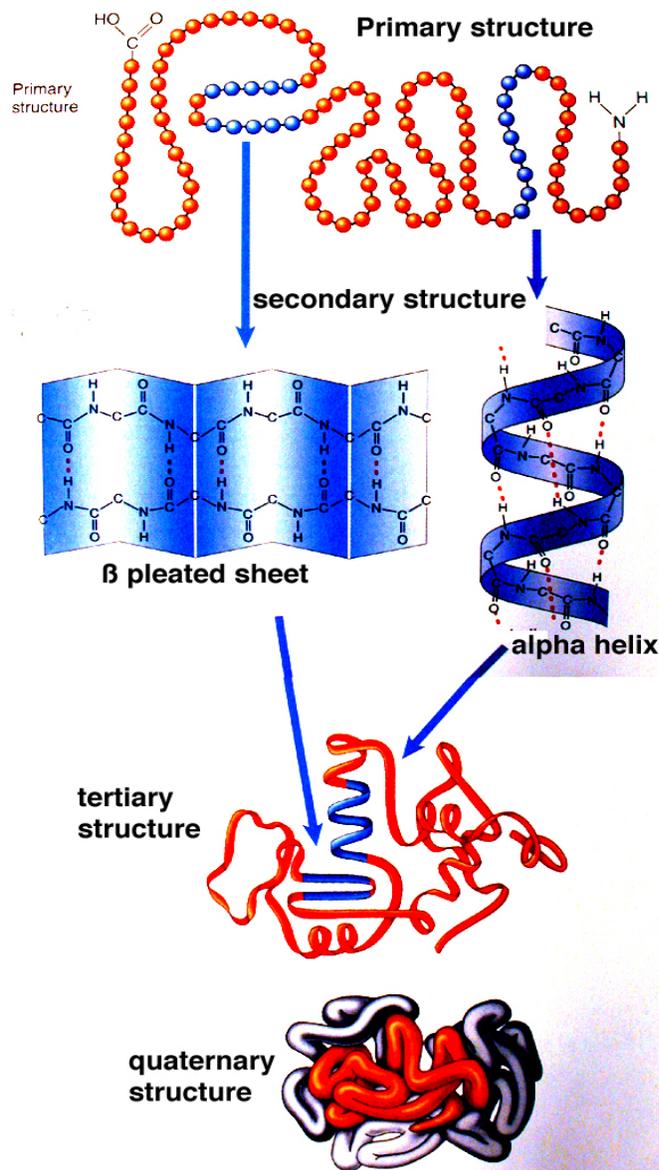
Two common ordered arrangements are **alpha helices** and **pleated sheets**. Alpha helices can be best imagined as a corkscrew. It is the most common secondary structure in proteins. (See figure below.)

When proteins are synthesized in the laboratory, they usually spontaneously coil or fold into the same arrangement as the natural protein and have the same biochemical activity. But a complete understanding of the mechanisms by which a protein folds into its stable native conformation remains a challenge. The folded or native state of a protein is considered to be thermodynamically stable, at a minimum of its free energy.

Additional folding or coiling of helices and sheets gives the protein **tertiary and quaternary structure**. (A simulation of folding at the molecular level with an atomic molecular model is found at <http://www.youtube.com/watch?v=1eSwDKZQpok&feature=related>.)

A more diagrammatic representation of the four types of protein structure can be found at http://www.accessexcellence.org/RC/VL/GG/nhgri_PDFs/protein.pdf.

A video that shows the molecular arrangement of the four basic types of protein structure with narration can be found at <http://www.youtube.com/watch?v=eUS6CEn4GSA&noredirect=1>.



(from http://academic.brooklyn.cuny.edu/biology/bio4fv/page/3d_prot.htm)

More on synthesis of protein

The production of protein within living cells is under the control of the genetic material in the nucleus of a cell. A genetic code that controls a particular protein synthesis and consequently a particular protein structure is found in a large molecule known as **DNA** (deoxyribonucleic acid). This information in turn is transferred to another nucleic acid known as **RNA** or ribonucleic acid. The RNA information has to get out of the nucleus and into a specialized structure called a ribosome in which amino acids will be linked up in a particular order, determined by the original information that came from the nuclear DNA. The movement of this information is done through an RNA known as **messenger RNA** that links up to the RNA within the ribosome or ribosomal RNA. From this point it is a matter of grabbing the needed individual amino acids in the cytoplasm of the cell. These amino acids attach by a covalent bond

to a specific type of RNA known as **transfer RNA**. The transfer RNA moves to the ribosomal structure for which a portion of the surface only accepts a particular transfer RNA with its specific amino acid in tow. Much of this activity, including the linkage (bonding) of the amino acids to form the polypeptide, is under specific enzyme (a protein) regulation. More technical terminology and a diagram about the transfer of genetic information to the ribosome can be found at http://www.accessexcellence.org/RC/VL/GG/protein_synthesis.php.

Anywhere along the way, from the DNA to the ribosomal RNA, there is room for synthesis error in the production of a protein, be it insulin, hemoglobin or a specialized enzyme needed to moderate a cellular biochemical reaction. Some of these errors, such as in the production of insulin, can produce what are known as metabolic diseases due to a defect in an enzyme that is part of a multistep reaction pathway. Some other metabolic diseases include hyperlipidemia and/or hypercholesterolemia, due to a disorder in the production of lipoproteins (such as cholesterol) or in their utilization. Another is phenylketonuria (PKU). This is a disorder in the metabolism of the amino acid, phenylalanine, due to a defective enzyme which is needed to convert the phenylalanine to another amino acid, tyrosine. If the phenylalanine accumulates, it can cause neurological problems, particularly mental retardation (though reversible with a change in diet that excludes foods containing large amounts of phenylalanine). The condition of PKU is detected in the urine of new-born babies using a simple chemical test and is routine in hospitals.

More on vegetarian diets

When health issues and solutions are promulgated or discussed, there is often a lack of good scientific evidence to support the solution. There is the grapevine approach, even with the Internet. As is true of many issues that are researched on the Web, it is important that students are able to evaluate the source of the information they might use in their problem solving, be it deciding what running shoes to buy or considering what values and limitations are there to a vegetarian diet. For the latter, students have an opportunity to seek out studies that have a scientific quality to them. And this could be an important exercise in chemistry class.

An all vegetarian diet has its limits and some potential health issues, depending on the individual and his/her particular biochemistry (tolerance). There are several categories of vegetarian diets. They include:

- **Vegan diets**, which exclude meat, poultry, fish, eggs and dairy products and foods that contain these products.
- **Lacto-vegetarian diets**, which exclude meat, fish, poultry and eggs, as well as foods that contain them. Dairy products, such as milk, cheese, yogurt and butter are allowed in a lacto-vegetarian diet.
- **Lacto-ovo vegetarian diets**, which exclude meat, fish and poultry, but allow eggs and dairy products.

Some people follow a semi-vegetarian diet—also called a “flexitarian” diet—which is primarily a plant-based diet but includes some meat, dairy, eggs, poultry and fish on occasion or in small amounts.



Vegetarian Food Guide Pyramid

(source: <http://www.mayoclinic.com/health/vegetarian-diet/HQ01596>)

With a diet that favors vegetables and other protein-rich foods (such as legumes and nuts), there could be an imbalance between the amount of protein and caloric types of food. As a result, an individual could get into some biochemical problems with an overload of protein. High-protein diets with restricted carbohydrate intake could result in nutritional deficiencies or insufficient fiber which can cause such health problems as constipation and diverticulitis, and may increase the risk of certain types of cancer. A high-protein diet increases the amount of waste products from protein metabolism including ketones. It is thought that having a diet in which protein makes up more than 30% of your caloric intake causes a buildup of these toxic ketones which have to be eliminated by the kidney with an increase in water excretion. As a result, dehydration is a risk, depending on the amount of exercise one does. A list (chart) of high protein/low fat foods with caloric value can be found at http://commonsensehealth.com/Diet-and-Nutrition/List_of_High_Protein_Foods.shtml. A sensible (meaning, balanced) article about the vegan diet and guidelines is found at <http://www.vrg.org/nutrition/protein.htm>.

Recommended amounts of protein in the daily diet are 56–70 grams for males and 46–58 grams for females. And many believe that more protein rather than less is not necessarily a good thing. The whole point is that you are trying to meet your amino acid needs, not your protein needs. So, depending on the type of food, you meet those needs through selection, not simply quantity. Two plant products that are low in two essential amino acids are grains (lysine) and legumes (methionine). What is interesting is that if you were to eat 2 ½ cups of tofu, you would be able to meet your daily requirements for all the essential amino acids. Other foods such as potatoes, corn and rice require considerably more (3–7 times as much) of that one food to accomplish what the tofu provides. A chart for this data which includes all the essential amino acids is found at <http://www.vrg.org/nutrition/protein.htm>.

More on alternative diets

Although a vegetarian diet is promoted primarily as a healthy alternative to a diet that has both animal- and plant-derived foods, it is also used as a way to lose excess weight. But for those who do not want to have an all-vegetarian diet, there are alternative programs that emphasize high protein/low carbohydrate diets (vs. those with high carbohydrate, low fat) that have been scientifically documented to work for weight loss, but with concerns. A high-carbohydrate, low-fat diet is not as effective. One such diet, the Atkins diet, has been subjected to good scientific evaluation (*Journal of the AMA*, 2005) after first being dismissed by the medical profession. This plan emphasizes high protein and low carbohydrate consumption. An independent analysis and summary report can be found at the Web site for the Committee for Responsible Medicine at <http://www.atkinsdietalert.org/advisory.html>. Included in this Web site are examples of menus as well as nutrient analysis of these sample diets. A high protein, low carbohydrate mix presents potential health problems. The diet is in stark contrast with the Mediterranean diet which follows below. The Atkins diet eliminates a wide range of foods that provide carbohydrates, including fruits, pasta, and starchy vegetables, among others, leaving a limited diet of foods that contain primarily fat and protein.

When the results of dieters on the Atkins diet are compared with other weight loss programs such as Weight Watchers, the Zone or Ornish over a year's time, the Atkins dieters had the lowest weight loss. The idea behind the Atkins diet is that if carbohydrates are restricted, then the body is forced to use body fat as the primary energy source. But in the process of relying on low carbohydrate intake, the Atkins plan allows the intake of foods with cholesterol, saturated fat and protein levels that exceed the recommended safe limits. And there is a dearth of foods that provide the essential nutrients needed for a heart-healthy diet. There is short term weight loss but not long term with the added risk of nutritional problems as mentioned. Another study that compares the same dieting programs done two years later (2007) reports different results in terms of the most effective weight loss strategy. Those results can be found at <http://www.hsph.harvard.edu/nutritionsource/what-should-you-eat/protein-full-story/index.html#soy>. This latter study is interesting in that it explains the difference in weight loss between the high-protein, low-carbohydrate diets and low-fat, high-carbohydrate diets. The former produces quicker, but only short term, weight losses. The explanations and some speculation show the quirks in research that involves human subjects who do not follow protocol (compared with mice!).

In contrast, the Mediterranean diet is considered a heart-healthy diet though not strictly vegetarian. And it produces equally good results in the long run compared with some low-fat, high-carbohydrate diets. Besides having a good mix of animal and plant products, it also brings in the use of olive oil and, for adults, the optional red wine. Again this particular diet has

undergone a scientific evaluation (some 1.5 million people studied) and is considered a healthy plan that reduces the risk of cardiovascular mortality, reduced incidence of cancer and cancer mortality, as well as a reduced incidence of Parkinson's and Alzheimer's diseases.

Key components of the Mediterranean diet

The Mediterranean diet emphasizes:

- Getting plenty of exercise
- Eating primarily plant-based foods, such as fruits and vegetables, whole grains, legumes and nuts
- Replacing butter with healthy fats, such as olive oil and canola oil
- Using herbs and spices, instead of salt, to flavor foods
- Limiting red meat to no more than a few times a month
- Eating fish and poultry at least twice a week
- Drinking red wine in moderation (optional)

(source: <http://www.mayoclinic.com/health/mediterranean-diet/CL00011>)



More on what soy does NOT do

There have been many claims about what soy products can do for health maintenance and curing health problems. But the evidence that has been collected does not support many of these claims. Some of these claims include the lowering of cholesterol and hot flashes, the prevention of breast and prostate cancer, aiding in weight loss, and warding off osteoporosis. Many of these claims were based on the fact that soy contains high concentrations of isoflavones, a type of plant-made estrogen (phytoestrogen). In recent years, a number of solid studies have tempered these claims.

One of the ways that soy affects cholesterol is that, if included in the diet, it tends to replace less healthy choices, such as red meat. The soy provides polyunsaturated fats (meat has saturated fat which is not desirable), vitamins, minerals and fiber. Soy lowers cholesterol (the LDL type) only about 3% when consuming 50 grams of that protein, which is equivalent to eating 1-½ pounds of tofu or drinking 8 glasses of milk—which is a lot!

The hot flash cure, based on the presence of those phytoestrogens, has not shown up in carefully studied programs. Statistics for the reduction of the incidence of breast cancer and the consumption of soy has not shown any correlation. And the possibility that eating soy would increase memory and thinking ability, particularly in older persons, has not been verified. And depending on the kind of diet, there might actually be a negative effect. One such study compared Hawaiian women of Japanese ancestry living on a traditional soy-based diet with Hawaiian women of Japanese ancestry living on a more Western diet. The women on the traditional soy-based diet developed memory problems compared to the women living on the more Western diet. These results have yet to be confirmed by other long term studies but could result from excessive intake of those phytoestrogens, or from some deficiency due to inadequate intake of something found in animal products, such as vitamin B-12, which is known to cause neurological problems if the minimum recommended intake is not met.

The Bottom Line: Recommendations for Protein Intake

- **Get a good mix of proteins.** Almost any reasonable diet will give you enough protein each day. Eating a variety of foods will ensure that you get all of the amino acids you need.
- **Pay attention to the protein “package”.** You rarely eat straight protein. Some protein comes packaged with healthful fiber and micronutrients, such as beans, nuts, and whole grains. Some protein comes packaged with lots of unhealthy fat, like when you eat marbled beef or drink whole milk. Fish and poultry are the best choices for meat eaters; if you are partial to red meat, such as beef, pork or lamb, steer yourself toward the leanest cuts, and make it only an occasional part of your diet. If you like dairy products, skim or low-fat versions are healthier choices.
- **Balance carbohydrates and protein.** Cutting back on highly processed carbohydrates and increasing protein intake improves levels of blood triglycerides and HDL, and so may reduce your chances of having a heart attack, stroke, or other form of cardiovascular disease. It may also make you feel full longer, and stave off hunger pangs.
- **Eat soy in moderation.** Soybeans, tofu, and other soy-based foods are an excellent alternative to red meat. In some cultures, tofu and soy foods are a protein staple, and researchers don't suggest any change in those diets. But if you haven't grown up eating

lots of soy, there's no reason to go overboard: two to four servings a week is a good target; eating more than that likely won't offer any health benefits and we can't yet be sure that there would be no harm.

(source: <http://www.hsph.harvard.edu/nutritionsource/what-should-you-eat/protein-full-story/index.html#12>)

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Covalent bond**—Protein molecules are synthesized from amino acids, utilizing a covalent bond, the peptide bond, that links the carboxyl group ($-\text{COOH}$) of one acid to the amine group ($-\text{NH}_2$) of another acid, which can continue producing very large molecules (polypeptides) which are needed in biological systems for structural use, such as long muscle fibers, elastic tissue and collagen.
2. **Hydrogen bond**—Because long protein molecules do not exist in straight chains, they fold into specific structures. The folds are held through three different types of bonds—hydrogen ($\text{O}\dots\text{H}$), disulfide ($\text{S}-\text{S}$), and ionic ($\text{NH}_3^+ \dots \text{COO}^-$)—which in turn produces very specific surfaces that determine chemical activity that is particularly important for enzyme function.
3. **Disulfide bond**—This type of bond forms between two cysteine amino acids' $-\text{SH}$ groups which draws a single peptide chain into a loop or holds two peptide chains together.
4. **Amino acid**—The amino acid molecule provides the basis for constructing very large and specific molecules, a polypeptide with linkage (covalent bond) between the basic amino group ($-\text{NH}_2$) of one acid with the acidic carboxyl ($-\text{COOH}$) group of another amino acid. The order of the amino acids dictates the specificity of the polypeptide. With twenty amino acids to select from, the number of possible combinations of amino acids in the polypeptide is exceptionally large.
5. **Carbohydrate**— This category of organic molecule abounds in nature, taking many forms such as starch, cotton, table sugar and wood. When considering food, carbohydrates are a primary caloric food for body metabolism, compared with proteins which are not prioritized for energy production in body metabolism. Carbohydrates can form polymers (polysaccharides) like amino acids (polypeptides). Carbohydrates can bond to proteins to form glycoproteins, the best example being collagen, a connective tissue material mentioned in the article.
6. **Protein**—A polymer that is formed from bonding between amino acids, these large molecules are the basis for structural applications in living organisms. (See #4.) There are more than 200 proteins (peptides) that are important to the proper functioning of the human body.
7. **Fat (Lipid)**— Fats perform a number of biological functions, including a direct source of energy for living cells, as a structural component for different types of cell membranes (muscle vs. brain), as special molecules that interact with hormones (steroids), and as storage units in specialized fat (adipose) tissue. The energy value of fat is twice that of carbohydrates or protein.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“Not eating fat will eliminate cholesterol from the body.”** *Cholesterol is produced by the human body itself because it is vital. Eating foods that contain cholesterol simply raises the*

level of that chemical in the blood. So limiting fatty foods may reduce the amount of cholesterol contained in that food (cholesterol molecules are a different type of fat that may be found in fatty foods) but it does not prevent the body from naturally synthesizing cholesterol.

2. **“Carbohydrates provide more energy per gram than fat.”** Actually fat provides 9 kcal per gram of fat “burned” whereas carbohydrates (and protein) provide 4 kcal per gram burned.
3. **“Taking ascorbic acid (vitamin C) daily and in any amount will prevent or cure colds as well as prevent cancer.”** Although ascorbic acid is a needed vitamin that can be obtained from citrus fruit as well as in tablet form, there is no evidence that it cures colds or prevents colds and cancer.

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

1. **“Why can you take certain vitamins daily in any quantity but is not the case for other vitamins?”** Vitamins, which are coenzymes (function along with enzymes), are of two types—fat soluble and water soluble. Water-soluble vitamins are absorbed in the bloodstream and will be excreted if present in amounts beyond what is needed by the body. Fat-soluble vitamins do not dissolve in the blood and therefore accumulate (stored in fat tissue, especially liver fat) if not utilized. This excess of vitamins in the fat can be dangerous. Fat-soluble vitamins include A, D, E and K. Water soluble vitamins include all the B’s and ascorbic acid, vitamin C.

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

1. You could conduct a lesson that has students looking into food groups and diet. Goals could include answering the following questions: What is the difference between an energy food and a protein source? What is a vitamin? Is fat bad for you? What is the difference between saturated and unsaturated fats. What is a trans fat? Should it be in your diet? Do you need any of these fats in your diet? There are several older *ChemMatters* articles on these subjects that are listed in the “References” section that follows.
2. A follow-up lesson could address whether a meatless diet is really a good idea. See the Background Material above for references.
3. There are standard tests for identifying proteins, carbohydrates (including starch), and fats. A starting point is a lab protocol at <http://www.accessexcellence.org/AE/ATG/data/released/0335-HeidiHaugen/>.
4. Separate out a mixture of amino acids using paper chromatography. Calculating Rf values allows the student to identify the particular amino acid based on reference information (which the teacher provides). See the reference http://en.wikibooks.org/wiki/School_Science/Paper_chromatography_of_amino_acids for the lab procedure. Also, if you are a member of ACS, you have access to another lab exercise for paper chromatography of amino acids at <http://pubs.acs.org/doi/abs/10.1021/ed049p547>. And an extensive explanation about paper chromatography of amino acids is found at this reference—<http://www.chemguide.co.uk/analysis/chromatography/paper.html>.
5. Students can be shown the process of denaturation of a protein and then explain about the disruption of the disulfide bonds that normally keep the protein’s secondary structure intact. Simply heat the egg white in hot water (your typical poached egg). Students themselves can take a strand of hair and pass it between two fingernails. The hair will curl, due to the frictional heat produced. The fact that enzymes are proteins also means they are sensitive to environmental temperatures. Too high a temperature will inactivate the enzyme due to

denaturation. Some people think that a fever is the body's attempt to inactivate the enzymes of infectious bacteria. But too high a fever also means potential destruction of the body's cellular enzymes, particularly in the brain.

6. Investigate the various factors (temperature, pH, substrate concentration, enzyme concentration) that affect the rate of an enzyme-controlled reaction. A suggested set-up uses powered catalase in solution to act on hydrogen peroxide. Rate can be determined by the rate at which paper disks float to the surface of the liquid in a beaker due to the production of oxygen bubbles. Details for this experiment can be found at <http://www.accessexcellence.org/AE/ATG/data/released/0074-GenNelson/index.php>. If you have computer-based interfacing equipment such as that from Vernier, you can use the equipment to perform the same experiment on catalase destruction of hydrogen peroxide. See http://www2.vernier.com/sample_labs/BWV-06A-COMP-enzyme_action_O2.pdf.
7. A teaching module from NIH focuses on the science of energy balance, dealing with caloric intake and physical activity. Refer to <http://science.education.nih.gov/supplements/nih4/energy/default.htm>.
8. Allow students to determine concentration of vitamin C from various sources. This can be done as a micro-lab. See <http://www.accessexcellence.org/AE/ATG/data/released/0490-MaryColvard/index.php> for an example of a lab procedure with teacher notes.
9. Have students bring in the labels on food containers and have them evaluate the nutrition facts—percent daily value for total fat, saturated, unsaturated, trans fat, cholesterol, carbohydrates, protein, vitamins and so forth. It becomes a teachable moment if students wonder about each type of fat, what the daily percentage values mean, etc.
10. Protein, amino acids, and legumes like soybeans are all connected to the nitrogen cycle. The whole idea of a cycle and the recycling of nitrogen may be new to students. A particular type of plant such as a legume is able to take nitrogen from the air, convert it to the ammonium ion or ammonia through bacterial action in the plant roots. Bacteria in the soil convert the ammonia or ammonium ions to nitrite, then to nitrate ions which are the usable form of nitrogen for the plant. In the plant, the nitrate ions become incorporated into the amine group of amino acids. Protein in the plants is passed on to animals. The decay process of plants, animals and animal excretions eventually returns the amino acids of protein back to free nitrogen in the atmosphere. And the cycle begins again. There are more chemical details that should be incorporated into this outline. A lead off question could be, "How does nitrogen in the air become tofu on the table?" Or, "How does dung from a camel in Egypt become part of the wheat grain in your bread?"

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

1. Research the various diet programs and how they work. Why do most people on diets fail to permanently keep off lost weight? A teaching module from NIH focuses on the science of energy balance—caloric intake and physical activity. Refer to <http://science.education.nih.gov/supplements/nih4/energy/default.htm>.
2. Research the various uses of soy bean products—the list is extensive. A starting point would be the Web sites <http://www.soynewuses.org/ProductsGuide/Default.aspx> and <http://www.soynewuses.org/ProductsGuide/Consumer.aspx>.
3. Other questions students might want to research:
 - a. What does research say about a high protein - low carbohydrate diet in terms of health?
 - b. What are the real reasons for the high incidence of juvenile obesity?
 - c. What is juvenile diabetes; is it related to obesity? What about type 2 diabetes?

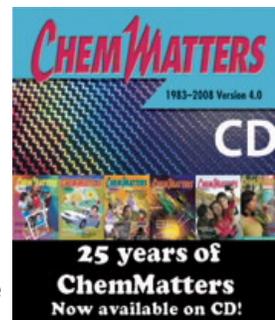
- d. Is dieting related to aging? Can certain diets (low carbohydrate diet) slow up aging? What is the scientific evidence? A place to start is http://www.accessexcellence.org/AE/AEC/CC/aging_background.php.
4. If there is student interest in analyzing protein, and if funds are available to purchase a commercial kit to analyze protein, there is available a bio assay kit from BioRad at <https://www.biorad.com/prd/en/US/adirect/biorad?cmd=catProductDetail&isFromSearch=true&productID=500-0001EDU&Country=US&vertical=LSE&parentCategoryGUID=db635a29-ab6d-47bc-a824-2a5896ebe89f>.
Another kit that is available for determining amino acid content and the sequence of amino acids in a tripeptide can be purchased at Science Kit—refer to the following URL for purchase information: <http://sciencekit.com/determining-the-amino-acid-sequence-in-a-peptide-kit/p/IG0020765/>.

References (non-Web-based information sources)

The ACS chemistry program entitled “**Chemistry in the Community**” (ChemCom) has an entire chapter on food (“Food: Matter and Energy for Life”) which includes some activities and lab exercises for the main food categories (carbohydrates, fats, proteins), background chemistry with molecular diagrams, chemical equations, energy diagrams (from sun to table food), energy requirements for teenagers engaged in a variety of activities, and caloric value of different foods among other topics. The book can be purchased at the ACS Web site—or access the Web site of the W. H. Freeman, the publisher (which also includes access to the ACS Web site) at <http://www.whfreeman.com/catalog/static/whf/chemcom/>.

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 Web site 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 Teacher’s Guides are available on the 25-year CD for all past issues, up to 2008.)



(<http://www.acs.org/chemmatters>)

Baxter, R. Permanent Waves. *ChemMatters*, April, **1993**, 11 (2), pp.8–11. This is good reference for visuals on the molecular structure of protein, showing the intramolecular bonding within the secondary structure, including hydrogen and disulfide bonding.

Grosser, A. Egg Cookery. *ChemMatters*, December, **1984**, 2 (4), pp 4–8. The article shows the structure of egg protein and the changes at the molecular level when the protein is denatured.

Siezen, R. Pumping Oxygen. *ChemMatters*, February, **1984**, 2 (1), pp 6–9. Another important protein is myoglobin which is fully illustrated in terms of structure as well as function.

McClure, M. Exploring Marfan Syndrome. *ChemMatters*, February, **1999**, 17 (1), pp 14–15. This syndrome is a good illustration of how a genetic defect translates into an error in the synthesis of a specific protein that is found in elastic tissue.

Parent, K and Jennifer Young. Biomimicry—Where Chemistry Lessons Come Naturally. *ChemMatters*, April, **2006**, 24 (2), pp 15–17. The extraordinary strength of spider silk comes from the unique protein structure of the material.

Rosin, J. Future Food. *ChemMatters*, April, **1989**, 7 (2), pp 8–10. This article delves into the manufacturing techniques for synthesizing food, including protein, rather than depending on animals. Some starting materials are obtained from plants.

Vos, S. Linus Pauling—American Hero. *ChemMatters*, October, **2007**, 25 (3), pp 7–10. This is a must read about one of the key figures in the elucidation of the structure of protein, including the proposal for the hydrogen bonding in the alpha helix. He also worked out the structure of vitamin C (ascorbic acid). He was twice a Nobel prize winner—for science and for peace.

Emsley, J. Artificial Sweeteners, *ChemMatters*, February, **1988**, 6 (1), pp 4–8. A twist from thinking amino acids are used only to synthesize protein, this article gives the history and chemistry of the artificial sweetener aspartame that is a molecule made from two amino acids, aspartyl (a residue or radical of aspartic acid) and D-phenylalanine.

Morton, R. Drug Detection at the Olympics, *ChemMatters*, December, **2000**, 18 (4), pp 7–9. Of interest to students might be all the business about anabolic steroids used by athletes to enhance performance. The steroids work by promoting the synthesis of protein for muscle tissue. This article describes how steroids are detected in the blood samples of athletes at major competitions such as the Olympics.

Ruth, C. Calorie-free Fat, *ChemMatters*, April, **1999**, 17 (2), pp 9–11. This article discusses the chemical composition of calorie-free fats and compares them with caloric fats or triglycerides. The calorie free fats are calorie free because they are not absorbed by the body's digestive system. And these calorie free fats are actually sucrose polyesters.

Baugh, M. Oil Changes, *ChemMatters*, December, **1989**, 7 (4), pp 7–9. This article provides a good basis for understanding the basics about fats and oils. Of importance is the explanation of saturated and unsaturated fats. This article would be a useful supplement to the study of packaging food labels that list the content of different categories of fat.

Kimbaugh, D. The Solid Facts About Trans Fats, *ChemMatters*, December, **2007**, 25 (4) pp 14–16. Providing additional information about the large category of fats and their role in nutrition, this article focuses on trans fats that are of concern when considering good nutrition. It also provides information about molecular structure if needed for a chemistry lesson.

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

More sites on an introduction to the basics about amino acids and protein

A very jazzy video for the classroom presents an overview of protein which includes the basics of peptide bond formation. This will capture the student's attention! See <http://www.youtube.com/watch?v=n9eWhSbjSFI&NR=1>.

More sites on protein structure

A visual summary of the four types of protein structure can be found at <http://www.youtube.com/watch?v=lijQ3a8yUYQ&feature=related>.

Another very good series of lecture notes with illustrations about the basics of protein structure can be found at <http://www.chemguide.co.uk/organicprops/aminoacids/proteinstruct.html>.

For model building as well as clear molecular diagrams for protein structures, refer to the Web site, <http://www.cas.vanderbilt.edu/bsci111a/protein-structure/supplemental.htm>. This site also has some additional Web site links.

Very clear drawings of bond types in tertiary protein structure (hydrogen, disulfide, ionic) can be found at <http://www.elmhurst.edu/~chm/vchembook/567tertprotein.html>.

More sites on proteins as enzymes

The Web site <http://www.chemguide.co.uk/organicprops/aminoacids/enzymes.html#top> provides all the details as to how the molecular structure of enzymes explains some of their functions at the structural surface created by all the folding of the protein chain.

More sites on vegetarian diets

A good series of short videos on the scientific knowledge about the value of vegetarian diets, and issues to be cautious about, can be found at http://www.huffingtonpost.com/2011/10/01/world-vegetarian-day-2011_n_989218.html.

The Web site for one vegetarian organization, the North American Vegetarian Society can be found at <http://www.navs-online.org/>. The site includes vegetarian FAQs, nutrition and health, food and recipes, animal issues, and the environment, among other topics.

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

A teaching module from NIH focuses on the science of energy balance—caloric intake and physical activity. Refer to <http://science.education.nih.gov/supplements/nih4/energy/default.htm>.

Changing the Course of Diabetes

Background Information (teacher information)

More on monomers and polymers

Monomers are the building blocks of polymer molecules. They are the repeating units that link together in covalent bonds to form the macromolecular polymers. Monomers typically are small molecules of one or two varieties: a small hydrocarbon molecule containing one or more double (or triple) bonds, or small organic molecules with two or more functional groups on the carbon chain.

Hydrocarbon molecules containing a double bond can react with each other when the double bond is broken. The breaking of the pi bond of the double bond forms a reactive site where that reactive monomer, called a repeat unit, can bond with another repeat unit to begin the formation of the macromolecule. This process is sometimes referred to as **addition polymerization**, where one repeat unit simply adds to another, creating a longer molecule. The more widely accepted term for this process is **chain-growth polymerization**. Addition of the reactive repeat units at the ends of the chain continues its growth into a polymer. This process usually proceeds by formation of a free radical or an ion. Since these reactions usually involve only one monomer for each, the products are referred to as homopolymers. Almost all of the more widely recycled polymer resins are homopolymers produced by this method; e.g.

Monomer Name	Polymer Name	Type	Recycle Symbol	Recycle Code #
Ethylene	Polyethylene	High Density	HDPE	2
Vinyl chloride	Poly(vinyl chloride)		PVC	3
Ethylene	Polyethylene	Low Density	LDPE	4
Propylene	Polypropylene		PP	5
Styrene	Polystyrene		PS	6

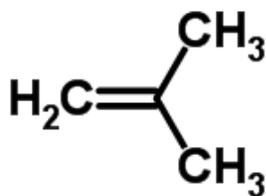
Di-functional (or tri-functional) organic molecules can also serve as monomers for polymerization reactions. In these reactions, called **condensation polymerization** reactions, or more correctly, **step-growth polymerization** reactions, the functional groups; e.g., acids, alcohols and amines, are the active sites. These active sites can react together on many monomers simultaneously, thus producing dimers, trimers, etc., on the way to oligomers (molecules containing a few monomer units) and finally, polymers. These reactions usually have two different monomers that react repeatedly with each other, forming copolymers. Polyamides (reactions between an acid and an amine), and polyesters (reactions between an acid and an alcohol) are typical products. The other main recycle code resin, PET, is produced by this method of polymerization.

Monomer Names	Polymer Name	Recycle Symbol	Recycle Code #
Ethylene glycol & Terephthalic acid	Polyethylene terephthalate	PET (or PETE)	1

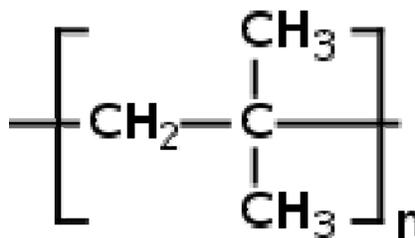
The passage below, taken from a previous *ChemMatters* Teacher's Guide (February 1999), provides further discussion for use with students on the topics of these two types of polymerization processes.

Addition polymerization occurs when a monomer molecule has a double (or triple) bond. Think of someone with their arms crossed as a double bond (their chest is one shared pair of electrons, their crossed arms are a second pair). If they open their arms (break the bond) they can link onto another monomer molecule. If everyone in the class did this, you could end up with one long chain of students—a "polystudent" chain.

Isobutylene [see structure below] can open its double bond to form a long chain molecule—polyisobutylene [see structure below]. When a monomer with *two* double bonds like isoprene is used, the long chain can include secondary chains. This alters the properties of the polymer. One possible result is a large molecule with the desired molecular weight, but which would be easier to process. Some examples of these kind of addition polymers are polyethylene (Baggies and milk jugs), polystyrene (foam cups and clear protractors), and polyvinylchloride (PVC) pipes.



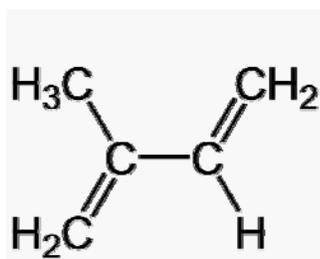
Isobutylene (2-methylpropene)



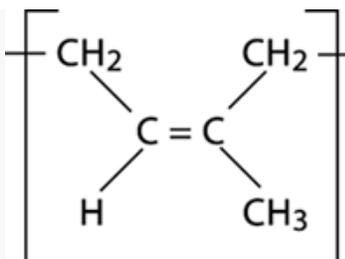
polyisobutylene

(Source, isobutylene: <http://www.chemspider.com/Chemical-Structure.7957.html>)

(Source, polyisobutylene: <http://fr.wikipedia.org/wiki/Polyisobutyl%C3%A8ne>)



Isoprene
(2-methyl-1,3-butadiene)



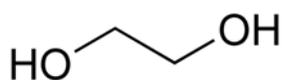
polyisoprene (cis-1,4-polyisoprene)

(Source, isoprene: <http://commons.wikimedia.org/wiki/File:Isoprene-Structure.png>)

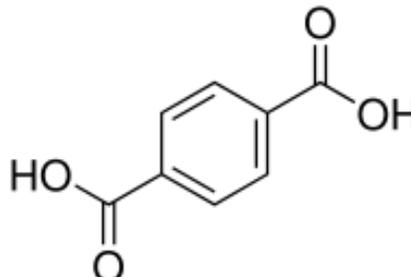
(Source, polyisoprene: <http://www.learnnc.org/lp/pages/4496>)

A second type of polymer is formed through a reaction between two functional groups on nearby monomers. For example, an ester is an organic molecule resulting from the reaction of an alcohol group on one

molecule with a carboxylic or organic acid group on another. A molecule of water is removed ($-OH$ from the acid and $-H$ from the alcohol). If the monomer has two alcohol groups (a *di-ol*) and another has two acid groups (a *di-acid*), a long chain can form. Since the link is an ester link, the polymer is called polyester. A common example of polyester is the plastic used for soda bottles, polyethylene terephthalate (PET).



ethylene glycol

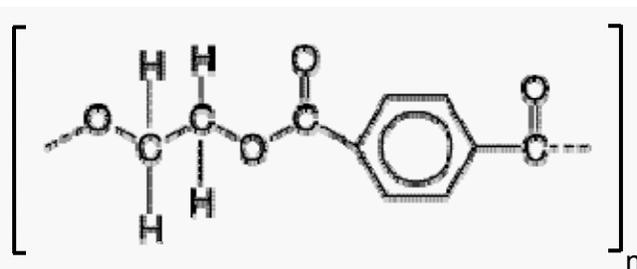


terephthalic acid

(Source, ethylene glycol: <http://chemistry.about.com/od/factsstructures/ig/Chemical-Structures---M/MEG---Monoethylene-Glycol.htm>)

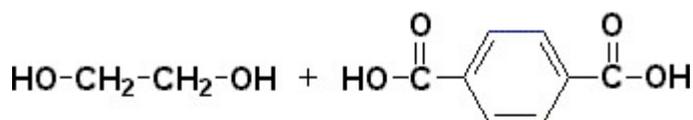
(Source, terephthalic acid:

<http://www.sigmaaldrich.com/thumb/structureimages/58/mfcd00002558.gif>)

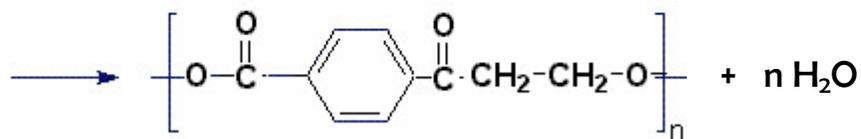


(Source, polyethylene terephthalate:

http://www.americanchemistry.com/hops/intro_to_plastics/teachers.html)



Ethylene Glycol + Terephthalic Acid



Polyethylene Terephthalate

(Source, polymerization reaction: http://www.conaplat.com.ar/pet/what_is_pet.htm)

In a similar way, a monomer with two acid groups can form a chain with a monomer containing two amine groups. This amide linkage results in a polyamide. Nylons are polyamides. Polyesters and nylons require two different difunctional monomers and are termed copolymers. The

addition polymers [above] can be formed from one kind of monomer and are called homopolymers. Sometimes a copolymer is formed to add desired properties as in the butyl rubber example in this article.

Ron Perkins, a retired chemistry teacher from Connecticut, devised an analogy for polymers using wooden blocks.



Blocks with two holes or two pegs are difunctional and would form copolymers in an analogous way to condensation polymers. The block with a peg and a hole could be thought of as a monomer with a double bond that is ready to bond with other monomers as in addition polymerization.

The block with a peg and a hole can also represent a monomer with two *different* functional groups that could link. This situation is what occurs in the natural polymer, proteins. Amino acids contain both an acid group and an amine. The hydrogen from the amine forms water with the hydroxyl (–OH) group from the acid. This is another example of a condensation reaction. When amino acids link, it is called a peptide bond. The chain of amino acids is called a polypeptide.

The properties of macromolecules depend on their structure. The longer the chains, the stronger the intermolecular forces of attraction. Think about serving spaghetti: The long strands tend to hold onto one another. When links form *between* chains, the material becomes even more solid. This linkage occurs when monomers that form several chains are introduced. Vulcanization also causes crosslinking of polymer chains. Polymers are important building materials because by controlling the average length of the chains, the extent of crosslinking, and the choice of monomers we can customize the properties of a material.

(ChemMatters Teacher's Guide, February 1999)

Here is a table, taken from Wikipedia, which compares the characteristics of step-growth and chain-growth polymerization reactions (http://en.wikipedia.org/wiki/Step-growth_polymerization):

Step-growth polymerization	Chain-growth polymerization
Growth throughout matrix	Growth by addition of monomer only at one end of chain
Rapid loss of monomer early in the reaction	Some monomer remains even at long reaction times
Similar steps repeated throughout reaction process	Different steps operate at different stages of mechanism (i.e. Initiation, propagation and termination)
Average molecular weight increases slowly at low conversion and high extents of reaction are required to obtain high chain length	Molar mass of backbone chain increases rapidly at early stage and remains approximately the same throughout the polymerization
Ends remain active (no termination)	Chains not active after termination

No initiator necessary	Initiator required
------------------------	--------------------

Wikipedia also provides much more information about step-growth polymerization at the above Web address.

More on natural polymers

Natural polymers have existed as long as life has been around; man did not invent them. As mentioned in the article, natural polymers include natural rubber from the rubber tree, DNA and proteins. But polymers are also present in all cytoplasm, in every organelle, in every cell, in every tissue, in every organ, in every organ system, in every organism that lives. Life could not exist without polymers.

Natural polymers are found in amino acids, proteins, DNA, RNA, cell membranes and cell walls, muscle tissue, blood vessels, nerve fibers, hair, skin, finger and toe nails, silk, wool, spider webs, chitin (shells of crustaceans), cotton, tree bark, wood, leather, glycogen, starches, meats, carbohydrates, shellac, amber, natural rubber, rhinoceros horn and elephant tusk, hemp, and mucus.

To study the role of polymers in cells, scientists have even begun to create their own “cells”, consisting of cell membrane and cytoplasm, directly from two different (synthetic) polymeric molecules. Their goal is not to “make life”, but to try “...to understand how the staggering complexity observed in biological systems might have arisen from seemingly simple chemical and physical principles”, says Christine Keating, lead investigator in the study, performed at Penn State University. Read more about the study and see photos of their “cell” in this article from *Science Daily*.

<http://www.sciencedaily.com/releases/2008/05/080515171023.htm>.

More on synthetic polymers

Since natural polymers have been around for so long, and since they are obviously very effective at what they do, man’s first attempts to make synthetic polymers used natural polymers as starting points. Typically, scientists tried to make synthetic polymers to replace natural polymers that had found multiple and varied uses in everyday life, but which had become scarce and therefore expensive. Cellulose nitrate, used in movie film, was made from cellulose. Cellulose nitrate was later used to make celluloid, recognized as the first real man-made plastic (although not completely man-made, having started with natural material), which found uses in manufacturing cheaper items like shirt collars and cuffs, and jewelry boxes and hair accessories that had previously been made of (ever-increasingly scarce and expensive) ivory. (See ChemMatters references in the References section below for an article discussing the history of celluloid plastic made to replace ivory.)

A later product (1930s) made from cellulose is “art silk”, or rayon. Rayon feels smooth on the skin, but it is weak when it gets wet, and it creases easily. Although other, better synthetic fabrics were developed, rayon is still used today, albeit in blends with other fabrics. In transparent sheet form, it is known as “cellophane”. (Remember cellophane tape?)

<http://www.packagingtoday.com/introcelluloid.htm>)

In contrast to synthetic polymers that started with natural polymeric material, Bakelite, produced by Leo Baekeland in 1907, was made from phenol, from the distillation of coal tar, and

formaldehyde, from the distillation of wood alcohol (methyl alcohol). Bakelite first appeared in 1907 and was in widespread use by the 1920s. This plastic was quickly followed by polyvinyl chloride in 1926 and polystyrene foam in 1930. Plexiglas, polymethyl methacrylate, came into use several years later.

In 1933, polyethylene was discovered, quite by accident; in 1934, nylon was discovered, as was a process called cold-drawing, which increased the strength of the nylon fibers. This led scientists to investigate the post-production processing of polymeric materials to increase their utility. Teflon was discovered in 1938; Dacron (actually polyethylene terephthalate), a higher-melting synthetic fiber that made possible wrinkle-free clothing, was unveiled in 1953. Lycra spandex was introduced in 1958, and Kevlar, in 1973. Many other polymer fibers have been discovered throughout the years since then.

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

More on types of polymers

There are five major groups of polymers: adhesives, elastomers and rubbers, fibers, films and coatings, and plastics. Students are most familiar with plastics, but the other groups play major roles in their daily lives as well.

Adhesives are so called because they join materials by bonding them together through adhesion, a surface attraction between dissimilar surfaces. Adhesives include glues, caulks, sealants, and binders for paints. They are used in construction, laminates, clothing, automotive finishing, nonwoven and film coatings, and paints and coatings, just to name a few.

Adhesives usually are liquids, until they “cure”. The curing process is accomplished by one of two ways: the solvent mixed in with the actual adhesive components to allow them to flow evaporates, leaving the adhesive chemicals bonded to the material, or the components of the adhesive come in contact with and react with oxygen from the air to produce a cured adhesive.

Adhesives can come from natural or synthetic sources. Some of the earliest natural adhesives used by man are birch bark tar (a simple glue) and plant gum and red ochre (a compound glue). Casein glue, made from milk protein, has been used since the time of the Egyptians, and animal-based glue (using hides, hooves, bones, etc.) was one of the earliest glues used by man, also evidenced in Egyptian artifacts. Fish remains were also used to make glue.

Synthetic adhesives are man-made glues, prepared from either thermoplastics (which can be heated and reformed), such as polyethylene hot glue, or thermosetting polymers (which form permanent, insoluble, heat-resistant bonds that can't be changed without degrading the bonds), such as epoxies.

On the practical side, if you simply want to know what glue to use to glue “this” to “that”, visit this site: <http://www.thisisthat.com/>. You can choose what two materials you want to glue together and this (pretty much non-scientific) site will choose a glue for you. (Last update was 2008.)

Elastomers & rubbers have the property of viscoelasticity, of being flexible and returning to their original shape. Bouncing rubber balls and rubber bands exhibit these properties. Elastomers are usually soft and partially deformable at room temperature. They are typically

thermosets, although there are also thermoplastic elastomers. Their monomers are usually petroleum-based hydrocarbons, which may include oxygen in the molecules, or else silicon-based compounds. Flexibility of an elastomer is achieved via the long chains of polymer molecules that can “flow” along their longitudinal axes, while the return of the polymer chains to the item’s original shape is ensured by cross-links that allow only limited flexibility of the chains. Without the cross-links the chains would easily deform as they slide past one another, and with too many cross-links, the material would not deform at all, resulting in a rigid material. The Macrogalleria has good background information on elastomers. (See the “More sites on polymers” section at the end of this section of the TG for Web links.)

The primary uses for elastomers are for seals, adhesives and molded flexible parts (and don’t forget toys). As in adhesives, elastomers can be either natural or man-made. Polyisoprene (actually *cis*-1,4-polyisoprene) is a naturally-occurring rubber, also called latex. It is a polymer of the monomer isoprene, 2-methyl-1,3-butadiene. It comes from the sap of the para rubber tree (*Hevea brasiliensis*). When the bark of the tree is scored, latex oozes from the wound. This scoring process can be done repeatedly, at intervals, to tap latex from the tree. Other plants also provide natural elastomers; gutta-percha, Panama rubber trees, dandelion and lettuce all have latex-like, sticky secretions. (Gutta percha is actually *trans*-1,4-polyisoprene.) During the early years of World War II, Germans did much research on these various sources of latex in the hopes of using them to produce natural rubber in large quantities for tire production, after their sources of natural rubber were eliminated by the Allies.

Ancient Mayans and Aztecs obtained polyisoprene to make waterproof footwear and crude balls they used to play games. Unfortunately, the untreated rubber was soft and remained sticky, even after exposure to air for long periods. (The Mayans boiled the latex, which congealed it into a ball for their sport.) Charles Goodyear discovered in 1839 that heating polyisoprene with sulfur resulted in a much stiffer, less sticky, more useful rubber. His process of vulcanization effectively added sulfur cross-links to the long chains of polyisoprene, thereby restricting its ability to deform and increasing its elasticity. Prior to vulcanization, polyisoprene is actually a thermoplastic elastomer.

One of the first synthetic elastomers was polybutadiene, a molecule very similar to natural latex, polyisoprene. The monomer for polybutadiene is 1,3-butadiene. Car tires are made of SBS rubber, poly(styrene-butadiene styrene), a copolymer of polybutadiene. Many synthetic elastomers have been developed, and many of these can be used in blends to provide more desirable elastomeric properties.

Fibers are thread-like materials that consist of continuous filaments or discrete long pieces. Uses of fibers include spinning them into filaments, string or rope, or matting them into sheets to make paper or felt, or using them to engineer other materials; e.g., high-strength carbon fibers and Kevlar. As before, both synthetic and natural fibers exist.

Natural fibers include plant sources: cotton, hemp and flax; animal fibers: wool, silk and animal hair or fur; and mineral fibers: asbestos and attapulgite.

Synthetic fibers can have any of three main sources: fibers such as cellulosic rayon, with the plant-based source, cellulose; fibers such as Fiberglass and carbon fibers, with mineral sources; or fibers such as polyesters and nylons, from petrochemical sources. Synthetic fibers coming from petrochemical sources vastly outnumber those from other sources, as well as those coming from natural sources in everyday use. The two main synthetic fiber types are polyesters and polyamides.

Man was restricted to natural sources for making fabrics until 1889, when rayon, then dubbed “artificial silk” was first (accidentally) discovered by Frenchman Hillaire de Chardonnet. It finally got its “official” name of rayon in 1924. The discovery of nylon was made by Wallace Carothers and his staff while working at DuPont. The discovery made headlines in 1940 when nylon stockings were introduced to US consumers. While this discovery was not an accident, the process by which it was processed, cold-drawing was serendipitous. Nylon as it is manufactured is a weak polymer, prone to tearing of the fiber. The cold-drawing process orients the polymer chains, resulting in a much stronger fiber. The team discovered this process in a “game” to see who could produce the longest fiber from a beaker of the polymer. As they drew the fiber from the beaker, they realized its strength must have been improved tremendously. The discovery of this cold-draw process made nylon a useful material.

The principle use of fibers that springs to mind is of course in the manufacture of fabrics, used in clothing. There are, however, lots of other uses for fibers. Tires, for example, utilize reinforcing cords of polyester or nylon to provide strength for high speeds and road hazards. Similar reinforcing fibers provide rigidity and strength in composite materials in use for items as diverse as car bodies, sports equipment and plumbing fixtures. Fibers spun into fabrics are also used in building construction (think Tyvek®), and medical devices like artificial organs and wound dressings. Circuit boards use fiber composites.

Cigarette filters use acetate fibers. Bullet-proof vests utilize Kevlar fibers to stop bullets. Yacht sails and skis use aramid fibers for strength, stability and flexibility. Carpet manufacturers use nylon fibers, and more recently, recycled PET, polyethylene terephthalate (from soda and water bottles) fibers for their stain and mildew-resistance properties. Artificial turf fields, disposable diapers and housing insulation are all composed of olefin fibers, which are also used to reinforce hoses and belts on machinery. The same fibers are used in tarps and ground cover to prevent erosion on slopes. Recycled polyesters (like PET) are seeing increased use in high-performance outerwear, such as sleeping bags and parkas. Airline seats contain flame-resistant rayon/wool blended fibers. As one can see, fibers are much more ubiquitous than one might have imagined. (<http://www.fibersource.com/f-tutor/uses.htm>)

Films and coatings are used to protect surfaces from wear and tear, heat, light, or reaction with components of air. The value of coatings to the global economy is enormous. Without films and coatings, for example, any objects made of steel would be exposed to oxygen in the air and would rust extensively. Exposed wood on buildings would rot due to exposure to moisture and air. Polymer coatings and films prevent all of this degradation—and more.

Uses of films and coatings include optical coatings, mirroring, paints and varnishes. In addition, films and coatings have many other uses. Reflective coatings in highway paints provide safety in low-light (with headlight) situations; powder (and non-powder) coatings allow latex and non-latex gloves to slip on easily; anti-glare films on glasses, anti-static coatings and anti-wrinkle treatments on fabrics and anti-slip coatings on walkways all do what they are intended to do. Films are also found in packaging materials. Their role there can be several-fold: to keep a product clean; e.g., dry-cleaning bags, to prevent material from exposure to oxygen from air; e.g., shrink-wrap meat wrap material, to keep a product dry; e.g., waterproofing (polymer-coating) a basement wall, to prevent theft; e.g., wrapping a small object in a larger film-wrapped cardboard container (like a pen, for example), or to make an item more attractive, therefore more saleable; e.g., potato chip bag with company logo and colors on bag.

In addition to the above uses for coatings, *Science Daily* reports on new research at MIT that has produced a nano-pore polymer coating for glass that prevents fog formation in warm, humid conditions. (Think car windshields and lab goggles.)

(http://www.sciencedaily.com/videos/2006/0112-fogfree_glass.htm) Other research has resulted in paints that require no solvents and thus introduce no polluting VOCs (volatile organic compounds) into the atmosphere. (<http://www.gtri.gatech.edu/casestudy/reducing-voc>) VOCs were a large fraction of the volume of paints and a large contributor to atmospheric pollution; they are being/have been phased out of paint production by legislative mandate.

Plastics are the type of polymer with which people are most familiar. Plastics are polymer materials that can be molded or shaped to make useful products. Plastics are of two types: thermoplastics, which can be heated, softened, molded and allowed to harden into a shape and then, if desired, reheated and softened and remolded into another shape; and thermosetting plastics, which, once heated and molded, cannot be reheated for reshaping without degrading the plastic. This difference can be explained by the existence or lack thereof of cross-linking in these plastics. In thermoplastics, the long chains of polymer are joined only by relatively weak secondary bonding along the strands, allowing them to remain in one shape at relatively low temperatures. Upon heating these long chains, increased molecular motion jostles the relatively weak secondary attractions, weakening them, allowing the chains to once again slide past one another, thus allowing them to be reshaped into new objects. Upon cooling, the weak attractions are once again enough to hold the chains in one (relatively) rigid shape.

Thermosets, on the other hand, originally react upon heating by forming cross-links between the long polymer strands. These are primary chemical bonds, and they hold the cross-linked polymer strands in a rigid configuration. Heating a thermoset for a second time does not allow the long chains to move relative to one another because the primary cross-links continue to hold the chains in place. Extensive heating may eventually break the cross-links, but by that time, the heat has probably also broken the primary carbon backbone of the polymer chains, resulting in the degradation of the polymer material. Thus, thermosets cannot be reheated and reshaped.

Plastics are ubiquitous in our everyday lives, comprising about 10% by weight of the content of municipal garbage.

(<http://www.britannica.com/EBchecked/topic/493996/recycling/4682/Plastics>)

The existence of the seven recycle codes is evidence of their ubiquity; the very fact that society recognizes the need to recycle these plastics shows how much of them we use daily. It also points to one of their principal advantages (and sometimes, a decided disadvantage)—their long life. If we don't recycle the most heavily used plastics, they will overrun our landfills.

Several aspects contribute to plastics' ubiquity: the abundance of the feedstocks needed to manufacture the plastics, their composition and their processing. Most plastics (and indeed, most polymers in general) come originally from petroleum or natural gas. Crude oil is (was) relatively cheap and easily transportable, thus making plastics very competitive economically with other materials; e.g., wood or metal.

Monomers of polymers come in many "shapes and sizes". Adding an extra carbon atom to the monomer backbone or as a side-chain to the main molecule will alter the properties of the resulting polymer. Adding a functional group to a hydrocarbon can make an entirely new type of polymer, again resulting in different properties. Chemists can now engineer polymers to have almost any desired property, based on the structure of the monomer, and on the processing of the polymer.

As mentioned previously, nylon and other polyamides had been known for several years before chemists were able to give it the properties for which it is so widely known today. The process of cold-drawing changed the orientation of the long polymer chains of nylon, making them much stronger and therefore much more useful as fibers. Other processing methods are used to give other polymers properties that make them more useful to society. Extruding, for instance, results in a polymer with chains aligned, forming a stronger plastic. Injection-, compression- and blow-molding techniques are just a few of the other processing methods that affect the properties (and shapes) of plastics. Many ChemMatters articles on plastics are cited in the “References” section, below.

Plastics have been used in medicine for many years. Here are a “Few Fast Facts” on plastics in medicine, from the SPI, the plastics trade industry association (<http://www.plasticsindustry.org/AboutPlastics/content.cfm?ItemNumber=815&navItemNumber=1280>):

- In the past few decades, plastics have made health care simpler and less painful and made new techniques and prostheses possible. They have reduced contamination, relieved pain and cut medical costs. They have prolonged, improved and saved lives.
- The United States has the lowest rate of cross-staph infection in the world as a result of its use of plastic medical disposables.
- Plastics are key components of modern prosthetic devices, providing comfort, flexibility, mobility and a life-like appearance.
- Artificial hips and knees use plastics to help provide smoothly working, trouble-free joints.
- Not too long ago, almost no medical packaging had tamper-evident seals. Today, nearly 100 percent of all pharmaceutical packaging does. In addition, child-resistant caps help keep medicines away from little hands.
- Surgical gloves made of soft pliable plastic help preserve the sterile environment of hospital operating rooms.
- Plastics permeate medicine. From the smallest tubing to the open MRI machine, plastics deliver when lives are on the line.
- Many of today's most innovative medical procedures are dependent on the use of plastics.
- From the machinery housing to petri dishes, plastics serve health-care needs both large and small.
- As the need for home health care continues to increase, plastics will play a major role in creating simple, portable and effective medical devices.
- Plastics have helped reduce the weight of eyeglass frames and lenses, while improving their strength and shatter resistance. Plastics also provide vision-impaired consumers with another option: contact lenses.

More on insulin and the pancreas

Insulin is a hormone produced and secreted by beta cells in the islets of Langerhans in the pancreas. Insulin causes blood glucose to be removed from the bloodstream and stored in muscle, fat and liver cells as glycogen, a polymer chain composed of 10,000–60,000 glucose units linked together per glycogen molecule. As blood glucose increases after food ingestion, additional insulin is secreted to help store glycogen in cells and bring glucose levels back down.

Glucagon is another hormone produced in the pancreas. It is manufactured and secreted from alpha cells, also in the islets of Langerhans. The role of glucagon is to raise blood glucose levels if they fall too low. Glucagon causes the liver to convert glycogen, the stored version of glucose, back into glucose, which is then released into the bloodstream to return glucose levels to normal. Glucagon essentially acts in opposition to insulin.

Amylin is the third hormone produced in the pancreas. It is secreted along with insulin. The function of amylin is to slow gastric emptying and to inhibit the release of glucagon from alpha cells in the nucleus. The result of amylin secretion is to spread out the blood glucose peak after eating, thus reducing the amount of insulin needed.

If glucose levels are too high (hyperglycemia), the pancreas secretes insulin and amylin, which allow liver, muscle and fat cells to take up glucose from the blood. If glucose levels are too low (hypoglycemia), the pancreas secretes glucagon, which causes the liver to convert glycogen to glucose and return the glucose to the blood. The three hormones thus comprise a closed feedback loop system to keep blood glucose levels relatively stable. See “Glucose Metabolism & Diabetes” at http://www.iit.edu/research/services/doc_ret_2004/POWERPOINT_PRESENTATION.ppt for a detailed PowerPoint presentation on the roles of the liver and the pancreas in digestion, their role in diabetes and the effects of diabetes on the body.

New research (April, 2009) is reported in *Science Daily* that shows that insulin plays a key role in suppressing glucagon levels in mice. Glucagon causes the liver to depolymerize glycogen back into glucose, which it then secretes into the bloodstream to raise levels of glucose. This usually happens when blood sugar levels in the blood are too low. But injecting insulin into diabetic patients would not only increase the removal of glucose (as desired) but also prevent the return of glucose from the liver if the extra insulin suppresses the level of glucagon, preventing it from acting on liver cells to depolymerize glycogen. This could explain why people with type 1 diabetes who inject insulin regularly are more prone to hypoglycemia (low blood sugar levels). Scientists hypothesize that with repeated insulin injections, the alpha cells that would normally produce the glucagon to keep glucose levels from getting too low may become desensitized and fail to produce glucagon. (<http://www.sciencedaily.com/releases/2009/04/090407130910.htm>)

Even newer research (January 2011) indicates that the reduction or elimination of glucagon effectively negates the role of insulin in the metabolism of mice. See a synopsis of the study in “Potential ‘Cure’ for Type 1 Diabetes?” in *Science Daily* at <http://www.sciencedaily.com/releases/2011/01/110126161835.htm>.

More on the artificial pancreas

An artificial pancreas would allow people with diabetes to automatically control their blood glucose level by providing a substitute for the hormones produced by the healthy pancreas. While present-day insulin replacement therapy is needed to save lives, it still requires time-consuming hands-on management just to regulate the wild swings in blood glucose levels.

Insulin pumps in use today to take care of some of the management of diabetes control are an improvement over daily injections, but the pump still requires the user to make calculations and to predict the required amount of insulin to pump based on measurement of blood glucose and estimates of carbohydrates consumed. This is referred to as an open-loop system, as there is no feedback mechanism, and glucose levels still are far-ranging.

“The goal of the artificial pancreas is threefold:

1. to improve insulin replacement therapy until glycemic control is practically normal as evident by the avoidance of the [complications](#) of hyperglycemia, and
2. to ease the burden of therapy for the insulin-dependent.
3. to mimic normal stimulation of the liver by the pancreas.”

Research is now being done on the inclusion of amylin with insulin therapy. It has been found that only half the normal insulin is needed when amylin is included. Injection of glucagon at the end of the insulin cycle is also being studied in smaller mammals and has demonstrated closed loop control without evidence of hypoglycemia. This 3-hormone treatment would be as close as possible to the natural pancreas-secreting cycle. Of course, it would still require constant monitoring of blood glucose levels.

In addition to the artificial pancreas involving the polymer-coated metal tube containing pancreatic cells from a pig mentioned in the article, other research ideas for an artificial pancreas include: new medical devices; e.g., using an insulin pump and a closed-loop control device that uses real-time data from a continuous blood glucose sensor; bioengineering that uses a surgically implanted biocompatible sheet of encapsulated beta cells (the insulin-producing cells in the pancreas) that would operate for years; and gene therapy research that would introduce a genetically engineered virus that causes DNA changes in intestinal cells resulting in their being able to produce insulin.

http://en.wikipedia.org/wiki/Artificial_pancreas)

More on carbohydrates, the glycemic index and managing diabetes

Both starch and glycogen are important polysaccharides which act to store the simple sugar monomers composing them. Both starch and glycogen polymerize within cells by a form of condensation synthesis in which a hydroxyl group of one monomer reacts with the anomeric carbon at the opposite end of a second monomer. Molecules of water are eliminated in the process. Simple sugars are released from storage when the polysaccharide undergoes the reverse process, hydrolysis, in which molecules of water are restored.

Starch is made by plant cells, and glycogen, by animals. Both of the polysaccharides, with their many exposed hydroxyl groups, become heavily hydrated in their cellular environments. Starch molecules— huge polysaccharides (m.w. often exceeding 1 million)—are generally of two types: amylose consisting of long, unbranched chains of D-glucose, and amylopectin, highly branched. Glycogen, similar to amylopectin, is even more highly branched. It generally appears in granules that also contain enzymes ready to degrade the molecule when conditions are right.

Both starch and glycogen are essentially insoluble. If the point is to have glucose ready for instant use as cellular fuel, why don't cells simply store the glucose molecules in solution? It turns out that having that many particles in solution would create a severe osmotic imbalance that would either cause the cells to swell and burst, or, at the very least, would

reach an equilibrium state in which no additional net gain in glucose molecules would occur.

(*ChemMatters* Teacher's Guide, "Carb Crazy", April 2004)

Although carbohydrates are typically converted to glucose in digestion, the rate of digestion of different types of carbohydrates into glucose varies widely, thus affecting the blood glucose level. The glycemic index or GI measures the effects of carbohydrates on blood sugar levels. The faster a carb breaks down into glucose, the higher the GI. Carbs that break down slowly have a low GI. Eating foods with lower GIs may result in more even blood glucose levels, avoiding the spikes encountered in people with diabetes, and usually require less insulin in the process. Thus one could say that there are "good" carbs and "bad" carbs.

GI is a relative scale (from 1–140), with glucose the standard at 100. Foods with GIs lower than glucose's 100 are digested more slowly and enter the bloodstream more slowly. These foods are more desirable from the standpoint of maintaining a more level glucose concentration in the blood.

"For example, if a food has a GI of 50, it is absorbed into the bloodstream half as fast as that of glucose. Good carbohydrates have a low GI, and bad carbohydrates have a high GI. White bread, for example, has a GI of 70, while pumpernickel has a GI of 41. Watermelon has a GI of 72, but a plum has a GI of only 24. Instant white rice has a GI of 91, while brown rice only has a GI of 55. Generally, the more refined the food, the quicker it can be broken down and the higher its GI. The more work our body must do to break down a substance, the slower it will be absorbed into the bloodstream. Apple juice has a higher GI than apples. Baked potatoes have the highest GI of all potatoes at 85. To avoid spikes in blood sugar, with the resultant insulin spike followed by a crash in blood sugar, choose carbohydrates with a low GI.

"The GI is not a perfect measure of what foods to eat, however. Fructose, for example, has a GI of only 20. Scientists actually give rats large doses of fructose to make them insulin resistant."

(*ChemMatters* Teacher's Guide, "Carb Crazy", April 2004)

An alternate scale with white bread at 100 is also used. This has the advantage of being more "user friendly", as it gives the average person a real-life example to which to compare other foods. On this scale, glucose is 140.

While the glycemic index is a useful tool to evaluate the effect of food on the body's glucose levels, it doesn't tell the whole story. What if one were to eat a huge piece of cake, rather than a thin sliver? Both have the same glycemic index, based on carbohydrate content, but the portion size certainly affects how much insulin is needed to help cells ingest the glucose. The **glycemic load** (GL) system incorporates GI and portion size ($GL = GI \times \text{amount of available carbohydrate}/100$).

GL is based on the idea that a little bit of a high GI carbohydrate can have the same GL as a lot of a low GI food. Thus the GL probably gives a closer approximation of the actual effect that eating the carb has on the blood glucose level than the GI alone. The rating system for glycemic load has been established: 10 or less on the GL scale is considered low; medium is 11–19 and ≥ 20 is considered high.

More on new devices to help manage diabetes

Three technological devices help diabetics manage their condition.

Finger sticks are painful. New technology that looks like a small smart phone lances your finger at a controlled depth (set by you) with an internal vibration-dampening mechanism, so that it is as painless as possible. A disk with 50 sterile lancets inserted in the device allows painless finger pricks. Pelikan Sun (\$199) [Note: this product may no longer be available in the US.]

A pen-like device that contains the syringe and insulin digitally remembers your insulin dosage, date and time. You set the dosage and it remembers the details. HumaPen Memoir (\$45) [also no longer available in US, although other diabetes pens are]

Use GlucoPhone cell phone to monitor your glucose levels when you're "on the go". Phone uses special test strip placed in device on which you put a drop of blood to record data. The phone displays your blood glucose level and can send results to your doctor or a family member via text message. GlucoPhone (\$100) [also cannot confirm availability]

(source of video on all three devices above: <http://video.about.com/diabetes/Diabetes-Devices.htm>)

Controlling diabetes in children with type 1 diabetes has always been especially difficult. They, and/or their parents must continuously monitor blood sugar levels and correct them if they vary too widely, usually with injections of insulin. To help with this problem, the Bayer Corporation has designed a glucose monitoring game for children with diabetes, ages 4–14. Called Didget, it consists of a glucose monitoring device and a connection to a Nintendo DS or DS Lite. It provides a set of games and two testing levels, and it offers rewards for consistent monitoring and for meeting personal blood glucose target ranges. "Players" who comply can earn points that unlock new game levels. See a report on the device from Health Tech at <http://www.healthtechzone.com/topics/medical-devices/articles/87685-glucose-monitoring-children-game.htm>.

More on recent research

The *ChemMatters* article, "Cinnamon: The Bark Heard 'Round the World", discusses research indicating cinnamon may be useful in the control of diabetes (much more research is needed):

Recently, researchers have begun to take a serious look at the medicinal uses of cinnamon. Now, cinnamon is "hot" in more ways than one. It's possible it might help treat type II diabetes, a serious disease that kills millions of people a year and often strikes in middle age. When the disease strikes, the body loses the ability to use insulin, causing blood sugar levels to go seriously out of balance.

Researchers at the Department of Agriculture tested some high calorie foods on volunteers, to see how they affected blood sugar. Most had the expected bad effect. But to researchers' amazement, apple pie lowered the subjects' blood sugar. The team didn't recommend eating more pie. Instead, they uncovered a hidden champion: the cinnamon in the pie.

A chemical known as MHCP, [methylhydroxy chalcone polymer, a flavonoid] found in powdered cinnamon (not in the oil or in cinnamon

candy) can actually mimic and enhance the effects of insulin in the body, and boost glycogen levels in the muscles. More research is needed, but some doctors are already recommending 1/4 to 1 teaspoon a day of cinnamon for patients with or at risk for type II diabetes.

An article from the journal *Agricultural Research*, July 2000 may have been the source for the *ChemMatters* article. (<http://www.ars.usda.gov/is/AR/archive/jul00/cinn0700.pdf>)

More recent studies (through 2008) have shown mixed results for cinnamon's abilities to manage diabetes. One 2003 study showed that people with type 2 diabetes who took cinnamon additives for 40 days showed significant reductions in fasting glucose, triglyceride, low-density cholesterol (LDL) and total cholesterol levels. Unfortunately, several other studies found no such relationships. For a short synopsis of the situation as well as several resources, see this article from *Diabetes Health*, December 25, 2008:

<http://www.diabeteshealth.com/read/2008/12/25/5703/cinnamon-should-it-be-taken-as-a-diabetes-medication/>

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Organic chemistry**—Most natural and synthetic polymers are made of organic monomers.
2. **Polymers**—Polymers are usually treated in one of the last chapters of most chemistry textbooks, but their ubiquity in nature and in man-made products probably warrants their being given greater coverage in our chemistry courses.
3. **Types of chemical reaction**—Many polymerization reactions are “simple” synthesis or direct combination reactions, where double bonds in monomers break, allowing new bonds to form as these new reactive species join to one another to augment the elongation of the polymer chain. Most other polymerization reactions are hydrolysis reactions, where a water (or some other small) molecule is split out each time two different monomers form a bond to add to the polymer chain.
4. **Health and biochemistry**—These topics don't usually get much coverage in a high school introduction to chemistry course, but this article provides material for such a discussion.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“I can catch diabetes from someone else.”** *While scientists are still not sure about the exact cause of diabetes and they suspect a genetic connection, they do know that it is not “catching”.*
2. **“Taking insulin cures diabetes.”** *Actually, insulin is needed by the body constantly. If the pancreas isn't producing insulin, the patient will need to take insulin for the rest of their lives. This is not a cure for the disease. Presently, there is no cure.*
3. **“Diabetes is caused by obesity or eating too much sugar.”** *Type 1 diabetes is believed to be genetic and not related directly to diet. Obesity has been identified as one of the “triggers” for type 2 diabetes, but it has not yet been identified as a direct cause.*

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

1. **“What’s the difference between type 1 diabetes and type 2 diabetes?”** *Type 1 diabetes, previously called juvenile onset diabetes occurs in children and sometimes in young adults. Type 1 diabetes is an auto-immune disease, where the immune system destroys all the body’s insulin-producing cells. People with this condition will need to take insulin daily for the rest of their lives. Type 2 diabetes is the most common form of diabetes. It can also arise from immune system destruction of beta-cells in the pancreas, from insufficient insulin production, or from cells in the body rejecting the insulin produced in the pancreas (insulin resistance). This type usually develops in adults. Type 2 diabetics may produce enough insulin that with change in diet, exercise and medication they may not need supplemental insulin, but eventually they will probably require more insulin than their bodies can produce.*
2. **“Do all diabetics need insulin?”** *Actually, everyone needs insulin. In non-diabetic people, the beta cells in the pancreas produce just the right amount of insulin for the body’s needs—eat more food, produce more insulin, eat less food, produce less insulin. The problem in diabetics is that either they don’t produce any insulin at all, don’t produce enough insulin, or can’t adequately absorb the insulin they produce. As a result, type 1 diabetics, who don’t produce any insulin, will require insulin, either through injection, insulin pump, inhalation therapy or beta-cell transplant. Type 2 diabetics may be able control their condition with medication, exercise and change of diet for a time, but eventually they will also need insulin supplementation.*
3. **“What does insulin actually do in the body?”** *Insulin in the blood allows fat, muscle and liver cells to absorb glucose from the bloodstream and store it as glycogen. Without insulin, our blood glucose levels would spike every time we eat, leading to hyperglycemia. Over long periods, this could lead to eye, kidney, and heart problems and nerve damage, similar to the effects suffered by diabetics over the long term.*
4. **“Can skinny people have diabetes?”** *Although obesity has been connected with type 2 diabetes, type 1 diabetes occurs in people who are genetically predisposed, and it has no connection to body weight. Frequently, type 1 diabetic patients appear rather thin due to their body’s inability to process food in a normal way.*

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

Insulin, sugar and the pancreas

1. A good connection to equilibrium chemistry is the blood buffer system. In diabetes, acidosis is a common condition. Using a pH meter, you can demonstrate the condition of acidosis and how the body compensates for the condition. See Ophardt, C. E. Blood Buffer Demonstration. *J. Chem. Educ.* 60 (6), 1983, pp 493–4.
2. You might want to begin (or end) a discussion about diabetes with a quiz for students to assess their understanding. A simple quiz on diabetes and lifestyle can be found at <http://www.nlm.nih.gov/medlineplus/magazine/issues/winter08/articles/winter08pg15.html> (answers here: <http://www.nlm.nih.gov/medlineplus/magazine/issues/winter08/articles/winter08pg16.html>), while a more complex set of quizzes on diabetes can be found here: <http://www.diabetes.co.il/>. Another quiz that assesses patient risk of developing type 2 diabetes can be found here: <http://www.diabetes.org/diabetes-basics/prevention/diabetes-risk-test/>. And here is a series of specific quizzes related to various topics related to

diabetes: http://www.dlife.com/diabetes_quizzes. Note that these are slow-paced as the screen changes completely with every question, and every comment.

3. You can have students determine experimentally the amount of sugar in various sodas and sports and fruit drinks. “Questions from the Classroom: The Great Soda Sellout”, an article in the October, 2004 issue of *ChemMatters*, discusses why soda machines are being banned from school cafeterias. It shows a photo of the amount of sugar in a soda—impressive! It discusses the difference in density between a “normal” soda and a diet soda, due to the different amounts of sweeteners in each. This sets students up for the next page in the magazine. This page offers students an experiment in which they can determine for themselves the amount of sugar in a soda and other juice drinks, based on the drinks’ densities and the densities of a set of standardized sugar solutions prepared in the lab.
4. “Testing for simple sugar in solution is accomplished by using a test reagent called Benedict Solution. The following instructions for making the reagent (also easily obtained from any chemical supply source [or perhaps a biology teacher colleague]) is as follows:
A solution of 17.3 g of sodium citrate and 10.0 g of anhydrous sodium carbonate in 80.0 mL of water is heated until the salts are dissolved. Additional water is added to bring the volume up to 85.0 mL. A solution of 1.73 g of hydrated copper sulfate in 10.0 mL of water is poured slowly with stirring into the solution of the citrate and the carbonate. Add water to make a final volume of 100 mL. ... [T]he presence of a strong reducing agent like glucose reacts upon heating with the blue cupric ions, readily changing them to Copper I which precipitates as an orange copper (I) oxide solid.”
(*ChemMatters* Teacher’s Guide for “Lab on a Sick”, April 2004)
5. It might be of interest to invite a medical technician to talk to the class about current advances in screening and diagnostic testing for diabetes, as well as management for the disease.
6. You can have students read the article “Carb Crazy” in the October 2004 issue of *ChemMatters* (available on the *ChemMatters* 25-year CD) and then complete a flow-chart of sorts for information involving metabolism, found on page 15 of the October 2004 Teacher’s Guide (also on the CD). Both the article and the Teacher’s Guide are also available online at http://portal.acs.org/portal/acs/corg/content?nfpb=true&pageLabel=PP_SUPERARTICLE&node_id=2119&use_sec=false&sec_url_var=region1&uid=065587a6-46ce-4834-82f2-1b1de9c615bd.
7. To show students osmotic pressure when water comes in contact with a polymer (analogous to osmotic pressure in cells), use superabsorbing polymer, sodium polyacrylate. See the December 1992 *ChemMatters* Teacher’s Guide “Superabsorbent Polymer Lab”, on page 3, available on the *ChemMatters* 25-year CD. Here’s a later version: the October 1999 issue of *ChemMatters*, page 6: “Super-Soakers: Just How Super Are They?” This student lab tests the claim that sodium polyacrylate can absorb 800 times its weight in water. Further experimenting is suggested.
8. To simulate kidney dialysis via a semi-permeable membrane, use starch and iodine and a Zip-loc® bag. See Experimenter: Kidney Dialysis—a Working Model You Can Make” on page 12 of the April 2001 *ChemMatters* magazine. (available on *ChemMatters* 25-year CD) Or try this version of the same lab, but inquiry-based, with background information for students: <http://kaffee.50webs.com/Science/labs/Chem/Lab-Dialysis.html>.
9. Here is a lab simulating the body’s control of digestion via insulin and the pancreas: http://www.lessonplansinc.com/lessonplans/feedback_mechanism_lab.pdf.

Polymers

10. A complete (albeit, older) two-week polymer project for high school students can be found at http://www.grc.nasa.gov/WWW/K-12/Summer_Training/Magnificat/Polymer_Project.html. It is designed as an end-of-the-year project for AP students, after they’ve taken the AP test.

Note that the site was published in 1998 and none of the many Web sites cited is still active. Nevertheless, there are four lab activities students can do.

11. Students can make a latex rubber ball (BEWARE latex allergies!) with Dave Katz's lab write-up at www.chymist.com/Rubber.pdf.
12. Students can do an experiment to test the adhesive qualities of various adhesive polymers. PBS Zoom has a Web page at <http://pbskids.org/zoom/activities/sci/stickometer.html> that describes a student experimental design for the test. Although this site is primarily for children, the idea behind the lab could be upgraded by having your class design their own "standard" test for evaluating the adhesives, and then proceed to do the test.
13. After discussing with students the Perkins polymer building blocks from the Background Information section above, you could check their understanding by asking the following question: Consider the following building blocks. Which ones could be put together to form a long chain? Would the chain(s) be considered a homopolymer or a copolymer? (There can be more than one polymer made from this set of blocks.)



Or you could ask them to list the correct sequence of the blocks if they were to represent a condensation polymerization process, or the sequence for an addition polymer (assuming you've discussed with them the difference between addition and condensation polymers).

14. A series of student activities on the topic of bioplastics and recycling of plastics can be found on page 55 in the April 2010 issue of the *ChemMatters* Teacher's Guide, "Plastics Go Green". It can be found online in the ChemMatters page at http://portal.acs.org/portal/acs/corg/content?nfpb=true&pageLabel=PP_SUPERARTICLE&node_id=2119&use_sec=false&sec_url_var=region1&uuid=3c57bd2f-91e0-4a2f-b532-1727071f0fe0.
15. For two student activities to test fibers and fabrics, visit this Smithsonian Web page: http://invention.smithsonian.org/centerpieces/whole_cloth/u7sf/u7materials/sfPac5.html.

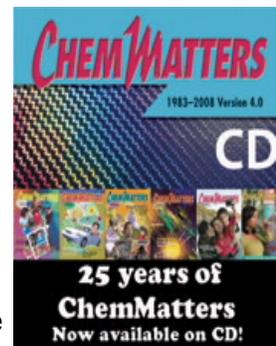
Out-of-class Activities and Projects (student research, class projects)

1. Students could do a laboratory research project to determine if there is any truth to the old tale of the doctor who diagnosed diabetes in a patron in a bar via the quick disintegration of foam on his beer. This was due to acetone exhalation in the diabetic. Might this work for other foamy substances, like root beer or a non-alcoholic beer (?), "elephant's toothpaste, or just soapy dishwater? Air can be bubbled through a solution to produce the foam, as the directions in this very brief article, "Beer, Acetone and Diabetes: A Story and a Demonstration", indicate. See the original reference in the *Journal of Chemical Education*. (Isenberg. *J. Chem. Educ.* 1972, 49 (3), p 151 DOI: 10.1021/ed049p151)
2. As a follow-up to #1, students may want to research the ability of dogs to detect when a person is about to go into insulin shock, hypoglycemia. See, for example, Dogs4Diabetics at <http://www.dogs4diabetics.com/about-d4d.html>. Of course, the focus for their chemistry class would be to ascertain what molecules the dogs sniff to detect the condition.
3. Students could do an analysis of their own diet to see what types of carbohydrates they consume, according to the glycemic index. Students with diabetes probably already do this on a regular basis. Perhaps one of these students would be willing to report to the class on their experiences as a person with diabetes.
4. Students can research the medical uses of polymers and present their findings to the class.

- Students might want to create a timeline of polymer discovery, or more specifically they might choose one type of polymer or one use of polymers to investigate.
- You could have students investigate the “eco-friendliness” of natural vs. synthetic fibers/fabrics. They could begin here: <http://justazipper.files.wordpress.com/2008/10/synthetic-fabric-vs-natural-fabric.pdf>. This site provides a description of fibers and the environment: <http://www.fibersource.com/f-tutor/fib-env.htm>, along with a very detailed analysis of the life cycle of materials found in a knit polyester blouse: <http://www.fibersource.com/f-tutor/LCA-Page.htm>.
- Students could test six-pack rings experimentally to verify their photodegradability via UV light. (This was mandated by the Federal government to ensure they would not be a long-term disposal hazard.) They may want to start here: <http://www.ringleader.com/>, although this site is about recycling the rings, rather than experimenting with them.

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>. (At the bottom of the Web site 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.)

Some of the more recent articles (2002 forward) referenced below may be available online 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. If they are available online, that will be noted.

Insulin and the pancreas

Rohrig, B. Carb Crazy. *ChemMatters* October, **2004**, 22 (3), pp 6–8. The article describes the role of carbohydrates in metabolism. It discusses blood glucose and its role in diabetes. It also discusses low-carb diets and ketosis. Rohrig also talks about polysaccharides and their relative indigestibility in our stomachs. (available online)

Brownlee, C. Lab on a Stick. *ChemMatters* October, **2004**, 22 (3), pp 9–11. In the same issue of *ChemMatters*, Christen Brownlee discusses the use and chemistry of test strips to determine blood sugar levels. The article is followed by a one-page interview with Dr. Helen Free, past ACS president and co-inventor (with her husband) of Clinistix, the first test strip that tested for glucose in the urine. Since this invention, chemists have included analyses for many other conditions, all on one multi-test strip. (available online)

Carroll, R. Abnormal Insulin. *ChemMatters* February, **1988**, 6 (1), pp 16–19. Author Carroll discusses the mysterious case of a person who produced more than enough insulin, but

it was a form that had been genetically altered within his body. This insulin was only “off” by one amino acid, but it was different enough that cells could not use it in normal metabolism, so they were being starved of glucose. This person had all the symptoms of type 2 diabetes, even though he was producing large quantities of insulin. The author also discusses cloning of the hormone in order to get enough of it to study, and HPLC to detect the differences in the insulin forms.

Emsley, J. Artificial Sweeteners. *ChemMatters* February, **1988**, 6 (1), pp 5–10. The author discusses the history of sweeteners, and includes artificial sweeteners only through saccharin and cyclamates (because the others weren’t marketed then). The real draw to this article is that it provides templates for students to make 3-dimensional paper models of both glucose and cyclamate molecules.

Brownlee, C. Sweet, But Good for You?. *ChemMatters* April, **2011**, 29 (2), pp 12–14. Author Brownlee discusses the role of high fructose corn syrup (HFCS) in our daily lives. Structures of glucose, sucrose, amylose and amylopectin are shown. You could tie this to the glucose-insulin balance in diabetics.

Haines, G.K. Sugar in the Blood Boosts Energy, *ChemMatters* October, **2011**, 29 (3), pp 6–7. In this article, author Haines describes the role of glucose in providing energy to the body. This will tie in directly with the insulin-glucose balance for the artificial pancreas article. (This article is not available online, but the Teacher’s Guide, which provides good background information on glucose as an energy source and its role in diabetes, is online, at the site previously mentioned. The Teacher’s Guide also provides a series of student in-class activities on the topic.

Rohrig, B. Serendipitous Chemistry. *ChemMatters* October, **2007**, 25 (3), pp 5–6. Among other stories in this article is a description of the discoveries of artificial sweeteners.

Polymers

A Successful Failure. *ChemMatters* February, **1998**, 16 (1), p 12. This is the story of the discovery and development of Silly Putty®, an inorganic elastomeric polymer.

Kydd, S. Nylon. *ChemMatters* December, **1990**, 8 (4), pp 4–6. Author Kydd describes the discovery of nylon by Wallace Carothers, and its “instant” commercial success. The author discusses the polymerization process leading to the polymer.

The Teacher’s Guide to this article provides more historical information, as well as ideas about nylon for the classroom.

Rohrig, B. The Science of Slime! *ChemMatters* December, **2004**, 22 (4), pp 13–16. Author Rohrig discusses the chemistry and physics of slime, a non-Newtonian polymer. The last page of the article tells students how to make slime and suggests a variation they can do with it. The Teacher’s Guide to this article suggests additional experiments students can do to test their product. (available online)

Robeson, D. Liquid Crystals. *ChemMatters* December, **1983**, 1 (4), pp 8–11. Although most of the article does not deal with polymers, the last page-and-a-half describes the composition and formation of Kevlar, a very strong polymer fiber.

Thielk, D. Kidney Dialysis: The Living Connection. *ChemMatters* April, **2001**, 19 (2), pp 10–11. The article describes the function of a kidney and how dialysis works. It describes the role of polymers in the semi-permeable membrane needed for dialysis. Page 12 provides an activity for students that simulates dialysis using a Zip-Loc® bag.

Goldfarb, B. Liquid Bandages—The Future Suture. *ChemMatters* February, **2000**, 18 (4), pp 9–10. Author Goldfarb describes the circuitous route to the discovery of cyanoacrylate—SuperGlue®—an anionic polymer. It is an adhesive, and adhesives are one type of polymer. This article also demonstrates a medical use of polymers (DermaBond) as mentioned in the current article.

The Teacher's Guide for this article provides a lot of background on various types of cyanoacrylates, as well as a timeline related to the discovery of these polymer adhesives.

Graham, T. An Orbitz Investigation: The Net Result. *ChemMatters* October, **1997**, 15 (3), pp 6–9. Orbitz®, before it was an online travel site, was a unique beverage that contained floating spheres of edible carbohydrate. It only lasted about 3 years (1997–2000?), due to poor sales. This article describes the author's investigations of the beverage, including on the last page, a full report of his findings. (A hint: it contained a polymer gel.)

Kyle, L. D. Contact Lenses. *ChemMatters* April, **1991**, 9 (2), pp 7–10. Author Kyle describes the history of contact lenses, showing evidence for the role of polymers in their production.

Rohrig, B. Food Packaging—Wrapping up Freshness. *ChemMatters* October, **2000**, 18 (3), pp 9–10. The article discusses the problems food packagers face in keeping foods fresh, and the role of polymers in helping to solve those problems.

The Teacher's Guide for the same issue discusses the various types of polymers used in various types of food packaging.

Plummer, C. PET Recycling. *ChemMatters* October, **1994**, 13 (3), pp 7–9. The recycling of polyethylene terephthalate (PET, for short), the polymer used in soda (and now water) bottles is discussed in this article.

The Teacher's Guide for this article discusses methods used commercially to recycle plastics, and it contains a student experiment to separate and identify commonly recycled plastic materials.

Shiber, L. Sticky Situations: The Wonders of Glue. *ChemMatters* December, **2006**, 24 (4), pp 8–10. Author Shiber describes several different types of glues (adhesives), one of the major types of polymers. She also discusses the role of polymers in each. (available online)

The Teacher's Guide for this article provides a great deal of background information on adhesives. (available online)

Miller, S. Spider Silk—Spinning a Strong Thread. *ChemMatters* February, **2001**, 19 (1), pp 10–11. The author discusses the complexity of spider silk and current attempts to duplicate its properties with a synthetic variety. Both are polymers.

Downey, C. Biodegradable Bags. *ChemMatters* October, **1991**, 9 (2), pp 4–6. This article precedes the article about biodegradable plastics referenced directly below, but it discusses biodegradable plastic used for garbage bags, which is made from polylactic acid that comes from potato peels.

Black, H. Putting a High Grade on Degradables. *ChemMatters* April, **1999**, 17 (2), pp 14–15. This article also discusses polymers involved in producing environmentally degradable polymers, with an emphasis on polylactic acid (PLA), the source of which for this article is corn. According to the article, in addition to the biodegradable garbage bag, other uses for biodegradable plastics are on the drawing board; e.g., biodegradable plastic used to replace sand in sandblasting. (You've got to read the article.)

Rohrig, B. Chemistry on the Fast Track: The Science of NASCAR. *ChemMatters* February, **2007**, 25 (1), pp 4–7. This article includes descriptions of the role of polymers in a race car and on the driver. (available online)

Alper, J. Polymers. *ChemMatters* April, **1986**, 4 (2), pp 4–7. This early ChemMatters article provides some history of synthetic polymers, based on a shortage of ivory for billiard balls in the 1860s. It includes discussion of the first partially man-made plastic—celluloid, and the first completely man-made plastic—Bakelite, as well as polyethylene terephthalate—PET. The author also notes that ivory is still used today (in very limited quantities) for specific uses, due to peculiar properties of the ivory that chemists have yet to be able to duplicate with synthetic polymers.

Scheinberg, S. Tyvek. *ChemMatters* April, **1986**, 4 (2), pp 8–11. Author Scheinberg discusses a special polymer—Tyvek®—and its physical and chemical properties and its uses. Page 11 provides a simple set of experiments for students to do to compare the properties of Tyvek to other plastic (synthetic polymer) materials and to paper (made of cellulose, a natural polymer).

Anderson, C. The Absorbing Story of the Thirsty Polymer. *ChemMatters* October, **1999**, 17 (3), pp 4–6. Author Anderson discusses the chemistry and uses of polyacrylates, super-absorbing polymers. The last page of the article provides a student experiment, “Super-Soakers—Just How Super Are They?”, to test the limits of absorbency of these polymers.

Banks, P. Kevlar: The Fabric of Steel. *ChemMatters* October, **1999**, 17 (3), pp 7–8. The article describes the discovery, chemistry and uses of Kevlar®.

Becker, R. Questions From the Classroom: Polymers in Iraq. *ChemMatters* April, **2007**, 25 (2), p 2. Author Becker answers a student question as he discusses serious uses for polymers, focusing on the war in Iraq. Topics include Dyneema®, a polymer stronger than Kevlar® for body armor, Kevlar® replacing steel for protection on Humvees, superabsorbers used to keep soldiers cool and to keep down dust from helicopter rotor wash brownouts, and even Silly String®, used to detect IEDs inside buildings. (available online)

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

More sites on the history of diabetes

The Juvenile Diabetes Research Foundation (JDRF) Web site has a brief timeline on the discovery of and research involving diabetes, most of which involves their research into the development of an artificial pancreas:

<http://artificialpancreasproject.com/milestones/default.html>.

More sites on measuring blood sugar

Scroll down this Wikipedia page to see a table of various chemical reactions used in blood glucose tests: http://en.wikipedia.org/wiki/Blood_glucose

More on digital sensors

An article in the July 25, 2011 issue of Chemical & Engineering News, "A Personal Meter For Everything", describes ways to use inexpensive personal glucose meters to measure myriad substances in blood, including cocaine, biomolecules like adenosine and interferon, and metals like uranium. (The article is available to ACS members only at <http://pubs.acs.org/isubscribe/journals/cen/89/i30/html/8930notw4.html>.)

More sites on sugars

A supplemental lecture on sugars by Professor Stephen Abedon can be found at <http://www.mansfield.ohio-state.edu/~sabedon/biol1025.htm>. It includes a quiz (with answers available via a "PEEK" button) to test student knowledge.

More sites on the role of insulin in blood sugar regulation

The Medical Biochemistry Page (<http://themedicalbiochemistrypage.org/insulin.html>) contains a very detailed discussion of the function of insulin in metabolism. It includes several useful diagrams to help the reader understand insulin's role in the metabolic process.

For a simple diagram of how the pancreas controls blood sugar, as well as basic articles about the pancreas, glucose levels and diabetes, see endocrineweb's page on diabetes at <http://www.endocrineweb.com/conditions/diabetes/normal-regulation-blood-glucose>.

You can view a short video clip from the MSOE Center for BioMolecular Modeling that uses animation and molecular modeling to describe the role of insulin in digestion at <http://cbm.msOE.edu/teachRes/animations/insulin.html>.

More sites on statistics about diabetes

The American Diabetes Association has a wealth of practical information about diabetes at <http://www.diabetes.org/>.

Check out the National Diabetes Information Clearinghouse (NDIC) Web site for statistics: <http://diabetes.niddk.nih.gov/dm/pubs/statistics/index.aspx#fast>.

For a comparison of diabetes effects and survival rates between 1950 and "now", visit <http://report.nih.gov/NIHfactsheets/ViewFactSheet.aspx?csid=120&key=D#D>. The paper shows how far research and treatment have come in that 60 year period.

More sites on diabetes

The National Diabetes Information Clearinghouse (NDIC) has a wealth of basic information about diabetes. (<http://diabetes.niddk.nih.gov/>)

The National Diabetes Education Program at <http://www.ndep.nih.gov/> provides lots of information about preventing diabetes and about treating diabetes.

Here is a great, very comprehensive Power Point presentation (100+ slides) on “Glucose Metabolism & Diabetes”:

http://www.iit.edu/research/services/doc_ret_2004/POWERPOINT_PRESENTATION.ppt. It includes the function of the liver and the pancreas in diabetes. It has more information than you probably want to use in your classes, but it would be great for an interested student, or for a biology teacher colleague, perhaps.

To view simple animations, descriptions and comparisons of normal digestion and digestion in type 1 and type 2 diabetic patients, go to the “My Dr.com” (Australian) Web site at <http://www.mydr.com.au/diabetes/animation-type-1-diabetes> and <http://www.mydr.com.au/diabetes/animation-type-2-diabetes>. The general Web site <http://www.mydr.com.au/gastrointestinal-health/pancreas-and-insulin> describes the role of the pancreas and insulin in metabolism and includes other related articles.

More sites on glycemic index

The Glycemic Index homepage, from the University of Sydney, Australia can be found at <http://www.glycemicindex.com/>. You can search on their database of ~2500 food products for the glycemic index (GI) for individual foods.

More sites on uses of polymers

The University of Akron Global Polymer Academy (AGPA) has a great deal of information on polymers for students and teachers. (<http://agpa.uakron.edu/p16/>) You can find a brief 19 slide presentation, with video and voice, of an introduction to polymers at <http://www.agpa.uakron.edu/p16/whatarepolymers/intro/player.html>.

The Polymer Ambassadors Web site at <http://www.polymerambassadors.org/index.html> offers ideas for activities for students.

More sites on polymers

Professor Lon Mathias of the Polymer Science Learning Center at the University of Southern Mississippi has developed with his university students a very extensive Web page at <http://pslc.ws/> that includes a wealth of materials for students and teachers (K–16) about polymers, including tabs on the following:

“Educational Resources” (<http://www.pslc.ws/teacher.html>), several modules highlighting the role of polymers in our lives, including “Polymers that Save Lives”, focusing on polymers in fire prevention and firefighting; “Protector Man”, a high school module dealing with polymer coatings; “That’s the Way the Ball Bounces”, dealing with elastomers (K–12); and finally, the Macrogalleria (See later reference for description).

“Activities and Demos”, a set of these for varying age groups, K–12, including a very open-ended activity for students to make their own polymer; demonstrations making polyurethane foam, superabsorbent polymers, and making a polymer solar engine; and experiments that are actually geared to college level chemistry, but which might be adapted for AP students;

“Matworld”, a Web page dedicated to types of materials in the material world, including polymers, metals, glass and ceramics. It contains information on 12 areas of interest; e.g., metals, silicon (glasses, concrete and ceramics) and hybrids (composites)

“Polydelphia”, a town complete with many buildings and commercial concerns that use polymers; e.g., Polyquarium, the Airport, the Sports Complex, etc. One can visit each place (via public transportation, of course) to learn more about polymers used in that industry or commercial activity;

And finally, “Macrogalleria: A Cyberwonderland of Polymer Fun”, a treasure trove of information and activities for students about polymers (and lots of learning) set in the structure of a shopping mall, complete with six levels of (increasing) understanding about polymers: Level 1) “Polymers are Everywhere”—about 20 stores in which polymers are used show students where they can find polymers in their daily lives; Level 2) “Polymers Up Close and Personal”—specific information about the many individual polymers one learned about in level 1; Level 3) “How They Work”—how polymers behave and why (this is where the chemistry begins its prominence); Level 4) “Makin’ Polymers”—this is where the polymerization processes are discussed (possibly beginning to go beyond high school chemistry); Level 5) “Getting Polymers to Talk”—methods of characterizing polymers (spectroscopic techniques, among others); and Level 6) “Processing”—extrusion processes in making plastics into useful products (<http://www.pslc.ws/macrog/index.htm>)

Note that the entire Web site has a very warm, friendly tone that should be welcoming to students.

The American Chemical Society has a Web page that discusses possible careers in polymer chemistry that might be of interest to students. It first describes briefly what polymers are, what the polymer business is about, and then it interviews six different chemists working in the polymer field. Find it at

http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_ARTICLEMAIN&node_id=1188&content_id=CTP_003399&use_sec=true&sec_url_var=region1&uuid=143acda6-1dc8-4db8-97f9-0ca4df301c2c.

More sites on the types of polymers

For more information on the history of adhesives and glues, you can download a 4-page history from the BSA, the Bearing Specialists Association, at <http://www.bsahome.org/Archive/html/escreports/HistoryofAdhesives.pdf>.

Modern Marvels did a video session on glue. View a 2-minute clip involving glue in home construction on YouTube at <http://www.youtube.com/watch?v=xmRp1cdGrNQ>.

The Encyclopedia Britannica Web site has a good page of basic information about adhesives at <http://www.britannica.com/EBchecked/topic/5823/adhesive/82534/Synthetic-adhesives>.

The Adhesive and Sealant Council Web site at <http://www.adhesives.org/> contains lots of information about what adhesives are and how they affect our lives. The site also contains technical (but not too technical) explanations of how adhesives work; see, for instance, “Adhesion and Cohesion” at <http://www.adhesives.org/trainingeducation/studentresources/adhesionandcohesion.aspx>.

Standard Gasket.com offers good coverage of the history of elastomers at http://standard-gasket.com/tech_specs/elastomer_develop.htm, and the chemistry of elastomers at http://standard-gasket.com/tech_specs/elastomer_chemistry.htm.

Fibersource, a one-stop information source about synthetic fibers, has a wealth of information at their Web site, <http://www.fibersource.com/Fiber.html>. The site includes a “Fiberworld Classroom”, just for teachers and students. This page contains basic polymer information, as well as the composition, history and uses of fibers.

The aapsPharmSciTech Web page on “Characterization of Coating Systems” discusses a series of experimental methods by which properties of coatings may be determined. (<http://www.fibersource.com/Fiber.html>) This is a rather technical discussion.

The American Coatings Association Web page, <http://www.paint.org/>, contains non-technical information about coatings and paint, including a 7-screen glossary of terms, data about sales, and a paper on the value added to our economy by coatings. Click on the “About Our Industry” pull-down tab at the top of their home page.

The New Zealand Institute of Chemistry (NZIC) Web site, <http://www.nzic.org.nz/ChemProcesses/polymers/index.html>, provides many links to other films and coatings Web sites, including a downloadable pdf report on the types of resins produced in New Zealand that are used in polymer coatings, as well as the chemistry (including reactions) behind their manufacture. The report was co-written by a high school teacher. (<http://www.nzic.org.nz/ChemProcesses/polymers/10A.pdf>) A similar report on paints and pigments is also available (<http://www.nzic.org.nz/ChemProcesses/polymers/10D.pdf>) The NZIC site also includes information on rubber (elastomers) and adhesives.

SPI, the plastics industry trade association, hosts a Web site that provides background information on plastics and the plastics industry at <http://www.plasticsindustry.org/>.

You can access a 4-minute video clip about the ubiquity of plastics, “Plastics: Past, Present and Future”, from SPI’s Web site. There is no narration, only music and a constant stream of photos showing plastics as they are used in everyday items. View it at <http://www.plasticsindustry.org/AboutPlastics/VideoDetail.cfm?itemnumber=6943>. Other videos about plastics and plastics processing can also be found there.

Your Body Under Construction

Background Information (teacher information)

Teacher Note: Some of the ideas in this article and in the Teacher's Guide might be considered part of sex education. Before discussing these topics in class it might be prudent to check with your building administrator, health education teacher or school policy about discussing these topics in a chemistry class. You can read an article about sex education policy here: <http://www.kff.org/womenshealth/upload/3224.pdf>.

More on hormones and the endocrine system

Hormones, as the article states, are chemical substances in the body that serve two basic functions. The first is to allow cells in the body to communication with each other. The second function, related to the first, is to control body processes by acting as chemical "triggers." Hormones are produced and secreted by small organs called glands that, taken together, form the human endocrine system. Hormones represent a variety of chemical structures, which correspond to their function and mechanism of acting in the body. The body produces hormones via a variety of chemical reactions and metabolizes and eliminates them in multiple ways. In terms of their chemical structure, hormones are classified as peptides (or proteins), steroids, or amino acid derivatives.

Peptide/Protein hormones—These hormones are produced by translation, which, of course, is part of overall gene expression. In this process messenger RNA is decoded by a cell ribosome to produce an amino acid chain called a polypeptide. Bonding in peptides (and proteins) is a covalent chemical bond formed when the carboxyl group ($-\text{COOH}$) of one molecule reacts with the amino group ($-\text{NH}_2$) of another molecule, releasing a water molecule. The resulting $-\text{C}(=\text{O})\text{NH}-$ bond is the peptide bond.

The eventual hormone may be part of a longer polypeptide precursor and then "clipped" out of the longer sequence for use as a hormone. If the peptide chain is very short, as short as three peptide units, for example, the hormone is thought of as derived from a peptide. Examples of this type of hormone include thyrotropin-releasing hormone (TRH) and vasopressin. TRH is made up of the three amino acids glutamic acid (Glu), histidine (His), proline (Pro), with an amine group attached, and it is produced in the hypothalamus gland and released by the anterior pituitary gland, which, in turn stimulates the thyroid gland. Vasopressin is a nine amino acid peptide with this sequence Cys-Tyr-Phe-Gln-Asn-Cys-Pro-Arg-Gly-NH₂. (For a list of amino acids and their abbreviations, see http://en.wikipedia.org/wiki/Amino_acid). Vasopressin controls multiple functions in the body, including blood pressure, regulation of water, glucose, and salts in the blood and, when released in the brain, it plays a role in social bonding.

If the polypeptide chain folds into an actual protein, followed by "clipping," then the hormone is referred to as protein-derived. In addition, the polypeptide units may also have carbohydrate side chains attached. In this case they are referred to as glycoproteins. Examples of protein hormones include insulin and growth hormone. Insulin is released by the pancreas to control blood sugar. Its formula is $\text{C}_{254} \text{H}_{377} \text{N}_{65} \text{O}_{75} \text{S}_6$ and it has a molecular weight of 5734 Da. It is made up of 51 amino acids in two separate chains which are connected by three disulfide bonds, sometimes called sulfide bridges, (see diagram) and structurally is one of the smallest

hormones in humans. Disulfide bonds are covalent bonds between two sulfur atoms and are often found connecting cysteine amino acid units.

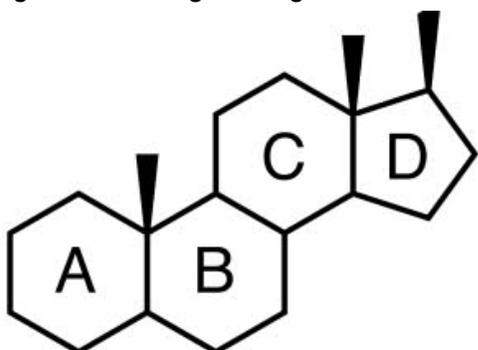
Human growth hormone is made up of 191 amino acids in a single-chain having a molecular weight of 22,124 Da. It is stored and secreted in the anterior pituitary gland and stimulates growth and cell reproduction in humans. The synthetic form is one of the controversial anabolic compounds abused by athletes.



Luteinizing hormone and thyroid-stimulating hormone are glycoprotein hormones. Luteinizing hormone is produced by the anterior pituitary gland and is made up of 212 amino acid units. In females this hormone stimulates ovulation and in male it triggers the production of testosterone, which is a major focus of the article. Thyroid stimulating hormone (TSH) also has 212 amino acid units and regulates the endocrine function of the thyroid gland. TSH causes the thyroid to produce two hormones triiodothyronine (T3) and thyroxine (T4), which help to control body metabolism and brain development.

Steroids and eicosanoids—These hormones are the ones emphasized in the article. Both testosterone and estrogen, the main topics of the article, are steroid hormones. Students certainly have heard about steroids as a result of the controversies over abuse of anabolic steroids, so it is important to provide appropriate background in this area.

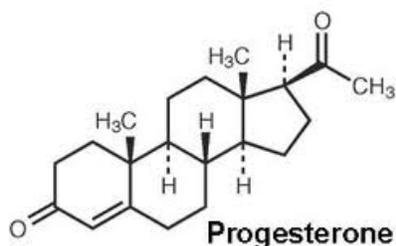
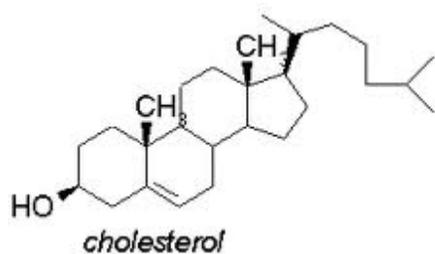
Chemically, steroid hormones all have a basic four-ring structure in common. There are three six-sided (cyclohexane) rings along with one five-sided (cyclopentane) ring. See the diagram below right. Rings A–C are the cyclohexane rings and ring D is the cyclopentane ring.

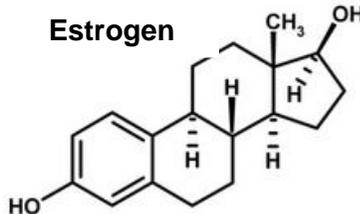
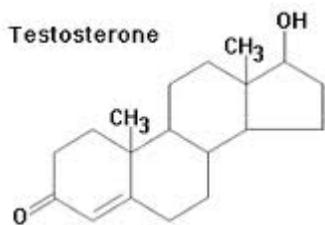


development of sexual traits.

Functional groups may be added to the basic structure to produce various hormones. This four-ring structure forms the backbone of the cholesterol molecule, so steroid hormones are said to be derived from cholesterol. Cholesterol is classified as a lipid compound. Most lipids are fat-soluble, allowing them to pass through cell walls easily. Steroid hormones help control metabolism, inflammation, electrolyte balance in the body, and most importantly in the context of the article, they help control the

The chemical structures of several steroid hormones are given below.

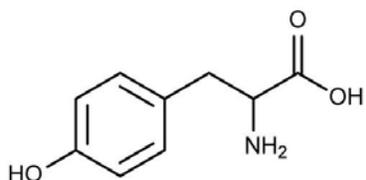




In addition to the sex hormones described in the article—androgens and estrogens—the other classes of steroid hormones are glucocorticoids, mineralocorticoids and progestogens. Glucocorticoids help to regulate blood sugar, the immune system and memory-related brain activity. Mineralocorticoids regulate electrolyte balance in the body. And progestogens are regulators of pregnancy and the menstrual cycle.

Eicosanoids include prostaglandin and related compounds that are produced from arachidonic acid, a 20-carbon polyunsaturated fatty acid. These hormones act on nearby cells and are not transported any great distances in the body. They are short-acting and are metabolized quickly in the body.

Amino acid derivatives—Two types of hormones are derived from the amino acid tyrosine, which has this structure:



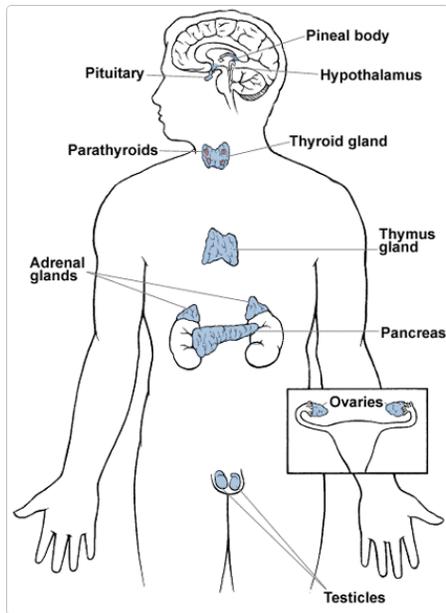
A combination of two tyrosine molecules plus iodine atoms results in hormones produced in the thyroid gland. Also derived from tyrosine are catecholamines, including epinephrine and norepinephrine, which are the “fight or flight” hormones produced in the adrenal glands. Tryptophan and glutamic acid are also used to produce hormones.

The endocrine system—As mentioned at the beginning of this section and in the article, the cells making up endocrine glands communicate with other cells by secreting a specific chemical, a hormone, and sending the chemical through the blood stream to other cells. Hormones regulate the body’s metabolism, and sexual development and function.

The major glands of the endocrine system are the hypothalamus, pituitary, thyroid, parathyroids, adrenals, pineal body, and the reproductive organs (ovaries and testes). The pancreas is also included in the endocrine system. See the diagram of the endocrine system, below (from the [American Medical Association](#)).

The hypothalamus is located in the brain and secretes hormones that regulate body temperature and metabolism and also stimulate the pituitary gland. The pituitary is located near the hypothalamus and is about the size of a pea. Its hormones regulate bone and muscle tissue growth, the production of sex hormones and milk production in females, and kidney water loss; it also stimulates thyroid secretions.

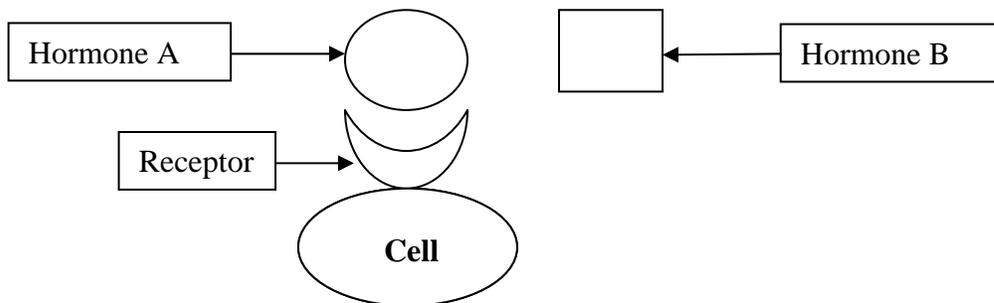
The thyroid gland, located in the neck, produces hormones that regulate metabolism, brain development, blood pressure, heart rate and some reproductive processes. On the surface of the thyroid are the parathyroid glands, which regulate bone metabolism and calcium



blood levels. Located on the kidneys, the adrenal glands produce steroid hormones that regulate metabolism, immune functions, stress and sexual processes. The pineal body secretes melatonin, the hormone that regulates the sleep cycle. Insulin is produced in the pancreas, and insulin regulates blood sugar. For more on the reproductive glands see the following section of this Teacher's Guide.

Hormones, Receptors and Target Cells—Hormones are secreted into the blood stream and are distributed to cells throughout the body. However, as the article and this Teacher's Guide have noted, each hormone affects some cells and not others. For example, insulin affects the level of glucose in the blood stream, but does not regulate the immune system or trigger development of secondary sex characteristics. Why is that, if hormones are distributed to many cells? As the article describes, any given hormone affects only those cells which have a "receptor" that "matches" that hormone.

Cells that are affected by a given hormone are called target cells. Remember that hormones are molecules, each with its own shape. Receptors are also molecules with a specific shape. If the shape of the hormone molecule matches the shape of the receptor, the cell to which the receptor is attached will be a target cell. In the simplified diagram below, Hormone A has a shape that matches the shape of the receptor on the cell, making the cell a target for Hormone A.



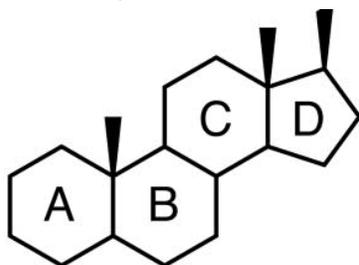
On the other hand, the shape of Hormone B does not match the shape of the receptor, so this cell will not be affected by Hormone B. Some cells have multiple receptors and so will be affected by more than one hormone. When a hormone becomes chemically bound to a receptor the receptor modifies its shape, which allows it to interact chemically with other molecules in the cell. This set of interactions produces biological changes like the ones involved in puberty, as described in the article.

In general, receptors are complex protein molecules. Receptors for water-soluble hormones are found on the cell surface since the cell wall is made up of lipids. These include proteins and peptides, catecholamines and eicosanoids. Lipid-soluble receptors, steroid hormones, are found in the cell cytoplasm or nucleus. There are two general mechanisms by which hormones actually work. One is that the hormone activates an enzyme in the cell that catalyzes the desired change. The other mechanism requires the hormone to bind with a specific section of DNA in the nucleus, which, in turn, produces change-inducing proteins.

More on anabolic steroids and their negative connotation

The article states that steroid hormones like testosterone and estrogen are anabolic in nature. Students might ask how these natural hormones are related to the anabolic steroids they hear about athletes using and abusing.

First, remind students that although the term “steroid” has come to have a negative connotation, it is a neutral term in chemistry. As described earlier in this Teacher’s Guide (see



“More on hormones and the endocrine system”), steroids are any chemical compounds that have the basic four-ring structure shown at left. Different combinations of atoms may be added to the rings, but the three six-sided (cyclohexane) rings and the one five-sided (cyclopentane) ring identifies a compound as a steroid. This four-ring structure forms the backbone of the cholesterol molecule, so steroid hormones are said to be derived from cholesterol.

Second, remind students that hormones like testosterone and estrogen are part of the body’s normal (and necessary) anabolism—that is, part of the natural growth process. Anabolic processes are those in which smaller molecules are combined to produce larger, more complex molecules. So, as humans grow, organs and tissues are built up. Cells grow and differentiate. Two typical examples are bone growth and development of muscle mass.

Third, remind students that as this article describes, hormones are natural and necessary parts of human development.

Students may or may not be aware that many of the steroid hormones have been synthesized artificially and that these synthetic steroids are the ones being abused. According to the [“Kids Health from Nemours”](#) (one of the largest nonprofit organizations devoted to children’s health) Web site:

Anabolic steroids are synthetic hormones that can boost the body’s ability to produce muscle and prevent muscle breakdown. Some athletes take steroids in the hopes that they will improve their ability to run faster, hit farther, lift heavier weights, jump higher, or have more endurance. In the United States, it is against the law to use anabolic steroids without a prescription.

Androstenedione, or “andro,” is a kind of anabolic steroid taken by athletes who want to build muscle. But research suggests that andro taken in large doses every day can significantly increase levels of testosterone, which can lead to a number of health problems.

How Do Anabolic Steroids Work?

Anabolic steroids are drugs that resemble the chemical structure of the body’s natural sex hormone **testosterone**, which is made naturally by the body. Testosterone directs the body to produce or enhance male characteristics such as increased muscle mass, facial hair growth, and deepening of the voice, and is an important part of male development during puberty.

When anabolic steroids increase the levels of testosterone in the blood, they stimulate muscle tissue in the body to grow larger and stronger.

However, the effects of too much testosterone circulating in the body can be harmful over time.

Dangers of Anabolic Steroids

Steroids are dangerous for two reasons: they are illegal, and they can damage a person's health, especially if used in large doses over time. Also, the health problems caused by steroids may not appear until years after the steroids are taken.

Although they might help build muscle, steroids can produce very serious side effects. Using steroids for a long time can negatively affect the reproductive system. In males, steroids can lead to impotence, a reduction in the amount of sperm produced in the testicles, and even reduced testicle size.

Females who use steroids may have problems with their menstrual cycles because steroids can disrupt the maturation and release of eggs from the ovaries. This disruption can cause long-term problems with fertility.

Steroids taken for an extended period of time also can cause:

- stunted growth in teens (by causing bones to mature too fast and stop growing at an early age)
- liver tumors
- abnormal enlargement of the heart muscles
- violent, aggressive behavior and mood swings
- blood lipid abnormalities that contribute to heart disease
- acne (or a worsening of acne)
- increased breast growth in males, especially teens
- irreversible stretch marks
- a heightened tendency for hair loss and male-pattern baldness
- muscle aches

Teen girls and women risk these additional side effects:

- male-type facial and body hair growth and male-pattern baldness
- deepening of the voice
- enlargement of the clitoris

Drug Testing

In addition to the health risks, kids who use steroids without prescription are breaking the law. Drug testing for all athletes has become more prevalent, and those who fail a drug test for steroids can face legal consequences, including jail time, monetary fines, exclusion from an event or team, or forfeiture of trophies or medals.

Andro use has been banned by many sports organizations, including the International Olympic Committee, the National Football League, the National Basketball Association, the National Collegiate Athletic Association, the Association of Tennis Professionals, and most high school athletic associations.

The [National Institute of Drug Abuse](#) adds:

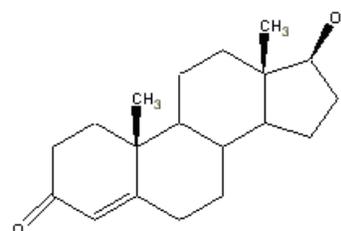
The immediate effects of AAS [androgenic anabolic steroids] in the brain are mediated by their binding to androgen (male sex hormone) and estrogen (female sex hormone) receptors on the surface of a cell. This AAS–receptor complex can then shuttle into the cell nucleus to influence

patterns of gene expression. Because of this, the acute effects of AAS in the brain are substantially different from those of other drugs of abuse. The most important difference is that AAS are not euphorogenic, meaning they do not trigger rapid increases in the neurotransmitter dopamine, which is responsible for the “high” that often drives substance abuse behaviors. However, long-term use of AAS can eventually have an impact on some of the same brain pathways and chemicals—such as dopamine, serotonin, and opioid systems—that are affected by other drugs of abuse. Considering the combined effect of their complex direct and indirect actions, it is not surprising that AAS can affect mood and behavior in significant ways.

More on testosterone

Testosterone is a white to off-white powder which is insoluble in water. It has a melting point between 153°C and 157°C. Its simple chemical formula is C₁₉H₂₈O₂ and its molecular weight = 288.42 Da. As the article shows, it has the familiar steroidal ring structure, right. You can see an interactive version of the testosterone molecule at http://www.worldofmolecules.com/3D/testosterone_3d.htm.

Although the compound is produced naturally in the body, it was first synthesized in 1935 by chemists Adolf Butenandt and Leopold Ruzicka, both of whom received the Nobel Prize in chemistry in 1939. The molecule is very unreactive since most



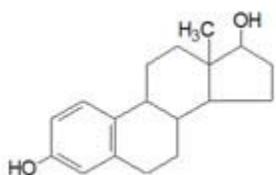
of the bonds are either carbon-carbon single bonds or carbon-hydrogen single bonds. This is not surprising since testosterone’s role in the body is as a hormone—its role is to bind to receptor sites on specific cells, which, in turn, produces changes within cells.

In males, testosterone is produced in the testes and circulates through the blood stream by protein carriers for thirty to sixty minutes. During this time it is either absorbed by various tissue or is decomposed by the liver and excreted in the urine. Testosterone’s role in the body is to stimulate the growth of male reproductive organs and secondary sexual characteristics—including body hair, baldness and deepening voice. It also promotes production of sperm, aids protein formation, and stimulates muscle and bone growth and red blood cells.

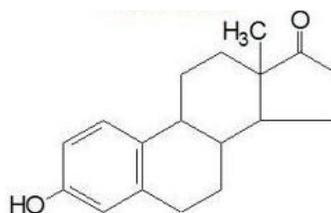
It is not just during puberty that testosterone levels are high in males. There is a surge in testosterone in unborn males between weeks seven and twelve, when male genitals begin to form. And the hormone levels climb in newborn males up until the age of six months when they return to their levels at birth. At around age nine, the process that leads to puberty begins in earnest. The hypothalamus releases gonadotropin-releasing hormone (GnRH) into the pituitary gland. The pituitary, in turn, releases two other hormones—follicle-stimulating hormone (FSH) and luteinizing hormone (LH). FSH causes the testes to form the seminiferous tubules which will eventually produce semen and, once they have formed, the body then produces sperm. LH stimulates Leydig cells in the testes to produce testosterone and other androgens. During the height of puberty, testosterone is produced twenty-four hours a day. In adult males the typical testosterone level is between 250ng/dl and 850 ng/dl. Testosterone reaches its highest point around age 40 and then declines steadily.

More on estrogens

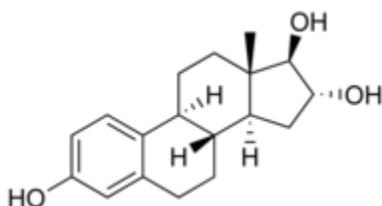
Estrogen is not a single compound, but rather the name given to a small group of steroid compounds that are important in the development of secondary female sex characteristics. The three most important compounds of this grouping are estradiol, estriol and estrone. A fourth compound, important during pregnancy, is progesterone. All four molecules are diagrammed below. It should be noted that the structural formula shown in the article is estradiol, far and away the most important of the estrogen compounds.



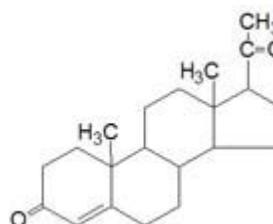
Estradiol



Estrone



Estriol



Progesterone

Estradiol is produced from testosterone and estrone from androstenedione. The most abundant of the estrogens is estradiol, which is the most potent of the female hormones. It is present in a female from the time of her first period until menopause. Estrone is weaker than estradiol, and in post-menopausal women more estrone is present than estradiol. The estrogen hormones are produced in the ovaries as a result of the action of two other hormones, follicle-stimulating hormone (FSH) and luteinizing hormone (LH). Like all steroid hormones, the estrogens are produced from cholesterol. The latter is converted first to androstenedione, then to testosterone and finally to estradiol. Estrone is converted directly from androstenedione.

These compounds are responsible for female sexual characteristics such as the formation of breasts, thickening of the endometrium and regulation of the menstrual cycle. The level of estradiol in females varies throughout the menstrual cycle, with the highest concentrations just prior to the onset of menstruation. As estradiol levels fall during the menstrual period, levels of progesterone rise in order to prepare the lining of the uterus for the egg to be implanted. If the egg is fertilized and pregnancy results, this hormonal pattern changes. Drops in estradiol and progesterone levels no longer occur, so there is no menstrual period. However, a new hormone, human chorionic gonadotrophin (HCG) is produced by the placenta and this stimulates the increased production of estrogens needed for pregnancy. Pregnancy kits are designed to detect HCG in a woman's urine. You can read about the science of this test at <http://www.sumanasinc.com/webcontent/animations/content/pregtest.html>. By the fourth month of pregnancy the placenta replaces the ovaries as the main source of estrogens, which at this point consist mainly of estriol. In addition to regulating sex characteristics,

estrogens also help regulate the cardiovascular, immune and central nervous systems, and affect the growth of bones.

The estrogens were discovered by Edward Adelbert Doisy, a biochemist who was studying the estrus cycle in mice. When he applied this work to humans he was able to isolate estrone and estriol from hundreds of gallons of urine from pregnant women. He later isolated estradiol.

More on puberty

Puberty is the time when both males and females begin to mature sexually. It involves a series of physical stages or steps that lead to the development of the secondary sex characteristics. In general puberty lasts for about five years. Boys experience the onset of puberty between the ages of nine and fourteen, females between eight and thirteen. The article describes some of the changes that hormones produce during puberty. These changes take place in a predictable way in the average teenager. In 1969, two pediatricians, Dr. W. A. Marshall and Dr. J. M. Tanner, described the stages of maturation of both males and females, and as part of that study they included changes we associate with puberty. You can read the two papers here, [one for boys](#) and [one for girls](#). This pattern of development has come to be known as Tanner stages. A summary follows:

Males

Tanner I: preadolescent

Tanner II: testicular enlargement and thinning of scrotal skin

Tanner III: penile enlargement and continued increase in testicular size

Tanner IV: further testicular/penile enlargement and appearance of pubic hair

Tanner V: adult testicular/penile size and pubic hair distribution

Females

Tanner I: preadolescent breast

Tanner II: breast tissue development with onset of areolar enlargement and sparse longitudinal labial pubic hair

Tanner III: increase in breast tissue volume and areolar enlargement, coarser and curlier pubic hair

Tanner IV: adult breast shape and elevation of the nipple thickening and broader distribution of pubic hair

Tanner V: mature adult breast shape and contour, adult pubic hair character and distribution

Marshall and Tanner also linked pubertal events to average age of onset:

Event	Average Age (years)	
	Males	Females
Breast development	N/A	11.2
Testicular enlargement	11.6	N/A
Pubic hair development	13.4	11.7
Peak growth spurt	14.1	12.1
Menarche	N/A	13.5
Adult pubic hair configuration	15.2	14.4
Adult breast	N/A	15.3

It should be noted that these ages were determined in 1969 and 1970 and are likely lower currently. There is more and more research about the early onset of puberty (precocious puberty), especially in females. For example, the average age of the onset of menstrual periods in girls was 15 in 1900. By the 1990s, this average had dropped to 12-and-a-half years of age. Researchers have identified some of the risk factors for precocious puberty in females. Among them are genetic, nutritional and social/psychological factors. For example, African-American females experience puberty earliest followed by Latinas, then Caucasian and finally Asian-American females. Nutritionally, girls with body mass indices (BMI) greater than 85% of the general population are prone to early puberty.

In addition to changes in sex characteristics during puberty, there are changes in:

Height—This is the well-known “growth spurt.” It usually happens in females before males. Between 17 and 18% of adult height is gained during this growth.

Bone Growth—Growth in bone length and bone density occurs here. Growth usually precedes increases in density so teenagers are more susceptible to fractures during this period.

Weight—Increase in weight and changes in distribution occur here. Females develop increased body fat, which distributes to both upper and lower parts of the body, giving females a “curvier” look. Males tend to increase in muscle mass.

It is worth noting to students, as the article describes, that all of these changes are caused by changes in chemicals called hormones, and that the changes themselves are chemical in nature.

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Biochemistry**—The article focuses on the role of chemicals in the body, which is usually considered biochemistry.
2. **Organic compounds**—All of the compounds discussed in the article are organic compounds.
3. **Structural formulas**— The “backbone” structure of cholesterol plays an important role in this article. In addition, several structural formulas are shown.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“Aren’t all steroids bad for you?”** *No, all steroids are not harmful to humans. You are probably thinking of artificial anabolic steroids, those that are taken by athletes to enhance performance. Many chemical compounds, some of them occurring naturally in the body and some that are used as medicines, are steroids. The term “steroid” refers to a specific chemical structure, not to something that is bad.*

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

1. **“Why do hormones affect only certain cells in the body?”** *This answer is based on the concept of form and function, the principle that the shape of molecules determines how they work. Many chemical mechanisms depend on the shape of molecules for their activity. Hormones are examples of this concept. It is just like what happens when you put the key into a lock. If the shape of the key is just right, it allows you to turn the key and open the lock. Cells that are affected by a hormone contain “receptors,” which act as locks to which hormones (the “keys”) bind. Hormone receptors are either on the surface of the cells or on the surface of the nucleus inside the cell. When a given hormone fits into a specific receptor, the two are like jigsaw pieces fitting together. What happens next depends on the type of hormone. In the case of testosterone the receptors are found in the nucleus of the target cell. When the testosterone binds to its receptor, it causes the receptor to change shape. This shape change then allows the receptor to attach to a strand of DNA in the nucleus. DNA, or deoxyribonucleic acid, is the chemical responsible for the genetic information that controls the function of the cell. Binding to specific sites on the strand of DNA causes the production of messenger RNA (mRNA), which carries the genetic information that directs the synthesis of proteins. Since proteins are the main structural materials of our body (muscles, hair, skin, organs), any change in protein production can have a big impact on how we look.” (from the article)*
2. **“The article says that estrogens can be produced from testosterone. How is it possible for female hormones to be produced from male hormones?”** *Both male and female hormones, remember, are derived from cholesterol, which has the basic four-ring structure. Compounds derived from cholesterol differ only in the functional groups added to the ring structure. So even though the estrogens and testosterone produce very different effects in the body, their structures are similar.*

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

1. This lesson plan describes a physical simulation of a feedback loop based on the endocrine system and insulin:
http://www.lessonplansinc.com/lessonplans/feedback_mechanism_lab.pdf.
2. The Yale-New Haven teacher Institute provides several worksheet-type activities about hormones and the endocrine system.
<http://www.yale.edu/ynhti/curriculum/units/1988/5/88.05.05.x.html>

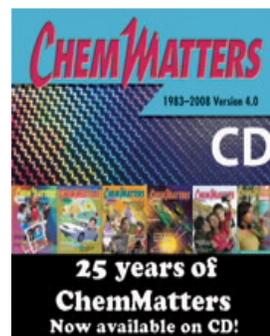
3. In this set of AP lesson plans, Day 14 Lessons are about plant hormones. Students can learn about the function of hormones in plants and transfer that knowledge to humans. (http://www.catalystlearningcurricula.com/samples/APBIO_sample.pdf)
4. The effect of gibberellic acid, a plant hormone, on plant growth is the topic of this lesson from the University of Georgia: <http://apps.caes.uga.edu/sbof/main/lessonPlan/plantHormones.pdf>.
5. Science NetLinks from AAAS focuses on hormones as cells communicators: <http://www.sciencenetlinks.com/lessons.php?DocID=65>. Note: some of the external links in this lesson are not working.

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

1. Depending on your situation and the appropriateness of expanding your chemistry class to activities about puberty, Discovery Channel and Nemours provide possible research topics for students to do either individually or in groups. You can have students emphasize the role of hormones and perhaps ask each research team to give information about the hormones as chemicals. (<http://www.discoveryeducation.com/teachers/free-lesson-plans/changes-of-puberty.cfm>)
2. Students could be assigned to create PowerPoint presentations on male and female sex hormones or on other hormones in the endocrine system.
3. Depending on appropriate school policy, groups of students could be assigned to prepare creative presentations on issues related to puberty. This might be a joint project with your health education colleague.

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 Web site 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 Teacher's Guides are available on the 25-year CD for all past issues, up to 2008.)

Graham, T. Anabolic Steroids: The Downside of Bulking Up. *ChemMatters* April, **2000**, 18 (2), p 12. This article will provide you with additional background information about anabolic steroids and drug testing for athletes.

Morton, R. Drug Testing at the Olympics—A Team Effort. *ChemMatters* December, **2000**, 18 (4), p. 7. This is another article that will give you background and examples of drug testing. It contains a section on anabolic steroid drugs.

Baxter, R. Sneeze and Wheeze. *ChemMatters* April, **2006**, 24 (2), p. 7. Although this article is about asthma, it contains a significant amount of background material on another type of steroids, corticosteroids.

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

More sites on amino acids

The University of Arizona Biology Project provides background on amino acids, which are important aspects of protein-derived hormones:

http://www.biology.arizona.edu/biochemistry/problem_sets/aa/aa.html.

Wikipedia has a convenient list of amino acids and their abbreviations at

http://en.wikipedia.org/wiki/Amino_acid.

More sites on the endocrine system

A complete overview of the endocrine system can be found here:

http://www.emedicinehealth.com/anatomy_of_the_endocrine_system/article_em.htm.

The National Institutes of Health has a site that gives detail on endocrinology:

<http://www.ncbi.nlm.nih.gov/books/NBK20/>. This site has excellent diagrams.

This site from Colorado State University provides a complete guide to the endocrine system, including hormone chemistry:

<http://arbl.cvmbs.colostate.edu/hbooks/pathphys/endocrine/index.html>.

This site on the endocrine system from Maricopa County Community Colleges has excellent diagrams:

<http://www.emc.maricopa.edu/faculty/farabee/BIOBK/BioBookENDOCR.html>.

More sites on hormones

For more on human hormones, see

<http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/H/Hormones.html>.

For a list of hormones, see <http://www.emcom.ca/primer/list.shtml>.

A second list of human hormones can be found here:

<http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/H/HormoneTable.html>. This list also has links to information about each hormone.

The lance Armstrong Foundation has information about female hormones at

<http://www.livestrong.com/article/26470-list-female-hormones/> and male hormones at <http://www.livestrong.com/article/164880-what-are-the-three-male-hormones/>.

From a unit developed at the Yale-New Haven Teachers Institute is a complete description of the effects of male and female hormones.

(<http://www.yale.edu/ynhti/curriculum/units/1988/5/88.05.04.x.html>)

More sites on the abuse of anabolic steroids

Nemours has a lot of information on its Web site about the effects of anabolic steroids:

<http://kidshealth.org/parent/emotions/behavior/steroids.html>.

The National Institute of Drug Abuse (National Institutes of Health) provides solid resources at <http://www.nida.nih.gov/infofacts/steroids.html>.

The National Institute of Drug Abuse also has a site aimed at teens:

http://teens.drugabuse.gov/mom/mom_ster1.php.

More sites on puberty

“How Stuff Works” describes several features of puberty in males at <http://science.howstuffworks.com/environmental/life/human-biology/male-puberty4.htm>, and in females at <http://www.howstuffworks.com/environmental/life/human-biology/female-puberty.htm>.

A more technical overview of puberty can be found on this eMedicine/Health page:

http://www.emedicinehealth.com/puberty/article_em.htm.

A description of the role of hormones and human reproduction can be found at

<http://www.yale.edu/ynhti/curriculum/units/1988/5/88.05.04.x.html#p> and at <http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/S/SexHormones.html>.

Titanic: Doomed by Chemistry?

Background Information (teacher information)

More on Titanic rediscovered

Titanic in 1985

Robert Ballard and his team from Woods Hole Oceanographic Institution (WHOI) discovered *Titanic* on the Atlantic Ocean floor in 1985 while onboard the WHOI research vessel *Knorr*, using deep sea submersibles *Argo*, a then-new deep-water towed sonar and video camera system, and ANGUS (Acoustically Navigated Geological Underwater Survey), another towed vehicle using 35 mm cameras.

The WHOI team worked jointly with a French oceanographic research team in the discovery. Several WHOI members joined the French team, sailing aboard their research vessel *Le Suroit*, as it tested a new sonar system of its own, the SAR (System Acoustique Remorqu ) in the Atlantic in early August. The French cruise preceded the WHOI trip and by the end of its itinerary had already ruled out a large portion of the 150 square mile area of ocean floor under study, so the WHOI vessel could focus on the remainder of the large plot of ocean floor. The discovery, made by the joint French-US team onboard the WHOI *Knorr*, happened just after 1:00 am on September 1, 1985 as the *Argo* took the first pictures of the debris from *Titanic*, including one of its boilers. It's interesting to note that both organizations were testing their new equipment (which effectively proved itself on the trips), and the discovery of *Titanic* was really a secondary discovery, but an exciting bonus.

Dr. Ballard and the team were recognized world-wide as celebration broke out when they returned home. While still at sea returning to Woods Hole, Dr. Ballard radioed to his colleagues that, "We are obviously very pleased and excited to have found *Titanic*, but we are also very aware of the significance of *Titanic* as a maritime disaster."

Titanic in 1986

The *Jason Jr.* submersible, a remotely operated vehicle (ROV), was taken back to *Titanic* site the next year to do more research for WHOI. It was launched from the *Alvin*, a 3-man submersible vessel. *Jason Jr.* ("JJ") was tethered by a cable to the *Alvin*, which sat on the ocean floor while *JJ* was able to move around the debris field and film the remains of *Titanic*.

The plan had been to launch *Jason* the larger version of *JJ* from *Argo*, sitting on the bottom of the ocean, which in turn would be connected to the *Knorr* on the surface. Two problems prevented this from happening: first, the *Knorr* on the surface would need to be fitted with a system to maintain its position on the surface, a dynamic positioning system, so that it could maintain its stationary connection with *Argo* at depth; and second, since *Jason* was a more sophisticated system with its stereo camera system and two remote manipulators, it had larger data storage and energy requirements that necessitated the use of fiber optic cable, rather than coaxial cable then in use for submersibles. Fiber optic cable was available for connection between two vessels on the ocean floor, but a fiber optic cable of sufficient length (2.5 miles) to connect *Argo* to the *Knorr* was not yet available; hence, WHOI decided to use a

smaller version of *Jason*, dubbed *Jason Jr.* (“*JJ*”) instead, using a shorter 60-m cable to tether *JJ* to the *Alvin* on the ocean floor. The *Alvin* had limited power, and *Jason*’s energy requirements were too great for the *Alvin*; *JJ* had a smaller energy requirement that the *Alvin* could handle. *JJ* was small enough that it was able to maneuver into the interior of parts of the ship.

The objectives of the 1986 research were threefold: 1) to test the components of *JJ* that were common to *Jason* so that progress could be made on the development of *Jason*, even though it was not present at the site; 2) to demonstrate that manned submersibles (the *Alvin*) could operate safely in the vicinity of wrecks (present-day events might require manned underwater vehicles; e.g., the space shuttle *Challenger* loss); and 3) to complete documenting via film the entire ship, to preserve it for perpetuity, and to show the state of the art technology used to film the wreck.

Major discoveries about *Titanic* from the 1986 study showed that, contrary to popular belief at that time, there was no evidence of a huge gash in the starboard hull from colliding with the iceberg that would explain the sinking. (Several other hypotheses have been offered since then, two of which are mentioned in the *ChemMatters* article.) Photos did show that rivets holding the hull plates together had popped, probably when the plates buckled under the impact with the iceberg. Slight separation of the plates then would have allowed water to enter.

Photos also showed two main sections of the ship (bow and stern) on the ocean floor, separated by about 2000 feet. This would imply that the stern probably broke off at or near the surface. (At least one eye witness account had reported seeing the ship “breaking apart”, but he wasn’t believed at the time.) The debris field is scattered across the entire distance between the two sections as the contents of the ship fell out of the openings in the sections at the parts descended.

The expedition did not take anything from the wreck site, either in 1986 or 1985. WHOI is treating the site as a gravesite and, as such, it deserves to remain as it was. The institution believes that photos and videos should be all we take from the site. Others can view them whenever they want, and there is no need to desecrate the site.

Although nothing was taken, two bronze plaques were left behind. The plaque on the bow commemorates the joint French-US team that made the original discovery. The one on the stern commemorates the 1502 people who did not survive the sinking. (Woods Hole Oceanographic Institution Web site at <http://www.whoi.edu/page.do?pid=7539>)

The Smithsonian Institution has a Web site, “Ocean Portal”, which includes a short video clip of “The *Titanic* Wrecksite” on the ocean bottom, probably taken in 1986. View it at <http://ocean.si.edu/ocean-videos/titanic-wrecksite>.

The Woods Hole Oceanographic Institution, (WHOI) obtained ownership rights to *Titanic* wreckage in 1994 revisited the site in August 2010. View their *Titanic* site at <http://www.whoi.edu/page.do?pid=7544&tid=282&cid=80448>.

More on chemistry at work in destroying *Titanic*

There is no doubt among oceanographers and conservationists that *Titanic* is deteriorating quickly.

Slipping beneath the waves on April 15, 1912, the R.M.S. *Titanic* famously disappeared from view until 1985, when it was rediscovered on the bottom of the North Atlantic

Now, scientists say, the legendary liner—beset by metal-eating life-forms, powerful currents, and possibly even human negligence—could be vanishing for good.

Titanic is falling apart.

Between 1987 and 1993, Nargeolet [leader of Expedition Titanic in 2010] observed the gymnasium roof corroding and collapsing as well as the upper promenade deck deteriorating. On an early '90s dive he saw that the crow's nest—previously seen still attached to the forward mast—had disappeared altogether, apparently damaged to the point where it snapped off and fell to an as yet unidentified location ([interactive Titanic wreck diagram](#)).

"In some places I saw a lot of difference, and in others almost nothing visible has happened," said Nargeolet, director of underwater research for [RMS Titanic, Inc.](#), a for-profit corporation that has retrieved *Titanic* artifacts for traveling exhibitions.

"For example, the stern section was the most destroyed part of the ship when it sank, and now most of the stern section is collapsed," he said. "The bow is pretty narrow and the strongest part of the ship, and it's still in relatively good condition."

(<http://news.nationalgeographic.com/news/2010/08/100818-titanic-3-d-expedition-shipwreck-science-collapsing/>, Handwerk, B. *National Geographic Daily News*, August 18, 2010.)

Physical and chemical processes have joined forces in the destruction of *Titanic*. As sand scours and ocean currents rumble across the ship and its artifacts, these physical processes gradually abrade the surfaces of materials until nothing is left. Mollusks and other underwater creatures are also eating away at the wood, physically degrading any materials made of wood. Other marine organisms are also attacking the iron of the ship, but we'll discuss that a bit further on in the Teacher's Guide. Although the physical processes contribute somewhat to *Titanic*'s destruction, they pale in comparison to the effects of the chemical processes at work.

Inorganic, electrochemical corrosion

Corrosion is playing havoc with *Titanic*. Salt water reacts with metal surfaces and slowly changes the metallic atoms into water-soluble ions. Despite the extremely cold water (around 0°C), absence of light (total darkness at that depth), and very low levels of oxygen—all of which would normally result in decreased reaction rates—*Titanic* is deteriorating rapidly. Some researchers who have visited *Titanic* on the ocean floor believe she may not survive another 100 years.

Iron (Fe) oxidizes to iron 2+ (Fe^{2+}) ions in the presence of an oxidizing agent. Iron is considered to be an active metal, meaning that when it corrodes, the products of corrosion do not form a protective coating on the metal that would prevent further corrosion. Rather, iron oxide produced when iron rusts forms a porous crust that is water-permeable. This allows more water to react with the iron beneath that porous crust. (Aluminum and copper are considered

passive metals, since they do form a protective layer that keeps the underlying metal from reacting further.)

The following information detailing the chemical reactions involved in corrosion of iron is taken from “Flaking Away”, *ChemMatters*, February, 2006, p 18.

- 1) $2 \text{Fe} \rightarrow 2 \text{Fe}^{2+} + 4 \text{e}^{-}$
(oxidation at anodic sites) [like the Titanic superstructure]
- 2) $4 \text{e}^{-} + \text{O}_2 + 2 \text{H}_2\text{O} \rightarrow 4 \text{OH}^{-}$
(reduction at cathodic sites)

The ions in this electrolyte solution can migrate together and react to form ferrous hydroxide, which reacts further with oxygen from the air to oxidize the ferrous ion and form insoluble ferric oxide, the chemical name for rust, as shown in these equations:

- 3) $\text{Fe}^{2+} + 2 \text{OH}^{-} \rightarrow \text{Fe}(\text{OH})_2$
(formation of ferrous hydroxide)
- 4) $4 \text{Fe}(\text{OH})_2 + \text{O}_2 \rightarrow 2 \text{Fe}_2\text{O}_3 + 4 \text{H}_2\text{O}$
(oxidation to ferric oxide or red ‘rust’)

The movement of ions through the electrolyte solution completes the electric circuit that allows the electrons from iron to move from the anode to the cathode.

Although oxygen is dissolved in ocean water (Henry’s law—the deeper the water, the greater the pressure, the greater the concentration of dissolved gases) it is not as prevalent as it is in air. In the lower concentration of oxygen in ocean water, reaction 2) is far less likely to occur. Instead, water is directly involved in the formation of $\text{Fe}(\text{OH})_2$, according to the following equation.

- 5) $\text{Fe}^{2+} + 2 \text{H}_2\text{O} \rightarrow \text{Fe}(\text{OH})_2 + 2 \text{H}^{+}$

Although seawater is rather alkaline, with a pH of approximately 8.2, objects undergoing oxidation-reduction reactions can experience much more acidic conditions in their own microenvironments, with pH’s around 4.2. The acidic conditions greatly speed up the rate of corrosion and subsequent degradation. Reaction 5 above shows one source of the acidity, H^{+} ions.

It has been noted that sulfides are frequently found covering artifacts. These are formed by the reduction of sulfates in the water, and they also contribute to the corrosion of iron in ocean water. Their origin is described below.

Organic, bacterial corrosion

But simple inorganic corrosion processes don’t explain the long “rusticles” found growing on those same metal surfaces. Anaerobic bacteria are also taking a toll on *Titanic*. The rusticles resemble icicles, made of rust; hence, the term, rusticles. They are the product of the bacteria “eating away” at the iron.

A Canadian research team is studying the corrosion of the iron from Titanic. Their goal in the study is "...to gain an insight into the geochemistry of iron and other metals that had accidentally been introduced into the deep-sea environment.'

Their study shows that bacteria play a major role in promoting corrosion of the *Titanic*, resulting in fast-growing structures such as rust flows and rusticles. Rusticles resemble stalactites and grow on the hull of the ship. They have a brittle hydrous iron oxide shell with a dark red outer surface and an orange inner surface. The core of the rusticle and the inner surface of the shell consist of spherical aggregates of small needlelike crystals of goethite [α -FeO(OH)]. The outer surface of the shell has the crystal structure of lepidocrocite [γ -FeO(OH)].

The Canadian study shows that a variety of bacteria are present in the rusticles. These are predominantly sulfate-reducing species that multiply rapidly in anaerobic conditions. The rust flakes contain a mixture of goethite, lepidocrocite, and other minerals. SEM examination of the flakes reveals a well-crystallized iron mineral, possibly hematite (Fe₂O₃), associated with a silicon-rich iron mineral. Black patches of siderite (FeCO₃) and iron-rich cubes, possibly magnetite, also are present. Surprisingly, the rust flakes have a thin coating of lead carbonate (PbCO₃). Small cubes of galena (PbS) also are common. The Canadian researchers suggest that the source of the lead is paint on the hull of the *Titanic*.

(Freemantle, M. Chemical Techniques Help Conserve Artifacts Raised from Titanic. *Chemical & Engineering News*, October 17, **1994**, 72 (42), pp 49–52.)

An article in *BBC News* online, "Ocean Reclaiming Titanic Liner", October 18, **2005**, http://news.bbc.co.uk/2/hi/uk_news/northern_ireland/4352568.stm, reveals the author's surprise at the state of Titanic:

At 12,850 feet, at the bottom of the Atlantic, there is no oxygen so, in theory, no rusting can take place. But I had not reckoned on bacteria being there.

In fact, the ship is in a terrible shape and the deterioration is getting faster and faster.

Decks are collapsing. Any structures that remained standing after the sinking are now starting to topple and show signs of being unstable. The ship has become unsafe and some divers won't approach certain parts because of the dangers.

Submersible pilots tell of seeing the roof of one section ripple from the force of the sub's propellers as she glided past.

If there is no rust because of a lack of oxygen to make the process work, then what is destroying the ship?

The answer, we now know, is bacteria. These micro-organisms are eating the manganese, iron and sulphur out of the steel.

In 2010, Canadian scientists discovered a new species of bacteria in the rusticles that have formed on Titanic. They're not sure yet whether this new bacteria, *Halomonas titanicae*, is working alone to corrode the steel, or if it has help from some of the 27 other microorganism species that thrive within the rusticles. (physorg.com, December 6, **2010**, <http://www.physorg.com/news/2010-12-microscopic-life-aboard-rms-titanic.html>)

A concern that worries scientists is whether these same bacteria might also eat away at other underwater structures, like offshore oil and gas pipelines.

Sulfate-reducing bacteria (SRB) are one of the bacteria types involved in the formation of the rusticles described above. Their role in the corrosion of metal at depth is described below.

- The wreck of the Titanic was found in 1985 in nearly 4000 metre deep waters. Some parts had long red rusticles ('rust-like, icicle-like') hanging while other parts had black iron(II) sulfide. Other parts of the Titanic had little corrosion. Experiments on samples collected from the wreck showed that sulfate reducing bacteria (SRB) were important in forming the red rusticles and black FeS.

Bacteria associated with the rusticles are sometimes called "iron-eating bacteria". Two types of bacteria are found with the rusticles. Anaerobic SRB which do not need oxygen are found on the inside. Oxygen-dependent aerobic bacteria are found on the outside of the rusticles. Chemical reactions carried out by this combination of bacteria increase the rate of corrosion of the iron Titanic. One microbiologist has suggested that iron corrosion driven by bacterial action will completely reduce the Titanic to a huge iron-ore deposit within 100 years.

- SRB produce the compound hydrogen sulfide (H₂S) from the sulfate ions that are plentiful in sea water:

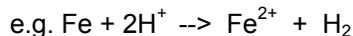


Note that the oxidation state of sulfur has been reduced from +6 in SO₄²⁻ to -2 in H₂S.

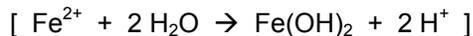
This is why the anaerobic bacteria that cause this change are called sulfate reducing bacteria.

- Sea water normally has a pH of about 8. The increased solubility of CO₂ with depth makes deep ocean water slightly acidic. As the pH drops with depth in ocean water the presence of more hydrogen ions favours corrosion of metals.

- Corrosion of metals produces metal ions,



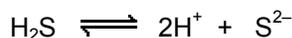
Some metal ions produced can undergo hydrolysis (reaction with water) to produce more hydrogen ions.



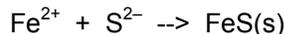
The SRB are able to change the H₂ to 2H⁺, which they then use to reduce sulfate ions to hydrogen sulfide.

- The release of hydrogen ions can produce small acidic environments as low as pH 4 in some locations around a shipwreck.

H₂S, produced by the action of SRB is a weak acid that releases hydrogen ions and sulfide ions,



The sulfide ions from the H₂S can precipitate Fe²⁺ ions to form insoluble, black iron (II) sulfide FeS:



The presence of black FeS indicates that SRB are present.

The precipitation of FeS removes sulfide ions and encourages further ionisation of H₂S releasing more H⁺.

- Metal near wood on the Titanic was badly corroded. As the wood cellulose, (C₆H₁₀O₅)_n, decayed, it released oxygen which stimulated the growth of aerobic bacteria. Waste from these aerobic bacteria provided nourishment to the anaerobic SRB. The SRB flourished and increased corrosion of the metal near wood.

(http://hsc.csu.edu.au/chemistry/options/shipwrecks/2733/ch966Dec2_03.htm#c1, New South Wales, Higher School Certificate, Department of Education and Communities Web site, a Charles Sturt University initiative)

More on chemistry at work in saving Titanic

Chemistry may be responsible for the degradation of Titanic and its artifacts, but chemistry is also at work to preserve those artifacts brought back from the Titanic debris field, 2.5 miles under the Atlantic. The artifacts include "...a porthole, a chandelier, buttons from crew uniforms, a pipe, and a leather cigarette case complete with cigarettes.

"Among the more delicate relics retrieved from the wreck are paper items found tightly wadded in leather bags. They include a newspaper published in Southampton on Tuesday, April 9, 1912, the day before the *Titanic* sailed from port on her maiden voyage."
(Freemantle, M. Chemical Techniques Help Conserve Artifacts Raised from Titanic Wreck. *Chemical & Engineering News* October 17, 1994, 72 (42), pp 49–52.)

According to this same source, not all metal objects raised from the wreck site are equally corroded. Objects made of bronze and nickel, like a bronze whistle and nickel coated pots appear brand new, while objects made of copper alloys are extensively corroded.

After the artifacts are brought to the surface, great care must be taken to wash off all acidic silt and solution from the objects and then the objects are stored in tanks of water until they are brought back to a conservation lab. There they are once again washed with fresh water and cleaned with a brush, if they aren't too fragile, to remove corrosion products. Frequent washings remove more surface salts, and salts trapped internally are removed by electrolysis or treated with reducing agents. The main substance that must be removed is chloride because it continues to promote corrosion of metals, and it depolymerizes organic substances.

Electrolytic reactions generally reverse the galvanic reactions that had been occurring on the artifacts when they were underwater. In addition, electrolysis assures that chloride ions, the major culprits behind corrosion, have been removed from deep within the artifact. Without salts in contact with the artifact, corrosion should stop.

Once the artifacts have been stabilized, they can be coated with a surface treatment, such as a polymer clear-coat or clear wax to protect them further corrosion. Once this is done, the artifact must be stored under very specific conditions of temperature and humidity, in order

to prevent corrosion from beginning all over again. More details about conservation work on Titanic artifacts can be found at the above-mentioned article in C & E News.

An article in Chemical & Engineering News, "Saving Shipwrecks", discusses the standard electrolytic methods for conserving corroded metal from sunken ships, but then it goes on to describe a new method, sub-critical water extraction, to remove the chloride ions from metal structures, to prevent further corrosion. The process utilizes water at 180 °C and 600–800 psi to remove the chlorides and to stabilize the metal. This process is much faster than the older electrolytic methods and may be the way of the future. As of the date of the article, the method has only been used on small items, like bolts, rivets and sections of artillery shells, but the researchers anticipate scaling up the process.

Although they don't yet know for sure why the process works so much faster, the chemists believe the process works because of "... improved transport properties of the subcritical fluid. The subcritical water has a higher diffusion rate and lower viscosity than water at ambient conditions. 'The corrosion goes deep into the pores. Things like surface tension and viscosity and transport properties become limiting factors,' Drew [Professor Michael Drew, professor emeritus in the School of Materials Science & Engineering at Clemson University] says." (<http://pubs.acs.org/cen/science/85/8502sci1.html>, Arnaud, C. Saving Shipwrecks. *Chem & Eng News*, January 8, 2007, 85 (02), pp 45–7.)

More on hypotheses about why Titanic sank

Three main hypotheses exist to explain the sinking.

1) Cold temperatures cause decreased malleability and increased brittleness in metals. This could have made the hull more susceptible to cracking and forming a gash as it collided with the iceberg, allowing water to flood the forward compartments. It could also have caused the shearing of the rivets (also made more brittle by the cold water) along the hull plate seams, similar to that described in the *ChemMatters* article (but for a different reason) that would have resulted in water rushing to the interior of the ship.

2) The relatively poor quality of the steel used in the hull plates that resulted in their increased brittleness. Indeed, the first piece of the hull of Titanic that was brought to the surface was tested by placing it in ice water and hitting it with a hammer. It shattered. People immediately jumped on this evidence as proof that the steel used to build Titanic was inferior. It was later found that other pieces of the hull were of better quality steel than that first piece; indeed the first piece was the only one to exhibit brittleness in the test.

Actually, sources have stated that the steel used for *Titanic* was possibly the best available at that time. It seems no expense was spared to make *Titanic*. Nevertheless, compared to today's steel, that of the 1900s contained more sulfur, and adding a nonmetal to iron will decrease its malleability and increase its brittleness or tendency to fracture.

3) The increased slag content of the rivets used to hold together *Titanic's* hull plates resulted in increased brittleness of the rivets which, in turn, may have resulted in the heads of those rivets being sheared off with the impact of the collision. This would have opened up seams along the hull plates where water would have entered. Harland & Wolff, the builders of Titanic and two other massive ships at the same time, found themselves short of materials to complete all three ships and used lower-quality materials where necessary. Rivets in the bow and stern of Titanic were pounded by hand, where large riveting machines wouldn't fit. These

are the sites believed to contain the substandard steel rivets, and the bow is where the opening of the hull began when it hit the iceberg. Regular steel rivets were used in the rest of the hull, where no rupture occurred. (Harland & Wolff, still in existence, flatly deny the idea of faulty rivets.)

The belief that Titanic tore apart at a 30-degree angle (or more), as depicted in the Cameron movie has been tested and found wanting. Examination of the hull pieces on the ocean floor indicate that the ship broke apart at a very shallow angle, perhaps as small as 11°. This would have allowed the stern to regain buoyancy as the ship cracked apart. It is now believed that the passengers in the stern may not have had much warning of the severity of the incident, and they may have thought there was not much danger of sinking and therefore had little reason to “man the lifeboats”.

(Ewers, J. The Secret of How the Titanic Sank. *US News*, September 25, 2008, <http://www.usnews.com/news/national/articles/2008/09/25/the-secret-of-how-the-titanic-sunk?PageNr=2>)

Galvanic corrosion may also have had a hand in sinking Titanic. The ship sat in seawater for a year after the hull was launched, in order to furnish the interior. It's possible that the substandard rivets in contact with the steel of the hull (two dissimilar metals) may have increased the rate of corrosion of either or both of them, weakening the steel at the points of contact.

(<http://www.corrosion-doctors.org/Landmarks/titan-sinking.htm>)

Connections to Chemistry Concepts (for correlation to course curriculum)

1. **Hypothesis vs. theory**—Researchers have valid reasons for believing what they do about why *Titanic* sank (brittle hull plates from too much sulfur in the steel, brittle rivets that sheared off from too much slag content), but since they cannot test and reproduce their results repeatedly, their hypotheses will remain just that; they will not become theories.
2. **Density**—Central to most chemistry courses, and also central to the story of the sinking of *Titanic*; this article gives teachers a great story with which to begin the study of density and buoyancy.
3. **Alloys**—Steel is a prime example of an alloy. Many types of steel exist: chrome steel, stainless steel, tungsten steel, etc. Of course, most students would rather discuss gold alloys; e.g., 24 karat, 18 karat, etc.
4. **Freezing point of pure substances vs. mixtures**—This article is a great example to introduce students to the idea that pure substances have their own characteristic melting/freezing (and boiling/condensing) temperature, but mixtures do not.
5. **Colligative properties**—See 4 above.
6. **Metallic bonding and valence electrons**—Bonding in metals using loose valence electrons is responsible for properties of malleability and ductility.
7. **Metals vs. nonmetals**—Sulfur, a nonmetal, and lacking ductility and malleability, lowers these properties in metals when used as an additive. It binds loose valence electrons in metals to its own valence shell, thus decreasing their ability to move from atom to atom.
8. **Properties of metals**—Malleability and ductility—or lack thereof—are caused by loose valence electrons in metals, or a lack thereof in nonmetals.

9. **Galvanic vs. electrolytic redox reactions**—Seawater is corroding any exposed metal on *Titanic*'s surface. Use this as an attention-getter when you discuss redox reactions. But reversing these spontaneous reactions using electrolysis is a way to conserve and protect metal objects from further degradation.

Possible Student Misconceptions (to aid teacher in addressing misconceptions)

1. **“The water temperature in the Atlantic Ocean on the night *Titanic* sank couldn't have been 31°C! The water would have been ice, because water freezes at 32°C.”** *While it is true that the normal freezing temperature for water is 32°C, that is for fresh (pure) water. Ocean water contains many dissolved compounds (as ions) that actually lower the freezing temperature of the water to below 32°C.*
2. **“Ships float because of the air trapped inside.”** *A ship would float whether air is trapped inside, or if it were another gas—or even a vacuum inside. All that is needed to have the ship float is to reduce the composite density of the ship to a number lower than the density of the water. This is done by making sure that the design of the ship has a lot of “empty” space that will add volume without adding substantial mass (to keep the $D = M/V$ ratio low). Since air is a gas, and gases tend to completely fill the space they occupy, air fills the voids in the ship, without adding appreciably to the overall weight of the ship.*
3. **“So, the density of the steel changed when *Titanic* took on more water?”** *No, the density of the steel didn't change, the density of the ship changed. Steel is a substance (albeit, a mixture, not a pure substance, although the same argument holds here), and you can't change the density of a substance. Density is a characteristic property of a pure substance. The only way you could effectively change the density of the steel would be to melt it down and add more or different additives (like carbon or sulfur) to the alloy. The ship, though, is an object, and you can change the density of an object—either by adding mass inside the object, or increasing its total volume.*
4. **“Since the density of air decreases with altitude (or gets greater as one descends through the atmosphere), does the density of water increase with depth? That would explain the increase in pressure with depth.”** *This sounds logical, but the problem is that air is a gas and water is a liquid. Gases are compressible because they are mostly empty space; liquids are not compressible (to any appreciable extent) because a liquid's molecules are adjacent to each other and can't be forced significantly closer. Thus, as one ascends to higher altitudes in the atmosphere, there are fewer air molecules in a given volume, so the density decreases. But a given volume of water contains approximately the same number of water molecules, no matter the depth, so its mass—and thus its density—doesn't change appreciably. So the argument about density being responsible for the pressure change works for air, but not for water. The reason for the increase in pressure at increasing depth in water is simply that there is a greater amount (and hence, greater weight) of water “overhead”, pressing down on any surface, and more force per surface area means more pressure.*

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

1. **“Was the water temperature a factor in Titanic’s sinking?”** *It is well known that metals become more brittle at lower temperatures, so the freezing temperature of the north Atlantic that night may well have contributed to the rupturing of Titanic’s hull. The question of whether the temperature was a factor in the sinking may remain unanswered, but temperature was unquestionably a factor in the relatively low number of survivors.*
2. **“How can a submarine ‘sink’ and then ‘float’ again?”** *A submarine can control its sinking and floating via tanks carried within the ship. These ballast tanks can be filled with seawater from outside, increasing the total mass of the submarine, without increasing its total external volume. This increases its density to the point where it is greater than seawater, and it sinks. To float to the surface again, it uses compressed air (from other tanks) to force out the water in the ballast tanks. This reduces the total mass of the submarine to the point where its density is once again less than the density of seawater, and it floats.*
3. **“The author said the density of Titanic changed. Can you change the density of an object? I thought density was a characteristic property.”** *Density IS a characteristic property—for a substance, but not for an object. The density of an object can be changed by adding (or removing) mass internally or increasing (or decreasing) volume externally. Density is a characteristic property, but only for pure substances. (See “Possible Student Misconception” 3, above.)*
4. **“When he discovered buoyancy while in a public bath, did Archimedes really run naked through the streets crying ‘Eureka’?”**
Ummm . . . maybe?

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

1. “For students to understand why the *Titanic* sank as quickly as it did, they need to understand the relationship between depth and pressure. Under high pressure, water pushes through an opening faster.
“To demonstrate this, have students cut four holes in a quart-size milk carton. Put tape over all the holes and fill the container with water. Place the container in a large sink and remove the top piece of tape. Have them mark the furthest distance the water stream reaches. Continue this with the second, third and fourth holes. Write a conclusion about why the water from the lowest (or deepest) hole went the greatest distance.
“Explain how this experiment relates to *Titanic*. Students should conclude that the deeper the water, the higher the pressure, causing water to push faster through any openings and rapidly flood the ship.” (<http://www.titanicattraction.com/titanic-education-science.php>)
2. You could use data about *Titanic* as a means of arousing student interest in unit analysis / dimensional analysis calculations early in the year; e.g., if each lifeboat held 65 people, how many lifeboats were needed to carry all 2,228 passengers and crew to safety? Data can be found here:
Ship facts: http://en.wikipedia.org/wiki/RMS_Titanic
Casualties and survivors: <http://www.anesi.com/titanic.htm>
Mortality data: <http://www.childrensmercy.org/stats/training/datasets/titanic.htm> (sobering to see so many names in a database)

Freezing Point Depression

3. You can use an ice-bath and salt to show students the phenomenon of freezing point depression, to help explain why the water in the Atlantic that night could be 31°F, below the normal freezing temperature of fresh water. Vernier has a nice lab using its temperature probes: “Using Freezing Point Depression to Find Molecular Weight”,

http://www.vernier.com/experiments/chem-a/4/using_freezing_point_depression_to_find_molecular_weight/.

Here is the same lab, using thermometers instead of the probes, from ChemSource's *Sourcebook*. The URL provides the entire 40-page module on solutions. The experiment, "Activity 2: The Freezing Point Depression of Lauric Acid", is on pages 12–15 and includes both student and teacher versions of the experiment:

<http://dwb.unl.edu/ChemSource/SourceBook/138SOLN.pdf>. (Archer, R.; Cumming, W.; Rennert, A. "Solutions" In *SourceBook*, Version 3.0, edited by Orna, M. V.; Smith, P. J. V. ChemSource, Inc.: New Rochelle, NY, 2010) The entire collection of 51 modules (2300 pages) containing everything a chemistry teacher could possibly use for his/her chemistry course can be purchased on a CD. Information is available at <http://www.chemsource.info/SourceBook-CD.html>.

The CD is available for \$59.95 through ACS at

https://www.store.acs.org/eweb/ACSTemplatePage.aspx?site=ACS_Store&WebCode=storeItemDetail&parentKey=cbf9d4e6-3ae0-411c-95d3-12808813daf1&catKey=07f5e41e-3faa-447b-a67d-6ccfda20cb94.

4. Of course, to make freezing point depressions more interesting to students, you could make ice cream in the lab to study colligative properties. Maybe start here:

<http://teachnet.com/lessonplans/science/plastic-bag-ice-cream-recipe/>.

The Journal of Chemical Education also has an ice cream lab and, although it uses only one real ice cream maker for the whole class—and you would probably not want to do a student lab with only one ice cream maker—the article does have some good questions for students to answer at the end of the experiment. (Martino, J. Filtrates & Residues: Ice Cream: Delicious Chemistry. *J Chem Ed*, November, 1983, 60 (11), pp 1004–5)

(<http://iweb.tntech.edu/DSwart/TILNICES/JCE1983p1004.pdf>)

And here's one that is part of the Lighthouse Initiative for Texas Classrooms that purports to be an AP ice cream lab: http://www.tealighthouse.org/science/hschem_freezing.php.

Corrosion/ impurities

5. The National Oceanic and Atmospheric Association Web site contains an activity that simulates the galvanic corrosion occurring on *Titanic* on the ocean floor. The experiment uses copper, zinc, iron and aluminum. View the activity, complete with National Science Education Standards, extension activities and links to other resources, at <http://oceanexplorer.noaa.gov/explorations/04titanic/edu/media/Titanic04.Galvanic.pdf>.
6. Many activities dealing with electrochemical corrosion can be found on page 52 in the "Demonstration and Lessons" section of the February 2006 issue of the *ChemMatters* Teacher's Guide, available online at http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/CTP_005410. The actual *ChemMatters* article to which this Teacher's Guide applies is entitled "Flaking Away" and it deals with corrosion of automobiles. It is also available online at http://portal.acs.org/portal/PublicWebSite/education/resources/highschool/chemmatters/archive/CNBP_025144.
7. To relate salinity of ocean water to conductivity that would help to explain the deterioration of *Titanic* due to corrosion, you can have students do an activity involving ocean data. "Using real-time data from buoys around the coastal U.S., students will explore the effects of salts in the water, as well as the effects of other parameters on the conductivity of the water." (from NOAA Sea Grant's The Bridge—"an ocean of free teacher-approved marine education resources", at http://www2.vims.edu/bridge/DATA.cfm?Bridge_Location=archive0905.html)
8. To simulate the effect of adding sulfur or slag to steel, you might want students to do an activity with Gluep or Glue-Goo, a polymer of poly(vinyl acetate) (Elmer's Glue) and borax

solution. By including additives like talcum powder, vegetable oil, calcium carbonate (chalk), etc., a process polymer chemists call compounding, students can see the effects of these additives on the properties of the original polymer. Check out “Designer Sneakers”, a complete learning cycle activity that asks students to use compounding to produce specific properties in various forms of Gluep. Both student and teacher versions are available. (<http://polymerambassadors.org/PolymerActivities2.htm>)

9. Here’s a lesson plan from NOAA that deals with corrosion and possible restoration of the Monitor: http://oceanservice.noaa.gov/education/lessons/iron_cheesebox.html.
10. The National Oceanic and Atmospheric Administration (NOAA) educational Web site has an activity for high school students in which they investigate the effects of rusting and rusticles on Titanic’s ultimate demise: <http://oceanexplorer.noaa.gov/explorations/04titanic/edu/media/Titanic04.Rusticles.pdf>. (The same site also contains a (middle school) activity on corrosion rates of various metals.)

Density and buoyancy

11. Students can experiment with making Cartesian divers to study density and buoyancy. The San Francisco Exploratorium Science Snacks Web site contains several short demonstration/experiments with Cartesian divers. (http://www.exploratorium.edu/snacks/condiment_diver/index.html and http://www.exploratorium.edu/snacks/descartes_diver/index.html). Here’s a complete 7-page lesson on Cartesian divers from Cornell Center for Materials Research: <http://www.ccmr.cornell.edu/education/modules/documents/CartesianDiver.pdf>. It includes a second type of Cartesian diver, a sealed diver (most divers are open systems). And *ChemMatters* has a good article that describes the science behind the diver, and suggestions for students to make divers. (Becker, B. Cartesian Divers: Squeeze Play. *ChemMatters* February, 2001, 19 (1), pp 4–6.)
12. The accompanying *ChemMatters* Teacher’s Guide for “Cartesian Divers: Squeeze Play” (February, 2001) contains a series of five common student-posed explanations for how a Cartesian diver works (“Possible Student Misconceptions” #2). It then suggests that your students be asked to generate their own hypothesis (“Demonstrations and Lessons”, #4) and you will see that their ideas will fall into one of the five mentioned categories. Then in “Suggestions for Student Projects”, #2, it is suggested that you ask students to devise experiments to test these hypotheses to see which one “stands the test of time”.
13. To investigate density and buoyancy, students can create their own clay or aluminum boat and then add pennies until the boat sinks. See <http://education.usace.army.mil/clubhouse/science/experiment.cfm?Topic=boats&Id=19> for a simple version of the activity, or visit this site for a clay boat competition: <http://www.rivermontcollegiate.org/RAI/RAI%20boat.doc>. This site offers a complete lesson plan for the activity, including extensions and questions for students.
14. To show density differences and their effect on buoyancy, you can show regular and diet Coca-Cola soft drinks sinking and floating, respectively, in water. Here’s a rather complete description of a demonstration, including a nice discussion about how to get students to better understand the explanation of why this happens: <http://www.middleschoolscience.com/dietcoke.htm>.
15. PhET from the University of Colorado at Boulder has a great simulation that lets students experiment with density and buoyancy by weighing and measuring volumes of wood and bricks, in air and in water. It also can show students the forces involved. Check it out at <http://phet.colorado.edu/en/simulation/buoyancy>.
16. Remember that objects don’t only float or sink in water. Air is another fluid that exerts buoyant force. Background information on hot air balloons and the gas laws can be found in the April 2002 issue of *ChemMatters*. The article is followed by a description of how

students can construct their own hot air balloon out of tissue paper and a camp stove. (Vanderborght, C. Hot Air Balloons: Gas and Go. *ChemMatters* April, **2002** 20 (2), pp 4–6.) A one-page explanation of the buoyant effect of air on a helium balloon appeared in the December 2006 edition of *ChemMatters*. (Becker, B. Questions from the Classroom. *ChemMatters* December, **2006** 24 (4), p 2.)

17. You can have students construct a density column to show their understanding of buoyancy based on density differences. The following site provides three different approaches to building a 5-layer density column: http://www.exo.net/%7Edonr/activities/Five-Layer_Density_Column.pdf. The first approach involves simply telling students what the substances are and how to add them to the column; the second approach assumes the materials are unknown to the student and allows them to investigate the system; and the third approach also assumes unknown identities and provides a systematic way for students to investigate the system in order to build the column.
18. Density can also be used to analyze different kinds of glass. See Rohrig, B. Glass: More Than Meets the Eye. *ChemMatters* October, **2006** 24 (3), pp 4–7, with an activity on page 8 to find the density of glass.

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

1. Students can research the possibility of raising *Titanic* from the ocean floor, how oceanographers plan/have planned to do this, and why it may not be a good idea.
2. Students could debate bringing up *Titanic* from the ocean floor. Questions they might address: Can *Titanic* survive the process of being brought up? Is it better off where it is? What cost is involved in bringing up the ship? Will it survive once it is out of the water? Do people want it brought up? Some of these questions involve chemistry, but others are more akin to sociology.
3. Students can research the idea of “women and children first”, by investigating the survival rate of the sexes, as well as socioeconomic groups’ survival rates. They can start here: Passenger & crew lists of data: http://www.encyclopedia-titanica.org/titanic_passenger_list/. This site provides lists of passengers by class of ticket purchased, and crew by department. It also has stories about many of the passengers.
(Beware: students may react adversely to seeing so many names in the database of victims.)
Another site, <http://www.tableausoftware.com/blog/titanic-data-analysis-from-tableau-customer>, attempts to use data and graphs to answer the question, “Did Passengers Get Their Money’s Worth?” (meaning, did they survive?) Interesting question . . .
4. Students might want to investigate sea gliders—autonomic underwater vehicles that use density and buoyancy to sample underwater environmental conditions throughout the oceans. Their research could start with an article that reports on the three types of active sea gliders (as of 2006). (Rudnick, D.; Eriksen, C.; Fratantoni, D.; Perry, M. J. Underwater Gliders for Ocean Research. *Marine Technology Society Journal* Spring, **2004**, 38 (1), pp 48–59.) View the pdf file at http://www-pord.ucsd.edu/~rdavis/publications/MTS_Glider.pdf. Students can view another article, from the ASME (American Society of Mechanical Engineers), “Robots Plumb the Depths”, that shows a few pictures of the active sea gliders, as well as other information about them. (<http://www.asme.org/kb/News---Articles/articles/Robotics/Robots-Plumb-the-Depths>)
And a 2008 report from *Science Daily*, “New Hybrid Vehicle Given Its First Test Drive in the Ocean”, tells of a more recent development in sea gliders—an environmentally powered robot vehicle that harvests heat energy from the ocean to power itself. This would give this

generation of sea gliders the ability to continue missions indefinitely, rather than being limited by battery-life, as is the case for previous generations.

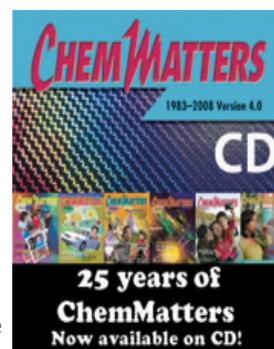
(<http://www.sciencedaily.com/releases/2008/02/080207140106.htm>)

5. Submarines are an interesting application of the concepts of density and buoyancy that might be of interest to students for a research project. Students could also compare the way a submarine floats or sinks to the process used by sperm whales to do the same thing (Alper, J. Killing for Oil. *ChemMatters* October **1988**, 6 (1), pp 4–8.)
6. Students can research the differences and similarities between corrosion occurring in shallow-water shipwrecks and corrosion in deep-water shipwrecks like Titanic. Students could research the mechanism by which a fish dives and compare that to the mechanism involved with a Cartesian diver.

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>. (At the bottom of the Web site 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.)



Some of the more recent articles (2002 forward) referenced below may also be available online at the URL listed above. Simply click on the “Past Issues and Teacher's Guides” button at the right. If the article is available online, that will be noted.

Brownlee, C. Flaking Away. *ChemMatters* February, **2006**, 24 (1), pp 17–19. This article deals with the chemistry of corrosion in automobiles, similar to what is happening to Titanic wreckage. According to the article, corrosion costs the US about \$275 million annually in lost goods and services.

Graham, T. Unusual Sunken Treasure. *ChemMatters* December, **2006**, 24 (4), pp 11–12. Author Graham describes another ship sunk around the same time as Titanic—in 1916—and her precious cargo, 2000 bottles of rare, vintage champagne. The article discusses the use of air bags to raise the Swedish schooner, Jonkoping, sunk by a German U-boat during World War I, and the recovery of the champagne. Graham discusses the critical roles that Henry's law and Boyle's law played in the preservation of the bubbly.

Barnwell, G. Salt-Gradient Solar Ponds. *ChemMatters* December, **1989**, 7 (4), pp 11–15. The article describes the use of a very high-concentration saline pond to trap solar heat energy, and then return that as useful energy. Part of the discussion centers on the density differences between fresh and salt water, and the lack of convection currents leading to heat build-up in the bottom layer of saltwater.

Two articles in the February, 2001 issue of ChemMatters focus on density and buoyancy:

Becker, B. Cartesian Divers: Squeeze Play. *ChemMatters* February, **2001**, 19 (1), pp 4–6., which describes how density and buoyancy explain the workings of a Cartesian diver, and Belleman, L. SCUBA: The Chemistry of an Adventure. *ChemMatters* February, **2001**, 19 (1), pp 7–9., which describes a scuba diver's adventure and the roles density and buoyancy play in scuba diving.

What do lava lamps have to do with Titanic? OK, it's a stretch, but "lava" floats or sinks based on density differences between the lumps of "lava" and the surrounding fluid, just as Titanic sank based on its density being greater than its surrounding fluid, water. Read about lava lamps in this *ChemMatters* article: McClure, M. Lava Lite: A Chemical Juggling Act. *ChemMatters* April, **1997**, 15 (2), pp 4–7.

Freemantle, M. Chemical Techniques Help Conserve Artifacts Raised from Titanic. *Chemical & Engineering News*, October 17, **1994**, 72 (42), pp 49–52. The author describes the corrosion processes and what chemists are doing to counteract the effects of corrosion on artifacts brought back from the Titanic debris field.

MacInnis, J. B. *Titanic: Tragedy in Three Dimensions*. *National Geographic* August, **1998**, pp 120–7.

Ballard, R. A Long Last Look at the *Titanic*. *National Geographic* December, **1986**, pp 698–727.

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

More sites on the history of *Titanic*

The Maryland Newspaper Project Web page contains three pages from the original April 16, 1912 edition of the *Baltimore American* newspaper, which carries all the news then available about the sinking of *Titanic*, as well as the rescue of its survivors. The pages can be downloaded as pdf files at <http://www.msa.md.gov/msa/stagser/s1259/121/7589/html/0000.html>.

More sites on steel composition on *Titanic*

<http://www.sciencedaily.com/releases/1997/12/971227000141.htm>

More sites on attempts to raise *Titanic*

The *New York Times* reported in 1996 of an almost-successful attempt to bring up a piece of the hull of *Titanic*. Unfortunately, after being brought up within 200 feet of the surface, the piece sank again. See <http://www.nytimes.com/1996/08/31/us/effort-to-raise-part-of-titanic-falters-as-sea-keeps-history.html>.

RMS Titanic tries again two years later and raises the large piece of *Titanic*'s hull. View a brief one-minute video clip here:

<http://www.youtube.com/watch?v=zxdJ85rJxwo&feature=related>.

RMS Titanic has a great Web site (the "official" Web site of Titanic) that offers photos of artifacts, videos of their underwater research, and the ability to dive down to Titanic (via your scroll bar). It has a wealth of information about Titanic. They essentially offer a "virtual raising" of Titanic, "preserving her legacy for all time."

(http://www.rmstitanic.net/expedition/?utm_source=expeditiontitanic&utm_medium=PRXI%20Referrals&utm_campaign=redirect)

More sites on studying Titanic on the bottom

The Smithsonian Institution has a Web site, "Ocean Portal", which includes a short video clip of "The *Titanic* Wrecksite" on the ocean bottom, probably taken in 1986. View it at

<http://ocean.si.edu/ocean-videos/titanic-wrecksite>.

The Woods Hole Oceanographic Institution, (WHOI) obtained ownership rights to the *Titanic* wreckage in 1994 revisited the site in August 2010. View their *Titanic* site at

<http://www.whoi.edu/page.do?pid=7544&tid=282&cid=80448>.

The National Geographic Society has some nice pages focusing on *Titanic*. A 2004 *National Geographic News* article ("Return to *Titanic*: Mission to Document Wreck's Destruction", April 23, 2004) discusses the natural destruction of the wreck. The article talks about the effects of humans visiting the wreck, as well as natural causes of its destruction, both galvanic and biological. View the story at

http://news.nationalgeographic.com/news/2004/04/0423_040423_titanicscience.html.

More sites on pictures/videos of Titanic

The History Channel documentary, "Lost Worlds: Building the Titanic (2007) can be view in its entirety (44:07:00) on YouTube at

<http://www.bing.com/videos/search?q=history+Titanic&mid=0E895852C035C0D876C60E895852C035C0D876C6&view=detail&FORM=VIRE5>. This video takes the viewer to Belfast, where Titanic was built, as it researches the designers, the design, and the construction of Titanic.

Another History Channel documentary on "*Titanic*'s Final Moments: Missing Pieces" (1:30:08), highlighting a Russian expedition to *Titanic*'s resting place in 2005, can be seen in its entirety on YouTube at http://www.youtube.com/watch?v=Td_wm9nZ-dY&feature=related.

National Geographic's Web site contains several pictures of *Titanic* taken at Ballard's 1985 discovery of *Titanic*. (http://ocean.nationalgeographic.com/ocean/photos/discovering-titanic/#/mir-submersible-kristof_18399_600x450.jpg)

And these, taken 25 years later, contain commentary on the degree of degradation observed since 1985: <http://news.nationalgeographic.com/news/2010/09/photogalleries/100901-titanic-pictures-3-d-25th-anniversary-photos-science-shipwreck/#>.

National Geographic photo-mosaic allows you to zoom in (like on a Web map) on the bow to see in great detail:

<http://ngm.nationalgeographic.com/ngm/0412/feature5/zoomify/main.html>.

The National Oceanic and Atmospheric Association (NOAA) Web site contains a photo gallery with pictures of the Russian expedition to *Titanic* in June, 2003 and the US expedition in June, 2004: <http://oceanexplorer.noaa.gov/gallery/cultural/cultural.html#titanic>.

A brief description of the US 2004 expedition is here:

<http://oceanexplorer.noaa.gov/explorations/04titanic/welcome.html>.

And a description of the Russian Mir 2003 expedition is here:

<http://oceanexplorer.noaa.gov/explorations/03titanic/welcome.html>.

A video by Robert Ballard on YouTube shows a 6-minute clip from his 2004 NOAA *Titanic* expedition: <http://www.youtube.com/watch?v=6Z7REEnwKOO>. Volume is low for first short clip when he talks, then improves (music, of sorts, only) for rest of video.

YouTube has a video (collection of photos and short video clips) of the original photos of *Titanic*, 1912, the aftermath (in newspapers), rediscovery in 1986 and the movie.

(<http://www.youtube.com/watch?v=xD9-z6Nw2FM&NR=1&feature=fvwp>)

RMS *Titanic*, Inc., the corporation who now has salvage rights on *Titanic* runs exhibits of *Titanic* artifacts around the world (entry fee required). Here is a short video clip showing some of the artifacts, including a 2-ton piece of the hull: <http://www.youtube.com/watch?v=rx0DG-gdVnY&feature=related>.

More sites on *Titanic*'s deterioration

Robert Ballard, discoverer of *Titanic* in 1986, reports in 2004 after his expedition that year that *Titanic* is degrading.

(http://news.nationalgeographic.com/news/2004/06/0604_040604_titanic.html, Warshawsky, D. *Titanic* Damaged by Tourists, Salvagers, Expedition Finds. *National Geographic News* June 4, 2004.)

This Web site presents information supporting the idea that the original research that produced the technology that led to the discovery of *Titanic* on the ocean floor actually occurred as a result of the US Navy's attempts to investigate two wrecked nuclear submarines.

(<http://news.nationalgeographic.com/news/2008/06/080602-titanic-secret.html>, Roach, J. *Titanic* Was Found During Secret Cold War Navy Mission. *National Geographic News* June 2, 2008.)

The August 18, 2010 *National Geographic Daily News* article, *Titanic* is Falling Apart" gives detailed information on the state of the ship:

<http://news.nationalgeographic.com/news/2010/08/100818-titanic-3-d-expedition-shipwreck-science-collapsing/>. The article contains many links, one of which shows a short animation of *Titanic* actually striking the iceberg and sinking to the ocean floor (http://ngm.nationalgeographic.com/ngm/0412/feature5/flash_pop_5a.html).

This article from Scribd, "Titanic – Resting or Reacting?", describes the role of sulfate-reducing bacteria on the corrosion of *Titanic*: <http://www.scribd.com/doc/11337904/Titanic-Resting-or-Reacting>.

The Corrosion Doctors Web site contains a wealth of information about corrosion:
<http://www.corrosion-doctors.org/>.

More sites on rules of reclamation and conservation

“Saving Shipwrecks” describes chemical methods being used to save other shipwrecks, including the *Monitor* and the *Hunley*, both from the Civil war.
(<http://pubs.acs.org/cen/science/85/8502sci1.html>), Arnaud, C. Saving Shipwrecks. *Chem & Eng News*, January 8, 2007, 85 (02), pp 45–7.)

The Federal Register has a 9-page set of guidelines for the salvage of materials from *Titanic* at <http://oceanexplorer.noaa.gov/explorations/04titanic/media/recoveryguidelines.pdf>

More sites on breakup of Titanic’s structure when sinking

A *History Channel* YouTube video clip provides “*Titanic* Breakup Theory”, another hypothesis about how (not why) *Titanic* broke apart as it began sinking:
<http://www.youtube.com/watch?v=LWzU-z1p1ro&feature=related>.

More sites on saltiness and density

Did your students (or you) ever wonder why the oceans are salty? Here’s a paper from the US Geological Survey that discusses that topic in some detail:
http://www.palomar.edu/oceanography/salty_ocean.htm.

Chem₁ General Chemistry Virtual Textbook has a nice Web page on density and buoyancy for freshman chemistry students, most of which would be appropriate for high school chemistry. View it at <http://www.chem1.com/acad/webtext/pre/density.html>.

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

While this site isn’t geared only to teachers, I needed to single it out to alert you to its existence. RMSTitanic is the official legal salvator of the *Titanic* wreck. It has the best Web site on all things *Titanic*, including an undersea dive down to *Titanic*’s resting place. And kids will really enjoy it. View it at
http://www.rmstitanic.net/expedition/?utm_source=expeditiontitanic&utm_medium=PRXI%20Referrals&utm_campaign=redirect.

This site contains a chemistry module of 7 lesson plans dealing with shipwrecks. This is an optional module in the New South Wales chemistry curriculum.

Topics include:

1. The ocean as an electrolyte
2. Corrosion of iron and its alloys
3. Electrolytic cells
4. Marine environment protection
5. Rate of decay and corrosion
6. Corrosion at great depths
7. Conservation and restoration

(<http://hsc.csu.edu.au/chemistry/options/shipwrecks/>,

New South Wales, Higher School Certificate, Department of Education and Communities Web site, a Charles Sturt University initiative)